PRINCIPLES OF

Field Crop Production

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Maize, America's premier crop, being harvested with a corn binder. (Courtesy International Harvester Company)

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PREFACE

This book presents some of the facts and fundamental principles essential to an understanding of field crop production in the United States. It is designed as a college text for a general course in field crops, especially for agricultural students who take only one course in crop production. It also should serve as a reference to those concerned with crop production. The subject matter probably is more advanced than that in other general crops books, but if so it should help raise the level of field crop instruction. The book is longer than can usually be covered in a one-semester course, but it offers a choice of subject matter to meet different institutional and local requirements. Some knowledge of botany and chemistry is desirable but not essential to an understanding of the material presented. Since the subject matter is of national scope it should be supplemented with lectures or assigned readings on local varieties and cropping practices. Crop varieties, and insect, disease, and weed control recommendations are changing so rapidly that the authors find it impossible to prepare and publish a completely up-to-date text.

This book was planned and started several years ago. The junior author assembled and amplified his lecture and reference material in mimeograph form and used it for class instruction. The subject matter was then revised, and expanded with the addition of several chapters by the senior author.

The references chosen are among those that seem to be pertinent to the subjects discussed, but many other references would be as applicable. It is impossible to cite all the worthwhile published articles. Foreign references are omitted for the most part because they are not accessible to, or usable by, large undergraduate classes.

The major crops are grouped into chapters in accordance with their botanical relationships. This should help avoid confusion concerning crop plant structure and behavior. It is realized fully that the arrangement, selection and presentation of topics and references might be better. Suggestions for improvement and reorganization of the subject matter will be very welcome.

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PART I GENERAL PRINCIPLES OF CROP PRODUCTION

1 THE ART AND SCIENCE OF CROP PRODUCTION

Crop Production as an Art

Primitive man lived on wild game, leaves, roots, seeds, berries, and fruits. As the population increased, the food supply was not always sufficiently stable or plentiful to supply his needs.[8] Crop production began when domestication of plants became essential to supplement natural supplies. The art of crop production is older than civilization, and its essential features have remained almost unchanged since the dawn of history. These features include: (1) gathering and preserving the seed of the desired crop plants, (2) destroying other kinds of vegetation growing on the land, (3) stirring the soil to form a seedbed, (4) planting the seed when the season and weather is right as shown by past experience, (5) destroying weeds, (6) protecting the crop from natural enemies, and (7) gathering, processing, and storing the products.

Farm machines merely speed the hand of man in doing these things, or enable him to do the work better.

According to the story of the Creation, man originally was expected to subsist solely upon horticultural and animal foods. Only after he had tasted the fruit of the "Tree of Knowledge" did he consume field crop products. Adam was banished from the Garden of Eden with the following warning: "Thorns also and thistles shall it bring forth to thee; and thou shalt eat the herb of the field. In the sweat of thy face shalt thou eat bread." It seems that the next grower of field crops clashed with a sheepherder and was driven

Note. Small superior numbers indicate numbered references at end of chapters.

to still poorer lands with these words: "When thou tillest the ground, it shall not henceforth yield unto thee her strength." With this burden the problems of the crop grower have continued through the ages. Today in the United States 97 per cent of the cropped land is devoted to field crops.

The early husbandman cultivated a limited number of crops, the cereals being among the first to be grown in most parts of the world. The same crop often was produced continuously on a field until low yields necessitated a shift to new land. This temporary abandonment of seemingly partly worn-out land has been almost universal in the history of agriculture. This is still a common and highly effective practice in growing tobacco and rice in parts of eastern and southern United States. A modification of this practice was the introduction of bare fallow every two or three years. The primitive husbandman hand picked destructive insects, and appeased the gods or practiced mystic rites to drive away the evil spirits whom he believed to be the cause of plant diseases. With advancing civilization materials such as sulfur, brine, ashes, whitewash, soap, and vinegar were applied to plants to suppress diseases or insects.

Romans of the first century A.D. intertilled many crops with iron hand knives. Intertillage was practiced on almost all crops grown by American Indians.[2] Intertillage with animal power was advocated in England in the seventeenth century.

The value of lime, marl, manures, and green manures for the maintenance of soil productivity was realized 2,000 years ago. Books on agriculture written by the Romans (Pliny, Varro, and Columella) of about the first century A.D. describe the growing of common crops including wheat, barley, clover, and alfalfa by procedures very similar to those in use today except that more of the work was done by hand, and the farm implements then used were crude.[3] However, in the experimental nursery plots of present-day agronomists, as well as in thousands of home gardens and on the small farms of many lands, we see crops being grown and harvested by hand methods almost identical with those followed by the slaves of the Nile Valley in the time of the Pharaohs 6,000 years ago.

The old art of crop production still predominates in farm practice throughout the world. Plant pathologists and entomologists have found ways to control plant diseases and insect pests more effectively. Chemists and agronomists have found supplements for the manure and ashes formerly used for fertilizers. Rotations perhaps are slightly improved. Many new crop varieties have been introduced.

Improved cultural methods doubtless followed observations made by primitive farmers. They found better crops in spots where manure, ashes, or broken limestone had been dropped, or where weeds were not allowed to grow, or where the soil was dark, and deep, or well watered, or where a crop followed certain other crops. Observations or empirical trials quickly revealed roughly the most favorable time, place, and manner of planting and cultivating various crops. These ideas were handed down through the generations. Observation, the only means of acquiring new knowledge until a century ago, continued to enrich the fund of crop lore. In recent centuries, the exchange of ideas, observations, and experiences, chiefly through agricultural societies and rural papers and magazines, spread the knowledge of crops.

Crop Production as a Science

Agronomy is the branch of agriculture that treats of the principles and practice of crop production and field management. The term was derived from two Greek words *agros* (field), and *nomos* (to manage). Scientific research in agronomy may be said to have begun with the establishment of the first experiment station by J. B. Boussingault in Alsace in 1834, although many empirical tests long before that time had established numerous facts regarding crops and soils. Agronomy has been a distinct and recognized branch of agricultural science only since about 1900. The American Society of Agronomy was organized in 1908. Agronomy had its origin largely in the sciences of botany, chemistry, and physics. Botanical writings describing crop plants began with the Greek, Theophrastus,[12] about 300 B.C., and were continued through the Dark Ages by herbalists in the monasteries and by medical practitioners. This was followed by modern systematic botany, and later by other plant sciences. Chemistry had its origin in ancient mystic alchemy and in the work of men who compounded medicines. Lavoisier, often called the father of chemistry, lived about 1770. The application of chemistry to agriculture dates from the publication of Sir Humphry Davy's book, *Essentials of Agricultural Chemistry*, in 1813. Physics arose from ancient philosophies. Agricultural engineering is largely applied physics.

Prior to the early years of the present century, crop experimenters usually were trained as botanists, chemists, or general agriculturists, or were interested farmers, gardeners, or naturalists who became agronomists by adoption. Thus a new science of agronomy was built up by coordination of knowledge derived from the natural and biological sciences with the written records of observations and empirical trials, and later of controlled experiments dealing with crop production.

Better crop production follows application of new discoveries, adoption of improved machines, and breeding of new crop varieties. New developments must be publicized to inform a few enterprising farmers in each community in which such developments might apply. Thereafter, in a free country, sound, demonstrated improvements spread with extreme rapidity. This is evident from the almost universal adoption in a few years of hybrid corn, disease-resistant grains, and combine-type grain sorghums in the sections of the middle west in which these crops are well adapted. On the other hand, abundant experience over a half century has shown the futility of attempting a drastic revolution in crop production merely by urging farmers to change their methods. In the main, farmers are eager to adopt any improvements that fit their conditions, and most of them are following approximately correct practices in so far as their immediate circumstances permit. Improvements in crop production from research and invention often arrive only after long and painstaking effort.

Population and Food Supply

Crop growing will always be an important industry because crop products are essential to man's existence. It has been stated that a man who goes without food for 24 hours will quarrel; one who is denied food for 48 hours will steal; and one who is without food for 72 hours will fight. Thus, the difference between peace and anarchy in most countries is a matter of only a few days without food.

The problem of sufficient food for a population that continues to increase in a world of limited land area was raised many years ago (1798) by Malthus.[9] He believed that the population could increase in a geometric ratio, while the food supply could increase only in an arithmetic ratio. Acre yields might be doubled once or even twice, but there is a limit beyond which increases are impossible. The basic check on population increase is the maximum limit of the food supply. This doctrine, that population tends inevitably to outgrow the food supply, has suffered many setbacks since the time of Malthus.[5] Doubtless Malthus underestimated the capabilities of future agronomists. Sometimes food production has outrun population as is indicated by political adventures in curtailing crop surpluses. This trend is due both to more efficient crop culture, and to a decline in birth rate in some countries. Despite surpluses in certain countries, there have always been large underfed populations who could have used these supplies were they financially able to obtain them. A world food shortage followed World War II. The additional food that will be required in the future for an ever growing world population is a challenge to the agronomist.

Origin of Cultivated Plants

All basic cultivated food plants are believed to have been derived from wild species, and they unquestionably were adapted to the needs of man long before the dawn of recorded history. Evidence from archeology and from literature of the ancients bears out their ancient origin.

The centers of origin of both agriculture and culture were peculiarly restricted to rather limited areas favored by a more or less equable climate.[10] Vavilov[13] determined the center of origin of a crop by finding the region where the greatest diversity of type occurred in that crop. DeCandolle[4] concluded that 199 cultivated plants originated in the old world, and 45 in America. The crop plants peculiar to America include the potato, sweetpotato, field bean, sunflower, Jerusalem artichoke, maize, and tobacco.[2] Eurasia yielded wheat, barley, rye, oats, millet, rice, peas, soybeans, sugar beets, sugarcane, and most of the cultivated forage crops. Sorghum and cowpeas seem to be indigenous to Africa.

Variation in Cultivated Plants

Cultivated plants have undergone extensive modifications from their wild prototypes as a result of the continuous efforts of man to improve them. The differences between cultivated and wild forms are largely in their increased usefulness to man, due to such factors as yield, quality, and reduced shattering of seed. Through the centuries man selected from among many thousands of plant species the few that were most satisfactory to his needs and which, at the same time, were amenable to culture. Primitive man was a past master in making these selections, for modern man has added little of basic importance.

All cultivated plants were divided by Vavilov [23] into two groups: (1) those, such as rye, oats, and vetch, that originated from weeds, and (2) fundamental crops known only in cultivation. Cultivated rye is believed to have originated from wild rye which even today is a troublesome weed in wheat and winter barley fields in certain parts of Asia. Oats are said to have come into culture as a weed found among ancient crops such as emmer and barley. Maize is known only in cultivation.

Spread of Cultivated Plants

In their migrations, people invariably have taken their basic cultivated plants with them to insure a permanent food supply and support their culture. This happened in prehistoric as well as in historic times. Man also transported weeds and disease and insect pests along with the crops. Pre-Columbian American agriculture was based on strictly native American plants and animals. None of the many plants involved were known in Europe or Asia prior to 1492, nor were cultivated plants native to Eurasia known in America before that time.[10]

Classification of Crop Plants

Crop plants may be classified on the basis of a morphological similarity of plant parts.[1, 6, 7, 11] (See Chapter 3.) From the agronomic standpoint they may be classified on the basis of use, but some crops have several different uses.

AGRONOMIC CLASSIFICATION

(1) Cereal or grain crops. Cereals are grasses grown for their edible seeds, the term cereal being applied either to the grain or to the plant itself. They include wheat, oats, barley, rye, rice, maize, grain sorghum, and proso, and in other countries pearl millet, teff, and Job's tears. *Grain* is a collective term applied to cereals. Buckwheat is used like a grain but it is not a cereal. Quinoa (*Chenopodium quinoa*) is grown in South Americá for its edible seed used as grain.

(2) Legumes for seed. The chief legumes grown for their seeds are peanuts, field beans, field peas, cowpeas, soybeans, lima beans, mung beans, chickpeas, and lentils.

(3) Forage crops. Forage refers to vegetable matter, fresh or preserved, utilized as feed for animals. Forage crops include grasses, legumes, crucifers, and other crops cultivated and used for hay, pasture, fodder, silage, or soilage.

(4) Root crops. Crops designated in this manner are grown for their enlarged roots. The root crops include sugar beets, mangels, carrots, turnips, rutabagas, sweetpotatoes, and cassava.

(5) Fiber crops. These include cotton, flax, ramie, and hemp. Broomcorn is grown for its brush fiber.*

(6) Tuber crops. Tuber crops include the potato and the Jerusalem artichoke. A tuber is not a root; it is a short, thickened, underground stem.

(7) Sugar crops. The sugar beet and sugarcane are grown for their sweet juice from which sucrose is extracted and crystallized. Sorghum as well as sugarcane is grown for sirup production. Dextrose (corn sugar) is made from corn and sorghum grain.

* For descriptions of additional fiber crops see *Mathew's Textile Fibers*, edited by H. R. Mauersberger, John Wiley and Sons, Inc., New York, 1947, pp. 1–1133.

(8) Drug crops. These include tobacco, mint, wormseed, and pyrethrum.

(9) Oil crops. These include flax, soybeans, peanuts, sunflower, safflower, sesame, castorbean, and perilla, the seeds of which contain useful oils. Cotton seed is an important source of oil, and corn also furnishes an edible oil.

(10) Rubber crops. The only field crop grown for rubber in the United States is guayule, but other plants such as kok-sagyz (Russian dandelion) are under investigation.

SPECIAL PURPOSE CLASSIFICATION

Cover crops are those seeded to provide a cover for the soil. Such a crop turned under while still green would be a *green manure* crop. Important green manure crops are the clovers, alfalfa, the vetches, soybeans, cowpeas, rye, and buckwheat.

Catch crops are substitute crops planted too late for regular crops or after the regular crop has failed. Short-season crops such as millet and buckwheat are often used for this purpose.

Soiling crops are crops cut and fed green, such as vetch, field peas, kale, and maize.

Silage crops are those preserved in a succulent condition by partial fermentation in a tight receptacle. Corn and sorghum are the crops most widely used for silage.

Companion crops, sometimes called nurse crops, are grown with a crop such as alfalfa or red clover in order to secure a return from the land the first year of a new seeding. Grain crops and flax are often used for this purpose.

The Leading Field Crops

The world production of the leading field crops (excluding forage crops and grain sorghum) is shown in Table 1. Wheat, corn, rice, oats, barley, rye, cotton, and potatoes are the most important. The acreage, yield, production, and value of the different field crops in the United States are shown in Table 2. Corn, hay, wheat, oats, and cotton occupy the largest acreage. The trend in acreage of these five crops in the United States is shown in Figure 1.

TABLE 1. WORLD PRODUCTION OF THE LEADING FIELD CROPS (EXCEPT GRAIN SORGHUM AND FORAGE CROPS). AVERAGE FOR THE FIVE YEARS, 1935 TO 1939

CROP	ACREAGE	ACRE YIELD	PRODUCTION (QUANTITY)	UNIT
Wheat	415,000,000	14	5,940,000,000	bushels
Corn	217,000,000	22	4,759,000,000	"
Rice	205,900,000	36	7,432,000,000	"
Oats	138,800,000	32	4,360,000,000	"
Barley	114,200,000	20	2,335,000,000	"
Rye	100,900,000	17	1,728,000,000	"
Cotton	81,515,000	0.38	30,995,000	500-pound bales of lint
Potatoes	52,280,000	135	8,124,640,000	bushels
Soybeans	28,300,000	16	458,300,000	"
Peanuts			18,573,200,000	pounds
Flaxseed	19,500,000	7	136,000,000	bushels
Sugarcane			22,511,000	short tons of sugar
Sugar beets	8,060,000	9.6	77,507,000	short tons of beets
Tobacco	7,477,000	740	6,001,688,000	pounds
Field beans			7,340,700,000	pounds

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TABLE 2. ACREAGE, YIELD, PRODUCTION AND FARM VALUE OF THE LEADING FIELD CROPS IN UNITED STATES. TEN-YEAR AVERAGE 1938–1947 (PRELIMINARY FIGURES)

CROP	ACREAGE HARVESTED (THOUSANDS)	ACRE YIELD	UNIT	PRODUCTION (THOUSANDS)	FARM VALUES IN DOLLARS (THOUSANDS)
Corn (all)	88,622	31.5	bushels	2,789,325	3,016,835
Wheat (all)	59,833	16.5	"	991,723	1,337,246
Oats	38,367	32.1	"	1,225,737	720,480
Barley	12,713	24.0	"	304,541	249,685
Rye	2,875	12.2	"	37,110	30,432
Buckwheat	419	16.9	"	7,043	7,369
Flaxseed	3,270	8.8	"	29,755	89,884
Rice	1,356	46.8	"	63,052	103,267
Popcorn	119	1380	pounds	165,685	4,474
Sorghums for grain	6,290	16.2	bushels	102,357	95,705
Sorghums for forage	8,313	1.42	tons	11,773	99,841
Sorghum for silage	867	5.8	"	5,015	—
Sorgo sirup	186	60.1	gallons	11,177	12,558
Broomcorn	271	307	pounds	83,800	7,456
Cotton, lint	21,934	254	bales	11,289	1,259,031 [a]
Hay	73,944	1.34	tons	99,506	1,218,687
Beans, dry edible	1,838	9.19	bags	18,384	93,956
Peas, dry field	442	12.31	"	5,619	22,919
Soybeans for beans	8,017	18.7	bushels	148,161	290,265
Cowpeas for peas	1,028	5.3	"	6,239	14,387
Peanuts (picked and threshed)	2,715	695	pounds	1,852,607	125,424
Velvetbeans (all)	1,787	803	"	1,426,800	14,287
Potatoes	2,732	145	bushels	392,940	435,288
Sweetpotatoes	713	89.7	"	63,769	96,866
Tobacco	1,656	1035	pounds	1,723,914	583,543
Sugarcane	299	19.9	tons	5,958	27,385

Sugarcane sirup	121	171	gallons	20,756	17,886
Sugar beets	797	12.7	tons	10,117	79,897
Hops	36	1238	pounds	44,000	21,747
Mint, oil	47	30	"	1,400	8,400
Hemp fiber	24	938	"	23,374	—
Total	341,667 [b]				

[a] Figure includes value of \$212,684,000 for 4,637,000 tons of cottonseed.

[b] Not including about 1,250,000 acres of peanuts harvested by livestock, 30,000 acres of mung beans, about 8000 acres each of fiber flax, sugar beet seed, and hemp seed. Also excluded are fully 5 million acres of legumes and 1 million acres of grasses harvested for seed, much of which were gathered from land also utilized for hay or pasture.

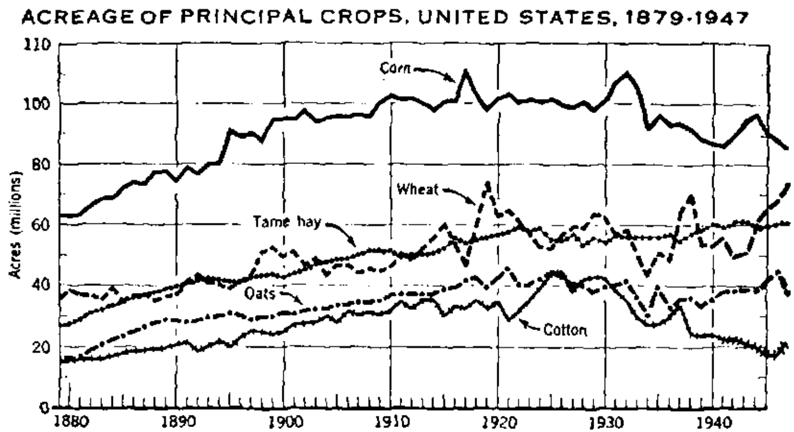

FIG. 1. The acreages of corn, wheat, hay, oats and cotton increased gradually up to 1919.

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2 CROP PLANTS IN RELATION TO ENVIRONMENT*

Factors in Crop Distribution

Staple agricultural crops show a marked tendency to geographic segregation despite the fact that they may grow well over wide areas. Thus corn and oats, although concentrated in the corn belt, are grown successfully in every state in the Union. The principal factors that influence localization are climate, topography, character of the soil, insect pests, plant diseases, and economic conditions.[19]

Crops are generally profitable only when grown in regions where they are well adapted. The best evidence of adaptation of a crop is a normal growth and uniformly high yields.[16, 17] Adapted crops usually produce satisfactory yields even on the poorer soils in a region.[31] The farther a crop is removed from its area of good adaptation, the more care is necessary for satisfactory production.

Climate

Climate is the dominant factor determining the suitability of a crop for a given area. Knowledge of the crops and crop varieties grown in a given region is a better measure of climate, as applied to crop production in that region, than are complete climatic records.[7] Thus we know that the climate in the Puget Sound region of Washington is more mild than that of eastern Maryland, and that the latter region is more mild than northern Texas, because winter oats survive the winter more regularly. We know, also, that conditions

* For a complete discussion of this subject, the reader is referred to K. H. Klages, *Ecological Crop Geography*, The Macmillan Company, New York, 1942; and R. O. Whyte, *Crop Production and Environment*, Faber and Faber, London, 1946.

in the winter wheat region of Sweden are not so severe as in many winter wheat regions in the United States, because the Swedish varieties are less cold resistant. We find climatic counterparts of American agricultural regions in various parts of the world. The Great Plains region is similar to the Ukraine because the same crop varieties thrive in both places. Many crop varieties are equally adapted to Australia and California. The irrigated regions of southern California and Arizona and south Texas are comparable to irrigated sections of the Mediterranean region. The wheats of Great Britain and Holland fail miserably in the United States except in the mild cool humid Pacific northwest where they thrive. The corn belt of the United States has a counterpart in the Danube Valley of Europe. Iowa grows a type of winter wheat similar to that grown in eastern Czechoslovakia.

GENERAL TYPES OF CLIMATE

Climatic differences are due chiefly to differences in latitude, altitude, distances from large bodies of water, ocean currents, and the direction and intensity of winds.

Continental climates, which occur in interior regions, are characterized by great extremes of temperature between day and night and between winter and summer. The ranges increase in general with the distance from the ocean. Some of these regions, such as the Steppes of Russia and the Great Plains of North America, are further characterized by an irregular approach of seasons, deficient rainfall, low humidity, and generally unobstructed winds.[14] The limited rainfall that occurs is usually sporadic and often torrential. The great wheat areas of the world are found in such climates. Other hardy crops also are grown there.

Oceanic or marine climates are more equable. Moderate temperature changes occur between day and night, and between winter and summer. They are influenced dominantly by the sea or other large bodies of water. This influence results from differences in the specific heat of water and land. Water takes up and gives off heat only one-fourth as rapidly as does land.

Three distinct climatic regions are recognized in the United States.[31] The first is a narrow strip of territory from the Pacific coast to the Cascade and Sierra Nevada mountains, a purely oceanic climate in which the rainfall ranges from less than 10 inches in southern California to over 100 inches per year in the northwest. In this region, the winters are mild, and the summers in the north part and along the southern coastline are cool. The second region is the upland plateau from these mountains eastward to the 100th meridian. The climate is continental over most of this area. The third region is from the 100th meridian, where a continental climate prevails, to the Atlantic, where conditions again are modified by the ocean. The change from one type to the other is gradual in this area.

PRECIPITATION

Rainfall has a dominant influence in crop production. In semiarid regions, such as the Great Plains and Great Basin, the conservation and utilization of the scanty rainfall is so important that it relegates all other factors, including soil fertility, to minor positions.

In regions of low rainfall, the deficiency may be partly overcome by moisture-conserving tillage and rotation practices, or by irrigation. Under dry farming conditions, red clover and sugar beets are failures, and alfalfa is unprofitable except on bottom lands. When such lands are irrigated, these crops may be highly successful in the same region.

Crop Areas Based upon Rainfall. Crop regions are frequently classified on the basis of average annual rainfall. It is obvious that these regions are arbitrary and that the actual boundaries may fluctuate from year to year. (1) The arid region is that in which the average annual rainfall is 10 inches or less. Irrigation is necessary for successful crop production in most of such areas. (2) The semiarid region is arbitrarily considered to be that in which the rainfall varies from 10 to 20 inches. Tillage methods that conserve moisture, and crop varieties adapted to dry farming regions, or irrigation, are necessary for successful crop production. (3) Annual rainfall in most subhumid areas varies from 20 to 30 inches (Figure 2). This amount of rainfall often is inadequate for satisfactory crop yields unless methods which utilize the rainfall to best advantage are followed in regions such as the southern Great Plains

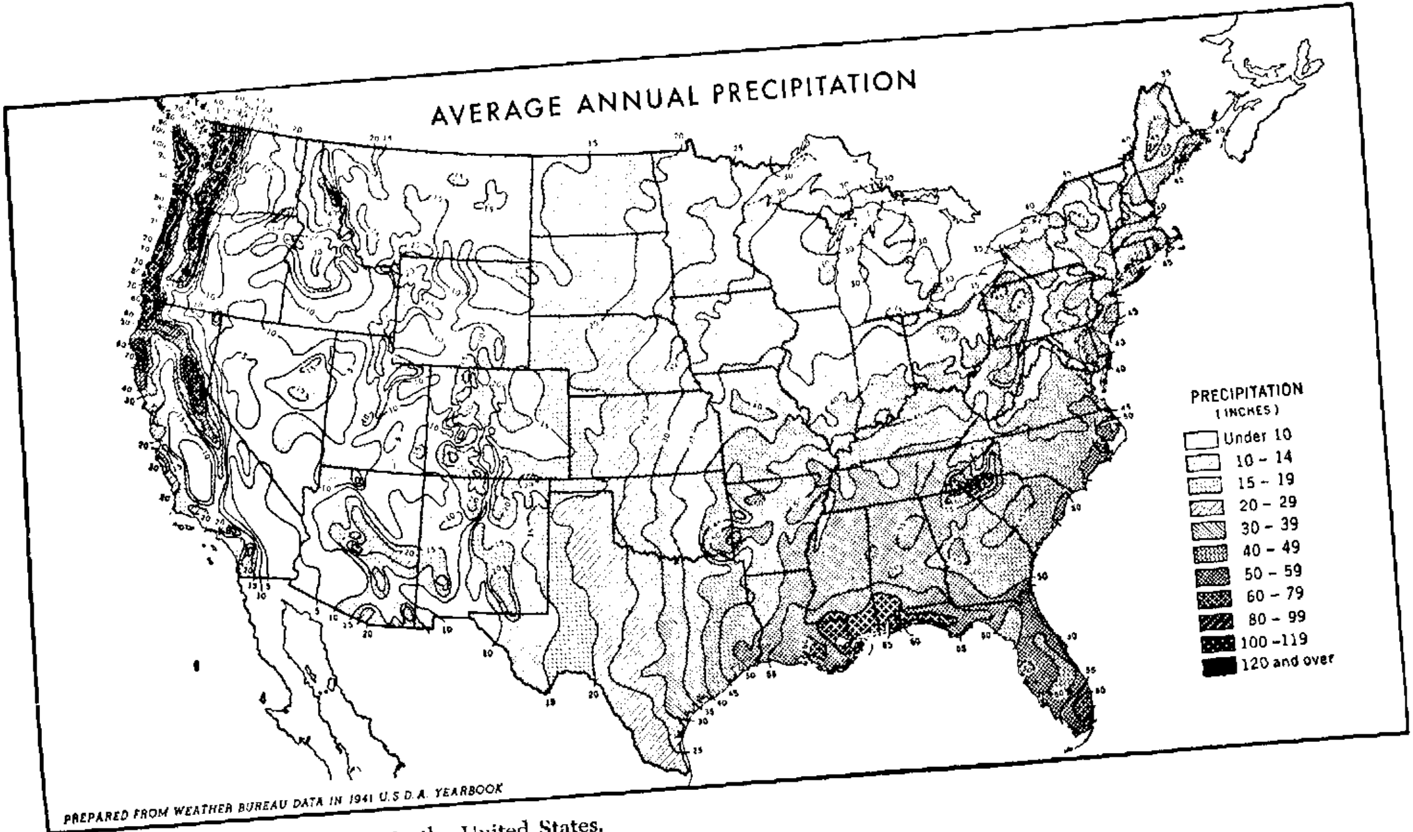


FIG. 2(a). Precipitation in the United States.

where seasonal evaporation is high. (4) The humid region is regarded as that in which the annual precipitation is more than 30 inches. There conservation of moisture is not the dominant factor in crop production.

Effectiveness of Rainfall. The effectiveness in crop production of

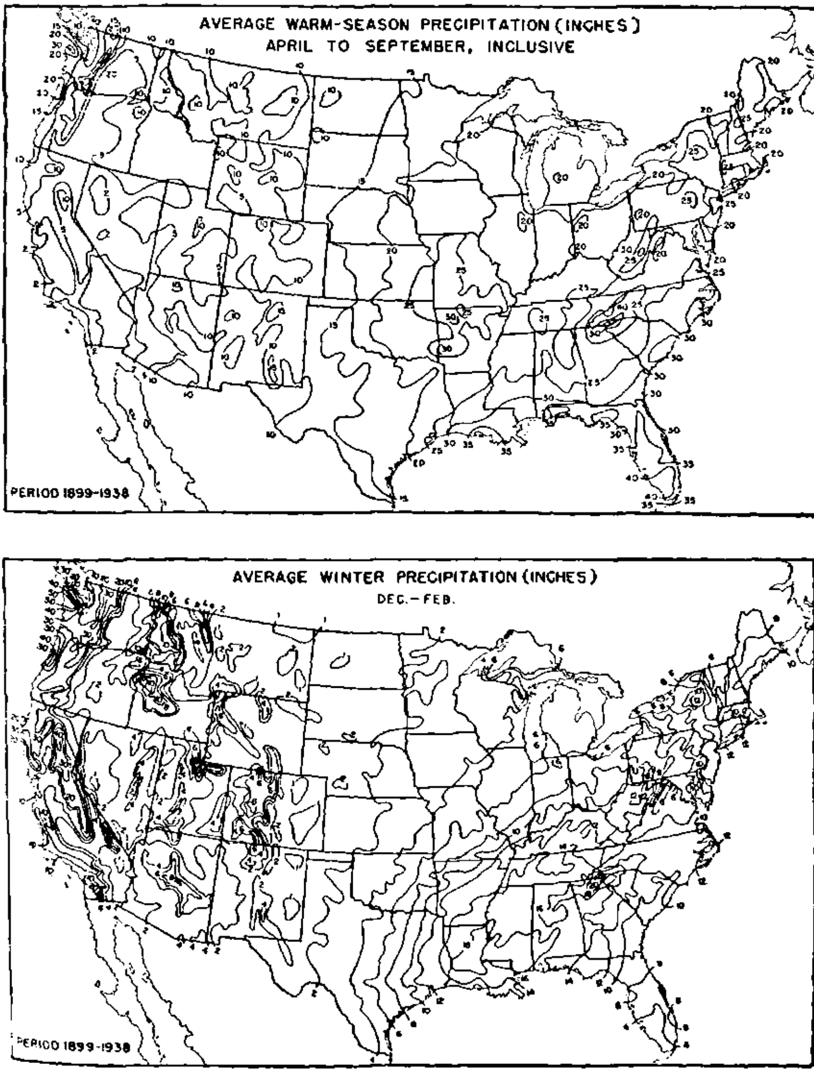


FIG. 2(b). Precipitation in the United States.

a given quantity of rainfall depends upon the time of year that it falls, and the rapidity and intensity of individual rains. Of still more importance is the seasonal evaporation.

The total rainfall fluctuates widely from year to year. Over a 10-year period, the annual precipitation at North Platte, Nebraska, in the Great Plains area, varied from 10 to more than 40 inches.[4] In general, the lines of equal rainfall from the Rocky Mountains eastward lie north and south, but shift eastward as they extend to the north. In the southern states east of Texas, equal rainfall lines follow the general outline of the Gulf coast.

Rainfall has its greatest value when it falls during the growing season, ordinarily between April 1 and September 30 for summer crops. The critical period for moisture for most crops occurs just before or after flowering.[12] In corn, the 10 days after tasseling and silking have an almost dominant effect on yield. In regions of winter rainfall, a greater portion of the water can be conserved by fallowing than in regions of summer rain because it falls during a period of low evaporation. Winter rainfall regions are especially suited to the growing of winter grains, although these crops thrive in summer rainfall regions also. Corn and sorghum are poorly adapted to winter rainfall regions because their greatest demands for moisture occur during the dry hot season.

East of the Mississippi River, the monthly precipitation distribution is rather uniform throughout the year, especially north of the cotton belt.[13] In Florida, however, the 7 months from November to May are comparatively dry, the rainfall being heavy in the summer months. On the Great Plains, approximately 70 to 80 per cent of the annual precipitation falls from April to September, inclusive. Most of the precipitation in the Pacific coast and intermountain regions comes in the winter months. In Arizona and adjacent sections, rainy periods frequently occur in both summer and winter.

Ordinarily, summer showers of less than one-half inch are of very little value in storing soil moisture for the use of crops unless they precede or follow other rains shortly. Light showers are largely lost by evaporation from plant foliage and the soil surface. Such showers, however, may benefit crops by reducing evaporation and cooling the atmosphere. Frequently, rain comes in torrential showers in the

Great Plains and states to the east, with the result that much of it is lost through runoff, especially on steep lands with heavy soils.

TEMPERATURE

Temperature also is an important factor in limiting the growing of certain crops (Figure 3). The 50° F. isotherm of monthly mean temperature during each summer month marks the growth limits for most plants. The great crop areas have 4 to 12 months in which the mean monthly temperature is between 50° and 68° F. This is in the temperate belt. Temperature is influenced by latitude and altitude as well as by exposure. A difference of 400 feet in altitude or 1 degree in latitude causes a difference of approximately 1 degree F. in mean annual and mean July temperatures and 1.5 degree F. in mean January temperatures in the United States.[8] Slopes that face south and west receive the most sunshine, and are regularly warmer than north and east slopes. Crops can be grown at much higher mountain elevations on the warm slopes.[24]

Effect of Temperature on Plants. Each crop plant has its own approximate temperature range, i.e., its minimum, optimum, and maximum for growth. Although they are subjected to a rather wide range of temperature, most crop plants make their best development between 60° and 90° F. They either cease growth or die when the temperature becomes either too low or too high. Temperatures of 110° to 130° F. will kill many plants. Most cool-weather crop plants cease growth at temperatures of 90° to 110° F., and annual crops are killed by low temperatures ranging from about 32° F. down to −40° F. The minimum temperature at which any plant can maintain life during the growing season is about the freezing point of water. The threshold value, or point at which appreciable growth can be detected, is usually taken at 40° or 43° F. This value varies for different crops. Winter rye in the sun may show signs of growth even when the temperature recorded in a shaded shelter is below freezing. Sorghum practically ceases growth at a temperature of 60° F.[19]

Crop areas have more or less definite boundaries that extend in an east–west direction in conformity with the isothermal trend.[12] The time to plant crops is defined by the temperature conditions of

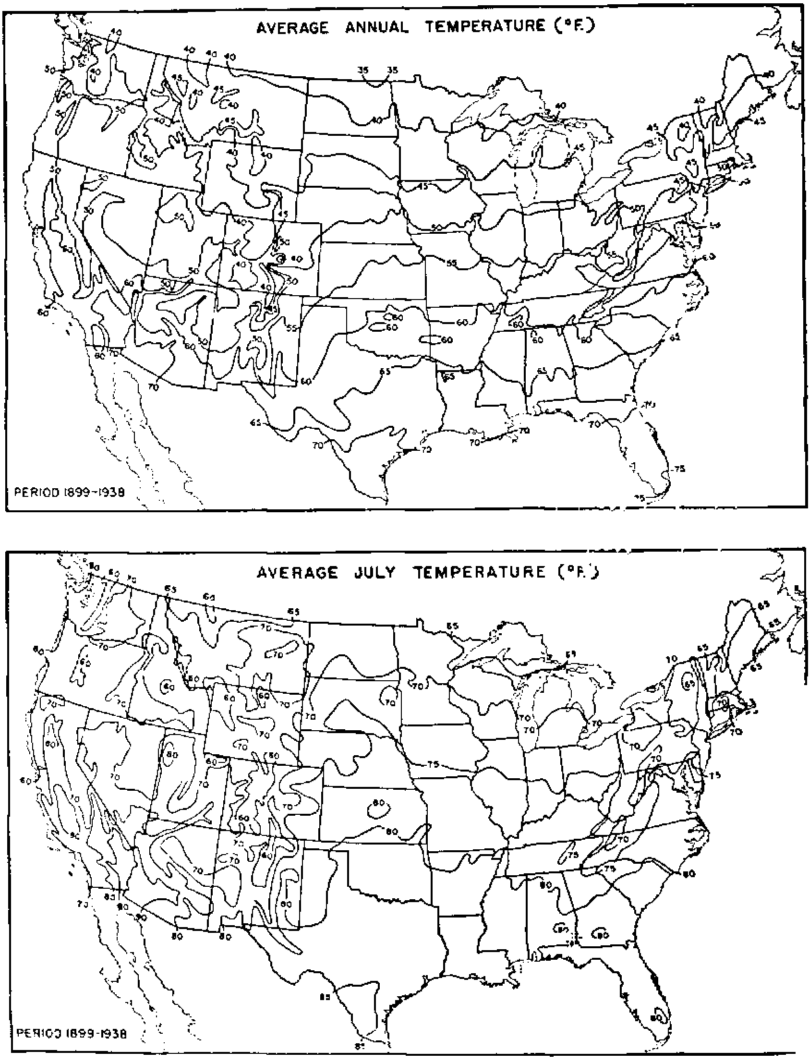


FIG. 3. Temperature of the United States.

the locality, but it is generally later as one proceeds northwar
According to Hopkin's *bioclimatic law,*[8] such events as seeding tin
vary 4 days for each 1 degree of latitude, 5 degrees of longitud
and 400 feet of altitude, being later northward, eastward, and u
ward in the United States (Figure 4). The normal daily temper

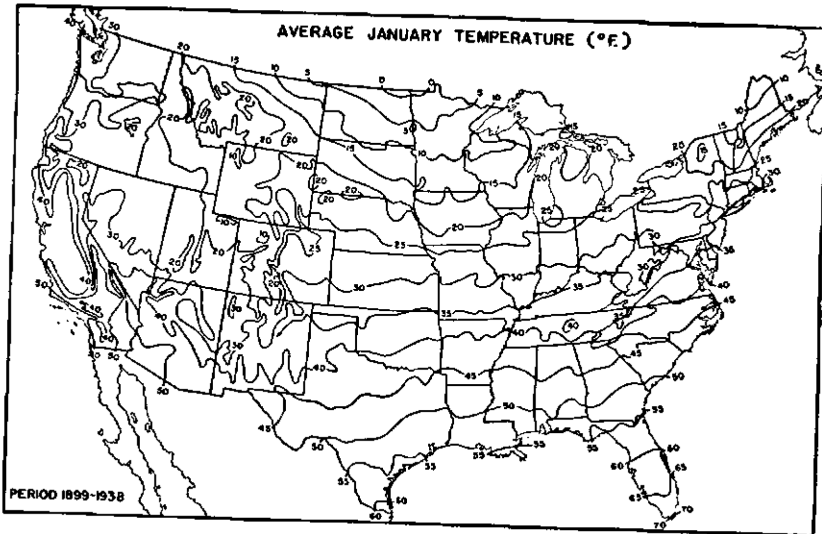


FIG. 3. Temperature of the United States.

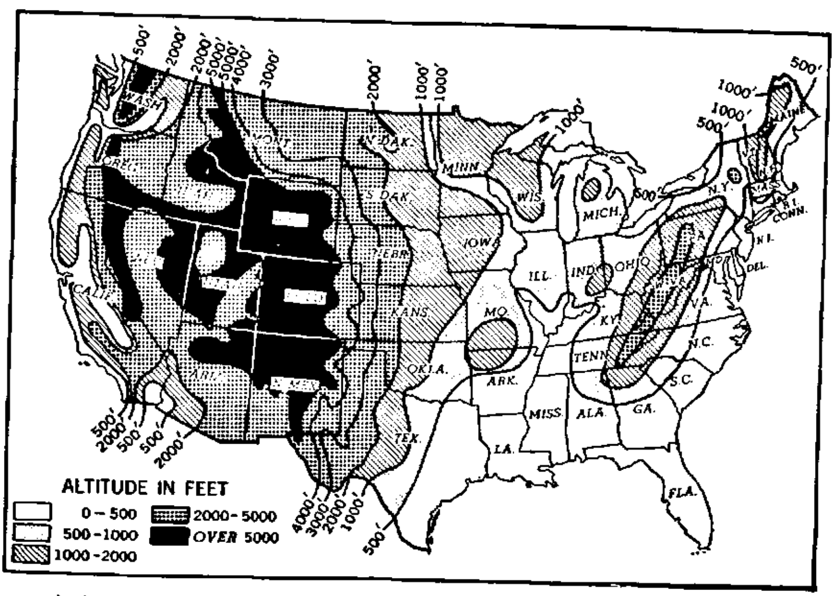


FIG. 4. Approximate general altitudes in the United States.

ture for spring planting of a given crop is rather uniform throughout the country. The seeding of spring wheat begins when the normal daily temperature rises to about 37° F., spring oats at 43° F., corn at 55° F., and cotton at 62° F.

Within suitable temperature ranges, growth increases with each rise in temperature, often in approximately proportional relationships corresponding to the Vant Hoff-Arrhenius law for monomolecular chemical reactions, i.e., a doubling in activity (or growth) for each 10 degrees C. (18 degrees F.) rise in temperature.

Crops differ in the number of heat units required to mature them. Heat units are usually computed by a summation of degree days for a growing season. A degree day is the number of degrees F. above an established minimum growing temperature, as for example, 50° F. for corn. Thus, where the sum of maximum daily temperatures above that minimum is 3,000 during a 100-day growing season, there are 3,000 total heat units. The number of heat units necessary to mature a given crop differs with the region. Increased growth is not directly proportional to increased temperatures. Also fewer units are required in a cool region where temperatures do not become so high as to retard plant growth. This relationship is recognized in Linsser's law, which states that in different regions the ratio of total heat units to the heat units necessary to mature a given crop is nearly constant.[29]

Cool- vs. Warm-Weather Crops. Crops may be classed broadly as warm- or cool-weather crops (Appendix Table 1). The crops that make their best growth under relatively cool conditions, and that are damaged by hot weather include wheat, oats, barley, rye, potatoes, flax, sugar beets, red clover, vetches, field peas, and many grasses. Field peas, the above small grains, flax, and northern grasses may withstand freezing temperatures at any time up to about the flowering stage. The 10° F. isotherm for daily mean temperatures for January and February coincides remarkably well with the northern boundary of the winter wheat belt, beyond which spring wheat is more important.[26] The isotherms for 20° and 30° F. coincide closely with the northern limits of winter barley and winter oats, respectively. Among the crop plants that prefer a warm season are corn, cotton, sorghum, rice, sugarcane, peanuts, cowpeas, soybeans, velvetbeans, Dallis grass, and Bermuda grass. Warm-weather crop plants, after they reach appreciable size, are killed by temperatures slightly below freezing, and sometimes at several degrees above freezing when exposed for prolonged periods.

LENGTH OF GROWING SEASON

The number of days between the average date of last spring frost and first fall frost usually is considered as the length of the growing season (Figure 5). A frost-free season of less than 125 days is an effective limitation to the production of most crops. Wheat, oats, and barley mature under a shorter frost-free period than does corn or sorghum because they can be sown safely 2 months before the average last spring frost. Cotton requires 200 days of frost-free weather, a fact which restricts its growth to the south. The length of the period for growth of a crop may be limited also by drought.

HUMIDITY

Humidity is water vapor in the air. Relative humidity is the amount of water vapor present in the air in terms of the percentage necessary to saturate the atmosphere at the particular temperature. A saturated atmosphere causing fog, dew, or rain has a theoretical relative humidity of 100 per cent. The lower the relative humidity at a given temperature the more rapidly will the air take up water transpired by the leaf or evaporated from a moist soil surface.

Evaporation and transpiration increase with increases in temperature and decreases in relative humidity. A high seasonal evaporation from a free-water surface is generally reflected in a high water requirement of crops. Evaporation determines the efficiency of rainfall, particularly under a rainfall of less than 30 inches per year. There is an increase in the water requirement of crops and in the seasonal evaporation from north to south in the Great Plains. In North Dakota a ton of alfalfa can be produced with 500 tons of water, while in the warmer Panhandle of Texas 1,000 tons would be required.[28]

The rainfall-evaporation ratio is sometimes used as an index of the external moisture relations of plants, a ratio of 100 per cent meaning that rainfall and evaporation are equal.[32] The rainfall-evaporation ratio along the Atlantic coast is approximately 130 per

FIG. 5(a). Frost-free period and frost dates.

FIG. 5(b). Frost-free period and frost dates.

FIG. 5(c). Frost-free period and frost dates.

cent. From there westward the ratio drops gradually to about 20 per cent at the base of the Rocky Mountains. Only plants with marked ability to conserve moisture, e.g., the desert shrubs and dry-land grasses can thrive where rainfall is so far below evaporation. True forests occur where rainfall exceeds evaporation.

Light

Light is necessary for photosynthesis, the process of manufacturing food essential to the growth of green plants. Within certain limits the larger the amount of light a plant receives, the greater is its growth. The hours of sunlight each day vary from a nearly uniform 12-hour day at the equator, to continuous light or darkness throughout the 24 hours for a part of the year at the poles (Table 1). The day length is approximately 12 hours everywhere at the time of the vernal and the autumnal equinoxes. At the northern border of the United States (49° N. latitude), the day length (sunrise to sunset during the year) ranges from about 8 hours 12 minutes to about 16 hours 6 minutes. At the southern tip of Florida (25° N. latitude) the seasonal range is only from 10 hours 35 minutes to 13 hours 42 minutes. The long summer days at high latitudes enable certain plants to develop and mature in a relatively short time. When timothy was grown from Georgia to Alaska, the vegetative period was progressively shortened from south to north.[5] The season of blooming was accelerated by longer days.

The life processes of many plants were found by Garner and Allard[6] to be influenced by length of day (which they called *photoperiodism*). This led to the distinction between long-day and short-day plants. Long-day plants require a relatively long day for the formation of inflorescences, and they increase in vegetative growth when the days are short. Among the long-day plants are red clover and the small grains (except rice), which ordinarily flower in the long days of early summer (Appendix Table 1). Long days hasten flowering and maturity of these crops, but reduce vegetative growth. Short-day plants are stimulated into vegetative growth, with delayed flowering and maturity, when the days are long, and produce flowers and fruits when the days are relatively short. Corn, sorghum, rice, millet, and soybeans are short-day plants.

TABLE 1. APPROXIMATE LENGTH OF DAY ON VARIOUS DATES AT DIFFERENT LATITUDES NORTH OF THE EQUATOR

LATITUDE (NORTH)	DEC. 21 (WINTER SOLSTICE)		MAR. 21 (SPRING EQUINOX)		APR. 21		MAY 21		JUNE 21 (SUMMER SOLSTICE)		JULY 21		AUG. 21		SEPT. 21 (AUTUMN EQUINOX)	
	hr.	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*	*hr.*	*min.*
0°	12	7	12	7	12	7	12	7	12	7	12	7	12	7	12	7
10°	11	33	12	7	12	24	12	37	12	43	12	38	12	24	12	8
20°	10	56	12	9	12	42	13	9	13	19	13	11	12	43	12	10
25°	10	35	12	10	12	53	13	28	13	42	13	29	12	54	12	10
30°	10	11	12	10	13	4	13	47	14	4	13	48	13	6	12	12
35°	9	48	12	12	13	17	14	9	14	32	14	12	13	18	12	12
40°	9	20	12	12	13	31	14	35	15	2	14	36	13	32	12	13
45°	8	46	12	14	13	48	15	4	15	38	15	6	13	49	12	15
50°	8	4	12	15	14	9	15	41	16	24	15	44	14	9	12	17
55°	7	10	12	17	14	34	16	29	17	24	16	33	14	35	12	19
60°	5	52	12	18	15	8	17	38	18	54	17	41	15	9	12	21

(Data from Allard and Zaumeyer. *U. S. Dept. Agr. Tech. Bul.* 867, 1944.)

Other crop plants and certain varieties of some of the above crops tend to be rather indifferent in their response to photoperiodic influences. Cotton, cultivated sunflowers, and buckwheat have been placed in the indifferent or indeterminate group. Day length and temperature are compensating in their effects to some extent.[9] Photoperiodic responses of a number of plants may be modified by temperature.[25]

The distribution and time of maturity of different crops and crop varieties are influenced by photoperiodic responses. Quick-maturing sorghum varieties may grow larger in the north where days are long than they do in the south where temperatures are more favorable. The time a crop is planted affects the period required to reach maturity. This is due to temperature and photoperiodic influences. The growing period for spring-sown crops decreases as seeding becomes later, except for very late seeding which forces the crop to complete its growth at a slower rate induced by cool autumn conditions.

Native grass species that extend from the northern to the southern portions of the United States are differentiated into numerous local strains, each adapted to its particular photoperiodic range. The northern strains are small and early when grown in the south, whereas southern strains are large and late when moved to the north. Wild rice and gramagrasses exhibit this variation to a marked degree.

Air

Air supplies carbon dioxide for plant growth, and furnishes nitrogen indirectly. It supplies oxygen for respiration of the plant and for chemical and biological processes in the soil. Air sometimes contains gaseous substances such as sulfur dioxide, chlorine, and hydrofluoric acid in concentrations harmful to plant growth; these gases usually come from industrial fumes. A concentration of sulfur dioxide of one part or more in two million parts of air is injurious to plants.

Wind may cause mechanical lacerations and bruises to the tissues of crop plants. High winds may bruise and tear the leaves or, as often happens with small grains grown on fertile soils, the plants may be blown over or lodged. The rate of transpiration or water loss from plants increases in proportion to the square root of the wind velocity. In high winds crop plants may be cut off by moving sand particles, completely uprooted, or buried under soil drifts.

Soil Requirements

Although less important than climate, soil texture and soil reaction (acidity) play a major role in determining which crops are grown. Despite popular belief to the contrary, they have only a minor effect in determining the variety of a particular crop that is grown. Surveys of crop varieties show that their distribution is determined largely by climatic and soil moisture factors.

Soils provide naturally, or after treatment, certain favorable conditions for plant growth. Soil not only furnishes a stratum for germination of the seed and spread and anchorage of the plant roots, but in addition, maintains a reasonably satisfactory balance of soil moisture and essential mineral elements for nutrition of the plants.

Soil is not essential for plant growth, however, as is evidenced by the frequent growing of many crop species in sand and water cultures, to which nutrients are supplied artificially. Spearmint was grown in water cultures by John Woodward[33] as early as 1699. Some 240 years later, the process of growing plants in water cultures was named hydroponics.[7] The growing of crops on heavily fertilized sandy lands in the high-rainfall southeastern region is, in effect, largely a sand culture.

TEXTURE

Soil texture has an important influence upon crop adaptation. Medium or heavy soils are best for fine-rooted grasses, wheat and oats, whereas the coarser rye, corn, and sorghum plants can thrive, and are commonly grown, on the light sandy soils. Rice demands a reasonably heavy soil with a nearly impervious subsoil that prevents excessive water losses from leaching.

Water percolates more quickly and also deeper into light soils, and this checks runoff, although heavy soils have the greater water storage capacity per cubic foot. Partly for this reason, crops in semiarid regions are less subject to drought on sandy soils than on heavy soils, whereas in regions of high rainfall where much of the water may percolate downward below the root zone, crops on sandy soils are more subject to drought.

Texture of a soil refers to the size of the individual grains or particles, grouped according to diameter as sand (2 to 0.05 mm.), silt (0.05 to 0.002 mm.), and clay (0.002 mm. and less). Soil class is recognized on the basis of the relative percentages of these separates. The principal classes as to texture are sand, loamy sand, sandy loam, silt loam, clay loam, silty clay loam, and clay, in increasing order of their content of fine separates. The farmer commonly calls a soil with a large proportion of clay particles a heavy soil, and one with a large proportion of sand a light soil, the difference being due to the ease of cultivation. The so-called hard and soft lands are a popular classification based on this same condition. In weight per unit volume light soil is heavier than heavy soil.

The finest particles having a diameter of 0.001 mm. or less (usually less than 0.0001) constitute the colloidal material which has been aptly designated the protoplasm of the soil. It has a tremendous influence on the ability of a soil to retain available plant nutrients and water by adsorption. The degree of adsorption depends upon the amount of surface. Fine particles have an enormous surface area per unit weight of soil. One pound of average soil colloidal particles has about 5 acres of surface.

In any soil, the fine clay and colloidal fractions contain most of the available nutrients and play a major role in determining its properties. The percentage of soil particles of clay size and smaller, and the moisture equivalent, are nearly equal in a large majority of soils. The moisture equivalent is a physical determination of the percentage of moisture that approximates the field capacity for moisture of most soils. The wilting point of many soils averages about 54 per cent of the moisture equivalent. The difference between the two is, in large part, the water that is available for crops. Where the moisture equivalent is 10 per cent, the wilting point is about 5.4 per cent, and the available water in a column of soil wet to its field capacity is about 4.6 per cent of its dry weight.

STRUCTURE

Soil structure determines the seedbed condition, the amenability of a soil to cultivation, and its susceptibility to wind or water erosion. It refers to the manner in which the individual grains are arranged. The soil grains may be grouped into crumbs or granules, i.e., compound particles so as to afford open irregular spaces through which air and water can circulate. A moist soil of good structure crumbles in the hand. This granular condition or tilth may be destroyed by flooding or by packing or working it when it is too wet. It is then puddled or deflocculated, i.e., the soil is made up of single unaggregated grains.

GREAT SOIL GROUPS AND THEIR RELATION TO CROP PRODUCTION

A line drawn from western Minnesota southward through central Texas roughly divides the country into two parts with regard to soil characteristics. East of this line (Figure 6), the soils called Pedalfers are leached so that no accumulation of lime is found in the soil depths occupied by the roots of most crop plants. Thus, eastern soils and those in the humid Pacific northwest are acid because basic materials (sodium, potassium, calcium, and magnesium) are leached out by the heavy rainfall. In most of the west, soils called Pedocals have an accumulation of calcium carbonate in either the subsurface or subsoil. The higher the rainfall, the deeper the carbonate zone is found. Pedocals tend to have an accumulation of soluble mineral salts due to the fact that the low rainfall is not adequate to leach them out. Owing to the natural fertility of unleached soils, and to the limiting of crop growth by inadequate rainfall, crops grown on Pedocals usually respond slightly, or not at all, to application of commercial fertilizers, except where leaching is brought about by irrigation. In consequence, commercial fertilizers and liming find little place in cropping practice in the western half of the United States except in the irrigated and humid portions.

The calcification process of soil development,[11, 2] maintained under grasses in sections of restricted rainfall, formed the Chernozem soils

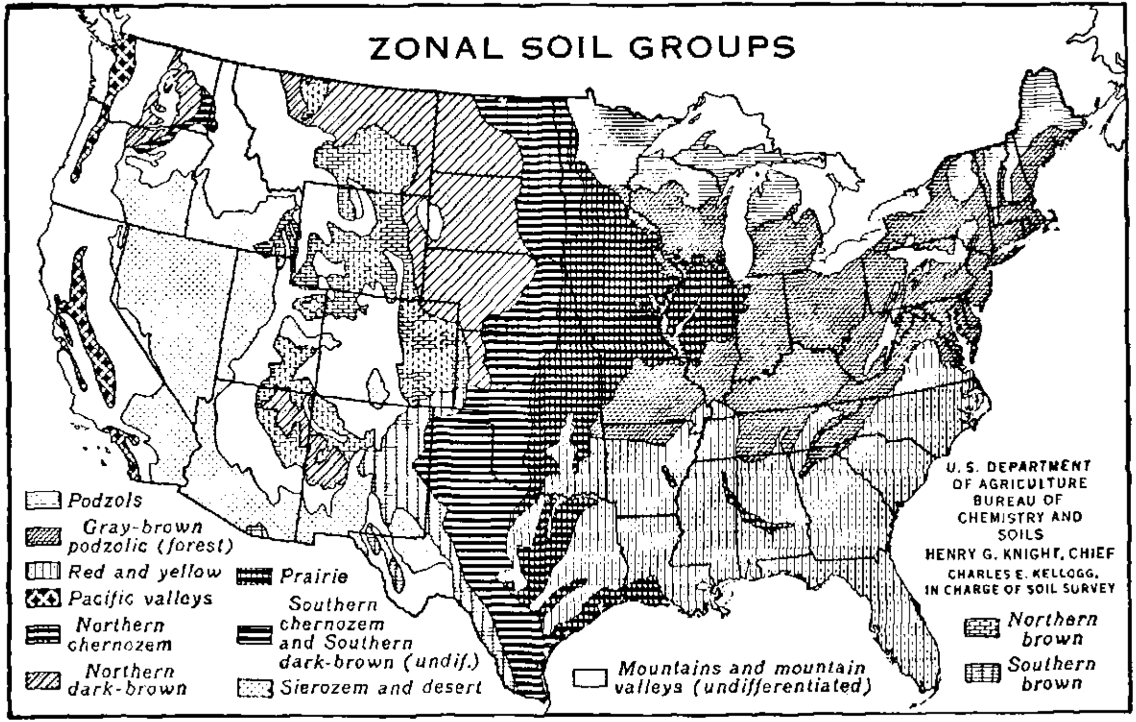


FIG. 6. A generalized map of the large soil groups in the United States. The eastern border of the Chernozem soils is approximately the line separating the pedalfers from the pedocals.

found in the most humid part of the drier region. Such a soil, which is black, very high in organic matter, and very fertile, is excellent for grasses and for small grains, especially wheat. In the progressively drier climates the vegetation becomes more sparse, and because of fewer plant roots and residues to decay, the soils become lighter in color and the solum (*A* and *B* horizons) thinner. To the west in the United States, beyond the Chernozem group, are the Chestnut soils, followed by the Brown soils, Sierozem (Gray) soils, and finally the desert soils (Figure 6). The Chestnut soils[11] are fertile and extensively used for wheat, but the climate is hazardous. The Brown soils are also used for wheat, but the climate is so hazarduous that in the driest areas land is used for grazing. The Sierozem soils found in semidesert regions are low in organic matter, high in soluble salts, comparatively shallow, and are suitable only for grazing or irrigation farming.

The Prairie soils of the corn belt are very dark brown in color, high in organic matter, and well supplied with the elements necessary for the growth of grains and other field crop plants. The high natural fertility of these soils, together with the accompanying favorable climate, make them among the most productive in the world. The Podzol soils found in the northern humid regions are likely to be acid due to the leaching of the carbonates of calcium and magnesium. The Podzols are not fertile, which explains why large areas of cutover forest lands in the northern Great Lakes region have never been put under cultivation. Podzol soils are better suited to hay and pastures than to grains. South of the Podzol soils lie the Gray-Brown Podzolic soils of the Great Lakes and eastern corn belt states, developed under a deciduous forest with a moist temperate climate. More bases are present in these soils than in the case of the Podzols. These soils are naturally more fertile for crop plants than those of the Podzol group, but less so than the Chernozems. On account of the desirable climate in the Gray-Brown Podzolic region, these soils are admirably adapted to general agriculture, especially when some fertilizers and lime are applied.

Peat and marsh (bog) soils usually are high in organic matter and nitrogen because the rate of oxidation of organic matter was slower than its production. Forest soils characteristically have a mantle or layer of humus or decayed organic matter at the soil surface usually not more than 6 inches thick.[22] On the other hand grasslands usually have a dark layer 6 to 18 inches in thickness, with a correspondingly higher productivity. Most tree species send their roots deep into the soil. After a tree dies it usually is uprooted as it falls, leaving nearly all the organic material to decay slowly above the soil surface. The dead roots left in the soil are scattered through considerable depths. Grass roots usually are largely distributed within the upper foot or two of soil, although some penetrate to a depth of several feet. The greatest concentration of roots is in the upper 6 inches. The roots of perennial grasses may live only about a year,[23] and in most cases not more than 3 years. Thus there is a replacement each year not only of all top growth but also of roots in perennial as well as annual grasses. The dead tops and roots quickly decay to form humus. Being underground the humus from the roots is protected from fire. As a result we find black grassland soils containing 120 to 600 tons of humus in which are 6 to 30 tons of nitrogen and a similar quantity of other minerals per acre, whereas forest soils have about 20 to 50 tons of humus containing 1 to 2½ tons of nitrogen per acre.

Certain soils of arid regions in which excessive bases (saline salts) accumulate in all parts of the soil profile are popularly referred to as alkali soils. They are unsuitable for crop production until the salts are leached by heavy irrigation. These Solonchak soils may not be highly alkaline in reaction because the sulfate and chloride ions present have a neutralizing effect. The unproductive Solonetz soils, commonly known as black alkali soils, are usually dark in color, greatly dispersed, and highly alkaline (*p*H 8.0 +) because the characteristic constituent is sodium carbonate.

SOIL CONSTITUENTS

Water, the most important constituent in the soil, occurs in three forms besides that in the form of vapor. So-called capillary water, held in the soil by surface tension, is that used mostly by plants. When plants wilt, the soil may still contain 2 to 17 per cent of moisture, depending upon its texture and humus content. Water below this so-called wilting coefficient is largely unavailable to plants. Gravitational water is that which moves downward by gravity and may percolate beyond reach of the roots of crop plants. Hygroscopic water, which is retained by an air-dry soil kept in a saturated atmosphere, is adsorbed on soil particles with such force that it is not available to plants.

The field capacity of soils, i.e., the amount of water held against the force of gravity, usually ranges from 1 to 2 inches in each foot of soil. The finer the soil particles, the more water the soil holds. Extremely coarse sandy soils are unable to store moisture in sufficient quantities for crop growth.

Air, which constitutes from 20 to 25 per cent by volume of an ordinary moist soil, supplies the oxygen necessary for root growth and for oxidation of organic matter and other soil constituents. Aeration may be too poor for plant growth in a soil with the water table too near the surface or in one with a heavy impervious subsoil that cannot be drained satisfactorily. Waterlogged soils are often relegated to native vegetation or low-grade grazing.

An adequate supply of plant nutrients is essential for the growth of crop plants. About 25 or 30 chemical elements are found in plants.* Carbon, oxygen, and hydrogen are most abundant. The essential elements most frequently deficient in soils are nitrogen, phosphorus, and potassium. Calcium, magnesium, and sulfur, also essential, are absorbed by crops in considerable quantities. Manganese, iron, boron, chlorine, copper, zinc, and molybdenum are essential to plants but only in small quantities. Silicon is essential to plant growth and is an important constituent of rice hulls and other plant parts, but is abundant in the soil. Sodium is required by sugar beets and mangels, and chlorine is needed to produce a suitable burning quality in flue-cured tobacco. On the other hand, chlorine in applied fertilizers impairs the burning quality of cigar tobacco. Usually sodium and chlorine are abundant in soils, except locally in the humid southeast. Soils deficient in cobalt and iodine may produce crops that are inadequate in these elements from the standpoint of animal nutrition. Crops may take up so much selenium

* The functions of mineral elements in plant nutrition as recognized up to 1945 are described in a series of articles in *Soil Science*, Vol. 60, Nos. 1 and 2; both numbers are devoted entirely to that subject.

and arsenic from soils with excessive quantities of these elements that they are toxic to livestock and humans.[20] Aluminum, which is abundant especially in clay soils, may be absorbed in quantities harmful to the plant when the soil is too acid.

Mineral deficiencies can often be detected or at least suspected from symptoms seen in crop plants.[3, 30] The symptoms, which differ in various crops, have been summarized in detail and are strikingly illustrated in a book *Hunger Signs in Crops*, prepared by a committee representing The American Society of Agronomy and The National Fertilizer Association, and published by Judd and Detweiler, Inc., Washington, D. C.

Some of the general characteristic symptoms indicating mineral deficiencies as reported by various workers, that apply to some but not all crops, are listed below:

Diagnosis of mineral deficiencies:

Plants stunted, leaves pale green: *nitrogen.*
Plants stunted, leaves dark green or tinted with purple: *phosphorus.*
Plants stunted, leaves bluish or dark green, margins and areas between veins scorched or brown: *potassium.*
Older leaves chlorotic between the veins: *magnesium.*
Leaf margins rolled upward: *calcium.*
Chlorotic mottling or striping (especially on calcareous soils): *iron.*
Chlorotic mottling and small discolored spots or lesions: *manganese.*
Root crops with decayed crown, distorted leaves, and hollow or decayed root: *boron.*

Good soils contain adequate amounts of available nutrients to meet the needs of the crop plant during all periods of growth, and do not contain harmful concentrations of any constituent. They are neither excessively acid nor excessively alkaline. In general, relatively permeable and fertile soils with a good water-holding capacity are favorable for the growth of the most important crop plants. With a suitable climatic environment, some soils seem to possess an especially wide range of crop adaptation. For example, Hagerstown silt loam of the Appalachian limestone valleys is capable of producing satisfactory yields of nearly every field crop.[21]

Arable soils require a topography suitable for cultural operations, and must be free from stones that would preclude tillage.[21] A soil depth of 1½ to 3 feet or more usually is essential to successful cropping. Intractable clay soils may be an effective barrier to profitable utilization for some crops. The peculiar erodibility of certain silt loams and very fine sandy soils operates against their long-time use without protective measures.

The crop grower has at his command numerous methods for improving the soil environment.

CROPS FOR SPECIAL SOIL CONDITIONS

Alkali-tolerant Crops. Grasses are more resistant than many legumes to alkali salts.[10] In soils with more than 1.5 per cent of soluble salts by weight, the concentration is too high for agricultural crops. Sugar beets, although able to produce a fair crop at concentrations of 1.0 to 1.5 per cent, are not recommended for such soils. At concentrations of 0.6 to 0.8 per cent, good crops of sugar beets and foxtail millets, as well as fair crops of sorgo and barley can be grown. At lower concentrations, good crops of redtop, timothy, orchard grass, rye, and cotton are possible. Forage plants are preferable for alkali land because their quality is seldom impaired by the environment.

Crops Tolerant to Acid Soils. A soil having a pH of 7 is neutral, one higher than pH 7 is alkaline, while a soil with a pH below 7 is acid. These pH values for hydrogen ion activity are reciprocal logarithmic expressions to the base or power of 10. Therefore a soil of pH 5 is 10 times, and one of pH 4 is 100 times, as acid as one of pH 6, as measured by hydrogen ion activity.

Many factors other than the direct acidity may complicate the growth of crop plants on soils with high acidity. High acidity may increase absorption of aluminum and retard absorption of calcium or phosphorus. Excessive alkalinity also may interfere with iron or phosphorus absorption. Microbial activities in the soil are greatly influenced by the soil reaction. Fortunately, most economic plants will grow well on acid soils. Among the plants that will respond well on moderately to rather highly acid soils (pH 4 to 5) when a moderate amount of active calcium is present are: lespedeza, redtop, millet, buckwheat, rye, soybeans, cowpeas, and alsike clover. Those that will grow on a slightly to moderately acid soil (pH 5 to 6) with a moderate amount of active calcium present are: corn, wheat, oats, barley, timothy, potatoes, field beans, and vetch. Certain plants require a neutral or only slightly acid soil with an abundant supply of active calcium. These are: alfalfa, red clover, sweetclover, and sugar beets. Abundant calcium rather than low acidity appears to be the critical factor in these crops. A good quality of tobacco cannot be grown on an alkaline soil.

Indicator Significance of Native Vegetation

The native plant cover was used by primitive man, as well as by the early settlers in this country, as a clue to the lands most productive for crops (Figure 7).[28] The type of vegetative cover often serves as an indication of overgrazing.

Farmers who settled on lands in the Ohio Valley covered with sugar maple and beech were more prosperous than those on oak and pine lands. The lands occupied by southern hard woods, river-bottom forests, southeastern pine forests, and northeastern hardwoods are regarded as valuable for agricultural production. In the west yellow pine forests often occupy slopes that are too steep or soils that are too stony and shallow for cultivated crops.[24] Small grains are grown for forage in the more favored spots. Lodgepole pine forests occupy areas too cool for cultivated crops and where the frost-free season is seldom longer than 75 days.

The true prairies, for the most part, were made up originally of tall coarse grasses such as big bluestem (*Andropogon furcatus*), little bluestem (*A. scoparius*), and Indian grass (*Sorghastrum nutans*). These lands are valuable for production of corn and most field crops. The short grass or plains grassland association, largely consisting of blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchloë dactyloides*), extends through the Great Plains from Montana southward.[1] Buffalo grass grows on tight land where the soil moisture, while the land is in grass, rarely penetrates below the second foot. The moisture often penetrates deeper when the land is kept cultivated between crops. Crop failures are to be expected there in years of much less than average moisture. Corn and wheat are the chief crops in the north, and wheat and grain sorghums in the southern part of this region. The sandier soils in the Great

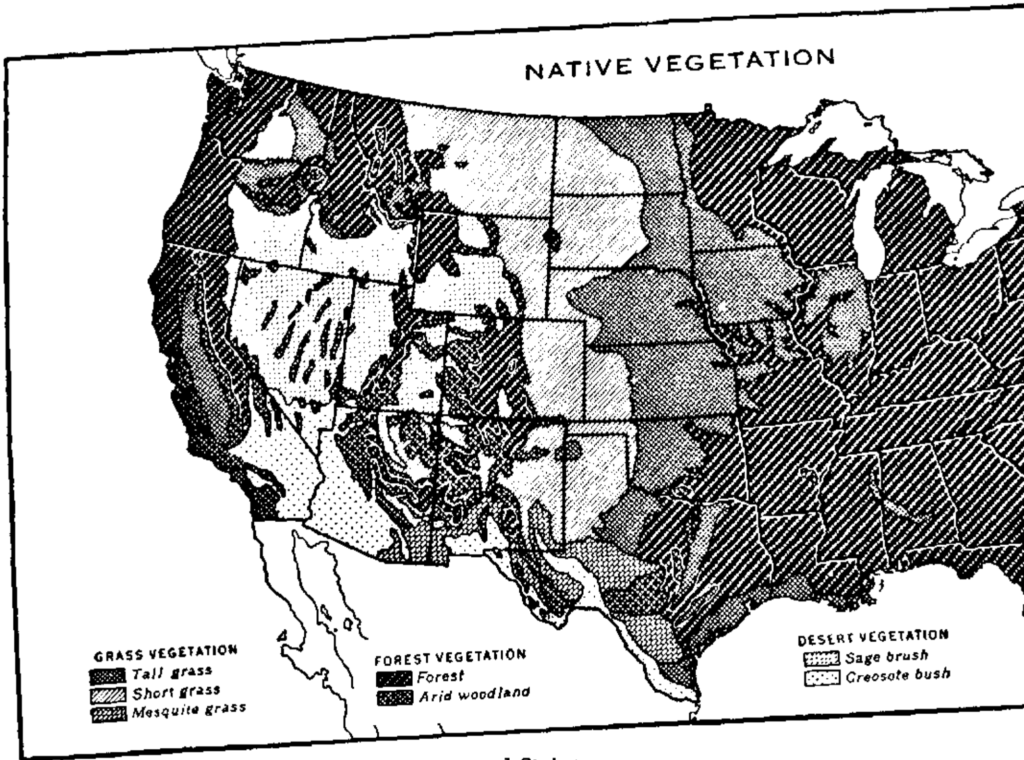
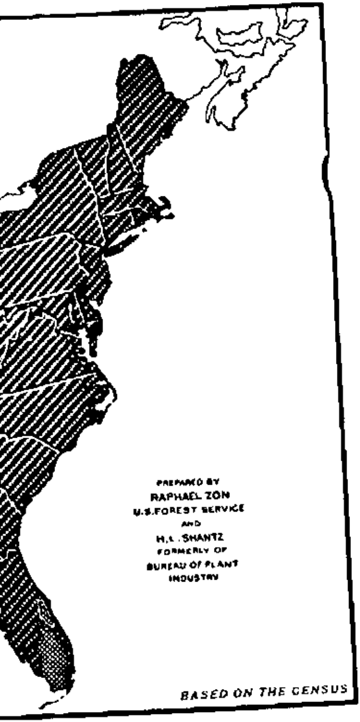


FIG. 7. Native vegetation in the United States.


PREPARED BY
RAPHAEL ZON
U.S.FOREST SERVICE
AND
H.L. SHANTZ
FORMERLY OF
BUREAU OF PLANT
INDUSTRY
BASED ON THE CENSUS

Plains are occupied by the taller bunch grasses and wire grasses.[27] Because such sandy lands have less runoff, they are less subject to crop failure in the drier years than are the short grass lands in the same locality.

Sagebrush (*Artemisia tridentata*) is a shrub that varies from one to seven feet in height. This is the most common shrub of the Great Basin, growing on well-drained loamy soils. Dense stands of tall sagebrush have long been accepted as an indication of favorable soil conditions for dry land small grains or for irrigated crops.

Salt-desert vegetation such as greasewood, shadscale, and seepweed indicates soils too high in salinity for good crop growth.

Insects and Diseases

Insect pests often determine the success or failure of a crop for a given district. Thus barley and milo often fail where chinch bugs are abundant. The alfalfa weevil, once nearly drove the alfalfa seed crop from certain irrigated valleys of the west. The boll weevil reduced the cotton acreage in the southeast, while the crop was expanding in the southern Great Plains where the weevil was not present. Grasshoppers and the southwestern corn borer have devastated corn in the Great Plains region and thus indirectly stimulated the growing of sorghum which seldom is injured. Control of these insects and the breeding of resistant varieties may alter the crop situation.

Diseases, likewise, may be responsible for the lack of adaptation of a crop. Thus sugar beet production, once discontinued in several localities of the west because of the curly top disease, was restored when resistant varieties were produced. The wilt disease caused the flax crop to migrate from the Atlantic coast to the Great Plains. Flax moved back east to the Mississippi Valley after resistant varieties became available. Losses from virus diseases were so severe that sugarcane culture was about to be abandoned in Louisiana just before resistant varieties became available about 1926.

Economic Factors in Crop Choice

Centers of crop production are determined in part by economic forces such as population,[15] demand, transportation, labor problems, and competition with other crops. Cheap lands in this country are often pastured or grazed, more intensive crops being grown as land values rise. High-priced labor is best employed on land adapted to production of high yields of specialized crops on fertile soils. Broomcorn, a nonperishable high-priced crop, is grown mostly some distance from population centers. It could be grown more widely in so far as climatic adaptation is concerned, but the market for brooms has almost a fixed limit. Special crops may remain localized where a ready market has become established. Durum wheat and flax, as a rule, must be grown in quantities locally sufficient for carload shipments because they are processed at a limited number of mills.

The average yields of wheat in the northeastern states are about double those obtained in the semiarid portions of Kansas and North Dakota where so much wheat is grown. However wheat is produced more efficiently in the latter areas where broad level fields of rich soil can be cropped by extensive methods without any expense for fertilizers. Also other agricultural enterprises do not compete seriously with wheat production on the loam soils of the semiarid regions.

Psychological factors often alter what would appear to be the logical crop choice upon the basis of relative economic returns. Thus farmers like to grow corn, wheat, and oats in preference to grain sorghum, flax, and barley, respectively, even where the favored crops yield a lower return per acre. The field stands of corn are more certain, and the crop can be harvested over a longer period with less hired labor, and is easier to store and feed than is grain sorghum. Sowing wheat involves less risk in getting stands or of establishing additional weeds than is the case with flax. Wheat is easier to harvest and thresh. Also flaxseed requires a very tight bin for storage. Oats are easier to bind, shock, pitch, and thresh than is barley, and the grain can be fed to horses without grinding. A factor f still greater importance is the presence of irritating rough awns on certain varieties of barley which farmers and their hired men heartily dislike. They also dislike handling clover hay because of its irritating dust, and broomcorn because of the itch caused by the irritating hairs released from the chaff. Many farmers grow a medium-height grain sorghum for forage in preference to a taller and higher-yielding sorgo because the long stalks of the latter are awkward to bind, shock, pitch, load, unload, stack, and feed. It is easier to grow a few additional acres of the lower-yielding variety, since these operations are performed from a tractor seat.

Of the approximate total land area in the United States, 1,905,000,000 acres, about 20 per cent, mostly in the western half of the country, is too hilly or rough for cultivation. Another 30 per cent is too infertile or the climate is too unfavorable for crop production by methods now in vogue.[12] According to the United States Census of 1945, about 1,142,000,000 acres were in farms, of which about 353,000,000 acres were used for crops, 50,000,000 acres were idle or fallow, and another 109,000,000 acres were in plowable pasture. Also, on farms were about 166,000,000 acres in woodland and 464,000,000 acres in unplowable pasture, roads, farmsteads, corrals, stockyards, ponds, swamps, waterways, and waste land.

Since less than half the land is wholly unsuited to any type of tillage, it is evident that the potential area for crops is greatly in excess of that now used if all arable land in pasture and woods were put into crop, and drainage and irrigation were extended. Large areas of the more level range land in the Great Plains and Great Basin could be cropped if prices were high enough to justify the risks of submarginal agriculture.

Changes in national economic and trade policies could produce drastic adjustments in the acreage of certain crops. The growing of sugarcane, sugar beets, flax, and rice are feasible largely because of a protective tariff.

General Crop Areas

The principal geographic areas are the Atlantic coast to the Great Plains, the Great Plains, and the Pacific coast.

ATLANTIC COAST TO THE GREAT PLAINS

The corn and wheat belts (Figure 8) coincide with the deciduous forest and prairie centers.[31] The production of these crops is greatest between the 60 and 100 per cent rainfall-evaporation lines.

The area from Ohio to central Nebraska is remarkably suited to

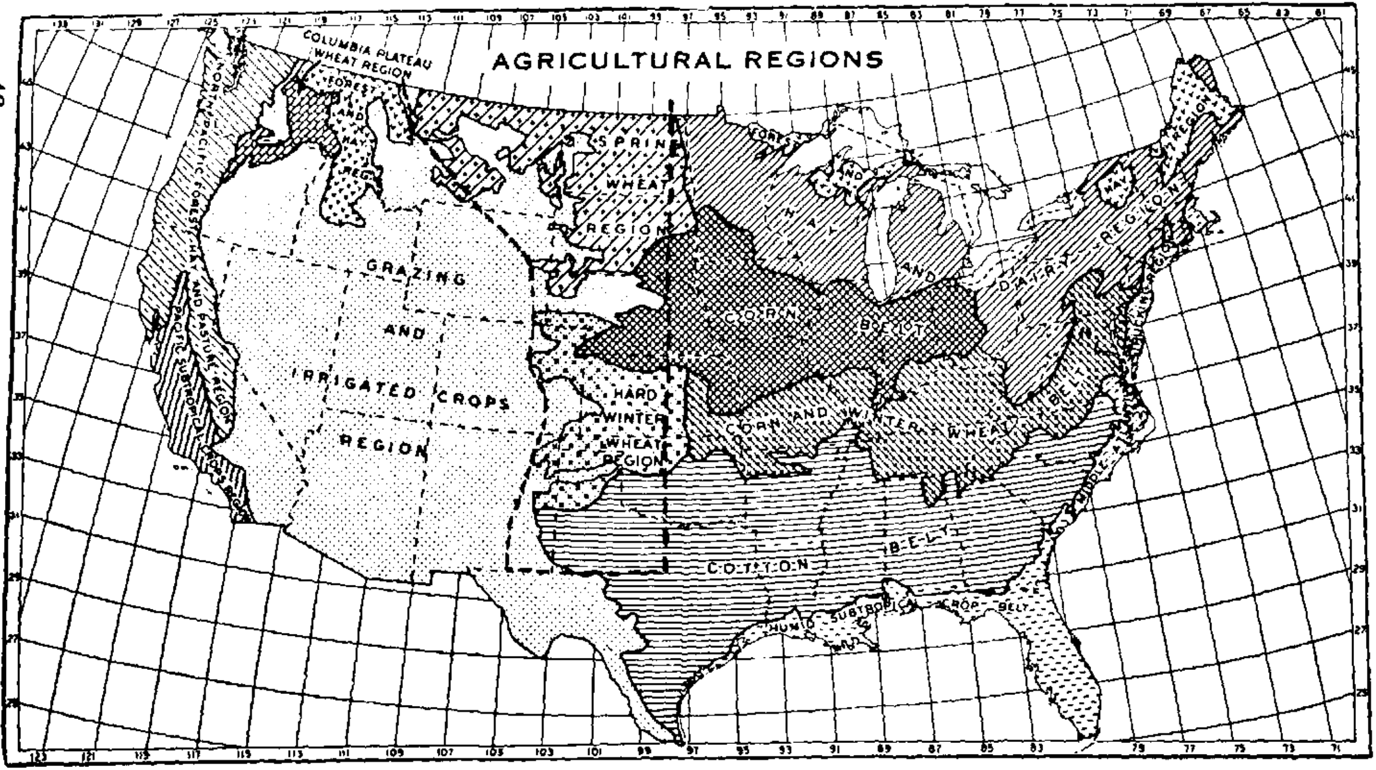


FIG. 8. Agricultural Regions. The Great Plains *is* the west-central area outlined.

corn production because of the hot summers, relatively high humidity, and an annual rainfall sufficient for plant growth. The geographic center of the corn belt is found in central Illinois where the soils are deep and rich in humus, and corn is well adapted. Further south, corn yields are less, owing to poorer soils, higher temperatures, intermittent droughts, and insect injury; there corn is unable to compete with cotton as a cash crop.

The center of wheat production lies west of the best corn lands, although wheat is well adapted and is grown on many farms in rotation with corn throughout the prairie and deciduous forest climaxes. Wheat is higher in protein when grown in a dry climate.

Oats center slightly north of the corn belt because of the cooler climatic conditions. Early disease-resistant varieties have pushed the center somewhat south.

The region southeast of the 100 per cent rainfall-evaporation ratio line is known ecologically as the southeast evergreen center. Cotton is the principal crop in this area, because of the high temperatures, and long growing season. In the cotton belt, cotton competes with grain and forage crops, tobacco, and peanuts, and on some soils, with sugarcane and rice.

The northern evergreen forest, north and east of the 110 per cent rainfall-evaporation ratio line, is devoted agriculturally to tame pastures and hay crops. The need for the bulkier hay and fodder crops, which grow well under the cool temperature conditions, makes cereal production less profitable in this region. Timothy is the principal hay crop. Rye and buckwheat are often grown on the poorer soils in this region.

GREAT PLAINS

In the western half of the country, evaporation consistently exceeds precipitation two or three times. To survive under such droughty conditions, the cultivated plants of the plains must be grown under the best methods known for conservation and utilization of the moisture captured by the soil. Irrigation is practiced, where stream flow and underground water supplies can be diverted to supplement the natural rainfall. Wheat is the major crop. Sorghums are grown in some of the more arid portions. Cotton, wheat, and sorghum predominate in the southern areas of the plains. Small grains, corn, flax, sorghum, and hay are grown in the northern parts.

PACIFIC COAST

The third distinct crop region, which is also defined by climate, is the Pacific coast. The northern half of this region is devoted primarily to feed, seed, special purpose, and horticultural crops. Wheat is an important crop in the intermountain section east of the Cascade Mountains in Oregon and Washington. The southern half of the Pacific coast is devoted to fruits, vegetables, and many different field crops, especially under irrigation.

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3 BOTANY OF CROP PLANTS

General Nature of Crop Plants

Most of the important crop plants are reproduced by seeds, and all are classified as spermatophytes or seed plants. In the life cycle of these plants the seed germinates and produces a seedling. The vegetative phase is characterized by increases in the number and size of roots, stems, and leaves. Finally the reproductive phase is reached in which the plant flowers and produces seeds.

The Plant Cell

Plants are composed of units called cells. A living cell contains protoplasm, the life substance of the plant organism. The denser central area of the protoplasm is the nucleus, which is embedded in the outer cytoplasm. The nucleus contains the chromosomes, the carriers of heredity. The cytoplasm contains chloroplasts, which in turn contain chlorophyll, the essential constituent of green plants. The cell is surrounded by a cell wall made up chiefly of cellulose. Cells differ in size and shape in accordance with their special functions (Figure 9).

All living cells give off carbon dioxide and absorb oxygen. This exchange of gases, known as respiration, is accomplished by the breaking down of sugars and the oxidation of the carbon in the sugar into carbon dioxide. The most important aspect of respiration is the consequent release of energy necessary for growth and maintenance of the plant.

Structure and Functions of Crop Plants

ROOTS

Sometimes as much as one-half, and in certain root crops more than one-half, of a crop plant is underground. The underground

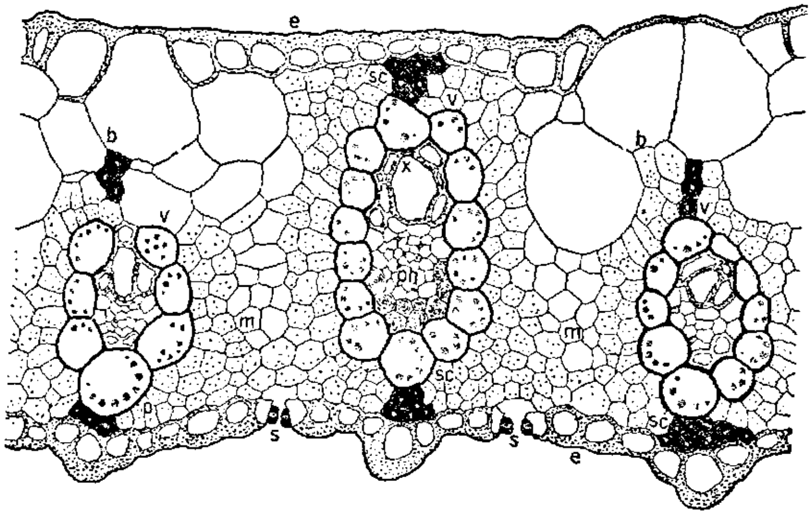


FIG. 9. Cells observable in a cross-section of a sugarcane leaf, a typical grass leaf: (b) bulliform or motor cells that shrink when the leaf wilts and cause the leaf to roll up, and later take up water, expand and flatten out the leaf; (e) epidermal cells; (m) mesophyll cells; (p) palisade-shaped cell of mesophyll; (ph) phloem; (s) stoma; (sc) sclerenchyma (stiffening) cells; (v) vascular bundle containing phloem and xylem; (x) xylem. (After Artschwager.)

plant parts are fully as important as the tops because water and mineral nutrients used by the plant are absorbed from the soil by the roots.[35]

Kinds of Roots. Two general types of roots are found in crop plants, fibrous roots and tap roots. Certain weeds, e.g., Canada thistle (Figure 10), field bindweed, and leafy spurge, also have lateral roots that send up new shoots which in turn establish new root systems.

Plants of cereals and other grasses have fibrous roots, i.e., many slender roots similar in diameter and length, and somewhat smaller branches. The seminal or primary roots develop when the seed germinates, growing from the lower end of the embryo. These roots sometimes have been erroneously called temporary roots in the belief that they function only in the earlier growth stages. They often remain active until the plant matures.[21, 22, 37] The seminal roots of corn often penetrate to a depth of 5 or 6 feet. In wheat they are the chief support of the main stem of the plant. Sorghum, rice, and proso produce only a single branched seminal root. After the young plant unfolds a few leaves, the coronal (crown or nodal) roots arising from stem nodes underground develop into an elaborate root system. Coronal roots arise about 1 inch, more or less, below the soil surface, even though the seed be planted much deeper. The subcrown internode between the seed and crown elongates until stopped by light striking the emerging coleoptile. At that stage the crown node is still below the surface. Frequently, roots grow from nodes above the soil surface as, for example, brace (or aerial) roots of corn. They are unbranched above the ground but are the same as other roots once they enter the soil.

Other crop plants, such as the sugar beet and other root crops, and the legumes, have a main taproot. The main root develops and pushes straight downward. It may branch throughout its length. The thickened taproot of biennial and perennial plants often serves as an organ for food storage.

The smallest subdivisions of the roots are the root hairs, the single-celled structures found on roots and root branches of both fibrous-rooted and tap-rooted plants.

Extent of Root Systems. Elongation at the rate of ½ inch per day is common in roots of many grasses. Seminal roots of winter wheat [36] may grow at that rate for 70 days. The main vertical roots of corn grow 2 to 2½ inches per day for a period of 3 or 4 weeks. Plant roots

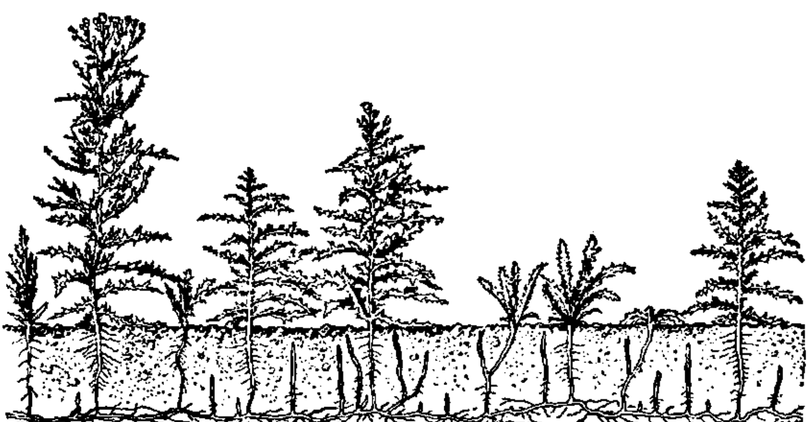


FIG. 10. Lateral roots of Canada thistle.

may extend as far or farther below the ground than the plant does above. The root system of a corn plant given ample space may occupy 200 cubic feet of soil. A corn plant grown 5 weeks in a loose soil produced 19 main roots with 1462 branches of the first order. Upon these were 3221 branches of the second and third orders. The main roots consisted of 4 to 5 per cent of the total root length, the primary branches 47 to 67 per cent, and the finer secondary and tertiary laterals 29 to 48 per cent of the total. A rather high correlation between root and top growth is found in corn.[38] Given ample space, the roots of a single plant may have a total spread of 4 feet in wheat, 8 feet in corn, and 12 feet in sorghum. Roots of small grains, corn, sorghum, and perennial grasses normally penetrate downward 3 to 6 feet and sometimes extend 8 or 10 feet. Alfalfa roots may penetrate more than 30 feet. The length of the entire root system, including all branches of a single large isolated plant of crested wheatgrass may be as much as 360 miles.[26]

The roots grow in moist soil but most crop plants do not extend roots into water-logged soil. The roots can penetrate short distances into dry soil when moisture for growth is supplied from roots penetrating adjacent moist soil.[5]

Absorption. Plants absorb water and the substances dissolved in it, viz., nitrogen and other mineral elements, largely through the root hairs. The root hairs absorb water by osmosis, and their walls act as differential membranes in selecting the different ions that the plants absorb. When the cell sap is more concentrated than the soil solution, water passes into the root hairs; this occurs except under very abnormal soil conditions. The rate of absorption of water may vary with the osmotic pressure of the cell.[24]

The more a plant needs water the more vigorously it is absorbed, provided the water supply remains ample. Water taken up in excess of the ability of the plant to transpire water vapor through the stomata is forced out through pores in the leaf called hydathodes. Most of the so-called dew drops are actually water globules from hydathodes. Plasmolysis (or cell collapse) results when the soil solution is more concentrated than that in the root hair and other cells. Such a condition may be found in highly saline, or "alkali," soils where water is actually withdrawn from the plant.

Nutrients are absorbed independently of the rate of water intake, being taken into the plant as ions by diffusion. Thus it is possible for mineral nutrients to be absorbed when the atmosphere is saturated and little water is being taken up and none is being transpired. Minerals in solution tend to pass through the differential cell membrane and reach an equilibrium. For instance, potassium nitrate (KNO_3) dissolves and becomes dissociated into K^+ and NO_3^- ions. These ions tend to reach an equilibrium regardless of the total concentration in the two solutions inside and outside the cell membrane.

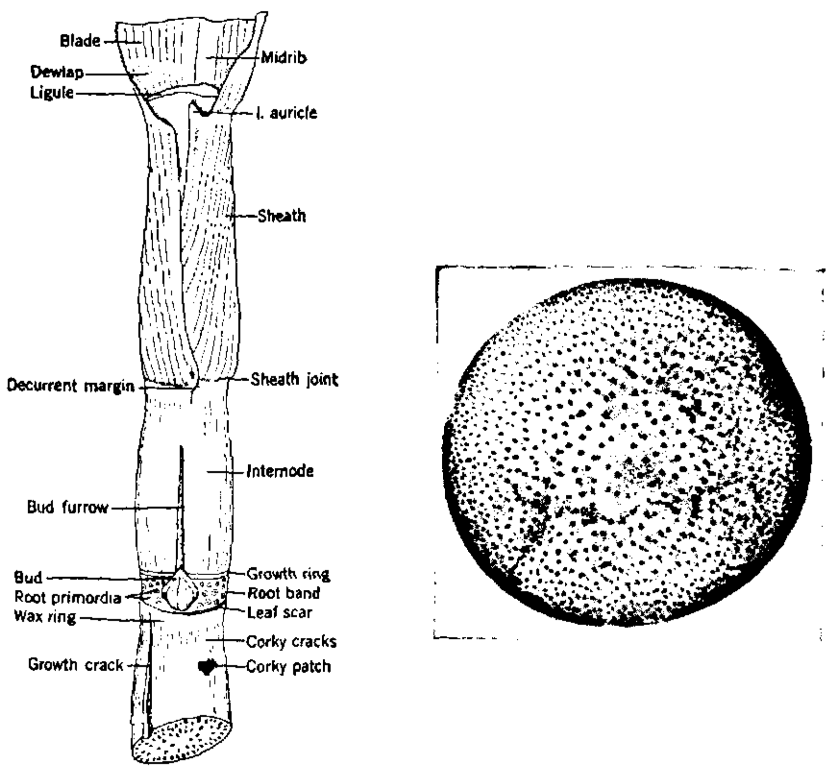


FIG. 11. (*Left*) A portion of the stem of sugarcane. A branch may arise from the bud at the node. (*Right*) Cross-section of sugarcane stem. The vascular strands are scattered through the pith and rind. The stems of corn and sorghum are similar except that more of the strands are concentrated in the outer rind. (After Artschwager.)

STEMS AND MODIFIED STEMS

After a grain of wheat germinates, the plumule internodes elongate into the first young stem. Stem elongation continues by growth (cell division and cell elongation) at the growth ring above each successive node while the cells are young and active. Growth in the diameter of the stem of cereals and other grasses is due to cell enlargement, not cell division, after the essential stem structures have been formed.

In dicotyledonous crop plants, i.e., those other than cereals and other grasses, growth is much like that of a tree, with new branches arising from buds or adventitious cells and the branches elongating by cell division and cell enlargement near the tips. Growth in diameter comes from cell division in the cambium layer under the bark or periderm, followed by cell enlargement.

General Nature of Stems. The stem is divided by joints or nodes, the stem section between the nodes being called internodes (Figure 11). In grasses the internodes when young are solid, i.e., filled with pith.[14] At maturity the pith usually disappears, sugarcane, corn, and sorghums being exceptions (Figure 11). The stem or culm of a grass is usually cylindrical or nearly so. The culms of most grasses die down to the soil surface each year, or usually after the seed has matured. Sugarcane may require more than a year after planting to reach maturity. In addition to the main stem, several branches known as tillers arise from the lower nodes (Figure 12). Large numbers of tillers may arise under favorable environmental conditions, each tiller developing a root system of its own.

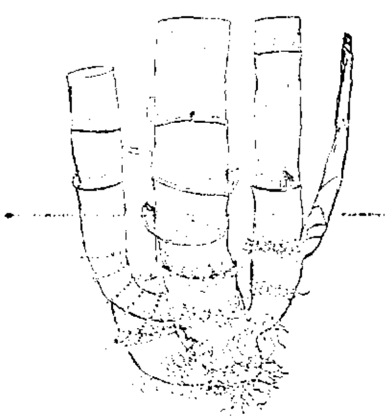


FIG. 12. Sugarcane tillers arise from the main culm or from other tillers and then send out their own roots. (After Artschwager.)

The type of stem may not remain the same during the entire life of the plant.[28] Sometimes the primary axis within the plumule remains so short that the leaves arise crowded together, usually in the form of a rosette. Winter annuals, e.g., winter wheat, exhibit this habit until sometime in the spring. Sugar beet and mangel plants have short contracted internodes during the first year. In the second year, the growing point of the stem, hidden in the center of the rosette, elongates and produces a shoot with long internodes and with the leaves at considerable intervals. Seed is produced on these shoots.

Temperature and day length may affect the growth habit of a plant. Thus certain varieties of winter oats may show a spreading habit when sown in the fall and an erect habit when sown in the spring.

A bud is an undeveloped stem, leaf, or flower. Buds may be terminal on the stem, axillary (side), supernumerary, or adventitious (arising out of order). Many buds are dormant.

Modified Stems. Several types of modified stems are recognized. These include:

(1) Rhizomes. Rhizomes (rootstalks) are underground horizontally elongated stems that bear scales at the nodes. They may arise extravaginally, i.e., the stems burst through leaf sheaths of older stems and elongate horizontally below the soil surface. Rhizomes produce new stem shoots from their joints, and this serves to propagate the plant. Some of the most pernicious weeds, quackgrass and Johnson grass (Figure 13), have rhizomes. Many desirable pasture plants, such as bromegrass and Kentucky bluegrass, are extravaginal or sod-forming grasses.

(2) Stolons. Stolons are modified propagative stems produced above ground, as in buffalo grass.

(3) Tubers. A fleshy underground stem is known as a tuber. Examples are the potato and the Jerusalem artichoke.

Lodging of Stems. Resistance to lodging, or the capacity of stems to withstand the adverse effects of rain and wind, is an important quality in cereals. Resistance to lodging often is a varietal character, but its expression is modified by environment. A thick heavy growth keeps much of the sunlight from reaching the base of the stems. Reduced light or shading causes the cell walls of the stems to be

FIG. 13. Rhizomes of Johnson grass.

thin and weak. No single morphological factor can be used as an index of standing power.[1] Abundant soil nitrogen may produce a lush growth that leads to increased lodging. Lodging may result from a low content of dry matter per unit length of culm,[39] or from a reduced content of lignin or of certain reserve di- and polysaccharides in the stem. Short, thick, heavy stems with thick cell walls are the best insurance against lodging.[2]

When a grass stem lodges before maturity it usually bends upward as a result of cell elongation on the lower side of the nodes. This in turn is the result of a response to an apogeotropic (opposed to gravity) stimulus. When a stem of a dicotyledonous plant is lodged the terminal portion tends to become erect also because of the same response. The thickened nodal tissue, which functions as above described to bend up the stem, occurs in both the sheath and culm of some grass plants, e.g., sorghum and corn, but is found only at the base of the sheath in wheat, oats, barley, and rye.

Functions of Stems. The functions of stems are as follows:[30]

(1) Conduction of water and mineral solutes from the soil chiefly through the vessels of the xylem, and of synthesized food materials through the phloem from the leaves to other parts of the plant.

(2) Support and protection of plant organs and display of leaves and flowers to the sunlight and to aid pollination.

(3) Storage of food materials as in sugarcane and sorgo.

(4) Manufacture of carbohydrates in the young stems containing chlorophyll.

LEAVES

Leaves arise from buds and are side or lateral appendages of the plant stem. Leaves are generally concerned with photosynthesis and transpiration.

General Characteristics. The principal parts of a leaf are the blade (or lamina) and the petiole or leaf stalk. Some leaves have stipules, which are two small leaves at the base of the petiole. The leaf is said to be sessile when the petiole is absent. Ordinary green foliage leaves may be classified as:

(1) Parallel-veined leaves of the grasses, which contain many veins about equal in size that run parallel and are joined by inconspicuous veinlets. Growth of such leaves takes place by elongation near the base.

(2) Netted-veined leaves, which have a few prominent veins with a large number of minor veins. Netted-veined leaves are found in all crop plants other than grasses.

Photosynthesis. The manufacture of food substances from carbon dioxide, water, and nutrient elements in the presence of light and chlorophyll is known as photosynthesis. The air near the surface of the earth normally contains about 0.04 per cent carbon dioxide.

In the process of photosynthesis carbon dioxide enters the plant through the stomata (breathing pores).[24] The carbon combines with water to form carbohydrates, while the oxygen is given off as a gas. Simultaneously with carbon assimilation in the green leaf, water is assimilated. Simple carbohydrates, such as sugars and starches, are formed by photosynthesis, but these then may be condensed into higher sugars and starches, hemicelluloses, celluloses, lignin, and other substances. Proteins are formed by combinations of organic substances with nitrogen and sulfur during photosynthesis. The energy for the photosynthetic process is supplied by the sun. The red and yellow rays of the sun are caught by the chlorophyll in the green leaves and transformed from radiant to chemical energy. The simple over-all equation commonly given for photosynthesis is as follows:

$$6\,CO_2 + 6\,H_2O + \text{sunlight} \longrightarrow C_6H_{12}O_6\ (\text{glucose}) + 6\,O_2.$$

The rate of photosynthesis increases with light intensity up to a certain point. An increase in carbon dioxide content of the atmosphere and an increase in temperature leads to increased photosynthesis within certain limits. About 85 to 95 per cent of the dry matter of the plant is made up of carbon, oxygen, and hydrogen in the form of organic materials manufactured in the leaves from carbon dioxide and water. The soil mass contributes the other 5 to 15 per cent in the form of mineral elements.

Chlorophyll deficiencies in plants may be caused by any of several conditions. Etiolation (white to yellowish foliage) results when plants ordinarily green are grown in darkness or deficient light. Chlorosis is a chlorophyll-deficient condition caused usually by the lack of available iron or magnesium in the tissues. Chlorophyll deficiencies may be caused by disease, as for example, mosaic in potatoes and tobacco. Certain deficiencies are hereditary, such as those found in albino seedlings and those with various shades and patterns of yellow or white. These, occasionally found in the seedlings of many crop plants, are due to the absence of hereditary factors essential to the normal process of chlorophyll formation or iron nutrition. Many heritable chlorophyll deficiencies, including all permanent albinos, are lethal, i.e., they lead to the death of the plant when the reserve food is exhausted.

TRANSPIRATION

Transpiration is the loss of water in a vapor form from a living plant or plant part. Nearly all the water taken in by plants is transpired, but a plant is unable to grow unless it has sufficient water at its disposal. Transpiration may take place from any part not covered by layer cork or cuticle, but it is usually through the stomata. The harmful effects of transpiration, i.e., wilting of the plant and exhaustion of soil moisture, generally outweigh the possible benefits attributed to the process. The possible benefits are:

cooling the leaves, rapid conduction of soil solutes, and more rapid dissolving of carbon dioxide.[7]

Transpiration occurs as follows: [17]

(1) The cell wall imbibes water from the cell contents. The water in the cell wall is then at a higher concentration than the surrounding gaseous environment of the substomatal cavity.

(2) The water evaporates from the cell wall and raises the concentration of water vapor in the cavity.

(3) This water vapor diffuses out through the stomata since the air in the substomatal cavity is more highly saturated than the outside air. Guard cells, which surround the stomatal opening, open and close with changes in the water balance.

The following conditions influence the rate of transpiration:

(1) Capacity of the leaves to supply water.

(2) Power of the aerial environment to extract water from the leaves, i.e., humidity, light, temperature, and wind influence.

(3) Structure of the transpiration parts, i.e., the number of stomata and the sizes of the openings.

(4) Modifications that tend to check excessive evaporation, including reduced plant surfaces, sunken stomata in special epidermal cavities, thickened cuticle, and waxy bloom on the cuticle of leaves and stems. A waxy bloom is conspicuous on sugarcane, sorghum, wheat, and barley.

Crop plants transpire 200 to 1000 pounds of water for every pound of dry matter produced, which means that the water requirement or *transpiration ratio* usually ranges from 200 to 1000 for different crops. Thus each acre-inch of rainfall (113 tons) stored in the soil and protected from evaporation would produce from 1130 pounds down to 226 pounds of dry matter in the form of crops. For a given crop, the transpiration ratio depends not only upon the factors mentioned above that influence transpiration rate, but also upon the growth and adaptation of the crop to the particular environment. Soil of high fertility, and a large volume of soil in which the roots can feed, contribute to a lower transpiration ratio than occurs with less favorable soil conditions.[17] Also, oats have a comparatively high water requirement when the temperatures are too high for optimum growth, under which conditions the warm-weather crops—sorghum and cotton—are relatively more efficient in the use of water.[32] In a cool season, the reverse may be true.

Crops having the lowest water requirement include millets, sorghum, and corn; the small grains are intermediate, whereas legumes such as alfalfa are relatively high in water requirement. The transpiration ratio is not necessarily a measure of the ability of a crop to produce well under drought conditions.[23] It merely measures the water transpired by the plants when the soil is supplied with water for optimum plant growth. For example, field peas and field beans (which have a high water requirement) are grown successfully in rows under dryland conditions where fair yields of seed are obtained from relatively small plant growth. The high value of the product compensates for the low production.

The adaptation of a crop to drought conditions depends also upon:

(1) Drought escapement or evasion, i.e., ability to complete its growth cycle before soil moisture is exhausted, e.g., early maturing varieties of small grain.

(2) Drought tolerance, i.e., the ability of the plant to withstand drying and recover later when moisture becomes available, e.g., sorghum.

(3) The ability of the plant to adjust its growth and development to the available water supply. Thus cotton not only regulates its growth with the moisture supply but also sheds squares (flower buds), flowers, some of the bolls and, finally, many of the leaves when moisture continues to be deficient. A so-called drought-resistant crop or crop variety shows one or more of these characteristics described above.

A summary of water requirements of several crops and pigweed (*Amaranthus retroflexus*) at Akron, Colorado, reported by Shantz and Piemeisel[32] is shown in the table on page 63. The lowest water requirement occurred in 1915, a cool year of high rainfall.

Weighted mean water requirements of other crops and weeds were as follows: proso 267, Sudan grass 380, sugar beet 377, buckwheat 540, potato 575, spring rye 634, red clover 698, bean 700, hairy vetch 587, soybean 646, sweetclover 731, field pea 747, flax 783, crested wheatgrass 678, bromegrass 828, Russian thistle 314,

WATER REQUIREMENTS OF CROPS AND PIGWEED AT AKRON, COLO.

CROP	*1913*	*1914*	*1915*	*1916*	*1917*	AVERAGE
Alfalfa	834	890	695	1047	822	858
Oats	617	599	448	876	635	635
Cowpeas	571	659	413	767	481	578
Cotton	657	574	443	612	522	562
Barley	513	501	404	664	522	521
Wheat	496	518	405	636	471	505
Corn	399	368	253	495	346	372
Blue gramagrass	389	389	312	336	290	343
Pigweed	320	306	229	340	307	300
Millet	286	295	202	367	284	287
Sorghum	298	284	203	296	272	271

purslane 281, and lambsquarter 658. All these water requirements are based not upon crop products but upon total dry matter in the plant above the ground, except for the sugar beet, in which case the roots also were harvested.

The water balance is the relation between absorption and loss of water by the plant.[23] There is a deficit when absorption is exceeded by water loss. A deficit often occurs in midday when transpiration exceeds absorption and plants show signs of wilting and leaf rolling. Increased and permanent wilting may cause injury and lead to complete ruin. *Permanent wilting* is defined as the point at which a plant cannot recover when placed in a saturated atmosphere. Plant species that endure great water loss without injury (e.g., guayule) are called xerophytes, those requiring medium supplies of water (most crop plants) are called mesophytes, while those growing best with abundant water, including aquatics (e.g., wild rice), are called hydrophytes. Important characteristics of xerophytes are high concentrations of cell sap, or high content of colloidal material or coverings that retard evaporation and ability to recover after drying. Many anatomical characters associated with drought resistant plants do not limit transpiration but permit a greater plasticity in growth, reproduction, or survival. They develop their vital functions with great intensity when there is sufficient water.

Reproductive Processes in Crop Plants

Crop plants reproduce either (a) sexually, i.e., by the fertilization of flowers to produce seeds, or (b) asexually.

ASEXUAL REPRODUCTION

Crop plants normally produced asexually, and the plant part used in propagation include the following:

(1) Roots—sweetpotato, cassava, kudzu.
(2) Tubers—potato, Jerusalem artichoke.
(3) Stolons—buffalo grass, creeping bent, Bermuda grass.
(4) Rhizomes—Bermuda grass.
(5) Stem cuttings—sugarcane, Napier grass.

Asexual reproduction perpetuates uniform progeny except for an occasional bud mutation such as the sudden appearance of a red tuber in a white variety of potato. Many varieties that are uniform when propagated asexually are found to be extremely heterozygous (or variable) in their hereditary make-up when propagated from seeds.

SEXUAL REPRODUCTION

The types of floral arrangement involved in sexual reproduction are as follows:

(1) Perfect or bisexual flowers contain both stamens and pistils. Most crop plants have perfect flowers although some of them are more or less self-sterile. Some unisexual flowers are found on crop plants that are bisexual, e.g., sorghum and barley.

(2) Imperfect or unisexual flowers contain either stamens or pistils but not both.

When the separate staminate and pistillate flowers are borne on the same plant, the plants are called monoecious. Examples of these are corn, castorbean, and wild rice.

When the two kinds of flowers are borne on separate plants, the plants are dioecious. These include hemp, hops, and buffalo grass.

An exception to ordinary sexual reproduction is a process called apomixis, a form of pathenogenesis or the production of seed by a stimulation of the ovary without fertilization. This is a common method of seed formation in Kentucky bluegrass, and consequently cross-pollination is rather rare in that crop.

Sexually propagated crop plants may be grouped into three general classes, on the basis of their normal habit of pollination. These are: (1) naturally self-pollinated, (2) often cross-pollinated, and (3) naturally cross-pollinated.

(1) Naturally self-pollinated. Crop plants naturally self-pollinated, including wheat, oats, barley, tobacco, potatoes, flax, rice, field peas, cowpeas, and soybeans, usually show less than 4 per cent of cross-pollination. The percentage of cross-pollination in these crops varies with variety and season or environment.[4, 8, 10, 31, 34] Any environmental or hereditary factor that interferes with normal pollination or fertilization may result in a high proportion of cross-pollination. In naturally self-pollinated plants, the pistil usually is pollinated by pollen from the same flower.

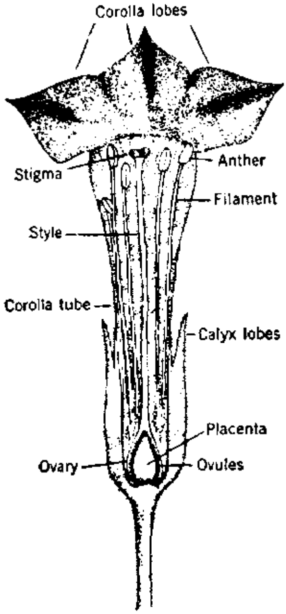
(2) Often cross-pollinated. These include cotton, sorghum, foxtail and proso millets, and several cultivated grasses. The pistil may be pollinated by pollen from the same flower or from another flower on the same plant or from another plant. Crossing among cotton flowers usually is due to insects, while that in the grass crops mentioned above is largely from air-borne pollen. Self-pollination usually is 94 to 95 per cent in sorghum.[33]

(3) Naturally cross-pollinated. Cross-pollination is the normal mode of reproduction in many crop plants, including maize, rye, clovers, alfalfa, buckwheat, sunflowers, some annual grasses, and most perennial cultivated grasses. The extent of self-pollination in corn is less than 5 per cent,[11] and sometimes as low as 0.7 per cent.[18] Most of the grasses are wind-pollinated, but buckwheat and legumes such as clovers and alfalfa are adapted to insect-pollination. Cross-pollination is essential to seed production in many plants of red clover, rye, and common buckwheat because of self-sterility.

Flowers. The flower arises from a bud either at the apex of the stem or in the leaf axil. Flowers are grouped on a more or less compact special shoot or axis called the inflorescence. The leaves on the inflorescence are known as bracts, while the axis is usually a rachis or a peduncle. An individual flower stalk is a pedicel.

A flower is composed of the stamens (male organs), pistils (female organs), calyx, and corolla (Figure 14). The latter two structures are replaced by glumes, lemma, and palea in the grasses.

The stamens and pistils are the organs of fertilization. The stamen is composed of a filament or stalk at the upper or outer end of which



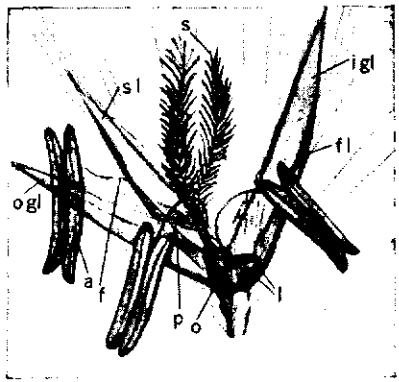


FIG. 14. (*Left*) A tobacco flower showing typical floral parts. (Drawn by H. A. Allard.) (*Right*) The parts of an opened grass (sugarcane) flower. (a) anther, (f) filament, (f l) fertile lemma, (i gl) inner glume, (l) lodicules, (o) ovary, (o gl) outer lemma, (p) palea, (s) stigmas and (s l) sterile lemma. (After Artschwager.)

is the anther. The interior lobes of the anthers are hollow spaces or pollen sacs in which the pollen is produced in the form of loose, round, pollen grains. Finally, each sac splits open (dehisces) to allow the pollen to escape. The pistil is composed of the stigma, style, and ovary. The ovary is the swollen, hollow base of the pistil (Figures 15, 16 & 17). The elongated portion is the style, at the apex of which is the stigma. The ovary contains the ovules, which are attached to the ovary walls. The ovule is generally an egg-shaped body.

In the grasses the flowers at the time of fertilization are forced open by the swelling of two small organs called lodicules, which lie between the ovary and the surrounding lemma and palea.

The perianth, composed of the calyx and corolla, is a nonessential part of the flower, except that it may aid in the attraction of insects. The calyx is made up of sepals which enclose the other floral parts

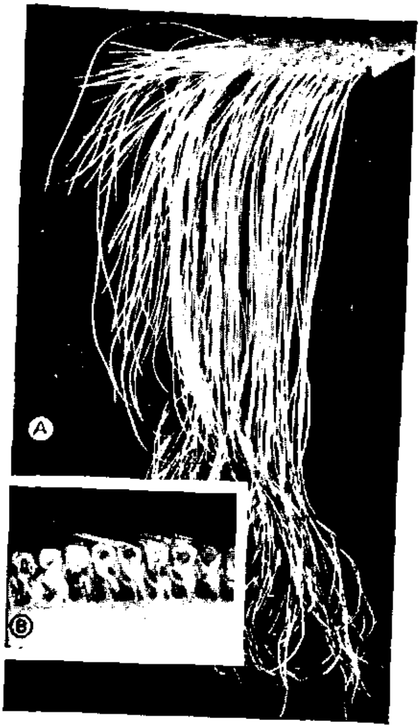


FIG. 15. Pistillate inflorescence of maize. (A) Unpollinated ear and silks. (B) Enlarged ovaries showing attachment of silks.

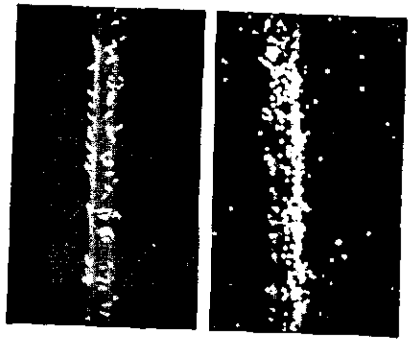


FIG. 16. Section of corn silk enlarged: unpollinated (*left*); pollinated (*right*).

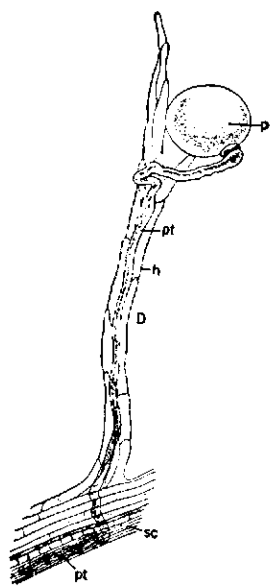


FIG. 17. Germinated maize pollen grain (p) and pollen tube (pt) passing down through stigma hair (h) into silk (sc). (After Miller.)

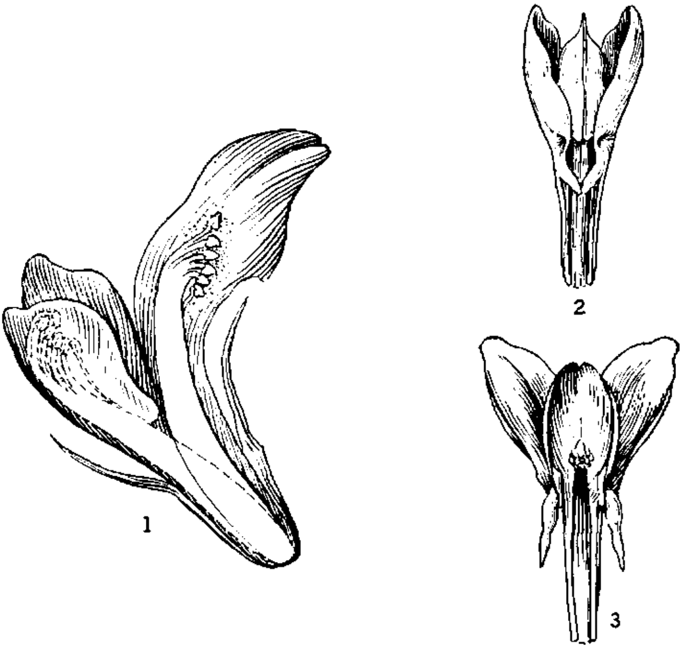


FIG. 18. Alfalfa flower, typical of legumes. (1) Opened flower showing position of style and anthers before tripping at left and after tripping at right. The large segment of the corolla at right is the "banner." (2) Unopened flower with the banner removed. (3) Open flower with banner removed to show the two wings (left and right), the two "petals" of the keel fused at rear, and the style and anthers at front.

in the bud and thus protect the young flower. The corolla is generally the showy part of the flower, being composed of petals (Figure 18).

Process of Fertilization. The ovule is composed of a nucellus surrounded by an inner and outer integument. The embryo sac is within the nucellus (Figure 19), and contains eight nuclei which are as follows: two synergids, and one egg cell at the micropylar end; three antipodal cells at the opposite end; and two endosperm or polar nuclei near the center. Pollen grains falling on the stigma of the pi til germinate in the sticky stigmatic excretion. The germinated pollen grain contains a tube nucleus and two sperm nuclei. The tube nucleus develops a pollen tube that elongates down through the style to the embryo sac. The pollen tube usually grows in the intercellular spaces of the style. One sperm nucleus unites with the egg cell while the other fuses with the two polar nuclei. The fusion of the second male nucleus with the polar nuclei has been termed double fertilization, which is believed to occur in all flowering plants. The mechanism of double fertilization accounts for the phenomenon of xenia, or the immediate observable effect of foreign pollen on the endosperm. The classical example is the various endosperm colors in maize produced by foreign pollen, which are evident as soon as the outcrossed grains ripen. Xenia has also been observed in rye, rice, barley, sorghum, peas, beans, and flax. When the pericarp or other maternal tissue also is modified by double fertilization as a result of adjustment to a change in size or shape of the affected endosperm, the process is called metaxenia. Fertilization in corn takes place within 26 to 28 hours after pollination.[25] In barley, Pope[29] found that the pollen germinated within 5 minutes after reaching the stigma, the male nuclei had entered the egg sac within 45 minutes, and the fertilized egg had begun division within 15 hours. Flax pollen germinates and the pollen tube penetrates to the base of the style in about 4 hours after pollination as determined by A. C. Dillman.

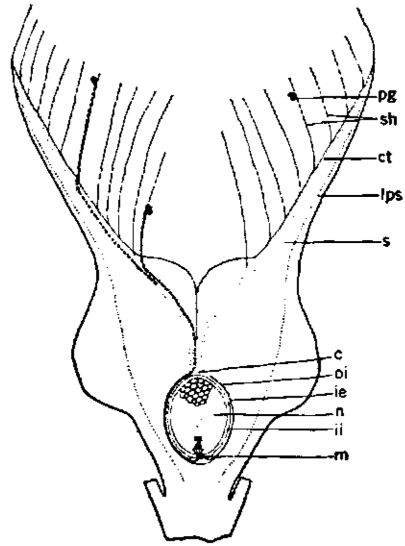


FIG. 19. The barley pistil, (c) cone-shaped tip of outer integument, (ie) inner epidermis of ovary wall, (ii) inner integument, (lps) lateral procambial strands, (m) micropyle, (n) nucellus which contains the embryo sac, (oi) outer integument, (pg) pollen grain, (s) style, and (sh) stigma hair. The broken line shows the course of the pollen tube from pollen grain to micropyle (m). Above the micropyle are two synergids and the egg nucleus, and above the latter are the two endosperm nuclei. The 3 antipodal cells higher up have already divided several times.

Crop seeds develop rapidly after pollination, being fully mature within 4 to 6 weeks in many crops and up to 9 weeks in others.

Seeds and Fruits

A representative mature seed consists of the seed coat (testa), nucellus, endosperm, and embryo. The embryo or germ is composed of the plumule (leaves), hypocotyl (stem), radicle (root), and one or two cotyledons. The seed may be defined as a matured ovule. The bean is a good example of a seed. It is attached to the ovary wall (pod) by a short stalk termed the funicle. The hilum is an elongated scar on the bean where the funicle was attached. Close to one end of the hilum is a small opening called the micropyle. A seed coat or testa covers the bean, beneath which are two fleshy halves called cotyledons. A typical endosperm is lacking in the bean, the cotyledons occupying most of the space within the seed coat.

A fruit is a matured ovary. It contains the seeds or matured ovules. The mature ovary wall is known as the pericarp. The entire bean pod is a fruit (Figure 20) but the *beans* are seeds. The buckwheat fruit (achene) and the grass fruit (caryopsis) are commonly called seeds.

In the indehiscent dry fruits, the pericarp is dry, woody, or leathery in texture, and does not split or open along any definite lines. The achene is a one-seeded fruit in which the pericarp can be readily separated from the seed as, for example, in buckwheat. The caryopsis of cereals and grasses is a one-seeded fruit. The seed within it is united with the ovary wall or pericarp. Percival [28] describes the wheat kernel as a kind of nut with a single seed. The wheat kernel (caryopsis) consists of the pericarp, endosperm, and embryo. The outer rim of the embryo is the scutellum, flattened, somewhat fleshy, shield-shaped structure which lies back of the plumule and close to the endosperm. The scutellum is regarded as the single cotyledon of a grass "seed."

In the dehiscent dry fruits, the pericarp splits in various ways or opens by pores. The seeds on the interior of the fruit are thus set free. The legume pod or fruit dehisces along two sutures, as in field peas or beans. In red clover, the capsule dehisces transversally, the upper part of the carpels falling off in the form of a cap or lid.

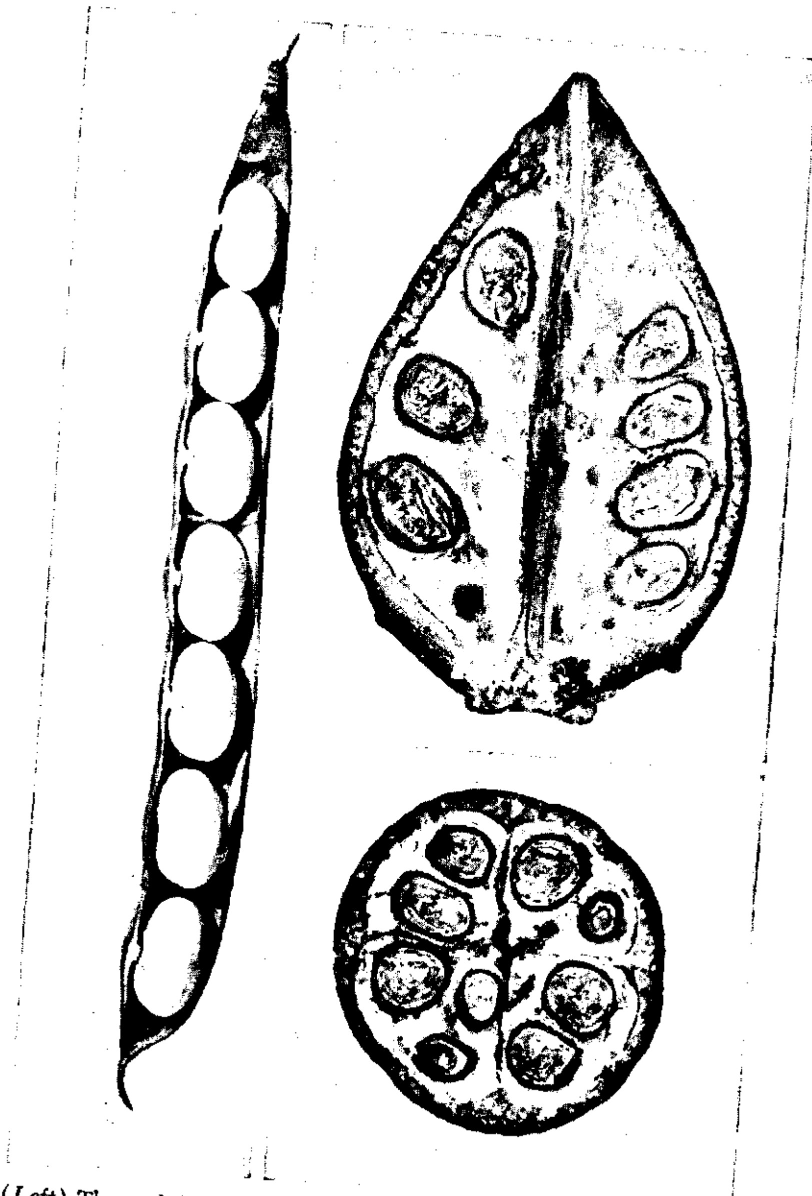


FIG. 20 (*Left*) The pod (fruit) and seeds (ovules) of the Pinto bean. (*Right*) Half of fruit (boll or capsule), and seeds (ovules) of cotton; the cross-section (below) shows 4 locks.

Growth Processes in Crop Plants

Growing plants pass through a gradual and regular vegetative cycle followed by maturity and reproduction.[16] The vegetative growth of most plants is characterized by three phases, viz., an initial slow start, a period in which the growth rate becomes gradually faster, and finally a period when it slows down again. Growth curves of sorghum [3] are shown in Figure 21. The processes involved in growth are extremely complex. Growth is usually measured by the amount of solid material or dry matter produced. This is often

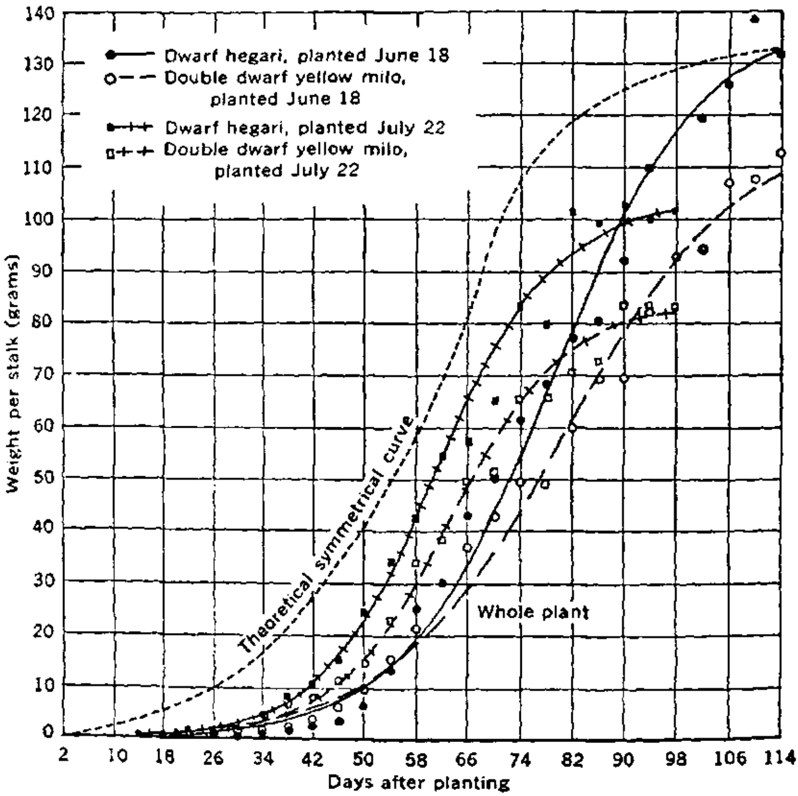


FIG. 21. Most crop plants, e.g., corn and barley, show a growth rate similar to the theoretical symmetrical curve. The sorghums, Dwarf hegari and Double Dwarf Yellow milo, have smaller seeds in proportion to the ultimate plant size and therefore show a slow growth rate at the beginning.

expressed agriculturally as yield of all or part of the plant. Vegetative development is interrupted by the reproductive phase in which the flowers and seeds are formed. Different species and crop varieties have a characteristic though highly variable vegetative period. However, the onset of the reproductive period may be altered greatly by changes in environmental conditions. Thus, a soil rich in nitrogen will tend to keep down the carbon-nitrogen ratio and delay flowering in *nitronegative* crops such as wheat, barley, oats, most pasture grasses, mustard, alfalfa, and clover. The excess of carbohydrates over nitrogen is usually very great, i.e., the carbon-nitrogen ratio is high after the plant commences to flower. However, changes in the carbon-nitrogen ratio in the cotton plant may be merely incidental rather than fundamental to flowering.[9] *Nitropositive* crops, such as corn, sorghum, millet, cotton, tobacco, lupines, sunflower, perilla, and pepper are reported to flower earlier with abundant nitrogen. The flowering time of *nitroneutral* crops, such as buckwheat, hemp, soybeans, peas, and beans is not affected appreciably by supplies of available nitrogen. Moisture shortage may cause plants to flower abnormally early, as is often observed in a dry season. The length of the daily illumination period affects the time that plants flower. Temperature alone and in combination with the other above factors also affects the onset of flowering.

Plant Competition

Regulation of the kind and amount of plant competition is an important ecological phase of crop production. Weeds are destroyed to keep them from competing with crop plants. Crops are spaced to obtain maximum yields of suitable quality, a moderate amount of competition between plants not being detrimental on an acre basis. A "struggle for existence" results when plants are grouped or occur in communities in such a way that their demands for an essential factor are in excess of the supply. Competition is a powerful natural force that tends towards elimination or extinction of the weak competitors. It is purely a physical process, i.e., it is essentially a decrease in the amount of water, nutrients, and light that otherwise would be utilized by each individual plant. It increases with the density of the plant population.

WEED COMPETITION

In farm fields, crops are often confronted with serious competition with weeds. Success of the crop depends on the readiness and uniformity of germination under adverse conditions, ability to develop a large assimilation surface in the early seedling stage, the possession of a large number of stomata, and a root system with a large mass of fibrous roots close to the surface but with its main roots penetrating deeply.[27] Crop plants have been classified in order of decreasing competitive ability against weeds as follows: barley>rye>wheat>oats>flax. Common wild mustard (*Brassica arvensis*) and wild oats (*Avena fatua*) are vigorous competitors among the annual weeds.[1] Wild oat plants may adapt their growth to the height of the grain with which they are competing.[12] In a flax field, however, the wild oat plants quickly outstrip the shorter flax plants.

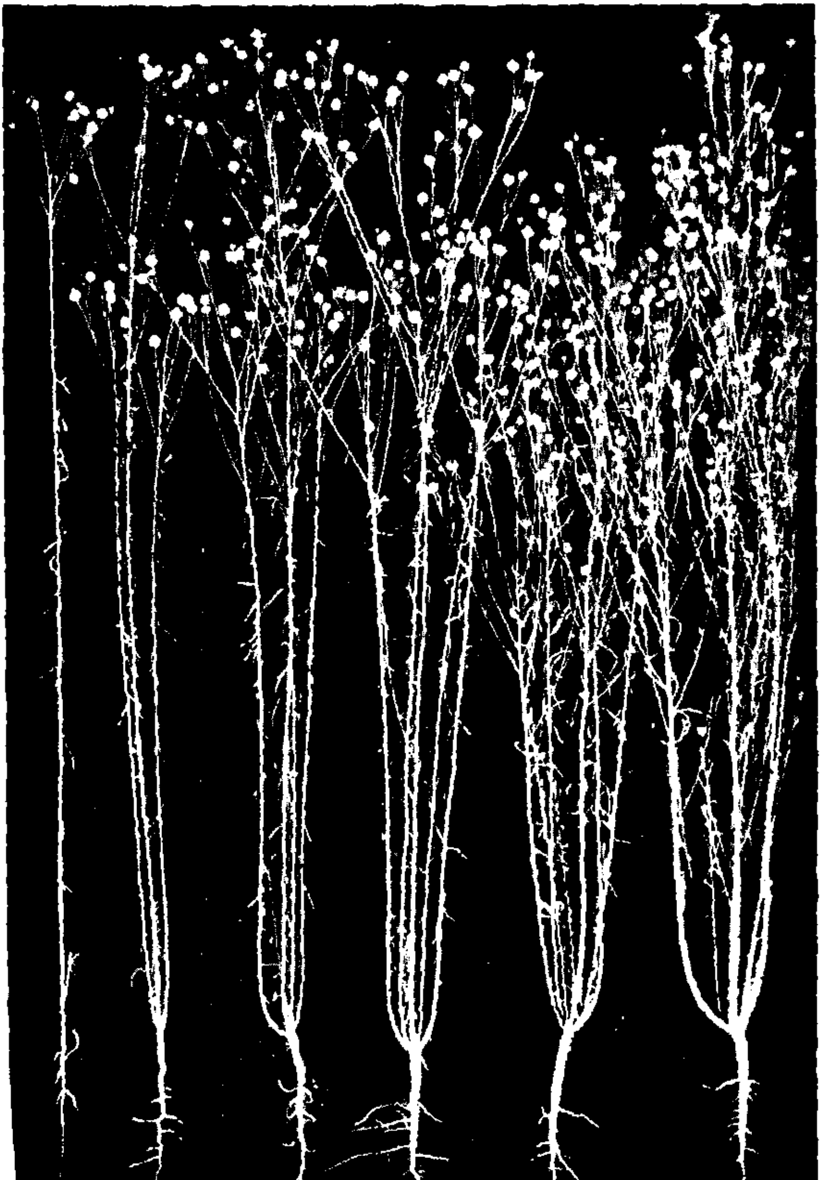
An important application of plant competition in agriculture is the use of so-called smother crops for weed control.

COMPETITION AMONG CULTIVATED CROPS

Competition is greatest between individuals of the same or closely related species because they make their demands for moisture, nutrients, and light at about the same time and at about the same level (Figure 22). Competition for moisture is especially important in dryland regions. In the grass crops competition for light reduces the number of heads, causes great irregularity in the number of tillers produced, diminishes the amount of dry matter formed, encourages shoot growth at the expense of root growth, and reduces the tillering, length of culm, and number of kernels per head.

The reduction in the yield of corn is not proportional to the reduction in stand, because of the adjustment of nearby plants that benefit by feeding in the space occupied by blank hills.[19] Considerable fluctuation in stand may occur without material effect on the final yield.

Sugar beets may respond to additional space so that they can increase in weight sufficiently to compensate for 96 per cent of the loss due to a blank hill.[6] Very close spacing in flax reduces the



48 12 6 4 3 2

FIG. 22. Representative flax plants grown at 6 different spacings. The single-stemmed plant at the left suffered from competition with other flax plants in the planting. The figures indicate the number of plants occupying a square foot.

height of plants materially.[20] As the space between plants increases there is an increase in number of bolls, yield per plant, weight per plant, and number of stems per plant.

In sorghum, within certain limits, medium-thick planting makes the plants taller because of greater competition for light. Very thick stands make the plants shorter because of inadequate moisture to support a good growth in so many plants.

Competition between different crop varieties causes marked changes in population after a few years when the original mixture comprises equal numbers of seeds of each variety. The ascendant varieties are not necessarily those that yield best when seeded alone.[13]

CROP ASSOCIATION

Competition between different crop species may not be so severe because one plant has an opportunity to fit in among some others. For example, in a mixture timothy and clover make different demands on the habitat at different times and at different soil depths. The more unlike plants are, the greater the differences in their needs.

In irrigated pastures in northern Colorado, it was found that competition played an important role in pasture mixtures. The most vigorous seedlings, especially of orchard grass, soon gained dominance even when seeded in amounts as small as 4 pounds in a total of 30 pounds of seed per acre. Kentucky bluegrass, white clover, and timothy suffered greatly in this competition.

Companion crops planted with new seedings of alfalfa, red clover, and similar crops to secure a return from the land the first year compete with the young seedlings, and usually are planted at about one-half the usual rate to reduce competition.

Mixtures of a small grain with a trailing vine legume such as vetch and field peas are very popular because the grain stems help support the legume vines. Korean lespedeza often is grown with small g ains. The planting of corn or sorghum with cowpeas, soybeans, or velvetbeans is widely practiced in the southeast with the object of increasing total yields as compared with the same crops grown alone. Some increase in yield is possible because of the different growing habits of the crops. In crop mixtures in which the cultural requirements for the individual crops are different, there may be sacrifice in quality or yield of one or both crops and an increase in production costs.

Botanical Classification of Crop Plants

METHOD OF BOTANICAL CLASSIFICATION

Botanical classification is based upon similarity of plant parts. Field crops belong to the Spermatophyte division of the plant kingdom, in which reproduction is carried on by seeds. Within this division the common crop plants belong to the subdivision angiosperms, which are characterized by having their ovules enclosed in an ovary wall. The angiosperms are divided into two classes, the monocotyledons and the dicotyledons. All the grasses, which include the cereals and sugarcane, are monocotyledonous plants. The legumes and other crop plants except the grasses are classified as dicotyledonous plants because the seeds have two cotyledons. These classes are subdivided into orders, families, genera, species, and varieties.

CROP PLANT FAMILIES

Most field crops belong to two botanical families, the grasses (Gramineae), and the legumes (Leguminoseae).

The Grass Family (*Gramineae*). The grass family includes about three-fourths of the cultivated forage crops and all the cereal crops. They are either annuals, winter annuals, or perennials. Grasses are almost all herbaceous (small nonwoody) plants, and usually with hollow cylindrical stems closed at the nodes,[14, 15] The stems are made up of nodes and internodes. The leaves are two-ranked and parallel-veined. These consist of two parts, the sheath which envelops the stem, and the blade. The roots are fibrous. The small, greenish flowers are collected in a compact or open inflorescence which is terminal on the stem. The flowers are usually perfect, small, and with no distinct perianth. The grain or caryopsis may be free as in wheat, or permanently enclosed in the floral bracts (lemma and palea), as in oats.

The Legume Family (*Leguminoseae*). Legumes may be annuals, biennials, or perennials. The leaves are alternate on the stems, stipulate, netted-veined, and mostly compound. The flowers are almost always arranged in racemes as in the pea, in heads as in the clovers, or in a spikelike raceme as in alfalfa. The flowers of field crop species of legumes are papilionaceous or butterflylike. The irregular flowers consist of five petals, a standard, two wings, and a keel that consists of two petals more or less united. The calyx is normally four or five toothed. The fruit is a pod containing one to several seeds. The seeds are usually without an endosperm, the two cotyledons being thick and full of stored food. Legumes have taproots. Often the roots have abnormal growths called nodules caused by the activities of a bacterium, *Rhizobium*, which has the ability to fix atmospheric nitrogen in their bodies and eventually in the plant residues.

The leading genera of legume field crops, all of which belong to the suborder Papilionaceae, are: *Trifolium* (clovers), *Medicago* (alfalfa, burclovers, and black medic), *Glycine* (soybean), *Lespedeza, Phaseolus* (field bean), *Pisum* (field pea), *Melilotus* (sweetclovers), *Vigna* (cowpea), *Vicia* (vetches), *Stizolobium* (velvetbean), *Lupinus* (lupines), *Crotalaria, Lotus* (trefoils) and *Pueraria* (kudzu).

Other Crop Families. Among the other botanical families that contain crop plants are: (1) Cannabaceae—hops and hemp; (2) Polygonaceae—buckwheat; (3) Chenopodiaceae—sugar beets, mangels, and wormseed; (4) Cruciferae—mustard, rape, and kale; (5) Linaceae—flax; (6) Malvaceae—cotton; (7) Solanaceae—potato and tobacco; and (8) Compositae—sunflower, Jerusalem artichoke, safflower, and pyrethrum.

BINOMIAL SYSTEM OF NOMENCLATURE

In a botanical classification, each plant species is given a binomial name. This provides two names for a plant, the genus and species. The binomial system of nomenclature is founded upon the publication by the Swedish botanist, Carl Linneaus, of his *Species Plantarum* in 1753. The name of the man who first gave the accepted name is affixed by a letter or abbreviation. For example, the letter L following the botanical name of corn or maize—*Zea mays* L—means that Linneaus named it (see Appendix Table 1). The binomial system provides a practically universal designation for a plant species, which avoids much confusion. Some crops, e.g., proso and roughpea, are known by several different common names in the United States.

A species is a group of plants that bear a close resemblance to each other and usually produce fertile progeny when intercrossed within the group. Nearly every crop plant comprises a distinct species or, in some cases, several closely related species of the same genus. Within a species, the plants usually are closely enough related to be interfertile. Interspecies crosses are infrequent in nature, but many of them have been made artificially.

Varietal names are sometimes added to the species name to make a trinomial, but ordinarily crop varieties are given a common name or serial number to designate them. Names are often confused in the designation of agricultural varieties. The variety of wheat known as Fulcaster has at least 60 different names or synonyms. Recent classifications of agricultural varieties have done much to standardize variety names. The American Society of Agronomy has adopted a rule to use a single short word for a variety name, and the variety is not to be named after a living person. That Society also registers properly-named improved varieties of several crops.

A comprehensive list of native and cultivated plants in American use or commerce, giving both the scientific and common names and the names of many varieties of cultivated plants is found in the book *Standardized Plant Names,* published in 1942 by J. Horace McFarland Company, Harrisburg, Pennsylvania.

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4 CROP IMPROVEMENT*

Possibilities in Crop Improvement

The creation of every new superior crop variety is a definite advance in human welfare, and the breeding of new varieties is the only stable method of crop improvement. Although crop yield and quality can be improved by disease and pest control, fertilizer application, and better cultural methods, such practices must be repeated each season. Maintenance of seed stocks by purification and field inspection, and distribution of superior varieties are popularly regarded as phases of crop improvement, although they are actually a means of helping growers to capitalize upon the accomplishments of the crop breeder.

Improvement of crops has been in progress since primitive man first exercised a choice in selecting seed from wild plants for growing under cultivation. The greatest advances were made before the dawn of civilization, but material progress was made thereafter. However, not until the present century when some knowledge of genetic principles was acquired has crop breeding become a science with the outcome of a breeding program reasonably predictable.[8] Much further improvement is possible by application of knowledge and materials now on hand. In fact, the only serious limitation to future progress is the failure, as yet, to find certain needed plant characteristics among the varieties being tested.

The increased gross income to farmers of the United States from

* The history and progress in breeding numerous crops up to recent times are described in detail in the *United States Department of Agriculture Yearbooks* for 1936 and 1937. These books are now out of print but can be found in most libraries. A comprehensive book on crop improvement, *Methods of Plant Breeding*, by H. K. Hayes and F. R. Immer, is published by the McGraw-Hill Book Co., Inc., New York and London.

the growing of hybrid corn averaged about 600 million dollars annually from 1941 to 1945. This is roughly equal to the total annual payments to farmers under the Agricultural Adjustment, Agricultural Conservation, and Parity Payment programs in the same period. The annual increased returns from improved varieties of all other field crops combined were even greater than those resulting from the growing of hybrid corn.

Crop breeders are concerned chiefly in more abundant, stable, and economical crop production, but they also are deeply imbued with social and humane motives.[18] We now have awnless and smooth-awned cereals that do not irritate the eyes, mouths, or skins of the farm workers and their domestic animals. We also have sweeter and more tender sweet corn, and lighter bread made from stronger wheats. Crops that are easier for man to harvest, and feed crops that are more palatable or less toxic to livestock have been developed within the past 15 years. Improved varieties have helped alleviate crop failures and their accompanying human privation and livestock starvation.

Objectives in Crop Breeding

A perfect crop variety is yet to be created. Every variety has several known defects that prevent production of crops of maximum yield and quality, except under rare ideal conditions. The objective of the crop breeder is to eliminate those defects. Most varieties have yielding capacities that are ample or nearly ample for the conditions under which they are grown if various deleterious factors usually were not present to restrict optimum development. Almost any adapted commercial variety is capable of producing 2 to 10 times the average yield of the particular crop in the United States. Losses from unfavorable conditions often can be reduced or controlled by crop breeding. Increased vigor as manifested by a greater inherent growth rate would markedly increase the yields of various crops when they are grown in favorable sections. Except in corn, however, the most rapid and important progress in crop breeding has been in the development of varieties of better quality that can withstand the hazards of adverse weather, diseases, insects, and unfavorable soil conditions.

Some of the chief objectives in crop breeding are improvements in:

Resistance to diseases, insects, drought, cold, heat, and alkali.

Adaptation to shorter seasons, longer seasons, heavy grazing, or frequent cutting.

Feeding quality—e.g., palatability, leafiness, hull percentage, nutritive value, and texture.

Market quality—e.g., higher content of textile fiber or of protein, sugar, starch, or other extractives; better processing quality for textiles, foods, beverages, and drugs; better color.

Seed quality—e.g., higher or lower seed-setting tendency, greater longevity, higher viability.

Growth habit—e.g., more erect or prostrate stems, more or less tillering or branching, more uniform flowering and maturity, more uniform height, longer life, better ratio of tops to roots.

Harvesting quality—e.g., shorter or taller stalks, erect stalks and heads, nonshattering, easier processing, freedom from irritating awns and fuzz.

Productive capacity—e.g., greater vigor, higher fertility, faster recovery after cutting.

Methods of Crop Breeding

Three general methods of crop improvement are commonly listed, viz., (1) introduction, (2) selection, and (3) hybridization. These methods are not wholly distinct because hybridization almost always must be preceded, or followed, or both preceded and followed, by some scheme of selection. Crop introduction, on the other hand, either is a substitute for crop breeding by bringing in a superior variety from some other section, or it furnishes foundation stocks for breeding.

INTRODUCTION

Some of the more recent foreign introductions that have become established crops in North America include crested wheatgrass, Balbo rye, Russian wild rye grass, and Ladak alfalfa. The introduction of Bond oats for hybridization with domestic varieties gave a new impetus to the breeding of disease-resistant oats.

Both individuals and public institutions have contributed to the rich collection of crop plants obtained from foreign shores. Since 1898, the Bureau of Plant Industry of the United States Department of Agriculture has introduced a majority of the exotic crop varieties that have reached America. They introduced hegari, Sudan grass, Federation wheat, Austrian winter pea, Hungarian vetch, Dallis grass, and Korean lespedeza, which have been grown on millions of acres.

Very few of the crop varieties introduced recently are superior to, or even equal to those already grown. Varieties that seemingly are worthless here, however, may possess resistance to some disease or insect, or have some other useful character that can be transferred to adapted varieties by hybridization.

SELECTION

Mass selection. Mass selection is a quick method of purifying or improving mixed or unadapted crop varieties. It is done by selecting a large number of plants of the desired type and then increasing the progeny. Field and crib selection of seed ears of corn is merely mass selection to partly eliminate undesirable types. Most of our open-pollinated varieties of corn such as Reid Yellow Dent and Johnson County White are products of mass selection.[9] Natural selection through survival of the more vigorous strains accomplishes the same objective. Tennessee Winter barley doubtless was improved in winter hardiness as a result of natural selection while being grown under cold conditions. Mass selection accomplishes nothing when selection is confined to vigorous plants that are merely favored by good environment such as thin stands or more favorable soil or moisture locations in the field.[15]

Pure line or pedigree selection. Pure-line, pedigree, or individual plant selection consists of the growing of individual progenies of each selected plant so that their performance can be observed, compared, and recorded. In crops that are largely self-fertilized, reselection is not necessary except for those progenies resulting from occasional natural hybrids or mutations that are still segregating. In crops that are partly or largely cross-fertilized, selection must be repeated until the strains appear to be uniform. Also cross-fertilized crop plants selected for propagation must be self-pollinated by covering the floral parts to exclude foreign pollen or by hand-pollinating, or both, or in some cases by isolating the plants.

More varieties of self-pollinated crops have been obtained from individual plant selection than from any other method. Until recently most crop varieties were mixtures of different genotypes. Pure-line selection offers a quick means of segregating desired types from such mixed varieties.[21] Numerous varieties of wheat and oats were originated by this method. Among these are Kanred, Nittany, Forward, Fulhio, and Karmont wheat,[3] and Richland, Gopher, Rainbow, Markton, Brunker, and Columbia oats.[23]

A simple procedure in breeding by selection may be illustrated by the method followed in developing resistant strains such as Texas milo, Resistant Sooner milo, and Double Dwarf 38, of grain sorghum varieties [17] that were highly susceptible to the root rot disease caused by the organism *Periconia circinati* (Figure 23).

First year. A field of Dwarf milo was almost a total failure because of the above disease. A few plants, perhaps one in 5,000, in the infested area appeared to be healthy. The heads from some 200 of these plants were saved.

Second year. The selections were planted in head rows in disease-infested soil, in comparison with the unselected variety and known resistant varieties. Some of the progenies that proved to be off-types were discarded immediately. Some of the rows broke up into various types, which showed that they were natural hybrids. These also were discarded. Other rows consisted entirely of diseased plants, showing that the selected plants had merely escaped the disease probably because they grew in an area of lightly infested soil. These likewise were discarded. Still other progeny rows were typical of the variety but contained many diseased plants which showed that they were heterozygous for disease resistance. The remaining progeny rows were fully resistant, except for occasional plants that probably grew from a seed that had developed from an outcross with a susceptible plant. Heads in the rows containing all healthy plants but otherwise typical of the original variety were covered with paper bags to exclude foreign pollen.

Third year. Seed from each of the bagged (self-pollinated) heads was again planted in individual head rows on disease-infested soil, and remnants of the seed were planted in yield tests and in isolated increase blocks, and many of the heads were bagged.

Fourth year. The seed of several selected strains was again planted in plots for yield tests on both infested and noninfested soil in several

FIG. 23. In 1935 this California farmer's milo crop was destroyed by "milo disease" except for 5 resistant plants one of which is shown at the left. The seed was saved and increased the next year. In 1937 the progeny from these five plants produced about 1200 bushels on 10 acres (*upper right*). Adjacent to it the unselected milo (*lower right*) was a complete failure.

localities. The bagged seed from the increase block of the most promising strain was released to a registered seed grower who planted a field isolated from other sorghum. The field was rogued carefully to eliminate all off-type plants. The crop from this field was the foundation seed for distribution to other growers of certified seed.

Fifth year. Certified seed growers produced the crop under established rules for purity and isolation. Their fields were inspected, and a threshed seed sample was tested for purity and germination. The growers were supplied with certification tags to attach to each bag of seed. Seed of the improved variety was then sold to farmers.

The above sketch is rather typical of selection procedure when the breeding objective is very simple, and plants apparently of the desired type are found readily. It is assumed that the occasional disease-resistant plants in a susceptible variety have originated by a spontaneous change in germ plasm called mutation.

Selection procedure in other cases may differ somewhat from the above outline in which a difference of only one genetic factor was involved. Usually, a minimum of 7 to 10 years elapses between the original selection and the release of a new variety to farmers. Modifications of the above methods are listed below:

(1) In self-pollinated crops the bagging and reselection usually are unnecessary.

(2) In cross-pollinated crops or when the original variety and the selections differ by several genetic factors, several (five or more) generations of selection may be required to purify the strains so that each will continue to breed true thereafter while being tested for yield.

(3) When the selections differ among themselves, or from the original variety, in hereditary make-up or in growth habit and morphology, as is usually the case, several years of yield tests are required to determine the relative merits of the different selections.

(4) Where improved yield is desired but the objectives otherwise are rather intangible, the following procedure is advisable.[11] This involves selection, in a self-pollinated crop, of a large number of heads (perhaps 1,000), continued progeny testing for several years with gradual elimination of low-yielding or otherwise undesirable types, and accompanying the yield tests with plantings of the same strains in a disease garden to determine the reaction to various diseases. After repeated tests for several years at several stations or in outlying experiments, the strain or strains having the best performance record, if suitable otherwise, are increased for distribution.

(5) Ear-to-row continued selection and progeny testing was a popular breeding method for the cross-pollinated corn crop from about 1900 to 1920, but the method has been discarded. Ear-to-row testing is effective in isolating some of the better strains of an unadapted variety during the early years of selection but progressive increases in yield have never been obtained.[6] The chief limitations to the method are the partial inbreeding that reduces yields, and the lack of complete control of the pollen parentage of the seed ears. Continued selection in cotton has met with some success because

purity is never obtained when the selections are grown without protection from insects that can effect intercrossing.

(6) The breeding of cross-pollinated grasses and legumes such as bromegrass, crested wheatgrass, and alfalfa[5, 14] usually has involved continued selection and self-pollination to isolate and purify improved strains. Some of these strains may be recombined into a synthetic variety later and allowed to intercross.[24]

Pure-Line Concept. The modern methods of handling, testing, and increasing individual selections of self-fertilized crops have as their basis the pure-line concept proposed in 1903 by W. L. Johannsen who worked with beans. According to this concept, variations in the progeny of a single plant of a self-fertilized species are not heritable but are due to environmental effects. Failure to recognize this principle before and, in some cases, as late as 15 years after Johannsen's discovery, resulted in some futile work in continuously selecting self-fertilized crops as wheat and barley. The centgener method of breeding wheat by continuous selection is a classic example of much misdirected effort.

When homozygous self-fertilized plants are selected, the progeny is pure for all characters until hybridization or mutation occurs.[8] It should be recognized, of course, that varieties that appear to be pure may be pure only for the characters that are observed under a particular environment. A pure line was originally defined as the descendants of a single, homozygous, self-fertilized individual. The definition commonly used today is that a pure line comprises the descendants of one or more individuals of like germinal constitution that have undergone no germinal change.

Inbreeding Cross-fertilized Crops. Before making hybrids between two varieties of a cross-fertilized crop, it may be desirable to select and inbreed the varieties for several generations or until they are reasonably pure for the characters desired. Without such inbreeding, the hybrid selections obtained from cross-fertilized crops are not reproducible. Artificial self-pollination in a normally cross-pollinated crop leads to segregation into pure uniform (homozygous) lines. There is often a rapid reduction in vigor, when self-pollination is practiced. In corn the reduction in vigor in the first generation of selfing is approximately one-half the difference in

FIG. 24. Thatcher wheat, produced by hybridization, and released to farmers in 1934, was grown on nearly 17 million acres in the United States and Canada in 1944.

vigor between the original corn and that of the homozygous inbred progeny. When appropriate lines of self-pollinated plants are intercrossed there usually is restoration of vigor, a fact that is applied in hybrid corn production.[13] In addition, certain abnormalities, such as sterility, poor chlorophyll development, dwarf habit, lethal seedlings, and susceptibility to diseases may appear as a result of inbreeding. These types must be discarded. Such abnormalities are mostly recessive characters that, under open-pollinated conditions, are largely suppressed as a result of crossing, usually with normal plants.

HYBRIDIZATION

Hybridization, the only effective means of combining the desirable characters of two or more crop varieties, offers far greater possibilities in crop improvement than can be obtained by selection alone.[11, 16] Many recently developed crop varieties are the result of hybridization (Figure 24). Among these are Mida, Pilot, Pawnee, and Comanche wheats; Mindo, Benton, and Clinton oats; Tregal and Mars barley; Koto and Crystal flax; Plainsman grain sorghum; and Texas Patna rice.

The first step in breeding by hybridization is to choose a parent that can supply the important character or characters that a good standard variety lacks. It is important to have definite characteristics in mind and to test the material for these characteristics repeatedly. Success occasionally has followed haphazard crossing between productive varieties but failure to accomplish any improvement by such a procedure is traditional.

Hybridization Techniques. In crossing self-fertilized crops the flowers are first emasculated, i.e., the anthers are removed or killed before they have shed pollen, and the flowers are then covered with a small paper, glassine, or cellophane bag to exclude insects and foreign pollen (Figures 25, 26 and 27). The anthers usually are removed with tweezers, a needle, or a jet of air or water, but rice and sorghum pollen can be killed by immersing the panicles in hot water at about 47° C. for 10 minutes. Pollen from the male parent is applied by brushing or dusting it on the pistil when the stigmatic surface of the latter is receptive. This receptiveness may be imme-

FIG. 25. Emasculating wheat. The three anthers in each flower are pulled out with tweezers.

FIG. 26. An oat flower showing the anthers, stigmas and ovary within the glumes and also removed to show the structure. Their structure in other small grains and most grasses is very similar.

FIG. 27. A tobacco flower is being pollinated by brushing the stigma with ripe anthers from another species.

diately after emasculation or one or two days later and is indicated by a sticky exudate covering the stigma. The techniques of hybridizing corn are shown in Figure 28.

The seeds that develop from the cross-pollinated flowers, when planted, produce plants of the first filial (or F_1) generation. These plants should be all alike, only the dominant characters being expressed. In the second (F_2) generation, the plants break up or segregate into all possible combinations of the dominant and recessive characters of the two parents. Plants of the types desired are selected, and these and several subsequent generations are handled as previously described under selection methods. Reselection continues thereafter until the desired strains are uniform, usually for 3 to 6 generations.

The size of the F_2 population may vary from 200 to 10,000 plants, the proper number depending upon the number of genetic factor differences involved in the cross. For example, if closely related

FIG. 28 (*Left*) Both tassel and ear shoot of corn are covered with bags. (*Right*) A pollen gun is used when several ears are hand-pollinated with the same lot of pollen, in experimental operations.

varieties are crossed to combine two single-factor character differences, one from each variety, an F_2 population of 200 to 500 plants should be ample because approximately $\frac{1}{16}$ of this number, or about 13 to 31 plants, should breed true for the desired recombination. On the other hand, with a six-factor difference between the two parents, e.g., two factors for smut resistance, two for seed color, and two for plant height, one would expect only $\frac{1}{4096}$, or not more than 3 in 10,000 F_2 plants, to breed true for the desired recombination. However, additional true-breeding plants of the desired recombination would be obtained in later generations from segregating F_3 lines. The expected proportion of true-breeding strains of a particular recombination in the F_2 generation is determined by the formula $\frac{1}{4^n}$ in which *n* is the number of genetic factor differences involved in the cross. Thus with one pair of factors (i.e., $n = 1$) $\frac{1}{4^1} = \frac{1}{4}$, and with six factors ($n = 6$) $\frac{1}{4^6} = \frac{1}{4096}$. It is obvious that in wide crosses, i.e., crosses between widely unrelated varieties, the number of factor differences is so large that the chances of finding the desired recombination in the first cross are extremely remote. In such cases the strain obtained that most closely approaches the desired recombination may be crossed with one of the parents, or with some other variety, and selection then resumed. The back-crossing method described later also is a useful method of securing a desired type from a wide cross.

The success of the above procedures in hybridization and selection is illustrated by the results from crossing two oat varieties, Markton and Rainbow.[20] Markton is resistant to smut, and Rainbow is resistant to rust. Marion, a selection from this cross, is resistant to both smut and rust.

Backcrossing. The backcross method of breeding crops was first suggested by Harlan and Pope,[7] and first put to important application by Briggs.[2] A specific type of selection accompanying backcrossing has been termed convergent improvement.[12] Backcrossing is particularly useful when it is desired to add only one or two new characters to an otherwise desirable variety. In this method the good variety is crossed with one having the other character desired. First-generation plants are backcrossed with the good variety. Thereafter in each segregating generation a number of plants approaching the desired new recombination are selected and backcrossed with the good commercial parent. Usually, with repeated rigid selection, the improved type is recovered approximately in about five backcrosses. Furthermore, little testing is necessary because the recovered variety is practically identical with the original adapted variety except that it has a new character such as disease resistance. Thus, by omitting several years of testing, the recovered variety may be quickly increased and distributed to farmers.

Bulk Propagation of Hybrid Material. In the bulk method of handling hybrid material the entire population from a cross is grown and harvested in mass each year. Successive crops of seed are sown for 5 to 10 years to allow natural selection for characters such as cold resistance or insect resistance, to take place. By this time the poorly adapted strains are largely eliminated and the remaining strains are mostly true breeding (or homozygous). Plants are then selected, and the progenies tested as previously described. Testing of large numbers of unadapted and heterozygous strains is thus avoided. It is recognized, however, that desirable types may be lost during the interim because of competition with aggressive but otherwise undesirable plants.

Breeding for Disease Resistance. Some of the most outstanding accomplishments in crop breeding have been in the development of disease-resistant varieties of wheat, oats, sugarcane, sugar beets, flax, potatoes, sorghum, and alfalfa. The plant breeding methods are the same as for other objectives except that the progenies must be exposed to the particular diseases either by artificial inoculation or by choosing conditions favorable for natural infection. Plants that resist the disease and are otherwise desirable are selected for further progeny tests.

The breeding of varieties resistant to diseases sometimes appears to be highly complex because of the existence of different physiologic races of the disease organism. Physiologic races of insect species, e.g., Hessian fly, also are known. The problem is further complicated by the fact that hereditary factors in both host and parasite may condition the disease interaction. The presence of numerous physiologic races often makes breeding for complete resistance rather tedious, because several successive crosses may be necessary to combine all the different essential factors for resistance.[1] However, crop strains frequently are obtained from hybrid combinations that under field conditions resist all races of the disease organism that are important in a given section.[22] When no race is able to cause appreciable crop damage to a variety, the fact that numerous races exist is a matter largely of academic interest. For example, Vernal (Yaroslav) emmer has been grown in the northern spring wheat region for at least 70 years. It is doubtful if any commercial field of this variety in North America has ever been damaged seriously by any of the numerous races of the black stem rust organism. The rust resistance of emmer has been transferred by hybridization to varieties of common wheat[10] such as Hope, Pilot, Rival, Mida, Cadet, Newthatch, Regent, and Renown. The high degree of resistance to numerous races of the stem rust organism in these varieties as compared with common rust-susceptible varieties is differentiated in large part by only a single genetic factor. The breeding of stem rust resistant wheat varieties for North America thus is relatively simple in so far as resistance alone is concerned. The chief problem is to obtain other desired characters along with stem rust resistance.

Physiologic races of a disease organism are separated upon the basis of their reaction on differential host varieties in greenhouse tests. Their existence is undetected until resistant varieties are found. Thus Race 1 may attack differential variety A but not variety B. Race 2 may attack variety B but not variety A. Race 3 may attack both A and B, while Race 4 attacks neither. The number of races that can be identified depends more upon the number of differential host varieties that are used than upon the number of collections of the disease organism that are available. The reaction to disease often is separated into only two simple categories—resistance and susceptibility—although some intermediate or irregular reactions also are known to occur. Considering merely the two reactions, resistance and susceptibility, the number of possible physiologic races equals 2^n where n is the number of differential hosts. Thus, with 12 differential hosts 4,096 races, and with 20 differential hosts 1,048,576 races are possible. Wheat breeders who have produced the varieties most resistant to stem rust selected their resistant plants upon the basis of field reaction. They thus avoided the tedious testing of all strains for reaction to numerous individual races by hand inoculation of seedlings. Furthermore, the reaction of wheat seedlings in the greenhouse often differs from the reaction of mature plants in the field.[19] In such cases the greenhouse tests may be misleading.

Experimental Methods

Progress in crop breeding can be measured only by experimental tests except when breeding for disease resistance, better color, or some other character that can be seen readily. Even then the investigator must know how the new strain compares in yield with the variety it is expected to replace. Field plot experiments are the chief activity of most research agronomists.

The comparative productive value of different varieties is determined by experimental field trials in which all varieties are sown under identical conditions in plots or nursery rows of uniform size, usually ranging from 15 square feet to $\frac{1}{40}$ acre. An experimental field should be very uniform in topography and soil character. The soil should be representative of the section to which the results are to be applied. Soil preparation, crop sequence, and fertilization should be identical for the entire field area included in a particular experiment. Seeding of all varieties should be done at the same time. It is customary to replicate or repeat the plantings of each variety in 3 to 10 plots or rows in order to equalize or smooth out differences due to variations in the soil and in the mechanical operations incident to field experimentation. Even the most uniform-appearing field varies considerably in productivity because of differences in soil origin, topography, or soil treatment. Standing water, runoff, dead furrows, weed clumps, compacted headlands, and animal excretions all detract from uniformity. Likewise, inequalities in tillage, seeding depth, cleanness of harvesting and threshing, waste of grain in threshing, weighing, and moisture content of the weighed crop all affect experimental accuracy.

Accepted statistical methods are used to compute an experimental error term, either the standard error or variance, which measures the variations in yield among the different plots of the same variety or treatment. The mathematical error term is based upon variations that are due to chance. It gives an estimate of the uniformity or reliability of the experiment, particularly the reliance that can be placed upon differences found between varieties or treatments. When one variety outyields another by a sufficiently consistent margin so that the computed odds for a real difference are 19 to 1 or better, it is commonly assumed to be superior. With lower odds, the difference observed between the two varieties is regarded as insignificant, i.e., largely due to chance. Sometimes the plots of the different varieties are repeated in the same systematic order so that similar varieties or those most promising are grouped together for an accurate observation and comparison. Since this arbitrary arrangement may accidentally favor certain varieties, the varieties often are arranged in a random order within definite experimental blocks of plots. Special experimental designs, especially the so-called lattice designs,[4] are used as a means of partly adjusting the plot yields to smooth out differences due to soil variation.

The size of plot is determined largely by convenience and by the availability of uniform land for the experiment. Nursery rows give reliable comparisons between varieties when they are repeated several times and protected from competition with adjacent varieties by the planting of border rows. Field plots give a better view of the behavior of the variety under field culture and also furnish more material for further experimentation or more seed for increase, but they are little more reliable, and they occupy more land than do nursery rows. Field plots of different varieties of small grain or forage crops are usually 4 to 8 rods long and one drill width (5 to 7 feet) wide. Corn usually is tested in plots two hills wide and 5 to 10 hills in length, and sorghum in 4-row plots 4 to 8 rods in length. Small grain nurseries usually are planted in rows one foot apart with the rows approximately one rod in length.

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5 TILLAGE PRACTICES

Development of Tillage Operations

Tillage began before the earliest written records of mankind. The first implements were hand tools to chop or dig the soil, usually made of wood, bone, or stone. They were used to subdue or destroy the native vegetation, make openings in the soil to receive seeds or plants, and reduce competition from native plants and weeds growing among the crops. The next stage of tillage, application of the power of domestic animals,[19] occurred in parts of the world before the dawn of history. This made possible development of implements with a steady forward movement. Among these were the crooked-stick plow to stir the soil, and the brush drag to pulverize the surface. Little further progress was made for many centuries except that eventually some plows were fitted with iron shares despite a common misapprehension that iron "poisoned" the soil. The development of steel in the nineteenth century resulted in 1833 in a steel plow with sharp edges that cut the soil layer, and a curved polished surface that permitted it to scour. That straight-line movement of the plow has since been supplemented with the rotary movement in such implements as disk plows and harrows, and in the rotary hoe and various pulverizing and stirring tools.

Very little was known about the effects of cultural operations in the Middle Ages.[58] In 1731, Jethro Tull published his *New Horse-Houghing Husbandry* in England. He believed that plants took up the minute soil particles and the more finely the soil was divided the more particles would be absorbed by the roots.

During the nineteenth century it became evident that nutrition of plants depended on certain chemical elements from the soil minerals, organic matter, water, and air. The foundation for this concept was laid by Justus von Liebig and others. The idea became widespread that tillage, by increasing the aeration in the soil, increased the oxidation of chemical compounds in the soil and made them more soluble.

Early American writers believed that tillage allowed the roots to penetrate more deeply, or fined the soil to make a greater surface to hold moisture, although certain others recognized its importance in weed control. That harmful effects might result from excessive tillage, particularly from greater oxidation of organic matter and from increased erosion, was also pointed out by early writers in this country. Not until after 1890 did experimental evidence begin to show the basic reasons for tillage.

Purposes of Tillage

The fundamental purposes of tillage [19] are: (1) to prepare a suitable seedbed, (2) to eliminate competition from weed growth, and (3) to improve the physical condition of the soil. This may involve destruction of native vegetation, weeds, or the sod of another crop. It may further involve removal, burial, or incorporation in the soil of manures or crop residues. In other cases, the tillage operation may be solely to loosen, compact, or pulverize the soil. The best system of tillage is then the one that accomplishes these objectives with the least expenditure of labor and materials.

The effect on soil erosion also must be considered in planning all tillage operations. The kind of tillage for seedbed preparation on drylands is governed almost entirely by their effects upon the conservation of soil moisture and the prevention of surface runoff and wind erosion.

THE QUALITIES OF THE SEEDBED

In seedbed preparation for grain sorghum under dryland conditions in Kansas, land cultivated with a disk harrow or duckfoot cultivator to control spring weed growth gave an average yield of 18.5 bushels.[69] That left uncultivated and with the weeds allowed to grow until it was listed at planting time produced only 10.8 bushels per acre.

Under most conditions, a desirable seedbed is one that is mellow yet compact enough so that the soil particles are in close contact with the seed, and is free from trash and vegetation that would interfere with seeding. The seedbed should contain sufficient moisture to germinate the seed when planted, and support subsequent growth. In irrigated regions, it is occasionally necessary to plant the crop and then irrigate the field in order to supply sufficient moisture for germination, but this practice is avoided whenever possible because of frequent irregular stands.

Implements for Seedbed Preparation

The moldboard plow breaks loose or shears off the furrow slice by forcing a triple wedge through the soil. This action inverts the soil and breaks it into lumps. Some pulverization takes place. Several different shapes of moldboard plow bottoms are used. At one extreme is the breaker type with a long moldboard adapted to virgin or tough sod for completely inverting without pulverization. At the other extreme is the stubble bottom with a short, abrupt moldboard which pulverizes the furrow slice while turning old ground such as small-grain stubble, so as to mix the stubble with the soil. The general-purpose or mellow-soil plow is intermediate between the above two types in length and slope and in its action. The two-way plow is adapted to steep hillsides because it throws the soil downhill when drawn across the slope in either direction, and is often used on irrigated land to avoid dead furrows (Figure 29). Better coverage of trash is facilitated on all plows by use of attachments such as coulters, jointers, rods, and chains. The majority of moldboard plows range in size from 7 to 18 inches in width of furrow cut.[30] The 14-inch width is very common. There are walking plows and sulky (wheeled) plows. Gang plows have more than one bottom. Large tractor-drawn gang plows turn up to 10 furrows.

In average moldboard plowing, for each 14-inch bottom, two or three horses or about five tractor drawbar-horsepower are used and, depending upon the net speed of travel, 0.15 to 0.60 acres per hour are covered. Originally an acre of land was the area that could be plowed with one ox in one day. In most field operations, horse-drawn implements cover 0.1 to 0.2 acres per hour per foot of width depend-

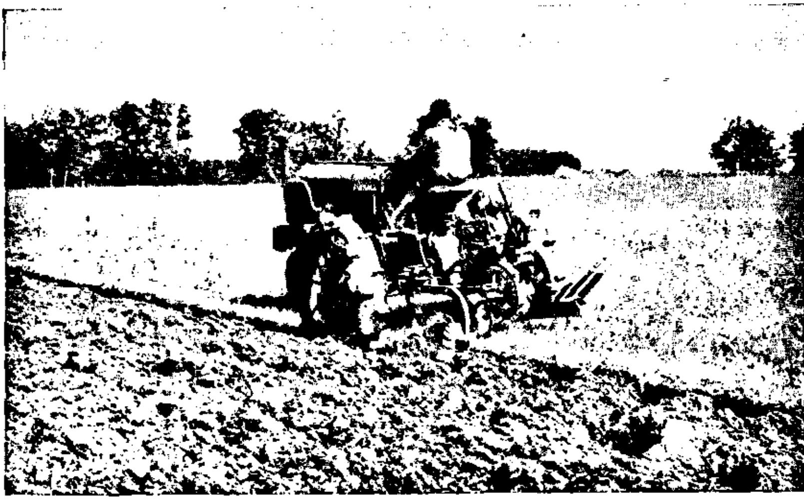

FIG. 29. The two-way plow carries two bottoms (right-hand and left-hand), so that the furrow is turned to the same side of the field in plowing either direction. (Courtesy of International Harvester Company.)

ing upon the draft. Tractor implements often cover two to four times as much.

Disk plows fill an important place in loose soils and in those too dry and hard for easy penetration of moldboard plows, or in some sticky soils where neither plow will scour when the soil is wet. In the latter case, scrapers help keep the disks clean. The disks vary in size from 20 to 30 inches, while the depth of plowing may be varied from 4 to 10 inches. The one-way disk plow (Figure 30), sometimes called the wheatland disk plow, is widely used in the stubble fields of the wheat belt for seedbed preparation. When there is sufficient stubble, straw, weeds, or aftermath available, it leaves the residues mixed with the surface soil with enough exposed to check wind erosion, except on light or other soils that tend to blow badly. The advantages [73] of the one-way disk plow are: (1) it will cover about three times as much ground as the moldboard plow; (2) the draft is less for the work done because the soil is moved a shorter distance; (3) the speed of operation makes early plowing possible; and (4) because of the rough surface left by this implement, snow is caught, and soil blowing is prevented. This plow should be avoided on dry soil, bare summer-fallowed land, or on fields sparsely covered with stubble or weeds where it tends to pulverize the soil so that it blows easily.

Several types of blade or subtillage implements, which leave crop residues on the surface of the soil, are being tried as a substitute for the plow. Straight-blade cultivators are satisfactory only where crop residues are so scanty that they do not cause clogging. Wide sweep blades clog less frequently. Either type will clog in heavy crop residues or numerous large weeds. Special seeding and planting equipment is needed for land covered with heavy crop residues. This so-called *stubble mulch* reduces erosion and runoff but does not increase soil moisture storage. Yields on subtilled land average no greater than on plowed land. The objectives of subtillage are practically accomplished by use of a one-way plow, followed by cultivation with a rotary rod weeder. This older established method takes care of the crop residues without complications.

The lister (middle buster) resembles a double plow with a right- and a left-hand bottom mounted back to back. In some of the southern humid sections, it is used to throw up beds on which to plant cotton, potatoes, or other row crops. In the semiarid re-

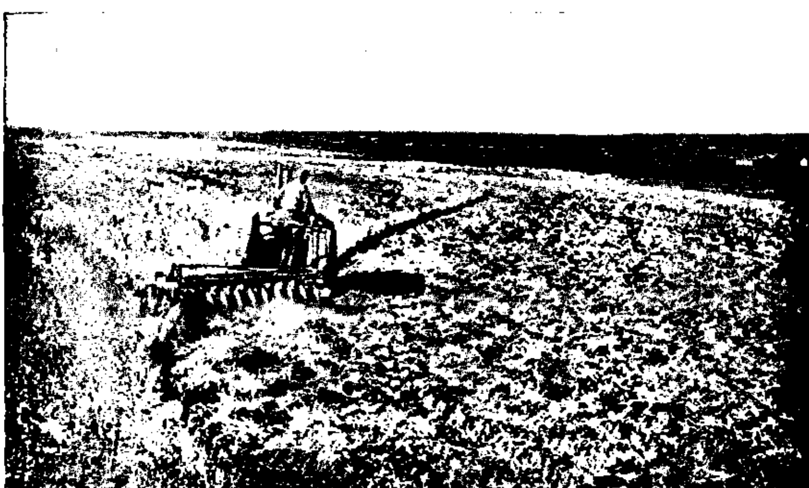

FIG. 30. One-way disk plows leave stubble mixed in the surface. (Courtesy J. I. Case Co.)

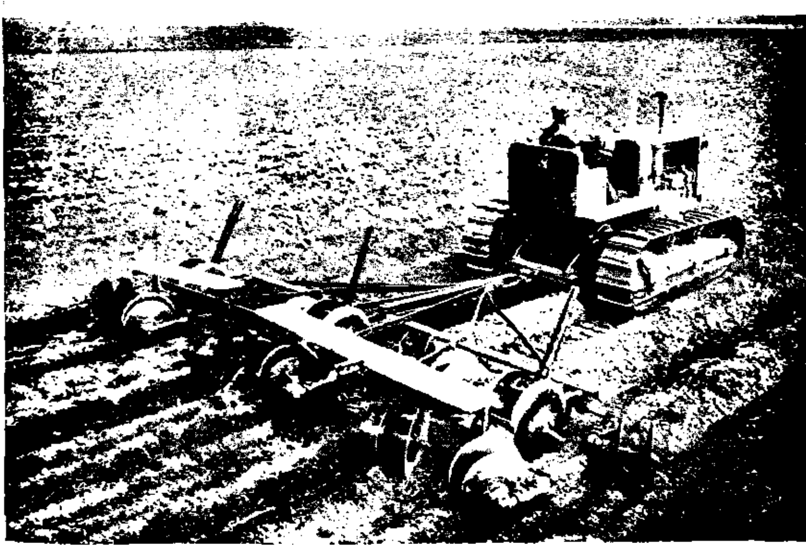

FIG. 31. Ridge buster levelling 6 lister furrows. (Courtesy Caterpillar Tractor Co.)

gions, it is used to furrow the land. It often takes the place of the moldboard plow in seedbed preparation in this area because it covers the field in half the time, and the ridges check wind erosion and snow drifting, and also may check runoff when the furrows run on the contour or across the slope. Row crops are planted in the moist soil at the bottom of the lister furrows. For drilled crops such as small grains, the lister ridges or middles are broken down or leveled, with ridge busters (Figure 31). A basin-forming, or damming, lister, designed to check water runoff, was popular for a time in the semiarid region.

Surface Implements in Seedbed Preparation

Tillage to prepare a seedbed after the land has been plowed is accomplished with harrows, field cultivators, or other machines equipped with disks, shovels, teeth, spikes, sweeps, knives, corrugated rolls, or packer wheels. Under most conditions, a smooth, finely pulverized seedbed should not be prepared until just before a crop is to be planted.

Harrows, which level the plowed soil, compact it, and destroy weeds, require less power than plows or listers. The disk harrow cuts, moves, and pulverizes the soil and destroys weeds. The spike-tooth harrow breaks clods, levels the land, and kills small weeds. Both disk and spike-tooth harrows are a menace on soil subject to blowing. The spring-tooth harrow consists of flexible spring steel teeth about 2 inches wide which will penetrate sufficiently to tear up deep clods or bring them to the surface while destroying weeds.

Plank clod mashers, and rollers are used to break up lumps left

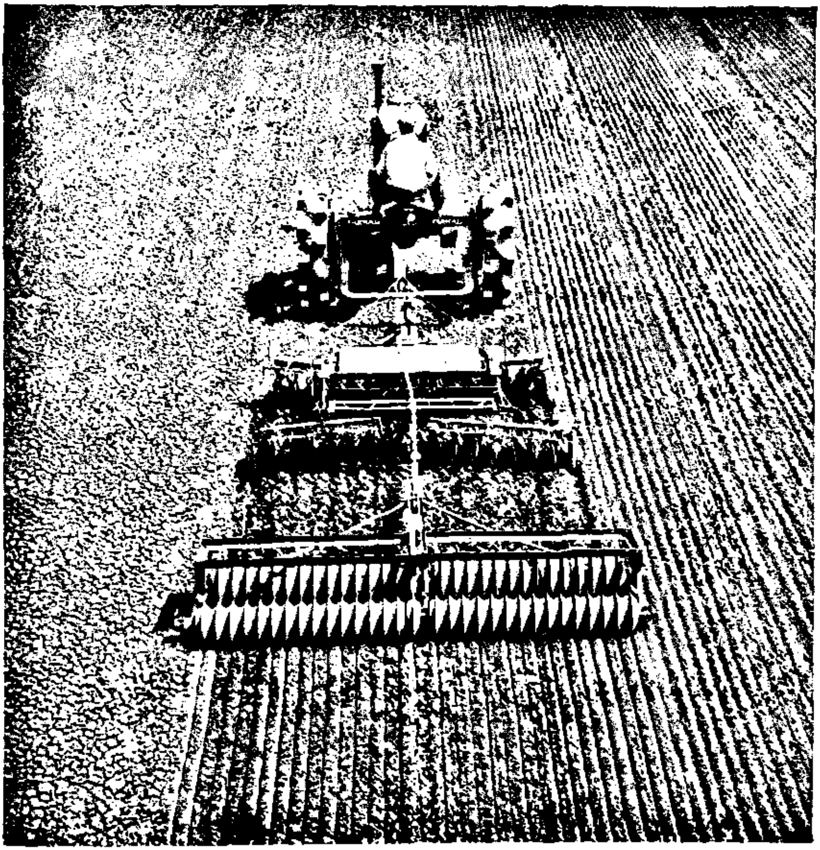

FIG. 32. The tandem disk and corrugated roller leave a firm seedbed suitable for small-seeded legumes. (Courtesy of International Harvester Company.)

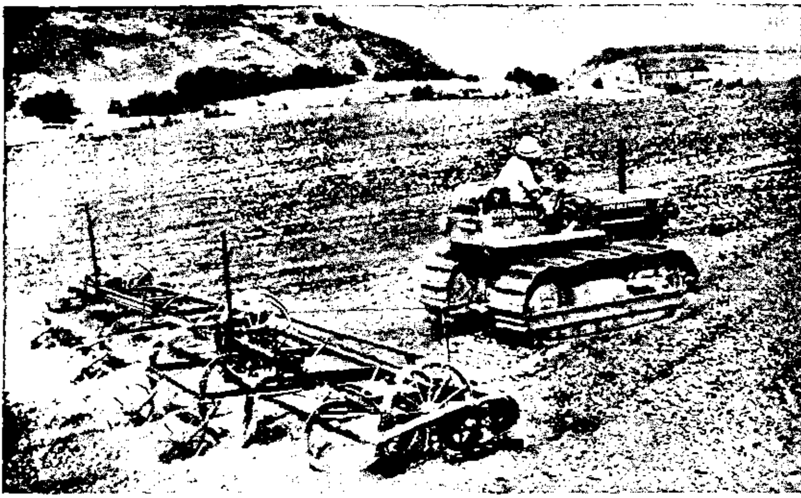

FIG. 33. Rotary rod weeder cultivating summer fallow. (Courtesy of International Harvester Company.)

by harrows. The corrugated roller is used to compact the seedbed, particularly for small legume and grass seeds to improve the chances for germination (Figure 32).

Several types of cultivators, chiefly the duckfoot or field cultivator, and the rod weeder are used in summer fallowing and seedbed preparation. The field cultivator has sweeps or shovels on the ends of stiff or spring bars. The bars are staggered in two rows, with the result that the weeds are cut off by the overlapping sweeps. This implement leaves the soil surface rough and cloddy, a condition necessary to check wind erosion. The principal feature of the rod weeder is a rotating horizontal square rod at right angles to the direction of travel at a depth of 3 to 6 inches below the soil surface, which pulls out the weeds. The rod is driven by gears or sprocket chains from one of the support wheels, so that it revolves in a direction opposite the direction of travel, which keeps the rod in the ground (Figure 33). The rotation of the rod keeps it from clogging, and weeds, straw, and clods are lifted toward the surface, where they check soil blowing.

Plowing in Seedbed Preparation

The reasons for plowing are: (1) removal from the surface of either green or dried material, (2) loosening the soil so other implements can operate, (3) removal or delay of competition with weeds, and (4) roughening the immediate surface so as to check runoff of rain water.[15] Other effects of plowing are control of certain insects and diseases and promoting nitrification. After a clean-cultivated row crop, the seedbed can often be doubledisked and harrowed to give adequate preparation without plowing.

TIME TO PLOW

Spring wheat, oats, and barley in the northern Great Plains yield slightly more after spring plowing than after fall plowing when the time of seeding is the same.[14] This difference is assumed to result from the increased moisture saved, because stubble and weeds retard the drifting of snow from the field. Despite this advantage, the farmer finds it impractical to delay much of the plowing until spring because of the extreme importance of early seeding of spring small grains. Thus the distribution of labor may become a controlling factor in tillage practices. Spring plowing for small grains must be early because of the necessity of early seeding. For corn or other later-planted crops, plowing need not be so early.

For winter wheat in the western half of the United States where moisture and nitrates are limiting factors in crop production, early plowing is necessary in order to destroy weeds and volunteer growth. Early plowing also permits preparation of a better seedbed to conserve moisture. Where winter wheat follows winter wheat or some other small grain, plowing as soon as possible after harvest has been found desirable.[9, 18, 37, 69] This permits a period of about 3 months in which the soil may accumulate moisture and nitrates if the weeds are controlled. Plowing, together with subsequent tillage by conserving moisture and encouraging decay of organic matter, puts the soil in condition for rapid nitrification.

Land to be summer-fallowed usually is not disturbed until the spring following harvest, the weeds and stubble being left to hold snow and check wind and water erosion. Early spring tillage for summer fallow is highly important [66] in order to stop weed growth and thus conserve moisture and permit accumulation of nitrates.

In the more humid regions, early seedbed preparation may be inadvisable because of water erosion.[25, 27] More than one-half the annual soil loss due to erosion may take place between July 15 and September 15 while the land is bare.

Spring-plowed land is regularly higher in nitrates than that left unplowed, but the increase is not always evident immediately after plowing.[1] The difference becomes pronounced during the summer season but almost disappears during the winter when the nitrates are leached downward. Significant increases in nitrates follow early fall plowing, with the greatest increases in soil plowed in the middle of July.

DEPTH OF PLOWING

The prevalent theories that favor very deep plowing are not based upon experimental evidence.[58] At the Pennsylvania Experiment Station deep 12-inch plowing was compared with ordinary 7.5-inch plowing for corn, wheat, oats, barley, alfalfa, clover, and timothy.[53] The average yields failed to show any advantage for the deeper plowing. Shepperd and Jeffrey [64] in 1897 recorded the yields of wheat from different methods of plowing in North Dakota (Table 1). The yields from shallow and deep plowing were nearly the same.

TABLE 1. YIELDS OF WHEAT ON SOIL PLOWED DIFFERENT DEPTHS IN NORTH DAKOTA

TIME PLOWED	YIELD OF WHEAT (BU. PER ACRE), TWO-YEAR AVERAGE (*6-inch depth*)	(*3-inch depth*)
Spring	17.42	17.59
Fall	21.15	21.54

In Kansas, soil plowed to a depth of 7 inches in July gave better yields than soil plowed to a depth of 3 inches.[59] The deeper plowing did not influence soil moisture conservation, but showed greater nitrate accumulation. Differences due to depth of plowing are less than from plowing on different dates [37] (Table 2). A gradual increase of about 2.5 bushels of wheat per acre may be expected as the depth of plowing increases from 4 to 7 inches. Plowing as deep as 10 inches is not considered to be advantageous, and in general plowing deeper than 7 inches does not increase crop yields.[58]

TABLE 2. EFFECT OF DEPTH PLOWING UPON GRAIN YIELD OF WINTER WHEAT IN NEBRASKA (1922–26)

	DEPTH OF PLOWING			
DATE OF PLOWING	*4 inches* (*bu.*)	*5.5 inches* (*bu.*)	*7 inches* (*bu.*)	*10 inches* (*bu.*)
September 15	20.5	—	20.1	21.4
August 15	23.0	24.8	25.5	27.2
July 15	25.7	27.5	28.4	27.4
Average July and August	24.4	26.2	27.0	27.3
Average three months	23.1	—	24.7	25.3

A depth-of-plowing experiment under semiarid conditions conducted at Nephi, Utah, for 20 years[4] gave wheat yields shown in Table 3.

TABLE 3. EFFECT OF DEPTH OF TILLAGE ON WHEAT YIELDS IN UTAH

TREATMENT	BUSHELS PER ACRE
Plowed 5 inches deep	22.7
Plowed 8 inches deep	25.2
Plowed 10 inches deep	25.0
Subsoiled 15 inches deep	24.1
Subsoiled 18 inches deep	23.9

In 1913, the year of lowest yields for the period, the best yield was from the 5-inch plowing. Plowing shallower than 5 to 8 inches was believed to preclude maximum returns on the clay loam soils of Utah dry farms.

The effect of depth of tillage on soil erosion was studied in Missouri.[27, 48] On land where no crop was grown the annual erosion from tilled soil was greater than from soil that was not stirred. Deep tillage (8 inches) reduced the soil loss only 13.4 per cent as compared to shallow tillage (4 inches), indicating that deep plowing is less effective in control of erosion than is usually supposed.

For perhaps 100 years advocates of deeper plowing have recommended that the depth of plowing be increased gradually so as not to turn up too much raw subsoil in any one year. The reasoning behind such a practice seems logical, but the writers have not been able to find any report of an experiment that would either prove or disprove the soundness of the recommendation.

Plows with very large moldboards that penetrate 1 to 4 feet deep are used for land reclamation operations such as turning under brush or turning up topsoil that has been buried with water-borne sand.

Subsoiling

Tillage below the depth reached by the ordinary plow formerly was advocated widely. There was a popular belief that plants utilize fully only the soil moved by man and that unusually deep tillage provides a greater opportunity for root development and moisture storage. A less extreme belief is that merely to loosen, stir, pulverize, or invert the deeper soil layers permits more effective plant growth. Chilcott and Cole [15] concluded that as a general practice no increase in yields can be expected from subsoiling or other methods of deep tillage in the Great Plains. These experiments covered a wide range of crops, soils, and conditions in 10 states. The same general results were obtained under other conditions.[4, 50, 58]

The reasons why subsoiling and deep tillage are ineffective seem rather obvious. Heavy soils shrink and leave wide cracks when they dry out, thus providing natural openings for water absorption and aeration periodically. When such soils are wetted, they swell tightly and the cracks close up so that any effect of subsoiling could be only temporary. Light soils do not shrink and swell much, but they are always rather open. Since crop plant roots ordinarily penetrate several feet below any tilled layer, deep tillage is not essential to deep rooting. The chisel, an implement having a series of points that break up the soil to a depth of 10 or 18 inches without turning it, an operation similar to subsoiling, is sometimes used on heavy soils, chiefly in California. As a substitute for plowing, it opens and roughens the soil so that heavy rains can be absorbed quickly without danger of wind or water erosion.

Summer Fallow

Land that is uncropped and kept cultivated throughout a growing season is known as summer fallow or summer tillage. Under humid conditions, however, land that merely lies idle for a year or two often is referred to as fallow. The most important function of summer fallow is storage of moisture in the soil, but fallowing also promotes nitrification, and is a means of controlling noxious weeds. Fallowing is a common practice in semiarid sections where the rainfall is insufficient to produce a satisfactory crop every year, especially where the annual precipitation is less than 15 inches. About 5 to 30 per cent of the precipitation in the fallow year may be stored in the soil for the next crop.[67]

In the semiarid regions, fallow has been most widely used in alternation with small grains. In southwestern Kansas, consistently higher yields of winter wheat were obtained on fallow than on land continuously cropped.[69] Fallow also was the best preparation for winter wheat at the Akron (Colorado) Field Station where the rainfall is about 18 inches per annum.[5, 7] In South Dakota where the mean annual rainfall averaged 16 inches, spring wheat produced 74 per cent more on fallowed land and 46 per cent more on disked corn land than on land continuously cropped to wheat.[44] The respective increases were 109 per cent and 48 per cent for winter wheat. The relative yields of barley and oats on fallow were much the same as those of spring wheat. Similar results were obtained at Havre, Montana, where the annual precipitation averaged 11 inches.[49] In comparison with small grains grown continuously, fallow gives a better distribution of yields between years, with much less frequent failures. At Mandan, North Dakota, fallow showed little advantage for spring wheat production.[57] Fallow may be replaced entirely by cultivated crops under such conditions, wheat being alternated with corn.

In the Great Basin region, where most of the precipitation occurs in the winter months, fallowing has been standard practice for wheat production for 50 years or more. Yields of winter wheat after fallow are nearly double those from continuous cropping. Continuous cropping is impractical in the driest sections. Fallowing operations seldom conflict with the seeding or harvesting of wheat, which fact enables a farmer to grow as large an acreage of wheat each year as he could by continuous cropping. Fallowing often involves only one to three additional rapid tillage operations. The higher yields from fallowing much more than compensate for the investment in double the acreage of tillable land as compared with continuous cropping.[31]

So-called trashy fallow is excellent for erosion control but detrimental to wheat yields in the Pacific northwest. Trashy fallow, which leaves most of the crop residues on the surface, is produced by the moldboard plow with the moldboard removed, or with a field cultivator, blade cultivator, or some other implement that does not turn the residues under.

The alternation of row crops with fallow is seldom advised, even under conditions where fallow has been found to be profitable for small grain production. However, grain sorghum, especially milo, responds well to fallow on the heavier soils of the southern Great Plains, the yields being almost double those from continuously cropped land.[69] In South Dakota corn produced only 35 per cent more on fallow than on continuously cropped land.[44] Sorgo showed little response to fallow in comparison with continuous cropping.

For successful summer fallowing certain principles must be observed: (1) the surface of the soil must be kept sufficiently rough to absorb rains and prevent wind erosion; (2) weed growth must be suppressed to conserve soil moisture; and (3) the operations must be accomplished at a low cost. Fallow should be plowed or listed early in the spring,[66] worked as little as is necessary to control weeds, and if not seeded to winter grains, also ridged in the fall at right angles to the prevailing winds where soil blowing is likely to occur. Field cultivators or rod weeders are most satisfactory for summer fallow tillage because they cut off the weeds and leave the surface rough and cloddy. The field cultivator also was used successfully as the sole tillage implement on binder-harvested stubble.[52] Yields of wheat after such a plowless fallow were as high as from land plowed for fallow in Wyoming.

Soil Mulches for Moisture Conservation

Soil mulches are created by stirring the surface soil until it is loose and open. The effectiveness of the soil mulch in conserving soil moisture has been investigated for many years.[39] Laboratory experiments with soil-filled cylinders show that a soil mulch reduces evaporation from the soil surface when free water is supplied at the bottom of the column only a few feet below the surface of the soil.[62] Water moves upward by capillarity 15 to 120 inches during a season.[63] Capillary movement to appreciable heights is very slow [45] and movement decreases as the soil moisture decreases. Water in sufficient quantities to support crop plants can be raised only a few inches from a moist subsoil.[40] Most of this movement takes place at moisture contents well above the wilting point. Capillarity and gravity combined may move moisture downward for greater distances and in about double the quantity occurring in the upward movement against gravity.

In eastern Kansas, plots with soil mulches actually lost more water than bare undisturbed plots where the weeds were kept down with a hoe.[12] In experiments in California where the water table was from 18 to 40 feet below the surface, mulching by thorough cultivation failed to save moisture.[68] On upland soils in Pennsylvania where there was no water table in the soil mantle, frequent cultivation did not decrease the evaporation loss materially.[46]

The early work of Burr [8] in Nebraska indicated that in soils partly dry and away from a source of free water, capillary movement was so slow that it could rarely be detected. He concluded that "water supply by capillarity is not an important factor in crop production on Nebraska upland soils." In experiments in the northern Great Plains no water moved up appreciable distances to replace that removed by roots. Water was supplied to wheat roots only by the soil they occupied, and only that part of the soil suffered exhaustion or reduction of its water content.[43] Water once in soil deep enough to escape rapid drying at the surface largely remains until it is reached and removed by plant roots.[8]

In semiarid regions, the rainfall is sufficient to wet the soil to a depth of only a few feet.[43] This usually is exhausted each year by growth of native vegetation or crops. The lower layers are dry except in the wettest of seasons. The water table may be 20 to 2,000 feet below the surface. Formerly a dust mulch was advocated to prevent moisture loss by capillary rise. After some disastrous experiences with soil blowing, the dust mulch theory was abandoned and a clod mulch was advocated. Soon thereafter the effectiveness of any soil mulch to check moisture loss under dryland field conditions began to be questioned.

Thus a soil mulch can reduce surface evaporation where the water table is so shallow that drainage rather than moisture conservation may be desirable. In field practice the mulch formed by tillage is merely incidental to weed control.

Cultivation in Relation to Soil Nitrates

Cultivation seems to be a positive benefit to a heavy waterlogged soil by drying and aerating it and thereby promoting nitrification. Controlling weeds by cultivation permits nitrates to accumulate, since nitrates are used up when a crop or weeds occupy the land. Weed control by cultivation also saves soil moisture and thus favors nitrification, which does not operate in dry soil. Cultivation otherwise has produced no regular increase in the accumulation of nitrates especially in light soils. Greater nitrification occurred in a compacted than in an uncompacted Kansas soil up to the point where the moisture content reached two-thirds of saturation. In Arkansas varied depths of cultivation had little effect on accumulation of nitrate nitrogen in a soil of rather open structure.[56] In Pennsylvania experiments, scraped soil and soil cultivated 3 to 8 times contained almost equal quantities of nitrate nitrogen.[46] Natural agencies appeared to promote sufficient aeration to admit needed oxygen in the soil. Excessive cultivation reduced the nitrates in Missouri soil where the cultivation kept so much surface soil continually dry that nitrate production apparently was retarded in the upper 7 inches.

Other experiments have shown either slight or distinct increases in nitrate accumulation from surface cultivation as compared with soil that was merely scraped.[1, 10, 38, 41, 60] The higher nitrate content in these cultivated soils may have been due to increased aeration.[41] In Kansas experiments ample accumulation of nitrates took place in the uncultivated soil to insure an excellent growth of wheat, provided weed growth was prevented, despite the lower nitrate content.[60] Nitrates leach downward so rapidly after rains that their measurement in the surface foot is of little significance.[38]

Other Effects of Cultivation

Cultivation may conserve soil moisture by preventing runoff. Under semiarid conditions, 88 per cent of the water in a dashing rain sometimes has been lost by runoff. A cultivated surface retains more water from a rain than does an uncultivated surface.[3] The faster the rain falls, the greater is the difference between a cultivated and uncultivated surface in the amount of water held. On the other hand, excessive pulverization of the surface soil is likely to result in a quickly puddled condition with great runoff losses. Under subhumid conditions there is little or no relation between the type of tillage treatment for a given crop and the amount of soil moisture. Fallow areas merely scraped to control weeds have proved to be slightly less effective in moisture conservation than those that received normal cultivations, probably as a result of increased runoff on the scraped plots.[38]

A loosened soil surface acts as an insulator, and cultivated soil is slightly cooler than uncultivated soil.[46]

In general, Sewell[58] concludes, many soils naturally have sufficient aeration for optimum bacterial and chemical activity without cultivation.

Intertillage or Cultivation

The primitive husbandman hoed or pulled out the weeds that grew among his crops planted at random in his small clearings. In ancient and medieval field husbandry, field crops were planted either broadcast or in close rows with the seed dropped in plow furrows. These crops were later weeded by hand or with crude hoes or knives. Jethro Tull introduced intertillage into English agriculture in 1731 when he applied it to crops like turnips planted in rows.

The primary purpose of intertillage is weed control. Intertillage also breaks a crust which otherwise might retard seedling development, and in some cases roughens the soil sufficiently to increase water infiltration. Some have claimed, without substantial proof, that intertillage brings about aeration of the soil, with the result that plant foods are more readily made available by increased bacterial and chemical action in the soil.

The crops that generally require planting in rows with sufficient space between them to permit cultivation during their growth include corn, cotton, grain sorghum, sugar beets, sugarcane, tobacco, potatoes, field beans, and broomcorn. Intertillage controls weeds that grow in the open spaces before the crop can shade the ground.

Crops with relatively slender stems, such as small grains, hay crops and flax, that thrive under close plant spacing, cover the land rather uniformly and tend to suppress weeds by root competition and shading without cultivation after they have been sown. Yields of these crops usually are low when they are planted in cultivated rows, because they do not utilize the land fully. Spring wheat grown in cultivated rows 24 inches apart yielded [64] 10 bushels per acre less than that sown in ordinary close drill rows without cultivation. Where conditions are so severe that small grain and hay crops succeed only in cultivated rows they are generally unprofitable.

INTERTILLAGE IMPLEMENTS

Many different types of implements are used for cultivation. They vary in size from those that cultivate only one side of one row to those that cultivate several rows at once. They come equipped with shovels, disks, teeth, sweeps, or knives.

The Georgia stock cultivator or single shovel cultivator has handles and a beam similar to an ordinary walking plow, but is much lighter. Different kinds of shovels or sweeps are attached to the beam. Pulled by one mule, it has been widely used in the cotton belt, particularly for cultivation around stumps, trees, and rocks. The double shovel cultivator is similar but it has two shanks for shovel or sweep attachments.

Ordinary Cultivators. The shovel cultivator is the type most generally used for intertillage, being suited to practically all soil conditions. Cultivators for more than one row should correspond with the planter in width so that they operate over a group of rows that were planted simultaneously.

Sweeps of various widths are used for shallow cultivation. Shovels or sweeps are sometimes replaced or supplemented by disks or disk hillers when it is desired to move considerable soil, or where a con-

FIG. 34. Rotary hoe cultivating young soybeans. (Courtesy of International Harvester Company.)

siderable amount of vines, trash, or roots is to be cut. Shovel cultivators are likely to clog under such conditions. In weedy corn, a cultivator with six pairs of disk hillers and one pair of sweeps has given the best results.[30]

Rotary Hoe. The rotary hoe (Figure 34) consists of a series of 18-inch hoe wheels each of which is fitted with teeth shaped like fingers. As the wheels rotate these teeth penetrate and stir the soil. It is particularly useful for uprooting small weeds. The rotary hoe has proved to be most valuable for *blind* cultivation before the crop is up, and for early cultivations of young corn and other row crops. Its success depends on its use before weeds have made as much growth as the crop, otherwise the crop plants would be kicked out also.[30] It also is effective in breaking crusts that result from hot sunshine after a torrential rain.

Other Cultivation Implements. The ordinary spike-tooth harrow is used to kill small weeds in corn when the corn plants are small, with little injury to the corn, when the field is comparatively free of trash. Special cultivators for listed crops planted in furrows are necessary for following the furrows and turning the soil along their sides. The lister cultivator (Figure 35) is equipped with disks or

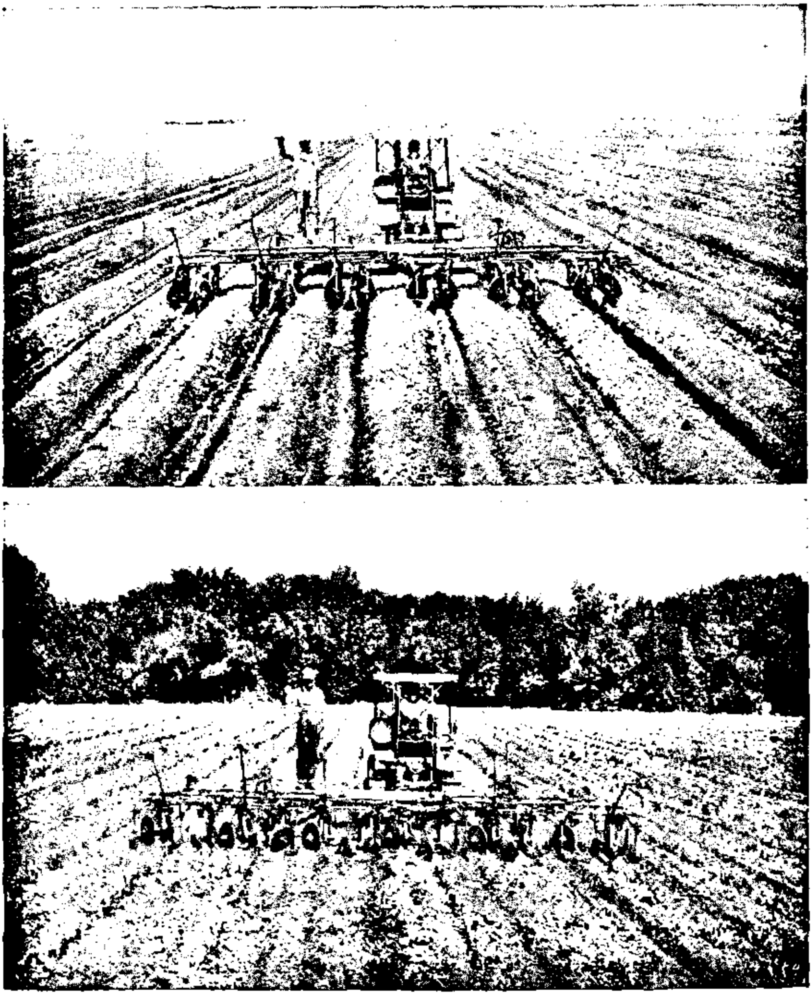

FIG. 35. Lister cultivator with disks set: for first cultivation, or "throwing-out" (*above*); and for second cultivation, or "throwing-in" (*below*).

knives, or both, and sometimes with disks and shovels. For the first cultivation, the disks are set to cut the weeds on the sides of the furrow, the soil being thrown away from the crop row. The shovels may be set to stir the soil near the plants. Hooded shields prevent the soil from rolling in on the young plants. For the second and usually final cultivation, the disks are set to roll the soil into the trench around the plants, thus burying the weeds in the row and leveling the rows. Knife cultivators (go-devils or knife sleds) cut off the weeds below the surface while slicing the lister ridges.

CULTIVATION FOR WEED CONTROL

Corn is practically a failure unless weeds are kept under control, as was shown by experiments in Nebraska[38] (Table 4).

TABLE 4. EFFECT OF CULTIVATION ON YIELD OF CORN IN NEBRASKA (1922 TO 1927)

CULTIVATION	YIELD OF SHELLED CORN per acre (bu.)	(%)
No cultivation (weeds allowed to grow)	7.1	19
1 normal cultivation	21.6	58
2 " "	33.6	90
3 " "	35.9	97
4 " "	37.2	100
4 " " and 2 continued late	35.2	95
Scraped to control weeds	35.1	94

In the corn belt about 4 cultivations are required for surface-planted corn. Experiments at the Illinois Agricultural Experiment Station[72] as early as 1888 to 1893 showed that corn yielded as well when the weeds were merely cut off with a hoe as when it received 4 or 5 deep cultivations (Figure 36). These results were not considered seriously because of the widespread firm belief that cultivation was necessary for reasons other than weed control.[71] About 20 years later Cates and Cox[13] summarized the results of 125 experiments with corn carried on for 6 years in 28 states, in which regular cultivation was compared with scraping with a hoe to destroy weeds. The average of all the tests showed that the scraped plots produced 95.1 per cent as much fodder and 99.1 per cent as much grain as did the cultivated plots. They concluded that cultivation was not beneficial to the corn except in destruction of weeds. Even these results were regarded with considerable skepticism until they were confirmed by additional experiments.[38, 46, 50] Other crops responded in a similar manner.[46] Competition for soil moisture is not the only reason for the low yields of corn in weedy fields, because irrigation of such fields increases the corn yield only slightly.[50]

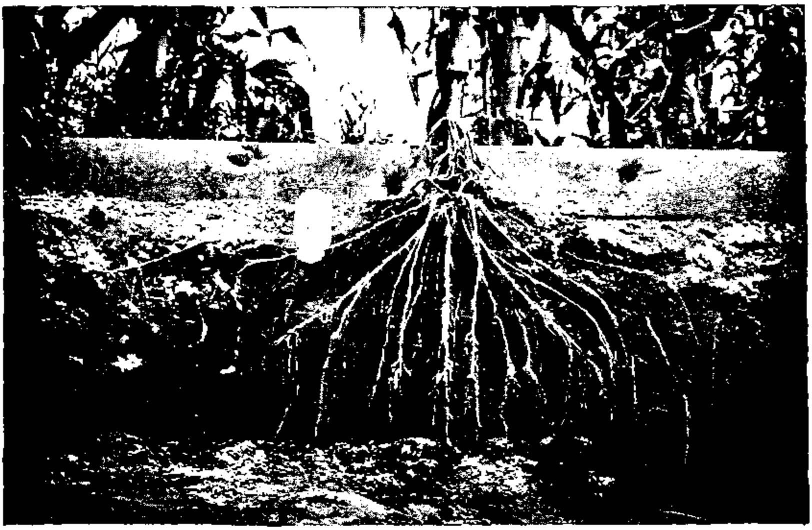

FIG. 36. Deep cultivation injures corn roots.

CULTIVATION OF DRILLED CROPS

Small grain fields sometimes are harrowed in the spring, but in general this has been of no benefit to the grain, nor has it eliminated all the weeds. Cultivation of alfalfa sod with the toothed renovator or disk harrow to destroy grassy weeds, which formerly was widely advocated, has been discontinued in the west since it was found that the resulting injury to the crowns permitted entrance of the bacterial wilt organism.

Straw and Other Artificial Mulches

Moisture loss from the surface foot of both irrigated and dryland soils in Utah[32] was retarded by a straw mulch. A depressive effect on nitrate accumulation in soils may occur where straw mulches are heavy enough to suppress weed growth.[1]

Implements with large sweeps or blades leave the stubble and straw on the surface to form a partial mulch. This so-called subsurface tillage[25] must be repeated during the season to control weeds, because the straw and stubble from a single crop is not sufficient to smother all the weeds. This partial mulch, however, checks soil blowing and runoff, and increases the surface infiltration of rainfall.

Paper mulches have been used extensively in the Hawaiian Islands for pineapples and to some extent on sugarcane fields. A specially prepared paper usually coated with asphalt is used. In California experiments,[61] paper mulch increased the mean temperature of the soil, and the temperature range was reduced. The moisture losses from the upper 6 inches of soil were reduced appreciably by the paper covering, but the crop yields were not increased. In similar studies in Ohio,[42] use of black paper along each side of the row increased the speed and percentage of germination of seedlings of vegetable crops. The daily mean temperature was as much as 6.5° F. higher under the paper than on bare soil during May, June, and July. The paper mulch prevented weed growth, but its cost probably would limit its use to small tracts of early crops.

Tillage and Water Erosion

Probably 75 per cent of the cultivated land in the United States has a slope greater than 2 per cent on which the wasteful processes of accelerated soil removal and runoff can occur if the land is not managed properly.[2, 3, 26] There are three types of water erosion, viz., sheet, rill, and gully erosion. Gully erosion causes deep channels in the field which interfere with cultivation, rill erosion produces small channels, while sheet erosion is the more nearly uniform removal of the topsoil from the entire slope. Severe sheet erosion on cultivated fields leads to gully formation.

Erosion probably is greatest in the southeastern states where the heavy rainfall, rolling topography, unfrozen soil, and predominance of intertilled crops combine to bring about excessive soil washing. The widely spaced crops, corn, cotton, tobacco, and soybeans are most generally associated with erosion in this country.[17, 23, 24, 47, 48, 51] The numerous fibrous roots of sorghum and its more complete drying of the soil may account for the lower erosion on sorghum land than is observed on the land devoted to the tap-rooted cotton plant.[23] The greatest losses are on bare land,[23] being about twice those on corn land.[45] However, on continuously fallowed land the soil is nearly saturated with moisture [65] and can absorb little more, so it runs off. Land in small-grain crops erodes very little except during periods when the soil is bare or nearly so.[25] Pasture and grass crops in general are very efficient in soil conservation[27] unless they are overgrazed and tramped. The erosion from continuous ungrazed untramped sod or meadow is almost negligible. Heavily grazed pasture may have more than three times the runoff of a moderately grazed pasture.[65] A 3-year corn, wheat, clover-timothy rotation showed only twice as much runoff as did grass land comparable to moderately grazed pasture.

Natural vegetative cover usually prevents or greatly retards erosion.[34] Davis[22] stated: "A field abandoned because of erosion soon shows these efforts of nature to prevent devastation."

The chief tillage methods for retarding soil erosion are: (1) reversion of steep slopes to woodlands or pastures; (2) contour tillage and planting; (3) strip cropping; (4) terracing;[22] and (5) stubble-mulching, as described previously.

Row crops are now commonly planted in contour lister furrows in the semiarid regions in order to check runoff and erosion.

Strip cropping, now widely advocated,[47] has been practiced for generations in sections of Pennsylvania. The alternate strips of thick-growing crops catch the soil washed from the areas occupied by cultivated row crops. The land is tilled and all crops are planted on the contour. A regular rotation may be followed if the strips are of approximately equal width.

The bench terrace long used in Europe, Asia, and the Philippine Islands is not feasible in this country because of its excessive cost. Terracing became a common practice in the southeast after the Mangum terrace was devised by P. H. Mangum of Wake Forest, N. C. in 1885. Later many of the old terraces were abandoned because of frequent failures of the terraces, high costs of maintenance, and questionable benefits from terracing. Many of these early terraces were built poorly or the land was managed improperly.[54, 55] When a terrace breaks, erosion losses exceed those on unterraced land. The broad-base ridge or Mangum terraces permit farm machines to pass over them. A modification of this terrace of the broad channel type and constructed with less labor is known as the Nichols terrace. The broad-base terrace[55] is 15 to 25 feet wide at the base and 15 to 24 inches high. The runoff water is carried away in a gradually sloping broad shallow channel at a low velocity. Level terraces are advised in parts of Texas where the rainfall is less than 30 inches per year, so as to hold all the water on the field until it is absorbed.[23] The terracing of steep slopes (more than 8 per cent) no longer is recommended universally because of the expense, and also because all of the topsoil may be scraped up to build the terraces.[17]

The nitrogen, phosphorus, calcium, and sulfur in the soil eroded from corn or wheat land may equal or exceed the amounts taken off in the crops.[27] Much of the soil carried by streams comes from stream and gully banks, *badlands, breaks,* deserts, and similar areas that have been eroding since time immemorial, and is not chiefly topsoil. A combination of computed estimates of the quantity of suspended soil carried into the sea by rivers of the United States[3, 22] indicates that the total is about 1,450 pounds per acre per year. If half of this is topsoil, the equivalent of the total topsoil is washed to the sea every 2,759 years. Thus only a small part of the erosion losses reported[2, 17] represent soil washed from the continent. Estimated soil losses sometimes greatly exceed those measured experimentally under the same conditions.[33]

Tillage and Wind Erosion

Soil blowing has been going on at times in various parts of the Great Plains for at least 25,000 years. It also occurs elsewhere in the United States when a high wind (20 mph. or more) strikes a bare, smooth, loose, deflocculated soil.[11, 36] The organic matter and fine soil particles in the topsoil contain much of the nitrogen.[2, 21] They may be carried great distances, and then be deposited in some humid area where the additional fertility is needed. When accumulated drifts are stirred and allowed to blow back onto eroded cultivated fields where the soil is caught by vegetation, the resulting aggraded soil may be very productive.[70] Uniform sand moves readily with wind where the surface is unprotected. Peat land is subject to serious wind damage. Heavy soils are subject to movement under certain conditions. The ideal structural condition to prevent erosion is coarse aggregation (clods and crumbs) too large to blow, and yet not so large as to interfere with cultivation and plant growth. There is no advantage in further pulverization.

Summer-fallowed land, except when protected by alternate strips of crops, is particularly hazardous in high winds unless it is cultivated to a minimum necessary to control weed growth, cultivated when the soil is moist, and with tools that do not pulverize the soil but that bring clods and plant residues to the surface. Land can be ranked as follows for decreasing severity of blowing: (1) bean fields, (2) corn and sorghum stubble, (3) cornstalks, (4) fallow seeded to winter rye or winter wheat, and (5) small grain or hay stubble.[6] Small-grain-stubble land rarely blows unless the organic debris is very scanty or has been turned under.

Tillage that furrows the ground or protects the surface soil with small clods and trash is especially desirable in wind erosion control. Furrows should be at right angles to the direction of the wind.[11, 16, 20, 25] Among the useful implements are the rod weeder, the lister, field cultivator, shovel cultivator, and spring-tooth harrow. Spike-tooth and disk harrows should be avoided because they pulverize the soil. The one-way disk plow pulverizes bare ground and fallowed land excessively, but is a highly satisfactory implement on land with a heavy stubble, because it leaves the residues mixed with and protruding from the surface soil. Cultivation checks wind erosion only temporarily,[11] but may delay destructive action until rains start a vegetative cover. Then blowing ceases to be a serious problem.

A permanent vegetative cover is the best protection against soil blowing.[16, 29] The soil is too dry for grass seedings to become established when soil blowing conditions prevail, and when rainfall is ample weeds cover the land and protect it from erosion without seeding. During severe droughts Russian thistles are the predominating weed cover in the Great Plains. These break off and blow away during the winter. In moist seasons, other weeds such as wild sunflower and pigweed become established, and these protect the soil while perennial weeds and grasses become established.

Strips of sorghum planted across the prevailing wind direction check soil blowing.[11, 35] This is a popular practice. Tree belts check soil blowing and accumulate drifted soil. They are of little economic

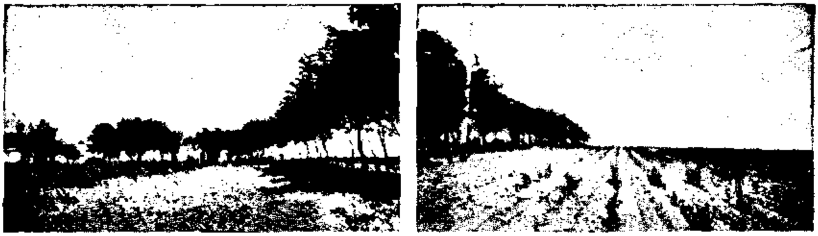

FIG. 37. Sorghum was a failure on both sides of this tree row for distances of about 4 rods. Ellis County, Kansas. The planting of intervening rows of shrubs, if effective in checking the spread of tree roots, would retard the growth of the trees.

benefit to field crops under semiarid conditions because they preclude crop growth for 4 rods on each side and seldom grow more than 20 feet high (Figure 37).

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6 FERTILIZER, GREEN MANURING, AND ROTATION PRACTICES

Object of Fertilization

Fertilizers are applied to the soil to promote greater plant growth or better crop quality. Farmers are interested in the kinds and amounts, if any, that will give a profitable crop response. Where a fertilizer does not stimulate the growth or improve the quality of a crop or turf, it is not needed to maintain the current productivity of the soil. Where fertilizer is needed and is applied in amounts sufficient to induce maximum profitable returns, a residue not utilized by the crop usually remains for soil maintenance. Fertilizers may improve the vegetative cover and thus indirectly reduce soil erosion.

A century ago Liebig proposed that we should return to the soil that which is removed in crops. This balance sheet theory is perfect arithmetic but often very unscientific agronomy, or as one writer has described it, "This reasoning is, of course, both specious and antiquated." Fortunately, farmers seldom have heeded the suggestion. To have done so would have impoverished thousands of them, especially in marginal dry areas where crops do not respond to fertilizers.

Mining fertilizer materials to apply to soils solely to maintain the status quo of fertilizer mineral elements may be wasteful of our natural resources. Nitrates, potash, calcium, and magnesium leach downward readily and are lost where the rainfall is high.[42] Phosphorus, when applied to the soil, is often fixed in the surface layers where it is subject to loss by erosion.[23]

Fertilizer needs can be determined only by experiments with the particular crop, variety, soil type, and environment. That is the purpose of fertilizer tests at experiment stations and in demonstration plots on farmers' fields. Fertilizer needs can be estimated by pot experiments, laboratory cultures, observing deficiency symptoms in plants, chemical tests of plant tissues and soils, and by a knowledge of soil types and fundamental principles.

Soil is the cheapest and the only ample source of fertilizer elements. Thomas Jefferson once said: "We can buy an acre of new land cheaper than we can manure an old one." High yields of crops remove more fertilizer elements from the soil than do low crop yields, but this fact does not justify crop neglect. The soil depletion that occurs under good management need not be viewed with too much alarm. Columella wrote in the first century A.D. that: "The earth neither grows old nor wears out, if it be dunged." This philosophy is confirmed on fields of Europe and Asia that have been farmed for centuries.

Any practice, other than fertilizer application, that improves total crop yields, even crop rotation, liming, and green manuring, speeds up depletion of the mineral elements of the soil.

A farmer can afford to apply fertilizers that give a profitable response only where crop growing with fertilization itself is profitable. Consequently improved varieties or other practices that bring profitable crop yields may actually facilitate soil improvement, when they encourage greater use of fertilizers. In most semiarid regions application of barnyard manure and commercial fertilizers and turning under legume residues becomes profitable only on land that is irrigated and devoted to intensive crops.

Before World War I, the nitrates and potash used in the United States were largely imported, and the rapid depletion of known world supplies seemed to presage a crisis. Since that time the synthetic nitrogen process has been perfected, and potash deposits were discovered in the southwest. Now we have an abundant domestic supply of both elements. More than 30,000 tons of atmospheric nitrogen lie over every acre of land.

In an effort to point out the rapidly approaching exhaustion of certain essential elements, it formerly was a common procedure to compute the number of crops that would completely exhaust each element. These calculations usually were based on analyses of only the surface of 6⅔ inches of soil. When the amounts in the total depth of soil in which annual crop plant roots customarily feed, viz., 3 to 6 feet, are considered, the situation becomes much less alarming. Phosphorus usually is distributed rather uniformly through the surface, subsurface, and subsoil layers. Potash also is distributed rather uniformly throughout the different horizons except in the sandy soils and under high rainfall conditions, where the potash content even increases with depth. Although nitrates leach downward several feet into the soil, the total nitrogen is mostly in the organic residues of the upper horizons. Calculations of its exhaustion by cropping computed by simple division are erroneous because the nitrogen content of the soil decreases with years of cropping on a curvilinear basis (Figure 38).

The popular notion that the soil has been worn out or misused wherever crops respond to fertilizers has no basis in fact. When Squanto, America's first extension agronomist, advised the Massachusetts colonists to put two dead fish in each hill of corn planted on new land just cleared from the forest, it was based upon the known fact that this treatment increased corn yields. Squanto did not know, as we do now, that the fish were rich in nitrogen, phosphorus, and calcium. George Washington found that his land in the coastal plain of northern Virginia would produce only two crops before it needed to be fertilized or rested for further cropping to succeed. The senior author was unable to establish bluegrass on a trial strip of virgin uneroded land in Maryland, until phosphorus and nitrogen fertilizers had been applied. This confirms the fact that forest soils in high rainfall regions on a rolling topography may be expected to respond to fertilizers immediately, or soon after they are cleared and farmed, and forever thereafter. On the other hand, the deep Chernozem soil of the level, drier, prairie of the Red River Valley showed no decrease in productivity in 60 years of continuous cropping to wheat without fertilizer or green manure.[44] Despite this fact wheat grown there in rotation outyielded continuous wheat. Fertilizers find little use on such rich soils except for special crops such as potatoes and sugarbeets, or for other crops in years of abundant rainfall and high prices. A large majority of American farmers are eager to apply fertilizers wherever their profitable use has been amply demonstrated.

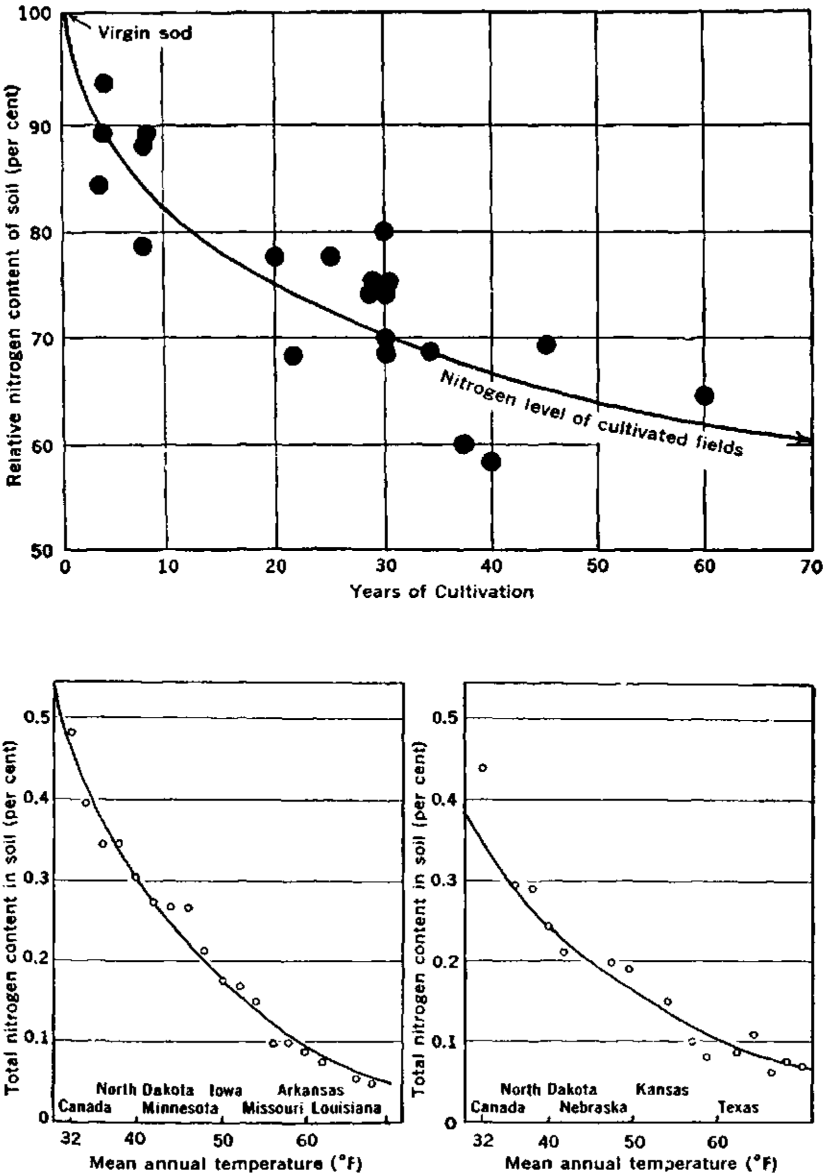


FIG. 38. Soil nitrogen content in the midwest declines on a curvilinear basis with years of cultivation, and with increase in temperature in subhumid and humid sections (*lower left*) and semiarid sections (*lower right*).

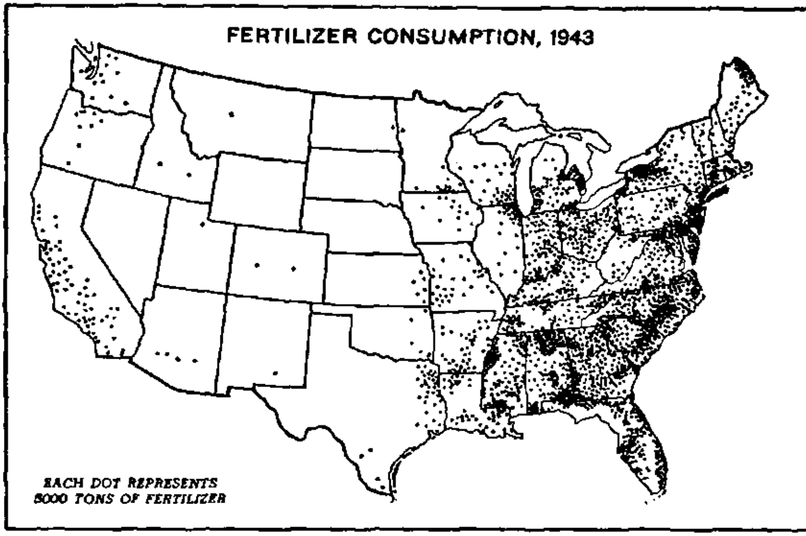
Effects of Nutrient Elements on Plant Growth *

While a number of elements are utilized by plants, only eight are likely to be limiting factors in plant growth. These are nitrogen, phosphorus, potassium, and calcium, and for some soils, sulfur, magnesium, boron, and manganese, in decreasing order. Other elements are deficient only in restricted areas. Elements may actually be deficient in soils, or their availability may be low. As a general rule, mineral elements are abundant in semiarid regions and deficient in most humid areas. Nearly 95 per cent of the domestic commercial fertilizer is used east of the 98th meridian (Figure 39). Most of that used in the west is applied on irrigated or humid-area lands devoted to intensive crops such as orchard fruits, vegetables, potatoes, and sugar beets. The heaviest use of fertilizer is in the southeastern states.

Nitrogen fertilizers give a response in crops grown on most soils of the humid areas except in black prairie soils and peat and muck, which also are high in organic matter. Nitrogen is absolutely essential to plant growth. Plants grown on soils with sufficient amounts of available nitrogen in the soil make a thrifty rapid growth with a healthy deep green color. Ample nitrogen has a tendency to encourage stem and leaf development. Deficiency of this element results in plants of poor color, poor quality, and low production. An oversupply of nitrogen in the soil tends to cause lodging, late maturity, and poor seed development in some crops, and to make plants more susceptible to certain diseases. On semiarid lands, surplus available nitrates cause excessive plant growth that exhausts the soil moisture in dry seasons before grain is produced. In humid areas abundant nitrogen may prevent firing of the leaves during dry periods.

Adequate amounts of phosphorus in soils favor rapid plant growth and early fruiting or maturity, and often improve the quality of vegetation. Liberal supplies of phosphorus enable late crops to mature in the north before they are injured by early freezes. Soils in the eastern half of the United States usually give a response to

* Most of the facts discussed hereafter in this chapter are covered in detail in Soils and Men, *U. S. Dept. Agr. Ybk.*, 1938.



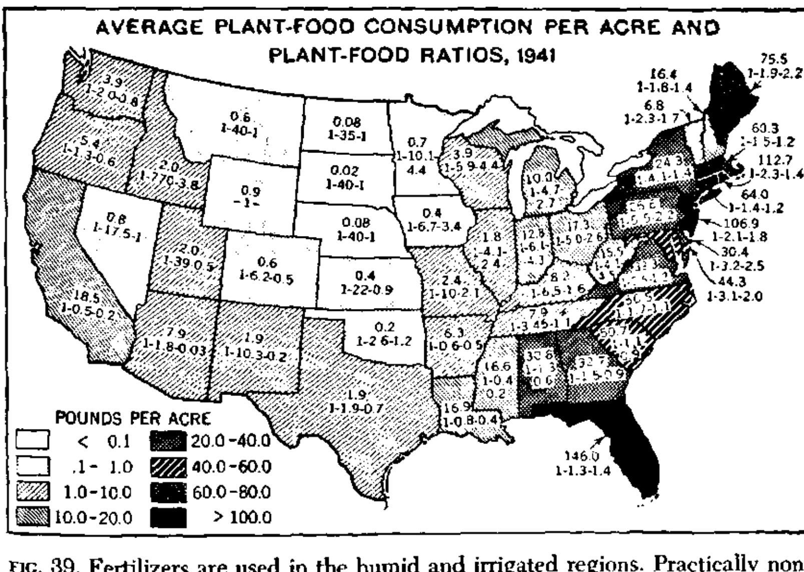


FIG. 39. Fertilizers are used in the humid and irrigated regions. Practically none are used in the semiarid regions of the Great Plains or Pacific Northwest.

phosphorus applications. An exception is the bluegrass region of Kentucky and Tennessee where the soils were formed from rocks high in phosphorus (Figure 40). Acid clay soils low in organic matter usually give a greater response to phosphate fertilizers than other soils of the same region.[23] In the west, some crops respond to phosphorus on irrigated lands after 3 to 30 years of cropping. Calcareous irrigated soils are most likely to respond to phosphorus.[18] Certain western soils are high in both phosphorus and calcium, but the availability of phosphorus is low, probably because of the high calcium content.[37]

An adequate supply of potassium in the soil improves the quality of the plant, insures greater efficiency in photosynthesis, increases resistance to certain diseases, helps to balance an oversupply of nitrogen, and helps plants to utilize soil moisture more advantageously. It also insures the development of well-filled kernels and stiff straw in the cereals, encourages growth in leguminous crops, assists in chlorophyll formation, and is particularly helpful in the production of starch- or sugar-forming crops.[4] Potassium is particularly beneficial to tobacco, potatoes, cotton, sugar beets, and certain cereals. Potatoes grown with too little potassium may be watery, low in starch, and generally poor in quality. With insufficient potassium the leaves of the tobacco plant may have poor color and flavor, and lack burning qualities. Crops usually respond to potash fertilizers in the Atlantic coastal plain, in regions of high rainfall in the eastern third of the United States (except in certain portions of the piedmont), and on sandy, muck, and peat soils of the Great Lakes region. Potash usually is abundant in soils of volcanic origin. The ordinary range of potassium expressed as potash (K_2O) in the plow surface of mineral soils is 0.15 per cent in sands to 4.0 per cent or more in clay soils.[4]

SOIL NITROGEN RELATIONS

The nitrogen in the soil is derived from the air. Aside from artificial fixation, the gaseous nitrogen is fixed with other elements through the activities of soil bacteria. It is introduced into the soil as organic nitrogen of plants or plant residues. Upon decomposition of the organic matter, some of the nitrogen passes into the air as

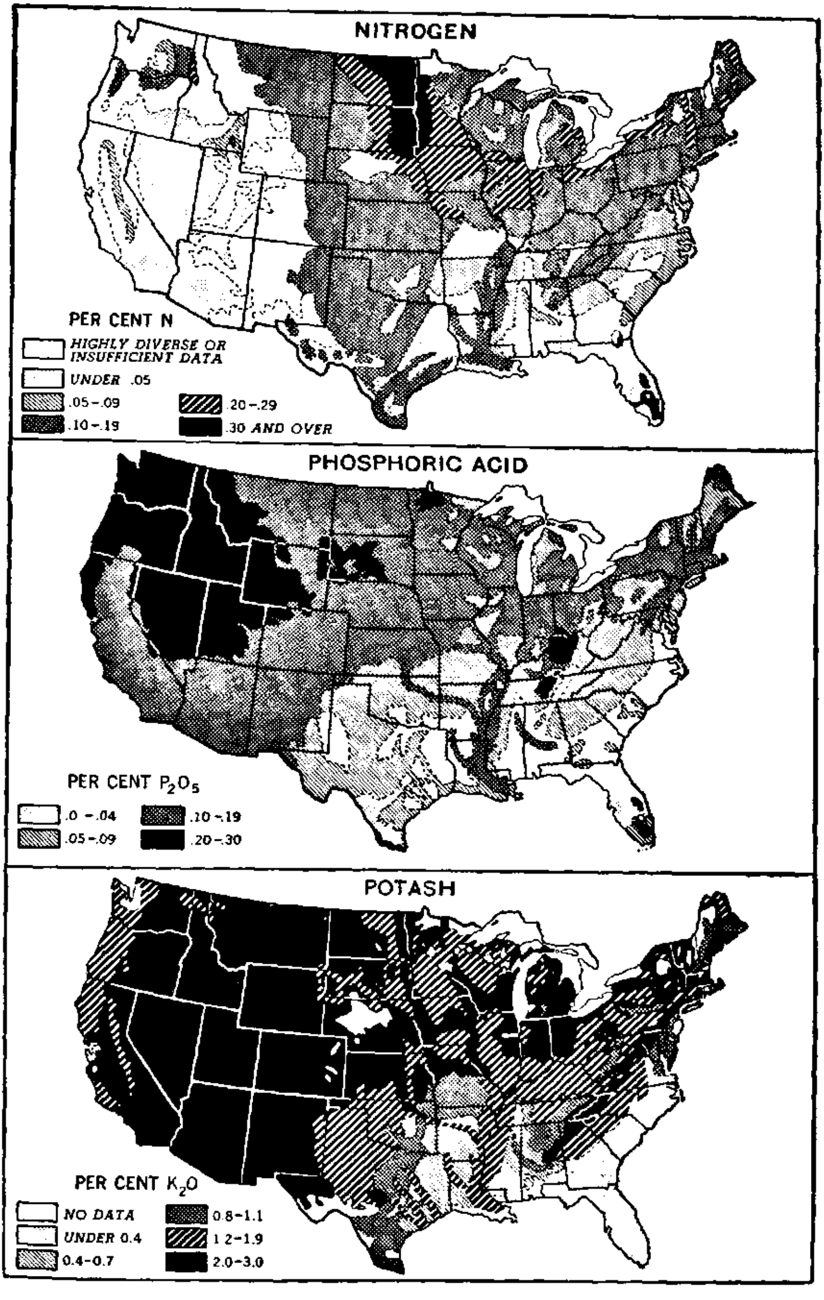


FIG. 40. The distribution of nitrogen, phosphoric acid and potash in the surface foot of United States soils.

elemental nitrogen or ammonia, while the part remaining in the soil is converted into ammonia and nitrites, and finally into nitrates. Ammonia and nitrates are used by plants or lost in the drainage waters. Some of the nitrogen remains in the soil a long time in the organic matter that is not fully broken down.

When plants are used as feed for animals, a part of the nitrogen is recovered in the manure as well as in animal by-products. Decomposition proceeds when manures or animal by-products are added to the soil. The nitrogen supply of the soil may be maintained by growth of legumes, use of manures, and by addition of nitrogen fertilizers.

Role of Bacteria in Nitrogen Fixation. Bacteria living in nodules on the roots of legumes fix nitrogen from the air into forms that the plant can utilize. This is sometimes called symbiotic fixation of nitrogen. An average of 50 to 130 pounds of nitrogen per acre is added to the soil by legume bacteria annually if the crop is plowed under.[8, 35] These *Rhizobium* bacteria function most effectively in soils low in nitrogen. Legume plants obtain their nitrogen supply from the soil unless they are supplied with the bacteria necessary to form nodules on the roots. The bacteria, which are specific for certain legume plants, often have to be added to the soil in pure cultures. The cultures are washed with water, which is then sprinkled over the seed just before planting. Soon after the seed germinates, the nodule bacteria enter the roots. After the soil becomes inoculated, further artificial inoculation becomes unnecessary if the proper legume is grown at frequent intervals. Different legumes require different bacterial strains. The groups of nodule bacteria[8] are: (1) alfalfa and sweetclover; (2) true clovers; (3) field peas, vetch, roughpeas, lentils, and horsebean; (4) field beans; (5) lupines and serradella; (6) cowpeas, peanuts, velvetbeans, crotalaria, guar, and lima beans; and (7) soybeans. Birdsfoot trefoil, big trefoil, sesbania, and chickpeas, each require specific distinct cultures.

Other bacteria convert atmospheric nitrogen into organic combinations by utilizing energy from decay of organic matter in the soil. In this process, called nonsymbiotic nitrogen fixation, the nitrogen becomes available to plants after the organisms die and their nitrogen is ammonified and nitrified. An average of 25 pounds of nitrogen per acre is added annually in this way.[35]

Nitrogen Distribution in Soils under Natural Conditions. The nitrogen content is highest in soils of the Prairie and Chernozem types of the central states, where it is estimated to average 16,000 pounds per acre to a depth of 40 inches. From this region the amount of nitrogen decreases down to 4,000 pounds per acre eastward, westward, and southward. The distribution of nitrogen in soils is closely related to climatic conditions.[12] In the east the high rainfall leaches out nitrates. In the drier west sparse plant growth retards accumulation of nitrogen-containing humus. The total nitrogen content of the soil in the United States decreases from north to south with increasing temperature. For every 18° F. rise in mean annual temperature, the average nitrogen content of the soil decreases one-half to two-thirds. The nitrogen in soils ranges from 0.01 to 1.0 per cent or more in this country, while the annual temperature ranges from 32° to 72° F. Because of favorable conditions for its preservation, the nitrogen content of soils in the north may be built up. In the south high temperatures, which favor decomposition, make it practically impossible to increase the nitrogen content of soils by green-manuring practices while the land is being cropped, except temporarily.

Under natural soil conditions there exists an equilibrium between the formation of organic matter by vegetation and its decomposition by microorganisms, the balance being determined primarily by climatic factors. Cultivation depletes both organic matter and nitrogen. In the wheat production areas, from 20 to 40 per cent of the original soil nitrogen has been lost after a period of from 20 to 40 years.[13] The end result is a new equilibrium point at a decidedly lower level than the original natural nitrogen content (Figure 38).

Commercial Fertilizers

NITROGENOUS FERTILIZERS

(1) Nitrate fertilizers are materials with their nitrogen combined in the nitrate form, as in sodium nitrate. Nitrate nitrogen, readily

soluble in water, is rapidly utilized by most crop plants. Sodium nitrate tends to make the soil alkaline.[36]

(2) Ammonium sulfate is typical of fertilizers with nitrogen combined in the form of ammonia or its compounds. Ammoniacal nitrogen, although soluble in water, is less readily leached from the soil than nitrate nitrogen. It can be used directly by crops, although it is often converted by bacteria to the nitrate form before being utilized by plants. Ammonium sulfate tends to make soils acid because of the presence of the sulfate ion.

(3) Organic nitrogen materials, such as tankage and cottonseed meal, constitute a class sometimes called organic ammoniates. The nitrogen in these materials (5 to 7 per cent in cottonseed meal) is combined in the form of complex organic compounds largely insoluble in water. This form of nitrogen must be converted to soluble forms by the processes of decay before plants can make use of it.

(4) Another class of nitrogenous fertilizers contains nitrogen in the form of amides, e.g., urea, with 46 per cent nitrogen, and calcium cyanamide with 21 to 24 per cent nitrogen. The nitrogen, which occurs in simple nonprotein compounds, dissolves entirely or largely in water. The nitrogen in these compounds usually is converted rapidly by soil bacteria to the ammoniacal or nitrate forms.

Nitrogen that is soluble in water is generally conceded to be available to plants. The most widely used nitrogen fertilizer materials are sodium nitrate and ammonium sulfate. Sodium nitrate contains from 15.4 to 16.5 per cent of nitrate nitrogen, while ammonium sulfate carries 19.5 to 21.2 per cent of ammoniacal nitrogen. Ammonium nitrate contains about 33 per cent nitrogen. The different fertilizer materials usually give similar results for each unit of nitrogen applied.

PHOSPHATE FERTILIZERS

Phosphorus must be dissolved in the soil solution before it can be taken up by plants. The phosphorus in fertilizers usually is in the form of phosphates, mostly of calcium. Phosphoric acid in phosphates of organic origin is conceded to be more readily available to plants than that in the raw mineral phosphates. The superphosphate industry began more than 100 years ago when it was found that phosphoric acid in rock phosphate could be made available to plants by treatment with sulfuric acid. The principal phosphatic fertilizer materials used in the United States are:

(1) Superphosphate with 16 to 20 per cent phosphoric acid.

(2) Treble superphosphate with 40 to 48 per cent phosphoric acid.

(3) Ammonium phosphate, which is chiefly mono-ammonium phosphate with 11 per cent nitrogen in the ammoniacal form, and with about 48 per cent phosphoric acid.

Other materials are bonemeal, basic slag, and finely ground raw rock phosphate. Since ammonium phosphate has a tendency to increase soil acidity, it is sometimes necessary to add lime to the soil to counteract potential acidity.

When phosphate fertilizer is applied to the soil it soon reacts to form compounds that are only slightly available. This is known as fixation. Under ordinary conditions, 10 to 20 per cent of the phosphorus in broadcast applications is recovered in the first crop. Some residual phosphorus is recovered in subsequent years. Phosphorus seldom leaches from soils. Accumulations may take place from heavy applications year after year, as in certain tobacco areas. More efficient use of phosphates has been obtained for row crops when the material is distributed in narrow bands on the side of the seed instead of being broadcast. Broadcast phosphates are fixed rapidly because the particles come in contact with a larger amount of soil.

POTASSIC FERTILIZER MATERIALS

The principal potash fertilizer materials used commercially are potassium chloride with 47 to 61 per cent potash (K_2O), potassium sulfate with 47 to 52 per cent, and the manure salts with 19 to 32 per cent. More than half the potash fertilizers consumed in 1937 were used in the southern states on cotton (Figure 41).

FERTILIZER USAGE

Commercial fertilizer usage in the United States was about 32,000 tons in 1860, 1,400,000 tons in 1890, 2,730,000 tons in 1900, 8,425,000 tons in 1930, and 12,468,000 tons in 1944.[20] The total plant

FIG. 41. An extreme response of cotton to fertilizers on a poor soil in the Southeast. (*Left*) fertilized, (*right*) unfertilized.

food content increased from 14.46 per cent in 1900 to 20.64 per cent in 1944. Considering all fertilizers combined, the average total plant food content in 1944 was roughly equivalent to a 5–10–5 mixture.

Relatively large quantities of potash in proportion to nitrogen were used in the Atlantic coast and north central states except in the piedmont region of Georgia, North Carolina, and South Caro... whereas nitrogen was the important fertilizer constituent in south central and western states. Aside from phosphorus only small quantities of fertilizer were used in the Great Plains and intermountain states. In South Dakota less than 1 in every 1,000 acres of crop land has been fertilized each year.

MIXED FERTILIZERS

A mixed fertilizer contains two or more fertilizer elements. About 75 per cent of the fertilizer distributed through commercial channels is a mixture. The cost of application for mixed fertilizers is less than where the various components are applied separately. The fertilizer is sold on the basis of its composition as ascertained by chemical analysis. The fertilizer formula indicates the composition of the mixture in terms of the three important elements often designated as NPK. For example, a 4–16–4 fertilizer contains 4 per cent of nitrogen, 16 per cent of phosphoric acid (P_2O_5), and 4 per cent of potash (K_2O). The remainder consists of other elements, usually calcium, sulfates, chlorides, and some *filler* (usually sand). It usually is more economical to purchase high-grade mixtures containing 20 points (20 per cent) or more of plant food constituents. The principal fertilizer grades applied to five of the most frequently fertilized crops in the states that consume 75 per cent of the total fertilizer tonnage [29] are given in Table 1.

APPLICATION OF FERTILIZERS

It is a common practice in certain districts to apply superphosphate or a mixed fertilizer (100 to 400 pounds per acre) to fall-sown grain at seeding time and top-dress with nitrate of soda (100 to 150 pounds per acre) the following spring. Corn is sometimes fertilized at planting time and then given a side dressing, near the row, of about 100 pounds per acre of nitrate of soda after the corn is well up. Such side dressings often are repeated when heavy rains leach out the nitrates and create a nitrogen deficiency. Other intertilled crops may require similar side dressings.

Fertilizer is ordinarily applied either (1) broadcast over the entire soil surface, (2) by hill or row placement in localized areas

TABLE 1. MOST COMMONLY USED FERTILIZER GRADES IN 1938

STATE	COTTON		CORN		PO
	Grade	*Rate per Acre (lb.)*	*Grade*	*Rate per Acre (lb.)*	*Grade*
Alabama	6–8–4	300	3–8–5	100	4–10–7
Florida	3–8–5	300	4–8–4	200	4–8–8
Georgia	4–8–4	350	3–9–3	200	
Indiana			2–12–6	125	0–10–10
Maryland			2–12–4	100	6–6–5
Mississippi	4–8–4	300	4–8–4	150	6–10–7
North Carolina	3–8–3	400	3–8–3	200	6–6–5
New York			4–12–4	300	4–8–7
Ohio			2–12–6	125	4–8–8
Pennsylvania			2–8–5	200	2–8–10
South Carolina	3–8–3	400	3–8–3	200	6–6–5
Virginia	0–10–4	400	3–8–3	200	6–6–5
Louisiana	4–8–4	200			4–12–4
Maine			3–10–6	600	4–8–10

TATOES	WHEAT		TOBACCO	
Rate per Acre (lb.)	*Grade*	*Rate per Acre (lb.)*	*Grade*	*Rate per Acre (lb.)*
1,000				
2,000			3–8–5	1,000
	2–10–4	200	3–8–5	1,000
500	2–12–6	125	2–12–6	200
2,000	2–8–5	250	4–8–12	800
1,000				
2,000	3–8–3	200	3–8–5	1,000
2,000	2–8–10	250		
1,000	2–12–6	200	4–10–6	400
1,000	3–12–6	250	4–8–7	750
2,000	3–8–3	200	3–8–5	600
2,000	0–16–0	300	3–10–6	1,000
800				
2,000				

close to the seed or plant, or (3) on the plow sole by dropping during plowing or by surface application before plowing.[32]

Localized applications of fertilizers near the plant favor early rapid growth. This in turn may hasten maturity of: (1) full-season crops such as corn and thus minimize frost damage, (2) wheat to mature in advance of midsummer drought, or (3) cotton to mature early enough to escape serious boll weevil damage. Localized applications also cause a greater response to small amounts of fertilizer. Advantages of localized placement are less marked in soils of high natural fertility or when heavy applications are made. Application of fertilizer at the sides of the seed or plant has been most efficient. This superiority has been explained by the tendency of fertilizer salts to move up and down in the soil with only a slight horizontal movement. The fertilizer bands vary from ¼ inch to 2 or more inches in width, the narrower bands being used for relatively light appli-

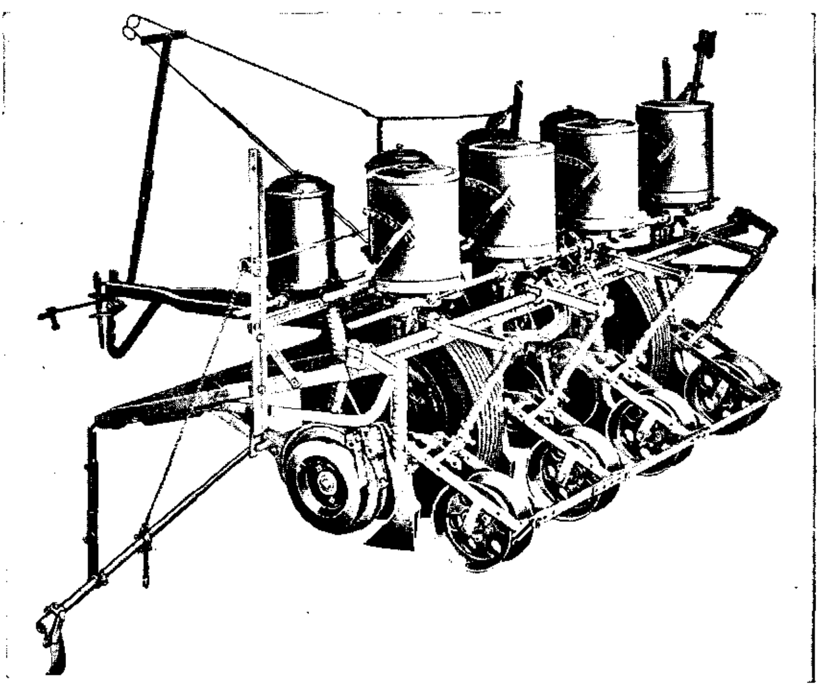


FIG. 42. Combination beet drill and fertilizer distributor. (Courtesy of International Harvester Company.)

cations of 100 to 200 pounds. The bands are placed ¾ inch to 2½ inches from the seed. The distance between the bands of seed and fertilizer ordinarily should be greater for heavy rates of application on coarse-textured soils, and for crops more sensitive to fertilizer injury. The fertilizer bands are placed at the same depth as the seed, or better, slightly below that level. Plow-sole applications may place the fertilizer at a depth more accessible to the roots of certain crop plants than is obtained from surface applications after the land is plowed.

Fertilizer Distributing Machinery. Fertilizer distributing machinery is classified[32] as follows: (1) machines used only in applying fertilizer, (2) combination machines for applying fertilizer and planting the crop in one operation (Figure 42), (3) combination machines for applying fertilizer and tilling the soil in one operation, and (4) machines for applying fertilizer in solution with irrigation water (Figure 43). Combination planter-fertilizer distributors for

FIG. 43. Metering liquid ammonia into irrigation water for nitrogen fertilization. Each drum contains 150 pounds of ammonia (NH_3), or enough for 1 to 5 acres. The water is being siphoned from the head or feeder ditch into each furrow or corrugation. (Courtesy Shell Chemical Corporation.)

side-band placement of fertilizers are now available. These include corn, cotton, potato, and bean planters. Some transplanters for setting tobacco carry attachments for applying fertilizer at the side of the plant.

Lime as a Soil Amendment

Lime usually is regarded as a soil amendment rather than a fertilizer, although calcium, the essential ingredient in lime, may be deficient in some cases. The principal effect of liming in some cowpea-wheat experiments[22] was to increase the amount of soil nitrogen available for crop use. Soil acidity can be corrected by applications of lime. Soils low in lime are frequently acid, a condition that occurs in humid regions where calcium is leached from the soil or removed by plants. Porous sandy soils leach readily and are more likely to be acid than are heavy soils under the same conditions. In South Carolina, approximately 40 per cent of the soils are strongly to extremely acid (*p*H 5.5 or less).[3] This acidity is too high for satisfactory growth of even the somewhat acid-tolerant crops, tobacco and cotton, without liming.

The chief forms of agricultural lime are crushed limestone, burned lime, and hydrated lime. Most lime originally comes from limestone rock where it occurs as calcium carbonate ($CaCO_3$), the active element being calcium. Dolomitic limestone contains considerable quantities of magnesium carbonate. The value of crushed limestone depends upon the purity as well as the degree of fineness of the crushed particles. Limestone becomes more effective as the rock is ground finer. A common recommendation is for the material to be sufficiently fine for all of it to pass through a 10-mesh sieve and for 40 per cent of it to pass through a 100-mesh sieve.

Burned lime or quicklime (calcium oxide, CaO) is prepared by burning limestone. Hydrated lime [$Ca(OH)_2$] is formed when water is added to burned lime. In neutralizing value 100 pounds of pure crushed limestone is equivalent to 74 pounds of hydrated lime or 56 pounds of burned lime. Limestone is only slightly soluble and it reacts slowly over a long period. Because of its lower cost, however, it is the form used almost exclusively for field application in acid soil regions.

APPLICATION OF LIME

In a discussion of lime losses, Truog[41] makes this statement:

> "For general farming in the North Central States, it may be conservatively estimated that the annual loss of lime (in terms of calcium carbonate) above what is returned in manure and crop residues ranges between 100 and 500 pounds per acre. Farther south, where the rainfall is heavier, and east, where the evaporation is less, the loss may in many cases be greater. For the North Central States, where the great bulk of the lime is now used, a 2-ton application of ground limestone per acre should in most cases take care of the total net loss over a period of 10 to 20 years."

About 2400 to 6000 pounds of limestone per acre are required to change a soil from *p*H 5.5 to *p*H 6.5, clay soils requiring the larger quantity. Certain chemical tests may be used as an indication of the lime requirement of a soil. Limestone can be applied at any time of the year and to a crop at any stage without injury. Burned lime should not come in contact with the foliage of plants. Broadcast applications are generally made in amounts as large as 1,000 pounds per acre. The material can be applied with a lime spreader. It should be thoroughly incorporated in the surface soil. A common practice is to plow the soil early, disk, and then apply the lime.

Barnyard Manure

VALUE OF MANURE

Approximately a billion tons of manure are produced annually by livestock on American farms. The crop nutrients it contains would cost, at prices for commercial fertilizers, more than six times as much as was expended for such fertilizers in 1936. Only about one-fourth to one-third of its potential value is taken up by crop and pasture land.[34] The remainder is lost by misplacement, drainage, leaching, or fermentation.

Farm manure is a mixture of animal excrements and stable litter. Its value for maintenance of soil productivity has been recognized since very early times. Manure brings about soil improvement because it contains fertilizer materials and possibly certain growth-promoting organic constituents, and because it adds humus to the soil.

COMPOSITION OF MANURE

The composition of manures [33] is given in Table 2.

Manure exposed to rain may lose a large proportion of the nitrogen, phosphorus, and potash by leaching.[30]

Comparisons of equal weights of fresh and rotted manure as fertilizer invariably favor the rotted product. Manure increases in concentration of nutrients with rotting.[38] This increase is obtained by the loss of more than one-half the organic matter and a considerable loss of nitrogen.[34] The claim that rotted manure does not *burn* the crop merely reflects the fact that the highly available ammonia nitrogen has been sacrificed in the rotting process.

APPLICATION OF MANURE

Maximum returns from manuring are obtained when the following facts are recognized: [33]

(1) Manure is relatively deficient in phosphoric acid, a ton being equivalent to 100 pounds of 3–5–10 or 4–5–10 commercial fertilizer. A phosphorus supplement often is profitable.

(2) Returns from a given quantity of manure usually are greater with lighter application to a larger area. The common rate of 8 tons per acre is equivalent in value to 1,000 pounds of a 20-unit mixed fertilizer. Residual effects beyond the first year are greater with heavier applications.

(3) Because of serious storage losses during the summer months, manure should be applied to spring crops rather than held in storage for fall application.

(4) Top dressing may result in improved stands of grass and legume seedlings despite the loss of available nitrogen from the manure.

(5) Often a supplementary application of fertilizer in the hill or row is much more economical than the excessive amount of manure that would be required to meet the early demands of the crop equally well.

(6) The greatest profit may be expected from applications to crops of high acre value, and to rotations that include such crops as tobacco or potatoes. Corn responds well to manure.

TABLE 2. AVERAGE DAILY AMOUNT AND COMPOSITION OF SOLID AND LIQUID EXCREMENT OF MATURE ANIMALS

ANIMAL	DAILY PRODUCTION PER ANIMAL		COMPOSITION OF THE FRESH EXCREMENT									
			Dry matter		*Nitrogen*		*Phosphoric acid*		*Potash*		*Lime*	
	Solid (*lb.*)	*Liquid* (*lb.*)	*Solid* (%)	*Liquid* (%)	*Solid* (%)	*Liquid* (%)	*Solid* (%)	*Liquid* (%)	*Solid* (%)	*Liquid* (%)	*Solid* (%)	*Liquid* (%)
Horses	35.5	8.0	24.3	9.9	0.50	1.20	0.30	Trace	0.24	1.50	0.15	0.45
Cattle	52.0	20.0	16.2	6.2	0.32	0.95	0.21	0.03	0.16	0.95	0.34	0.01
Sheep	2.5	1.5	34.5	12.8	0.65	1.68	0.46	0.03	0.23	2.10	0.46	0.16
Hogs	6.0	3.5	18.0	3.3	0.60	0.30	0.46	0.12	0.44	1.00	0.09	0.00
Hens	0.1	—	35.0	—	1.00	—	0.80	—	0.40	—	—	—

(7) The returns from a ton of manure applied to poor land may be expected to be greater than from an equal quantity applied to land already highly productive, provided the poor land is unproductive only because of lack of fertility.

Manuring of semiarid land usually results in an increase in average total crop yield. In grain yield, on the other hand, manure usually produces increases in wet years only, with decreases in dry years, and no benefit in average seasons.[2] Thus in dryland regions manure should be applied to fields to be planted to forage crops such as sorghum.

Green Manure

PURPOSE OF GREEN MANURING

A green manure crop is grown to be turned under for soil improvement while in a succulent condition. A cover crop is one used to cover and protect the soil surface, especially during the winter. Cover crops are commonly turned under for green manure.

Green manures are used primarily to increase the yield of subsequent crops and improve the friability of the soil. This is brought about by: (1) an increase in the organic matter content of the soil to counterbalance its losses through cultivation, (2) prevention of leaching of plant nutrients from the soil during periods between regular crops, and (3) an increase in the supply of combined nitrogen in the soil when leguminous plants are turned under.

Crops such as buckwheat, rye, lespedeza, and sweetclover, which are able to grow fairly well on poor soils, when plowed under and allowed to decay, may release nutrients that were unavailable to other crops.

The use of rye for green manure on very sandy soils being brought under irrigation adds organic matter that helps hold moisture and retard sand drifting while alfalfa is being established. Heavy green manuring helps cotton to overcome injury from the *Phymatotrichum* root rot disease.

While turning under a leguminous green manure may be expected to add nitrogen, neither legumes nor nonlegumes add mineral elements to the soil. When either type of green manure increases crop yields it also hastens depletion of phosphorus, potash, calcium, magnesium, and sulfur in the soil, and a nonlegume speeds up nitrogen depletion also.

The practice of green manuring is very ancient, being known to the Greeks and Chinese before the Christian era. Lupines, peas, vetch, lentils, and weeds were being turned under as green manures 2,000 years ago.[23] Leguminous green manure crops, as well as buckwheat, oats, and rye, were used by the American colonists.

The use of cover crops planted especially to turn under for green manures is most widespread along the Atlantic seaboard and in the southern states. Their value for soil improvement from the standpoint of yields of subsequent crops appears to be greatest in this general region.[24, 25, 26, 27]

CROPS FOR GREEN MANURES

The most important green manure crops in this country are hairy vetch, Austrian winter peas, rye, crimson clover, lupines, crotalaria, sweetclover, and alfalfa.[27] Buckwheat and other crops are used in limited areas.

Along the Atlantic seaboard, crimson clover, vetch, burclover, and Austrian winter peas are being used, especially from Virginia southward to South Carolina. Potato growers in New Jersey use rye as a green manure crop and depend upon commercial fertilizers for their nitrogen supply.

In the cotton belt, vetch has increased the yields of corn and cotton particularly in Alabama. The Austrian winter pea has been popular in Georgia because of its winter hardiness. Other crops used in this region include crotalaria, lespedeza, cowpeas, soybeans, lupines, kudzu, and velvetbeans. Crotalaria appears to be better adapted to soils of low fertility, particularly sandy soils, than are most other crops. Lespedeza as a cover crop has been effective in reducing erosion in North Carolina.

In the corn belt, sweetclover has been widely used for green manuring. It has a deep taproot and produces a large tonnage of organic matter. Sweetclover is a very satisfactory legume in a corn-small grain-rotation. Red clover is used to some extent as a green-manure crop.

Rye, field peas, sweetclover, and cowpeas have been tried but seldom used as green-manure crops in the semiarid regions of the western states.

Sesbania is a popular green-manure crop on irrigated lands of the southwest.

In the humid and irrigated sections of the Pacific coast states, vetches, Ladino clover, burclover, sourclover, field peas, rye, and other crops are used for green-manure and winter-cover crops.

DECOMPOSITION OF GREEN MANURES

The green manure must be decomposed before its nutrients become available for plant growth or the organic residues become a part of the soil humus.[43] Young plants and substances high in nitrogen decompose most rapidly. As decomposition progresses, it becomes slower because of the comparatively greater resistance of the residual organic matter to decay. Green manures furnish energy to the microorganisms that bring about decomposition. The water-soluble constituents, largely sugars, organic acids, alcohols, glucosides, starches, and amino acids, are decomposed most rapidly and completely. The nitrogen-fixing bacteria use most of these substances as a source of energy. Green manures may contain 20 to 40 per cent of the total dry matter in water-soluble form. The microorganisms that decompose hemicelluloses and celluloses take up nitrogen from the soil in the process. The proteins decompose quickly, but the nitrogen liberated is immediately assimilated by microorganisms that attack the celluloses and hemicelluloses. The lignins are very resistant to decomposition and usually add to the soil humus.

The average availability of nitrogen in green-manure material harvested, applied to other lands, and turned under, is about 50 to 80 per cent.[17]

EFFECTS OF GREEN MANURES ON SUBSEQUENT CROP YIELDS

In the Great Plains, because of moisture shortages, as good or better yields are obtained after fallow than after green manure, in experiments conducted for many years.[2] There, the less growth the green-manure crop makes before it is turned under, the less moisture it uses up, and the greater are the yields of the subsequent crop.

Where moisture is the chief limiting factor in crop yields, green manuring may be expected to remain unprofitable as long as the organic matter in the soil continues at the prevalent general level. However, green manures are beneficial under irrigation, e.g., sweetclover turned under has increased yields of sugar beets.

In Georgia and in Louisiana, increases in cotton yields after turning under legumes ranged from approximately 22 to 100 per cent. Winter legumes plowed under generally increase corn yields from 24 to 78 per cent in Georgia, Mississippi, South Carolina, and Virginia. Similar results have been obtained in the corn belt when sweetclover for green manure precedes corn. Some data from Georgia [16] are given in Table 3.

TABLE 3. INFLUENCE OF WINTER GREEN MANURE CROPS ON YIELD OF COTTON AND CORN IN GEORGIA, 1926–37.*

GREEN MANURE	AVERAGE YIELD PER ACRE Corn (bu.)	Cotton (lb.)
Monantha vetch	45.8	1,286
Hairy vetch	45.7	1,266
Austrian peas	50.3	1,351
Abruzzi rye	30.6	1,079
None	31.2	772

* No supplemental nitrogen fertilizers added.

Turning under summer legumes also has increased yields. In Alabama, corn after velvetbeans plowed under, without addition of phosphate, yielded 58 per cent more than without velvetbeans but with phosphate. The increased yields of corn in Arkansas after turning under the following legumes were: cowpeas 62 per cent, soybeans 7 per cent, and velvetbeans 27 per cent. When these legumes were cut for hay, with only the stubble turned under, the increased corn yields were 30, 14, and 24 per cent, respectively. In Tennessee,[22] wheat yielded 8 bushels more per acre as a 20-year average where cowpeas were turned under than where the land was similarly fertilized but the cowpeas removed. Also in Tennessee, the yield of corn was increased 52 to 151 per cent by sweetclover, and 27 to 132 per cent by lespedeza green manure. Corn after lespedeza in North Carolina gave increased yields of 74 to 310 per cent in various trials.

The turning under of rye has often resulted in decreased yield of the subsequent cotton or corn crop because of the temporary exhaustion of the available soil nitrogen. The depressing effect is increased as the rye approaches maturity before it is turned under.

In a Georgia experiment, rye turned under March 1 increased the yield of the subsequent cotton crop by 39 per cent, while the increase after Austrian winter peas was 76 per cent. In the same test, rye turned under March 15 depressed the yield of corn grown with nitrogen fertilization by 1 per cent, and without the nitrogen by 6 per cent. The yields of cotton were depressed by 12 per cent in Louisiana when oats were turned under March 20, and by 8 per cent by rye similarly treated.

Small-grain crops used as green manures either must be turned under in an immature stage, or adequate available nitrogen must be added to the soil to facilitate decay. Rye 10 to 14 inches high contained 2.5 per cent total nitrogen, while mature plants contained only 0.24 per cent under the same conditions.[48]

UTILIZATION OF GREEN MANURES

A crop is seldom economically feasible for green manure when it requires the entire crop season for its growth, although velvetbeans grown on sandy soils in the south may be an exception. The most desirable green-manure crop occupies the land for a part of the season without interference with the regular crops in the rotation. Winter cover crops serve effectively as green manures in the south, while catch crops are often used for this purpose in the north. Legumes grown with grain crops can be turned under in the fall.

In the south, when a legume is plowed under in the fall, it should be followed by a winter cover crop to hold the nutrients released by the decomposition of the summer green manure until the crop planted next season can utilize them. On the Norfolk coarse sands of South Carolina, the subsequent yields of both cotton and corn were improved when summer leguminous green manures were followed by winter rye.[19]

When large quantities of green materials are turned under, some time should be allowed to elapse before a subsequent crop is planted, in order to avoid seedling injury from the decomposition products. In the south, a green manure should be plowed under about 2 weeks before corn is planted, and 3 weeks before planting cotton.[27]

Crop Rotation

PRINCIPLES OF CROP ROTATION

Crop rotation may be defined as a system of growing different kinds of crops in recurrent succession on the same land.[7, 14, 15, 40, 45] A rotation may be good or bad as measured by its effects on soil productivity or on its economic returns. A good rotation that provides for maintenance or improvement of soil productivity usually includes a legume crop to promote fixation of nitrogen, a grass or legume sod crop for maintenance of humus, a cultivated or intertilled crop for weed control, and the application of fertilizers.

Modern crop rotation was established about the year 1730 in England. The famous Norfolk 4-year rotation consisted of turnips, barley, clover, and wheat. On a particular field turnips would be grown the first year, barley the second, clover the third, and wheat the fourth. The wheat is followed by turnips in the fifth year to repeat the rotation. In some rotations a crop may occupy the land 2 or more years.

The Rothamsted (England) experiments include rotations that have been continued for more than 100 years. In this country, the Pennsylvania, Ohio, Illinois, and Missouri investigations have been conducted for many years.

FACTORS THAT AFFECT CROP ROTATIONS

The choice of a rotation for a particular farm depends upon the crops adapted to the particular soil, climatic, and economic conditions. In addition, weeds, plant diseases, and insect pests may limit the kinds of crops to be grown in a locality.

Rotations, except in the case of an alternate grain-fallow system, provide some diversification of crops. Diversification may assure more economical use of irrigation water and other facilities. The risk of complete failure due to weather, pests, and low prices is less with several crops than with one. Crops may be selected so as to spread labor requirements throughout the year. Seasonal labor requirements conflict with certain crops such as alfalfa, corn, and winter wheat in Kansas and Nebraska.

MAINTENANCE OF SOIL PRODUCTIVITY

Loss of organic matter as a result of continuously growing the same crop has a bad effect on tilth. Growth of grass, pasture, and deep-rooted legume crops in rotation tends to correct this condition through maintenance of organic matter. Nitrogen is added to the soil when legumes are included in the crop sequence, particularly if the soil is low in this element. Well-arranged systems of crop rotation make practicable the application of manure and fertilizers to the most responsive crops or to those with high cash value. Growth of cover crops minimizes leaching; they add to the organic matter content when turned under for green manure. The alternation of deep- and shallow-rooted crops prevents continuous absorption of plant nutrients from the same root zone year after year. Deep-rooted plants like alfalfa improve the physical condition of the subsoil when the underground parts decay.[15]

The nitrogen requirements of nonleguminous crops may be provided by legumes in the rotation, but rotations cannot supply other plant nutrients in which the soil may be deficient. The production of larger crops, made possible by rotation, depletes the soil more rapidly than does continuous cropping. These larger yields cannot continue indefinitely without application of manures and fertilizers. In a corn-wheat-clover rotation in Indiana, the yields of unfertilized plots dropped one-third in 10 years.[47]

LEGUMES IN ROTATIONS

Clover is superior to soybeans for addition of nitrogen.[28] For satisfactory growth of legumes, deficient soils may require application of minerals such as lime and phosphorus. Some experiments in Pennsylvania indicate that crop rotation is unable to maintain yields at a high level unless the soil is fertile enough to maintain production of clover also. When legumes such as soybeans and lespedeza are harvested from fertile land, more nitrogen may be taken from the soil than is added to it by the legume.

On poor lands in the south, rotations that do not include a legume still produce low crop yields because of nitrogen deficiency. In an unfertilized cotton-oats-corn rotation, the acre yields were as follows:[9] cotton 168 pounds, oats 6.9 bushels, and corn 11.3 bushels. When legumes were included as cover and green-manure crops, the yields were: cotton 706 pounds, oats 9.0 bushels, and corn 22.7 bushels.

Legumes are more efficient in fixation of nitrogen on soils with low rather than high nitrogen content, because they obtain nitrogen from the air only to the extent that the supply in the soil is insufficient. For this reason, a legume will be more effective as a nitrogen gatherer when two or more crops come between applications of barnyard manure. It is usually customary to grow legume crops previous to crops that require large amounts of nitrogen. For example, the dark tobaccos in Ohio and Wisconsin are grown on heavily manured clover sods.

CROP SEQUENCES

The preceding crop has an important influence on crop yields. A Rhode Island experiment was designed to study crop sequence in which 16 different crops were grown for two seasons, followed the third year with one of the crops grown over the entire original area.[10] Alsike clover gave the lowest yields after clover and carrots, and the highest yields after rye and redtop. The yields probably were influenced by soil acidity.

Growth of crops in descending order of their lime requirements sometimes is advisable.[1] For example, for a soil heavily limed for alfalfa, clover, or soybeans the sequence might be (1) alfalfa, sugar beets, barley; (2) red clover, tobacco, wheat; (3) alsike clover, corn, oats; or (4) soybeans, potatoes, rye.

The amount of nitrogen left in the soil by a crop may influence the yield of the crop that follows it. In a West Virginia experiment[6] the yields of wheat, oats, and corn were higher after soybeans harvested for hay than the yields after oats harvested for grain.

Crop sequences are very important under dryland conditions because of the differences in residual soil moisture left by different crops, as well as the length of the fallow period for moisture storage between crops. Thus small grains yield more after corn than after small grains or sorghum in the Great Plains region, because corn leaves more moisture in the soil.[2] Most dryland crops yield poorly after alfalfa because the excessive nitrogen and depleted soil moisture cause the crops to burn except in wet seasons.

RELATION OF ROTATION TO THE CONTROL OF DISEASES AND INSECT PESTS

Crop rotation aids in control of many plant diseases. Certain parasites that live over in the soil tend to accumulate when a susceptible crop is grown year after year. Finally the disease may become too severe for profitable crop production. Rotation is particularly effective in the control of this group of parasites. A list of some crop diseases that can be at least partly controlled by rotation was compiled by Leighty.[15]

Many insects are destructive to only one kind of crop. The life cycle is broken when crops are grown that are unfavorable to the development of the insect pest. The sugar beet nematode is controlled by a rotation in which sugar beets are grown on the land only once in 4 or 5 years. Cotton root-knot can be prevented by the growth of immune crops in the crop sequence.

CROP ROTATION AND WEED CONTROL

Crop rotation is the most effective practical method for control of many farm weeds. Some weed species are particularly adapted to cultivated crops, others to small grains, while another group thrives in meadows. The continuous growth of small grains on the same land encourages weeds. In Utah, plots continuously cropped to wheat for 7 years became so infested with wild oats as to reduce the yield seriously.[39] The chief practical difficulty affecting continuous growth of wheat on Broadbalk field at Rothamsted, England, has been the weed problem.[31]

Except for some 30 noxious species, weeds, of which there are more than 1,200 species, are not able to thrive indefinitely on crop-rotated land.[15] Annual weeds are restricted by a rotation that includes a small grain crop, a cultivated crop, and a meadow crop. Rotations that include smother crops such as alfalfa, rye, buckwheat, sorghum hay, and Sudan grass offer another means of controlling certain weeds.

CROPPING SYSTEMS AND EROSION CONTROL

In Missouri a corn-small grain-clover rotation was effective in reducing erosion in comparison with continuous corn.[21] A one-year rotation of lespedeza and winter grain also was effective. Grass-legume mixtures in rotations have been very effective in the reduction of erosion.[7]

YIELD COMPARISONS OF CROP ROTATION WITH CONTINUOUS CULTURE

Crop rotation alone is 75 per cent as effective as fertilizers for increasing crop yields as a whole, or 90 per cent when only the results for corn, wheat, and oats are averaged.[45, 46] The long-time experiments at the Rothamsted Experimental Station in England indicate the trend in yields when a crop is grown in rotation or in continuous culture. Some results with wheat are shown in Table 4.

TABLE 4. YIELDS OF WHEAT AT ROTHAMSTED FROM 1851 TO 1919

TREATMENT	AVERAGE YIELD PER ACRE (*bu.*)
Continuous wheat unfertilized	12.33
Continuous wheat fertilized	23.58
Wheat in a 4-year rotation without fertilizer (turnips, barley, clover, wheat)	24.05
Wheat in a 4-year rotation fertilized	32.49

It is obvious that the highest yield occurred where both crop rotation and fertilization were practiced. Similar results were obtained with corn in the Morrow plots in Illinois, operated since 1888.[5]

ROTATIONS IN PRACTICE

Corn Belt. Crop rotations that supply organic matter and nitrogen are built around corn as the major crop.[15] Continuous corn has resulted in reduced yields where it has been practiced for any length of time. The corn-oats-clover rotation is used in the northern part of the region. A 4-year rotation of corn, oats, wheat, and clover or mixed clover and timothy is followed in the northeastern part of the corn belt where corn is a less important crop. A rotation of corn, wheat, and clover is widely used in central Indiana.

Where soybeans can be grown, a 5-year rotation of corn, corn, soybeans, wheat, and clover is suggested.[47] Yields can be maintained when cover crops can be seeded in both corn crops, and manure and phosphate can be applied to the corn.

Cotton Belt. Definite crop sequences are less common in the cotton belt than in many other regions.[9] Cotton normally occupies a larger percentage of the cropped land than any other crop. On relatively productive soils, a typical cropping system appears to be one year of corn or an annual hay crop followed by 2 to 4 years of cotton. Interplanted legumes are used in this sequence in some instances. Two suggested rotations are as follows:

(1) Three-year rotation for land equally adapted to corn and cotton: cotton; summer legumes (cowpeas or soybeans) for hay or seed, followed by winter legumes; and corn interplanted with cowpeas, soybeans, or velvetbeans.

(2) Four-year rotation for areas where half of crop land is planted to cotton: cotton, followed in part by a winter legume; cotton; summer legumes for hay or seed followed by winter legumes; corn interplanted with summer legumes.

Hay-Pasture Region. Hay and pastures predominate in the northeastern states. A 3-year rotation of corn for silage, oats, and clover is popular on dairy farms of the Lake states where considerable land is available for pasture. Potatoes are sometimes substituted for corn as an intertilled crop. Clover-timothy or alfalfa-timothy mixtures may be sown with spring small grains and kept 2 years for hay.[48] A large percentage of the crop land is devoted to hay on many New England farms.

Wheat Regions. In the east-central area from Missouri to Virginia, various modifications of the corn, wheat, clover, or grass rotation are used. In the northeastern part of the winter-wheat area, a rotation that can be used is: corn 2 years, oats or barley 1 year, and wheat 2 years. Sweetclover or some hay crop may be included as a modification of this sequence. In the spring-wheat area of the Red River valley, a rotation of (1) small grains, 2 years; (2) sweetclover for hay, pasture, or green manure; and (3) corn or potatoes is often approximated. Definite crop rotations are not prevalent in the major wheat-production areas.

DRYLAND AREAS. In the Pacific northwest, dryland wheat has been produced under a wheat-summer fallow rotation.

Winter or spring wheat is the most important cash crop of the Great Plains and intermountain dryland areas. The rotations in this area are characterized by summer fallow periods, absence of sod crops, and ineffectiveness of green or barnyard manures. In the southern Great Plains a summer fallow-wheat-grain-sorghum rotation may be adapted. Alternate wheat and fallow is a common cropping system in the drier areas (12–18 inches of precipitation per year), while alternate corn and wheat is a practical sequence with slightly more precipitation. Continuous cropping has given satisfactory results in many parts of the semiarid region.

Irrigated Regions. In Utah, a crop rotation that included alfalfa and cultivated crops with rather heavy applications of manure effectively maintained high yields of wheat, potatoes, sugar beets, field peas, oats, and alfalfa.[39] Two satisfactory irrigated rotations for western Nebraska[11] are: (1) alfalfa (3 years), potatoes, sugar beets (manured), sugar beets, and oats; and (2) oats seeded with sweetclover, sweetclover pastured, sugar beets, and sugar beets.

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7 SEEDS AND SEEDING

Importance of Good Seeds

Reasonably good seed is a prime essential to successful crop production, whereas poor seed is a serious farm hazard. The variety and the approximate germination and purity of seed should be known before it is planted.[72] Introduction of weeds in the seed often increases the labor of caring for the crop, reduces crop yields,[69] and contaminates the current product as well as the seed and soil in future seasons.

Seed Germination

EXTERNAL CONDITIONS FOR GERMINATION

The most important external conditions necessary for germination of matured seeds are ample supplies of moisture and oxygen, a suitable temperature, and for some seeds certain light conditions. A deficiency in any factor may prevent germination.

Good seed shows a germination of 90 to 100 per cent in the laboratory. Some sound crop seeds, particularly small grains, show a seedling emergence of as high as 90 per cent of the seed when sown under good field conditions. Even corn, which is a rather sensitive seed, often produces stands of 90 per cent or more in the field. Sorghum and cotton give a lower percentage of emergence because they are more susceptible to attack from seed-rotting fungi. In sorghum, a field emergence of 70 per cent is exceptional, and 50 per cent emergence is all that is normally expected from seed having a 95 per cent laboratory germination, even in a good seedbed. However, if the seed germinates only 60 to 70 per cent in the laboratory, many of the sprouts will be so weakened that a field emergence of 20 to 25 per cent is all that can reasonably be expected. In a poor seedbed, the emergence may be much less. Seeds that germinate slowly may produce weak seedlings. However, the strong seeds in a low-germinating sample may give good yields if enough seed is planted.[44]

Legumes such as alfalfa, red clover, and sweetclover are seeded at heavy rates to allow for the hard seeds, many of which fail to grow immediately when sown. In seeded grass pasture mixtures, the species with the most viable seeds often predominates in the immediate stand.[25] Small-seeded grasses usually are sown at rates greatly in excess of those required if all of the seeds were to produce seedlings, because the mortality of the seeds and seedlings is likely to be high. Thus, in a bluegrass pasture a seeding rate of 25 pounds per acre provides more than 1,000 seeds per square foot, whereas 100 plants per square foot would soon provide dense turf.

Commercial seed of Kentucky bluegrass and certain other grasses often does not germinate more than 70 per cent, as a result of harvesting when many of the panicles are immature, followed by damage from heating in the piles of curing panicles. Any dicotyledonous plant with an indeterminate flowering habit, or a grass that sends up new tillers and panicles over a considerable period will not mature its seed uniformly. With such crops, immature seed is gathered even though harvesting is delayed until the ripest seeds have already been lost by shattering.

Moisture. Abundant water is necessary for rapid germination. This is readily supplied by damp blotters or paper towels in a germinator or by soil that contains about 50 to 70 per cent of its water-holding capacity. Field crop seeds start to germinate when their moisture content (on a dry basis) reaches 26 to 75 per cent; e.g., 26 per cent in sorghum, millet, and Sudan grass; 45 to 50 per cent in small grains;[61] and as high as 75 per cent for soybeans. The minimum moisture for germination of corn is approximately 35 per cent in the whole grain and 60 per cent in the embryo.[80]

The water usually enters the seed through the micropyle or hilum, or it may penetrate the seed coat directly. Water enters certain seeds, such as castorbean and sweetclover, through the strophiole or caruncle, an appendage of the hilum.[59] Water inside the seed coat is imbibed by the embryo, scutellum, and endosperm. The imbibed water causes the colloidal proteins and starch of the seed to swell. The enormous imbibitional power of certain seeds enables them to draw water from soil that is even below the wilting coefficient, but not in sufficient amounts to complete germination, because the adjacent soil particles become dehydrated. Seeds sown in dry soil therefore may fail to germinate, or they may absorb sufficient moisture to swell and partly germinate. Wheat, barley, oats, corn, and peas have been sprouted, allowed to dry, and resprouted three to seven times before germination was fully destroyed.[95] Germination was lower, however, with each repeated sprouting. Wheat seeds can absorb water from a saturated atmosphere until they reach a moisture content exceeding 30 per cent, but this is not high enough to start germination.[18]

Oxygen. Many dry seeds, particularly peas and beans, are practically impervious to gases, including oxygen. Absorption of moisture may at the same time render the seed permeable to oxygen. Weed seeds often remain alive but ungerminated when buried in the soil, but germinate promptly when brought near the surface where more oxygen is available. Seeds planted too deeply may be prevented from germinating through an oxygen deficiency. Many seeds fail to germinate in a saturated soil because of a lack of oxygen. Rice apparently is less restricted in its oxygen needs than most seeds since it will germinate on the soil surface under 6 inches of water. However, an atmosphere of pure oxygen is harmful to seeds as it is to man.

Temperature. The extreme temperature range for the germination of field crop seeds is from 32° to 120° F. In general, cool-season crops germinate at lower temperatures than warm-season crops.

Wheat, oats, barley, and rye may germinate somewhat at the temperature of melting ice.[10] Buckwheat, flax, red clover, alfalfa, field peas, soybeans, and perennial ryegrass germinate at 41° F. or less. The minimum temperature for germination of sorghum and corn is about 48° F. Tobacco seeds [37] germinate slowly below 57° F. Of the commonly grown crops, seeds of alfalfa and the clovers will germinate more readily at low temperatures than any others. Starchy seeds appear to be more easily destroyed by rots, and thus are less likely to produce sprouts at low temperatures than are oily or corneous seeds of the same species.[20, 50] Smooth hard hybrid seed corns give better stands than do rough softer types.

A temperature of 59° F. is about optimum for wheat, with progressively decreasing germination at higher temperatures.[36] Mold attack increases directly with increased temperatures. Soybeans of good quality may germinate almost equally well at all temperatures from 50° to 86° F., but seeds of low vitality germinate best at 77° F.

The most favorable temperature for germination of tobacco seed is about 88° F.[37] The optimum laboratory germination for seeds of most cool-weather crops is about 68° F. (20° C.), with certain fescues and other grasses requiring a somewhat lower temperature. Warm-weather crops, particularly the southern legumes and grasses such as crotalaria and Bermuda grass, germinate best at 86° to 97° F. Most crop seeds are germinated at alternating night and day temperatures of 68° F. and 86° F. in laboratory tests. The alternation of temperatures, which simulates field conditions, favors better germination.

Maximum temperatures at which seeds will germinate are approximately 104° F. or less for the small grains, flax,[19] and tobacco;[37] 111° F. or less for buckwheat, beans, alfalfa, red clover, crimson clover, and sunflower, and 115–122° F. for corn, sorghum, and millets. At temperatures too high for germination, the seeds may be killed or be merely forced into secondary dormancy. The killing has been ascribed to destruction of enzymes and coagulation of cell proteins. These reactions as a rule are not observed at temperatures as low as 122° F., but might occur over a time as long as the 24 to 28 hours or more necessary to start germination. The secondary dormancy induced by heat may be an oxygen relationship.

Light. Most field crop seeds germinate in either light or darkness. Many of the grasses germinate more promptly in the presence of, or after exposure to light, especially when the seeds are fresh. Among these are bentgrass, Bermuda grass, Kentucky bluegrass, Canada bluegrass, and slender wheatgrass. Light is necessary for germination of some types of tobacco, but most standard American varieties will germinate in its absence, although the rate and percentage of germination may be considerably retarded. The light requirement in all cases is small.[37]

PROCESS OF GERMINATION

When placed under the proper conditions, seeds capable of immediate germination gradually absorb water, until after some 3 days their moisture content may be 60 to 100 per cent of the dry weight. Meanwhile the seed coats have become softened and the seeds swollen. Soluble nutrients, particularly sugars, go into solution. Starch is hydrolyzed into maltose by the enzyme diastase, which is found in greatest quantities in the epithelial (outer) layer of the scutellum.[56] The maltose is hydrolyzed into glucose by the enzyme maltase. The soluble glucose is transported to the growing sprout chiefly by diffusion from cell to cell, and there is synthesized into cellulose, nonreducing sugars, and starch. Proteins broken down by proteolytic enzymes into amides, e.g., asparagin, and into amino acids, then build proteins in the seedling. Fats, which occur chiefly in the cotyledons of certain oil-bearing seeds and in the embryo of cereal seeds, are split by enzymes called lipases into fatty acids and glycerol, and these in turn undergo chemical changes to form sugars, which are used to build up the carbohydrates and fats in the seedlings. Energy for the chemical and biological processes of germination and growth is supplied by respiration, or biological oxidation of carbon and hydrogen into carbon dioxide and water. During germination respiration proceeds rapidly at a rate hundreds of times that in dry seeds.

The energy consumed during germination may amount to one-half the dry weight of the seed.[68] The germination of a bushel of wheat utilizes the equivalent of all the oxygen in 900 cubic feet of air and requires energy equivalent to that expended in plowing an acre of land. Emerging seedlings exposed to light begin photosynthesis early, but even then their dry weight may not equal the dry weight of the seed until 7 to 14 days or more after the seedling appears above the soil surface.

In promptly germinating seeds, the growing embryo ruptures the seed coat within one or two days after the seeds are wetted. The radicle, or embryonic root, is the first organ to emerge in nearly all cases. The radicle is soon followed by the plumule or young shoot (Figures 44 and 45). In many dicotyledonous plants such as the bean and flax, the cotyledons emerge from the soil and function as the first leaves. The plumule emerges in a bent or curved position (Figure 46), and the arch thus formed serves to protect the cotyledons as they are brought above the surface of the soil by the elongating hypocotyl. This is called hypogeal germination.

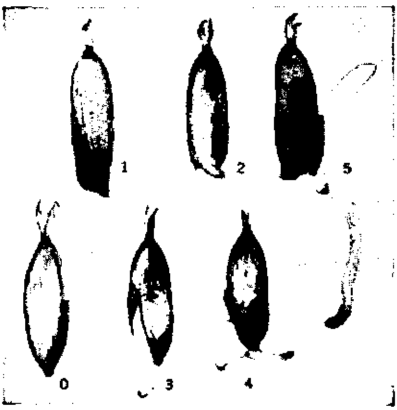

FIG. 44. Six successive daily stages in the germination of the sugarcane seed.

In grasses (monocotyledonous plants), and in a few legumes such as the pea and the vetches, the cotyledons remain in the soil. The plumule grows or is pushed upward by the elongation of an epicotyl or a subcrown internode. This is called epigeal germination. The subcrown internode of different grasses has been variously called a mesocotyl, epicotyl, or hypocotyl, depending upon the seedling node from which it arises.

The coleoptile of grasses emerges from the soil as a pale tubelike structure enclosing the first true leaf. A slit develops at the vent on the tip of the coleoptile and the leaf emerges through it. Then photosynthesis begins and the seedling gradually establishes independent metabolism as the stored food of the seed nears exhaustion. The roots are well developed by that time.

QUALITIES IN SEEDS FOR GERMINATION

Whole vs. Broken Seeds. A marked decrease in germination of mutilated wheat, corn, and alfalfa seeds occurs when the germ is injured.[94] Broken seeds containing the embryo germinate less, have a higher seedling mortality, and produce smaller plants than whole seeds.[3, 79] Breaks in the seed coat of cereals are deleterious to germination, injury at the embryo end being most serious.[53] Broken or cracked seeds mold more than do whole seeds.[50] Mechanical injury due to broken seed coats and splitting frequently occurs in field

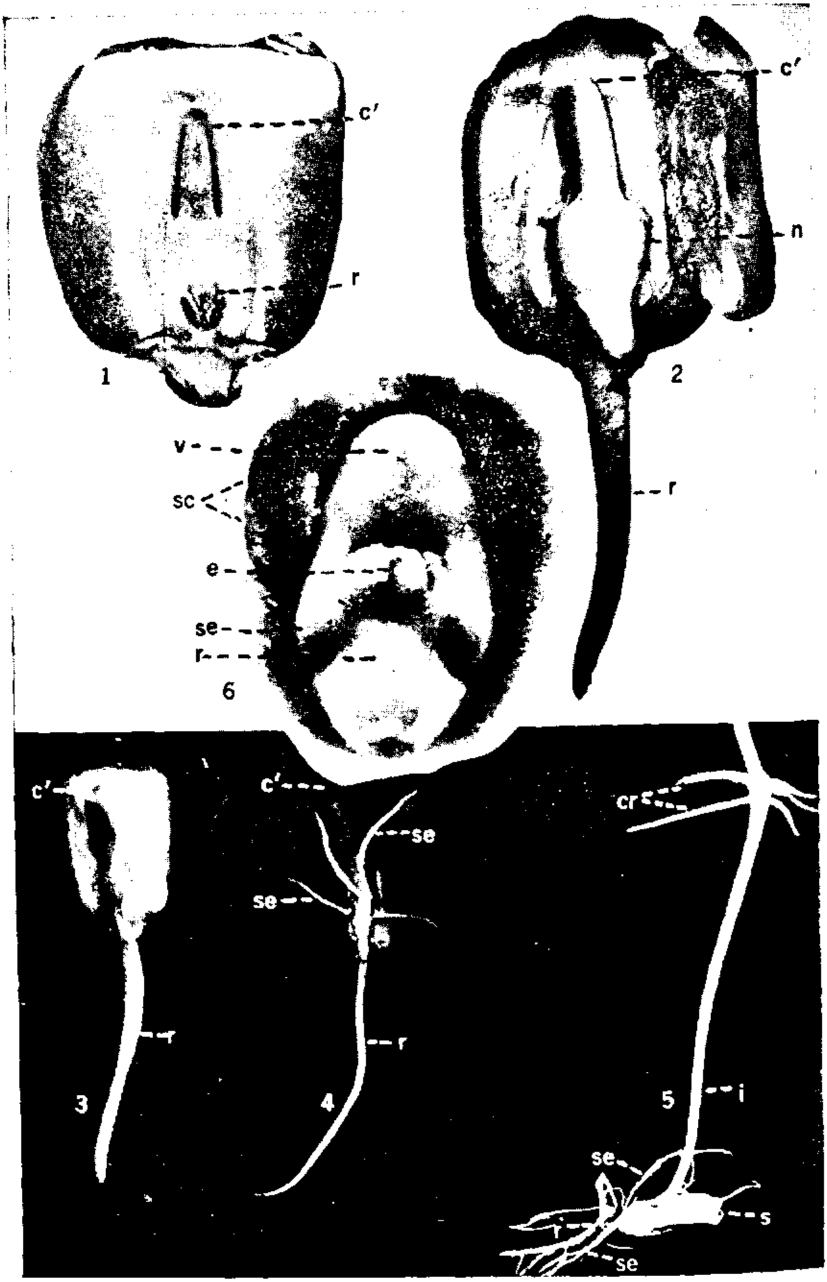

FIG. 45. Stages in corn germination: (1) before germination; (2) germinated 36 hours; (3) 48 hours; (4) 4 days; (5) 8 days. In the two upper views (Cour-

peas. Cracked peas, consisting of the embryo and a single cotyledon or a part of one may fail to germinate.[31]

The viability of seeds may be destroyed quickly by molding or heating as a result of the growth of fungi and bacteria on damp seeds stored in a warm place. These organisms break down and absorb the constituents of the seed. The fats are broken down into fatty acids, and germination drops as fat acidity goes up. After planting, the seeds are exposed to organisms in the soil as well as to those on the seed. The organisms utilize the food materials in the seed, thus starving the young sprout, and certain organisms even invade and kill the young sprouts. Seed-borne and soil-inhabiting organisms often prevent seedling emergence. Sowing sound seeds at the optimum temperature for germination helps to retard seed rots and seedling blights. Thus, small grains and field peas should be sown when the soil is cool, and planting of corn, sorghum, cotton, peanuts, soybeans, and millet should be delayed until the soil is warm. The best protection against seed rots and seedling blights is treatment of the seed with approved disinfectants containing mercury, copper, or some other chemical that is toxic to fungi and bacteria. The fungi commonly associated with the molding and rotting of seeds and the blighting of seedlings are mostly commonly prevalent species of several genera including *Pythium, Fusarium, Rhizopus, Penicillium, Aspergillus, Gibberella, Diplodia, Helminthosporium, Cladysporium, Basisporium,* and *Colletotrichum.*[46, 50]

Seed Maturity. Mature seed is preferable, but occasionally growers are obliged to plant seeds that failed to reach full maturity. Prematurely harvested barley kernels have germinated and produced small seedlings when the seeds had attained only one-seventh of

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tesy of T. A. Kiesselbach), the seedcoat has been removed to expose the embryo. In germinating, the radicle or first seminal root (r) pushes out quickly; the nodal region (n) swells; the coleoptile, which encloses the first leaves and has a vent at the tip (c'), grows upward; additional seminal roots (se) arise, usually in pairs, above the radicle after 3 days. Finally the coronal or crown roots (cr) develop and the food substance in the seed (s) is practically exhausted. At (6) a wheat germ enlarged about 25 times shows the scutellum (sc), vent in coleoptile (v), epiblast (e), seminal root swellings (se), and radicle (r) which is enclosed in the coleorhiza.

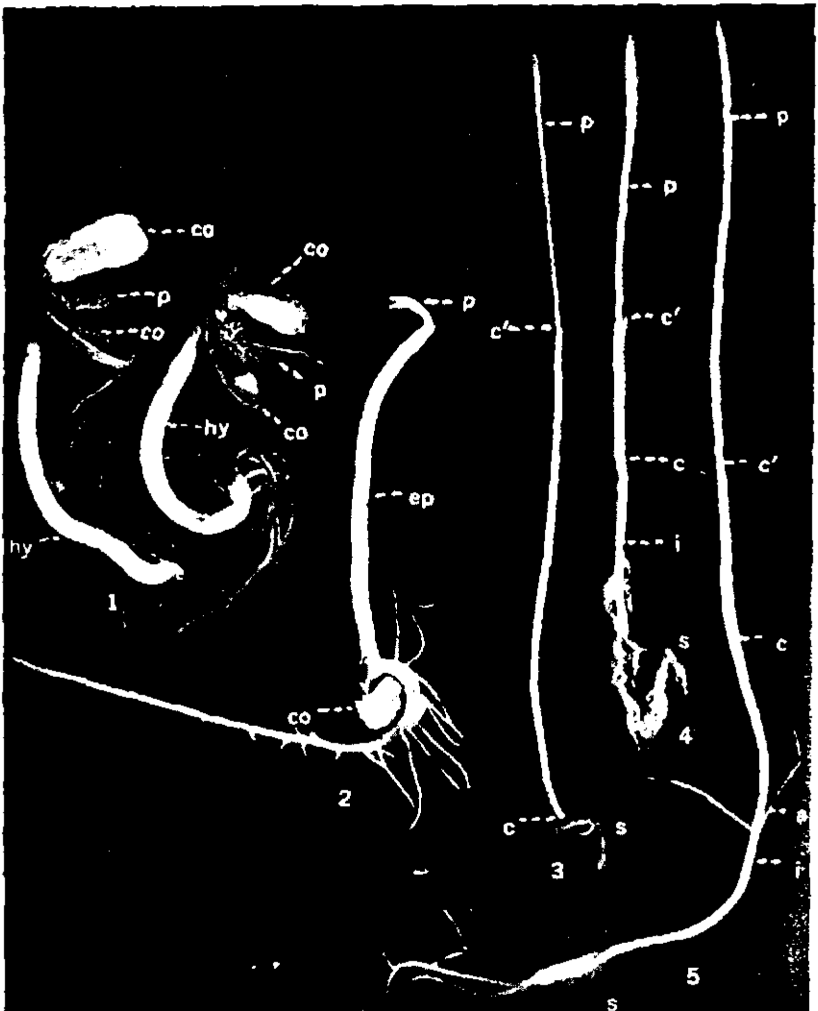

FIG. 46. Seedlings of (1) bean, (2) pea, (3) rye, (4) sorghum and (5) oats. In germinating the cotyledons (co) of the bean are pushed up by the elongating hypocotyl (hy), then the cotyledons separate and the plumule or true leaves (p) emerges. *In the germinating pea the epicotyl (ep) grows upward from the* cotyledons (co) and the plumule (p) grows out from the tip of the epicotyl. In the cereals the coleoptile grows or is pushed to the soil surface and then the plumule (p) grows out through a slit (c') at the tip of the coleoptile. In rye, as in wheat and barley, the coleoptile base (c) arises at the seed (s) and the crown node lies somewhere within the coleoptile. In sorghum, as in corn, the coleoptile base (c) is at the crown node which is carried upward from the seed

their normal weight.[26, 27] Corn seeds grew when gathered as early as 20 days after fertilization of the silks, provided they were carefully dried.[39] Such poorly developed seeds obviously are unsatisfactory for field planting. Table 1 shows that corn gathered as early as the denting stage is suitable for seed.[42]

TABLE 1. EFFECT OF MATURITY OF SEED UPON THE GRAIN YIELD OF DENT CORN (5-YEAR AVERAGE)

WEEKS BEFORE RIPE	SEED HARVESTED DATE	DAYS SINCE FERTILIZATION	CONDITION OF GRAIN	FIELD GERMINATION (%)	YIELD SHELLED CORN PER ACRE (*bu.*)
Ripe	September 28	51	Mature	94	55.8
1	September 21	44	Glazing	94	54.4
2	September 14	37	Denting	93	54.9

Mature corn produces heavier sprouts than that harvested at immature stages.[36] Immature corn shows more disease infection and yields slightly less than mature corn.[46, 47]

Immature seed,[4] because of its small size has a low reserve food supply, and usually produces poor plants when conditions are adverse at planting time. It must be carefully harvested and stored in a manner that will prevent frost injury when it is high in moisture content.

Seed Size. Small seeds invariably produce small seedlings. The logarithms of seedling and seed weights are directly proportional[5] (Figure 47).

In Nebraska experiments[40] small seeds of winter wheat, spring wheat, and oats yielded 18 per cent less than the large when equal numbers of seeds were sown per acre at an optimum rate for the large seed, but only 5 per cent less when equal weights of seed were sown, also at an optimum rate for the large seed. Grain drills sow about equal volumes per acre of large or small seeds of any

(s) by the elongating subcrown internode (i). In oats, as in rice, the node at the coleoptile base (c) stands just below the crown node and also is carried upward from the seed (s) by the elongating subcrown internode. Occasionally adventitious roots (a) arise from the subcrown internode (i) in oats and the other cereals. (The irregular direction of roots resulted from germination between blotters instead of in the soil.)

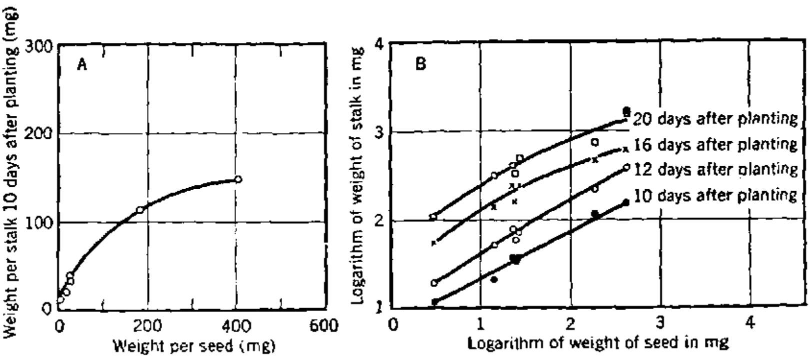

FIG. 47. The seedling weight (10 to 12 days after planting) shows a direct logarithmic relation to seed weight. A, Relation between weight per seed and weight per stalk 10 days after planting of corn, sorghum, and proso; B, relation between logarithms of the seed weights and of the stalk weights taken at various intervals up to 20 days after planting.

particular grain, so the latter comparison is of the most practical significance. When unselected seed was used, it yielded 4 per cent less than the large when equal numbers were sown per acre, but only 1 per cent less when equal weights of seed were sown.

In comparisons of fanning mill grades of winter wheat over a 17-year period, the heaviest one-fourth yielded 0.3 per cent more, and the lightest one-fourth 2.0 per cent less, than the unselected seed. Similar results were obtained with oats.

There is no material or practical gain in grain yield from grading normally developed small grain seed that is reasonably free from trash. Large seeds produce more vigorous seedlings, which survive adverse conditions better, but this advantage within certain limits is largely offset by the greater number of plants obtained from an equal weight of smaller seeds.

The germination and seedling size of shrunken and plump spring wheat having test weights ranging from 39.5 to 60.8 pounds per bushel was determined.[49] Test weight shows little relation to viability, but shrunken seeds produce such small weak seedlings that sowing of wheat testing less than 50 pounds per bushel is not recommended. Kernels of wheat testing 60 pounds per bushel are about twice as heavy as those testing 50 pounds. A reduction in test weight of one-third, i.e., from 60 down to 40 pounds per bushel reduces the weight of an individual kernel nearly two-thirds,[85] and seedling weights are reduced nearly as much. In general, seeds less than one-half normal size are unsuitable for sowing.

Formerly the usual recommendation was to throw away the butt and tip kernels of the corn ear, and plant only seed from the middle portion. Extensive experiments showed that the average yield of butt seed was 103 per cent of that from the middle of the ear, and the yield from the tips 105 per cent.[48] In a similar comparison, seeds from the tips, butts, and middles of corn ears averaged 55.3, 55.4, and 56.0 bushels per acre, respectively.[43] Thus butt and tip kernels are not inferior for seed purposes but may give irregular stands with ordinary corn planter plates. Shelled butt and tip kernels of hybrid corn separated with a seed corn grader are planted with special plates. However, they sell at a lower price than the more popular seed from the middle of the ear called large flat seed.

Dormancy in Seeds. Seeds of some crop species show dormancy, i.e., they fail to grow immediately after maturity even though external conditions favor germination, until they have passed through a rest or after-ripening period. This is more common in wild than in cultivated plants. Dormancy in cereal seeds is indicated by inability to germinate at higher temperatures when it germinates well at 36° to 50° F.

CAUSES OF DORMANCY. Dormancy may result from the following seed characteristics or environmental conditions: [13]

(1) Thick or hard seed coats prevent intake of water and probably also of oxygen. The *hard seeds* in many legumes are an example.

(2) Seed coats that interfere with the absorption of oxygen, e.g., cocklebur, oats, and barley.

(3) Immature embryos. In some species the embryo has not yet reached its full development at harvest.

(4) The embryos in still other seeds appear to be mature but must undergo certain changes before they will germinate. Wheat and barley seeds harvested at certain stages before maturity, i.e., 12 to 24 days after flowering, and dried quickly, may retain their green color, germinate poorly and produce weak seedlings.

Such green seeds also are found in wheat that has been frosted before maturity. Dormant varieties of winter barley apparently acquire dormancy during ripening or drying because seeds of such varieties sprouted in the head before maturity when the seedcoats were kept wet by artificial watering.[71]

HARD SEEDS IN LEGUMES. Hard or impermeable seeds that prevent penetration of water and cause an apparent enforced dormancy period are common in alfalfa, and are found in most small-seeded legumes.[82] Hard seeds in alfalfa are due to inability of the palisade cells to absorb water.[55] Apparently the cuticle does not restrict the intake of water. The percentage of hard seeds varies among different branches of the same plant. Probably as a result of some scarification, machine-threshed seed contains fewer hard seeds than that which is hand-threshed. Plump seed is more likely to be dormant than is shriveled or immature seed.

AFTER-RIPENING. Seeds of peanuts, alfalfa, clover, and lupines planted soon after maturity under conditions nearly optimum for germination frequently show dormancy ranging up to 2 years. The rest period appears to be one of after-ripening in peanuts.[32]

Seeds of many small grain varieties require a short period of dry storage after harvest in order to after-ripen and give good germination at temperatures as high as 20° C. Seeds usually are stored several months before germination tests are made, but in winter cereals it may be necessary to test the seeds immediately after threshing to determine their viability for fall planting. Storage of oats at 105° F. for 3 months largely eliminated dormancy,[8] and also destroyed most of the molds on the seed.

The embryos of cereals are never essentially dormant, the dormancy being imposed by the seed coats. Artificial dry heating, opening of the coat structures over the embryo, and cutting off the brush ends admit oxygen and induce germination of non-after-ripened or partially after-ripened seeds of wheat, oats, or barley. A temperature considerably below 20° C. is most satisfactory for germination of freshly harvested seed of these crops.[29]

Immature, poorly cured wheat has a higher percentage of dormancy than do ripe kernels.[93] Dormancy may decrease to a minimum after 4 to 12 weeks of storage, and can be broken immediately by placing the seeds in an ice chest at 4° to 6° C. for five days, and transferring them to an alternation of temperature from 20° to 30°C. for three days. Some wheats grown under high altitude conditions may be dormant as long as 60 days after harvest.[54] Seedsmen have repeatedly encountered difficulty in getting satisfactory germination in laboratory tests of sound plump durum wheat, especially in the fall and early winter. After-ripening is completed during warm spring weather. Good stands are obtained in field planting in cool soil even though durum wheat germinates slowly in laboratory tests until spring.[91] After-ripening of mature corn is coincident with loss of moisture.[60] It may be necessary to reduce the moisture content of immature seeds to approximately 25 per cent before normal germination occurs. The mechanism that inhibits normal germination of such seeds is believed to occur in the scutellum rather than in the endosperm or pericarp.

Slow germination of freshly harvested seeds is extremely desirable in a wet harvest season, when heavy losses occur from grain sprouting in the shock. Dormant varieties do not sprout appreciably.[17, 39] All degrees of prompt, slow, and delayed germination occur in freshly harvested common oats, but cultivated red oats regularly show slow or delayed germination.[11] Dormancy disappears in most oat varieties after 30 days. Grain sorghums often sprout in the head in the field during rainy periods before harvest.

The usual dormancy in buffalo grass seed can be broken by soaking the seed in a 0.5 per cent solution of potassium nitrate for 24 hours and then chilling it at 41° F. for 6 weeks in a cold storage room, followed by drying.[92] Hulling of the seed is fully as effective, and the treatment is more simple and economical.

SECONDARY DORMANCY. High temperatures in storage or in the germinator or seedbed may throw seeds of cereals or grasses into a secondary dormancy.[14] Such seeds usually germinate later at normal temperatures after they have been subjected to cold treatment.

Very dry cotton seeds may fail to germinate as promptly or as vigorously as those with a moisture content of approximately 12 per cent when planted. A marked increase of hard seeds occurs when they are dried down to 5 or 6 per cent moisture.[90] Excessively dry seed gives satisfactory germination if moistened at planting time with about 2 gallons of water per 100 pounds of seed. Certain Texas samples entered into a secondary dormancy and failed to produce a crop when the proper seedbed conditions were not present.

SCARIFICATION OF HARD SEEDS

Germination of impermeable seeds in legumes such as alfalfa, sweetclover, and the true clovers may be brought about in several ways.[54]

In the mechanical scarifier, the seed is thrown against a roughened surface of sandpaper or other abrasives to scratch the seedcoats. The scarified seeds imbibe water and germinate in a normal manner. However, mechanical scarification is practiced less now than formerly. In tests in Utah[83] scarification of alfalfa seed increased germination about 30 per cent, but there were more weak and moldy seedlings from the scarified seed. Scarification injured about as much good seed as it made hard seeds germinable. Mechanically scarified seed has been found to deteriorate rapidly in storage. If scarified at all, seed should be planted immediately.

In New York, fall-sown sweetclover seeds softened and grew the next spring, with 50 to 75 per cent of the seeds producing plants. This is about as high a percentage as is ordinarily obtained in field seeding,[14] and 90 to 100 per cent hard sweetclover seeds fall-sown will yield better results under such conditions than scarified seeds sown at any time of the year.

OTHER HARD SEED TREATMENTS

Aging brings about slow natural deterioration of the seed coat in dry storage. In certain experiments one-third to two-thirds of the hard seeds in red clover were still impermeable after 4 years, but a majority of the impermeable seeds of alfalfa and hairy vetch became permeable before they were 2 years old.[28] In another experiment one-half of the impermeable seeds in alfalfa germinated after 1½ years, while all germinated after 11 years in storage.[55] The percentage of hard seeds in Korean lespedeza is high when the seeds are tested for germination immediately after harvest, but most of them become permeable during the winter.[62] The average percentages of hard seeds in tests made in November, January, and March were 47.25, 12.25, and 11.05, respectively.

Alternate freezing and thawing sometimes stimulates germination of hard seeds of alfalfa and sweetclover, but may also destroy some seeds that germinate normally.[76] The breaking of dormancy while in the soil may be due to a period of cold.[14]

VERNALIZATION OF SEEDS

Temperatures affect the flowering time of many plants. Winter wheat sown in the spring fails to produce heads unless the sprouting seeds or growing plants are subjected to cold or cool conditions. Winter varieties of cereal crops head normally from spring sowing and behave like spring varieties if the seeds are germinated at temperatures slightly above freezing before they are sown. The degree of sprouting during the cold treatment can be restricted by wetting the seeds only enough to start germination. This process is called vernalization.

Winter varieties of cereals are treated by soaking the seed for 12 to 24 hours and then storing them for 4 to 9 weeks at a temperature of about 2° C., while maintaining the moisture content of the grain at about 50 per cent (on a dry weight basis). Winter annual legumes and grasses may respond to similar treatments. Vernalization is so laborious and complicated that it is useful only in certain experiments. The sprouted seeds are difficult to store and sow, germination often is damaged by the treatment,[58] and drying and storing the seed at warm temperatures often causes the seeds to lose much of the effect of the cold treatment. Vernalized spring-sown winter grain yields much less than when sown in the autumn in the field, and about the same or somewhat less than adapted spring varieties sown at the same time as the vernalized grain. Certain spring varieties of cereals that have a partial or intermediate winter growth habit usually respond to vernalization treatment when sown late in the spring,[87] but true spring varieties are not affected. Russian workers have reported that special vernalization of corn, sorghum, millet, and other warm-temperature crops has been effective in hastening flowering. This treatment consists of germinating the seeds in the dark at normal temperature while restricting the sprouting by adding only limited quantities of water, largely in the form of dilute salt solutions. Extensive experiments in other countries have failed to substantiate claims for this type of vernalization.[2] The seeds often mold and lose their viability during treatment.

LONGEVITY OF SEEDS

Most farm crop seeds are probably dead after 25 years, even under favorable storage conditions. The alleged germination of seeds after prolonged storage in ancient tombs is known to be a myth, although fresh seeds that have been placed in tombs shortly before the visits of gullible travelers often germinate very well. Authentic seeds from the ancient tombs are highly carbonized and have lost much of their original substance.

Seeds in Dry Storage. Probably the optimum condition for storing seeds that will endure drying is a 5 to 7 per cent moisture content with sealed storage in the absence of oxygen and at a low temperature. In hot climates, seeds often can be kept viable between seasons only by storing them in airtight containers after the seeds have been well dried.[21] Seeds of wheat, oats, and barley kept in dry storage under cool semiarid conditions in Colorado exhibited a gradual decline in germination, the germination being approximately 10 per cent lower at the end of the 10-year period than when the seeds were 1 year old.[74] The germination of rye and soybeans decreased about 10 per cent in 5 years, but Black Amber sorgo dropped only 2 per cent in 6 years. Yellow Dent corn germinated well for the first 5 years, but decreased rapidly after the sixth year. After 15 years of storage under the above conditions,[75] average germination percentages for various crop seeds were as follows: wheat, 80.5; unhulled barley, 95.8; hulless (naked) barley, 73.9; rye, 8.2; and corn, 36.0. The drop in germination was as great or greater from the tenth to the fifteenth year as it was from the first to the tenth year.

Under Nebraska conditions, corn 4 years old was satisfactory for seed.[42] Kafir seed retained its germination well for 10 years in western Texas, but deteriorated almost completely during the next 7 years.[38]

Flaxseed of good quality stored under favorable conditions may be expected to maintain its viability for 6 to 8 years. Seeds 9, 12, 15, and 18 years old germinated 99, 89, 56, and 58 per cent, respectively.[19]

Tobacco seed usually retains ability to germinate over many years. One lot of seed germinated 25 per cent after 20 years.[37] However, there was a marked retardation in rate of germination in seed more than 10 years old.

While many farm seeds in ordinary storage in drier climates may have a life span of 15 years, they might live 50 or even 100 years in sealed storage at low temperatures in the absence of oxygen and after proper desiccation.[15] Seeds of *Albizzia* germinated after storage for 147 years in a British herbarium.

Buried Seeds. Seeds of some species of wild plants retain their vitality in moist soil for 50 years or more.[15] In the U. S. Department of Agriculture buried seed experiment a total of 107 species of seed were mixed with sterilized soil and buried in pots in 1902. None of the cereals or legumes whose seeds are used for food germinated on being dug up after 20 years. The seeds of wild plants grew better than those of cultivated plants. Several persistent weeds showed high germination after 20 years in the soil, some of them being the docks, lambsquarters, plantains, purslane, jimsonweed, and ragweed.[22] Seeds still alive when finally dug up 39 years after they were buried included Kentucky bluegrass, red clover, tobacco, ramie, and some 25 species of weeds. Wild morningglory germinated within 2 days after it was dug up after being buried 30 years.

The classical experiment with buried seeds was started in 1879 by Dr. W. J. Beal of Michigan State College. Seeds of 20 species were placed in sand in bottles and buried under 18 inches of soil. The chess and white clover seeds were dead after 5 years, while common mallow survived until the 25-year test. Curled dock and evening primrose germinated 60 years after burial.*

Germination and Purity Tests

The real value of a seed lot depends upon its purity and the proportion of pure seed in it that will grow. Seeds after threshing

* *American Journal of Botany,* 28(4):271–273 (1941).

usually contain foreign materials such as chaff, dirt, weed seeds, and seeds of other crop plants. These can be removed to a large extent but not entirely by cleaning machinery.

The object of laboratory seed testing is to determine the percentages of germination, pure seed, other crop seed, inert matter, and weed seed present, including the kinds of weed seeds and in so far as possible the kind and variety of the seed sample. This serves as an aid in selecting suitable seed, in adjusting seeding rates to germination percentages, in giving warning of impending weed problems, and in reducing dissemination of serious weeds. Seed testing should be done by well-trained seed analysts. Then the label is an accurate guide to the value of the seed.

Germination tests should include 400 seeds counted from the sample indiscriminately and divided into four or more separate tests. Purity tests should be made by hand separation of a sample containing approximately 3,000 seeds. The size of sample specified for purity tests is indicated in Table 2.

The final germination count for legumes having hard seeds in

TABLE 2. METHODS FOR TESTING TYPICAL SEEDS

CROP SEED	SEEDS PER GRAM	MINIMUM WEIGHT FOR NOXIOUS WEED EXAMINATION	MINIMUM WEIGHT FOR PURITY ANALYSIS	GERMINATION TEST			SPECIAL TREATMENTS
				Temperature	First count	Final count	
		Grams	*Grams*	°*C.*	*Days*	*Days*	
Alfalfa	500	50	5	20	3	7–12	
Alsike clover	1500	50	2	20	3	7–12	
Bahia grass	366	50	10	30–35	3	21	Light; hulling
Barley	30	500	100	20	3	7	
Bean (field)	4	500	500	20–30	5	8–13	
Buckwheat	60	300	50	20–30	3	6	
Crimson clover	330	50	10	20	3	7–12	
Kentucky bluegrass	4800	25	1	20–30	7	28	Light
Meadow fescue	500	50	5	20–30	5	14	

the sample is extended for five days, as indicated, when partly sprouted seeds are present. Fresh seeds may require pre-chilling, or treatment with 0.1 per cent or 0.2 per cent potassium nitrate, or even scarifying. Different seeds are germinated between blotters, on top of blotters, in paper toweling, in rolled towels, in sand, or in soil.

Seed Laws and Regulations

FEDERAL SEED ACT

For many years, low grade, foul, and adulterated seeds from abroad were dumped in this country. The Federal Seed Act was passed in 1912 to protect the American farmer from such seed. The act was amended in 1916 to include a minimum requirement of live pure seed. Another amendment was passed in 1926[7] to provide for staining imported red clover and alfalfa seed so as to indicate its origin. Investigations have shown that many foreign importations are unadapted to certain regions in this country. Red clover seed from Italy is strikingly unadapted to general use in this country, as is alfalfa seed from Turkestan and South Africa. The Federal Seed Act of 1939 was much more drastic and inclusive than the original act in requiring correct labeling as to variety as well as to purity and germination, in establishing heavier penalties, and in permitting assessment of penalties for mislabeling without having to prove fraudulent intent.

False advertising is prohibited. Punishments for violation of the act include fines up to $2,000, seizure of the seed, and orders to "cease and desist" violations of the act.

The act prohibits importation of seed that is adulterated or unfit for seeding purposes. Adulterated seed is considered as that containing more than 5 per cent mixture of other kinds of seed, except for mixtures that are not detrimental. Seed specified as unfit for seeding purposes is that containing more than one noxious seed in 10 grams of small-seeded grasses and legumes; one in 25 grams of medium-sized seeds such as Sudan grass, sorghum, and buckwheat; and one in 100 grams of grains and other large seeds. It also prohibits importation of seed containing more than 2 per cent weed seeds or (with several exceptions) * less than 75 per cent of pure live seed. Noxious weeds specified are whitetop (*Lepidium draba*, *L. repens*, and *Hymenophysa pubescens*), Canada thistle (*Cirsium arvense*), dodder (*Cuscuta* species), quackgrass (*Agropyron repens*), Johnson grass (*Sorghum halepense*), bindweed (*Convolvulus arvensis*), Russian knapweed (*Centaurea picris*), perennial sowthistle (*Sonchus arvensis*), leafy spurge (*Euphorbia esula*), and other seeds or bulblets of any other kinds which, after investigation, the Secretary of Agriculture finds should be included in the list.

The act also prohibits shipment in interstate commerce of agricultural seeds containing noxious weeds in excess of quantities allowed by the laws of the state or territory to which the seed is shipped, or as established by the Secretary of Agriculture. Such seeds must be labeled as to kind and variety or type, lot number, origin (of certain kinds), percentage of weed seeds including noxious weeds, kinds and rate of occurrence of noxious weeds, percentages of mixtures of other seeds, germination, hard seed percentage, month and year of germination test, and the name and address of the shipper and consignee.

In enforcement regulations of the Federal Seed Act, tolerances are specified to allow for variations in determination of germination and purity.

STATE SEED LAWS

All states have seed laws designed to regulate the quality of agricultural seeds sold within their borders. These laws have done much to reduce the spread of weed seeds, especially of noxious weeds. Most of the laws were patterned after the Uniform State Seed Law drawn up by the Association of Official Seed Analysts, originally in 1917, and more recently are being revised to conform more closely with the present Federal Seed Act.[3, 65] There is considerable variation in the details of the laws adopted by the various states, but all require seeds in commerce to be labeled. The laws

* Admittable germination percentages for these are: Bahia grass 50, bluegrass 65, carrots 55, chicory 70, Dallis grass 35, guinea grass 10, molasses grass 25, and Rhodes grass 35 per cent.

embody many of these specifications as to information on the labels: (1) the commonly accepted name of the agricultural seeds, (2) the approximate total percentage by weight of purity, i.e., the freedom of the seeds from inert matter and from other seeds, (3) the approximate total percentage of weight of weed seeds, (4) the name and approximate number per pound of each of the kinds of noxious weed seeds and bulblets, (5) the approximate percentage of germination of such agricultural seed, together with the month and year that the seed was tested.

The weed seeds regarded as noxious vary from state to state, but those so regarded by 10 or more states include: dodders, Canada thistle, quackgrass, wild mustards, buckhorn plantain, corn cockle, wild oats, wild onion, narrow-leaved plantain, wild carrot, ox-eye daisy, leafy spurge, Russian knapweed, bindweed, perennial sow-thistle, and curled dock.

The seed laws usually are enforced by designated state officials. Field inspectors are authorized to draw samples from seeds offered for sale. These are tested in official laboratories and penalties are inflicted on dealers who sell seeds in violation of the state law.

Seed Associations

Most states have seed or crop improvement associations of growers who produce quality agricultural seeds under strict regulations. These associations usually cooperate closely with their state agricultural colleges. These associations have arisen to bring superior crop varieties into widespread use.[12] Such associations furnish large amounts of high-grade farm seeds to the farmer at a reasonable cost.

Registered or Certified Seed

The seed associations, whose rules and regulations differ somewhat among the states, supervise the growing of seeds by their members for certification and registration. The definitions for foundation, registered, and certified seed proposed by the International Crop Improvement Association in 1946 follow:

(1) Foundation Seed. Foundation seed, including elite in Canada, shall be seed stocks that are so handled as to most nearly maintain spe-

cific genetic identity and purity and that may be designated or distributed by an agricultural experiment station. Production must be carefully supervised or approved by representatives of an agricultural experiment station. Foundation seed shall be the source of all other certified seed classes, either directly or through registered seed.

(2) Registered Seed. Registered seed shall be the progeny of foundation or registered seed that is so handled as to maintain satisfactory genetic identity and purity, and that has been approved and certified by the certifying agency. This class of seed should be of a quality suitable for production of certified seed.

(3) Certified Seed. Certified seed shall be the progeny of foundation, registered, or certified seed that is so handled as to maintain satisfactory genetic identity and purity, and that has been approved and certified by the certifying agency.

REQUIREMENTS FOR REGISTRATION OR CERTIFICATION

The majority of seed associations require a grower to start with registered seed or foundation seed from an experiment station or equally reliable source.[67] The seed is inspected in the field before harvest for varietal purity, freedom from disease, and freedom from noxious weeds. An inspector either takes a bin sample after the crop is threshed, or the grower is instructed to send in a representative sample for purity and germination tests. The seed that comes up to the standard set by the association for the particular crop is registered or certified. This seed is sound, plump, and of good color; it has high germination, and is free from noxious weeds. It is usually well cleaned and graded. Registered or certified seed is sold under specific tag labels which carry the necessary pedigree information as well as that required under the state seed law.

Sources of Farm Seeds

A farmer who desires a new variety or a fresh seed supply may secure high-quality pure seed of the standard varieties of most field crops from members of crop improvement associations at reasonable prices. These certified seeds often are available in the community. Seed lists are issued each year, giving the name and address of the grower, the crop and variety grown, the amount of seed available, and the price. In general, certified seed is the highest quality of seed available for field crop production. Certified seed of hybrid corn is especially desirable because quality as determined by freedom from inbreeding or outcrossing seldom can be assured otherwise. Also the true pedigrees of certified corn hybrids are known to the buyer. However, the yields obtained from certified seed are not measurably higher than from uncertified seed of good quality of the same variety having only a small admixture of other varieties. For commercial crop production an appreciably higher price for certified seed may not be justified when good uncertified seed is available unless the grower wishes to obtain a new improved variety or to be assured of seed relatively free from disease.

Good seed of most adapted crops can be grown on the home farm with care to prevent admixtures and weed contamination. The seed can be cleaned with an ordinary fanning mill unless it contains weed seeds that can be removed only with the special equipment described in Chapter 9.

The farmer usually finds it necessary to purchase hybrid corn seed and small seeds such as clover, alfalfa, and forage grasses. Most commercial seed houses endeavor to sell correctly labeled seeds, but use a disclaimer clause for their protection, because the crop produced by the farmer is entirely beyond the control of the seed seller. The disclaimer usually is stated as follows:

> "The ——— Company gives no warranty, express or implied, as to the productiveness of any seeds or bulbs it sells and will not in any way be responsible for the crop."

This statement appears on letterheads and seed tags—usually in small type. This disclaimer, however, may not exempt dealers from legal redress if the seed is misbranded or fraudulently represented.

Seeding Crops

IMPLEMENTS USED IN SEEDING

Seeders and planters used for field crops vary in size from one-row horse-drawn planters to multiple-row tractor-drawn implements.

Grain Drills. Combination grain and fertilizer drills are used in some regions. The single-disk furrow opener is best for penetrating a hard seed bed or cutting through trash (Figure 48). Double-disk

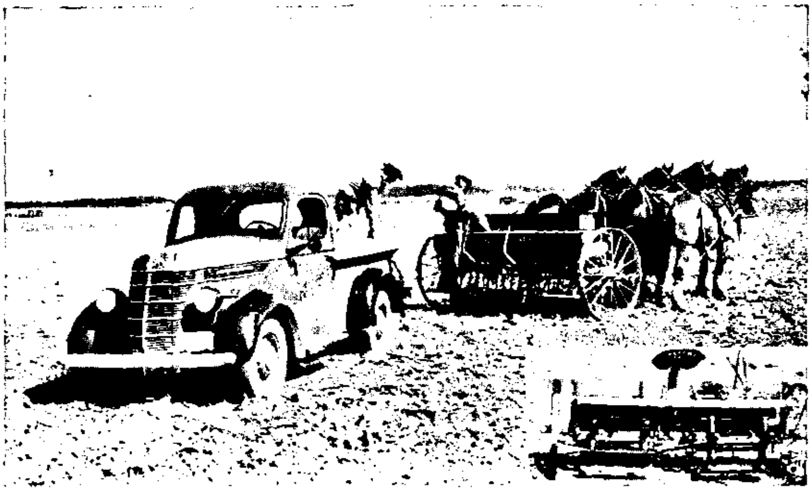

FIG. 48. Drilling oats on disked corn ground. Insert at lower right: the use of a stalk cutter shown here would have left a cleaner-appearing seedbed. (Courtesy of International Harvester Company.)

and shoe openers are best for mellow seed beds that are firm below. The hoe-type opener is best in loose soil or where soil blowing is likely to occur. The hoe drill turns up clods and trash and does not pulverize the soil to any extent. The surface drill is used under humid conditions, while the furrow drill is widely used for winter wheat, particularly in the Great Plains under dryland conditions. The furrow drill places the seed deep in moist soil. The ridges and furrows hold snow, reduce winter-killing, and tend to protect the young plants from wind erosion.

In comparative tests with winter wheat, the furrow drill has shown no advantage over the surface drill except where winter-killing is frequent.[43, 60, 77]

Row Planters. The two-row corn planter and the four-row tractor planter probably are most widely used for planting intertilled crops. These planters, when used with a wire check, drop the seed in hills. Checked corn is planted so as to permit cultivation in both directions for more complete mechanical weed control. The rows are spaced 24 to 48 inches apart, usually 36 to 44 inches. By proper selection of drill plates, the corn planter can be used to plant sorghum, beans, and some other row crops. The lister planter is a combination tillage machine and planter, which is widely used under semiarid conditions to plant sorghum, corn, cotton, and other row crops in the bottom of furrows. They are mostly of one-row, two-row, and three-row sizes, but some plant six rows.

The cotton grower requires a planter that will plant cotton, corn, and other row crops. A variable-depth planter which plants cotton in depths of 0 to 1.5 inches in cycles of about 18 inches [23] usually does away with the necessity of replanting, because suitable moisture and temperature conditions for germination and seedling emergence are likely to be present at some depths.

METHODS OF PLANTING

Surface or level seedbed planting prevails where moisture conditions are favorable. In high rainfall sections of the south, crops often are planted on elevated beds made with a lister in order to provide drainage. In the semiarid Great Plains, row crops generally are planted in the bottom of furrows. This places the seed in contact with moist (and often too cool) soil, but the chief reason for lister planting is the saving of labor in controlling weeds within the row.

Listed corn and sorghum start growth slowly, and flower and mature later than from the level and furrow plantings.[36, 78] Crop stands frequently are destroyed by heavy rains that wash soil into the bottoms of the lister furrows, thus burying the seedlings or covering the ungerminated seeds too deep for emergence. Most of the advantages of lister planting without its disadvantages can be achieved with the surface planter equipped with disk furrow openers. The retarded germination and growth following lister planting is avoided by this method.

TIME OF SEEDING

The time to seed or plant various field crops is governed by the environmental requirements for the crop, and by the necessity of evading the ravages of diseases and insect pests.

Small Grains. Spring small grains, like other cool-season crops, generally are seeded early in the season to permit maximum growth and development toward maturity before the advent of hot weather, drought, and diseases. Nineteen hundred years ago Columella wrote:

"If the conditions of the lands and of the weather will allow it, the sooner we sow, the better it will grow, and the more increase we shall have."

For winter wheat in the western states,[57] the optimum date of seeding occurs when the mean daily temperature lies between 50° and 62° F., the higher temperatures prevailing in the south and the lower ranges in the north. In the cold semiarid regions, winter wheat sown early enough in the fall merely to allow the seedlings to become established before the soil freezes gives maximum protection against cold.

In humid regions, it is essential that the plants be well rooted in order to avoid winter injury from heaving. Columella recommended seeding between October 24 and December 7 in temperate regions, while for colder regions he advised seeding October 1—"so the roots of the corns [grains] grow strong before they be infested with winter showers, frosts or hoar frosts.[11] Plants heaved up have many of their roots broken and then[34] are killed by desiccation. Losses from heaving are a common occurrence in late-sown small grains in the eastern half of the United States. Seeding late enough to escape severe injury from Hessian fly is important for winter wheat where that pest is prevalent. In the case of cereal crops, practices that lead to maximum average yields are also satisfactory from the standpoint of crop quality.[41]

Early-sown crops mature earlier than those sown later but they require a longer growing period. Consequently the difference in harvest date is less than the difference in planting date. This reaction in broomcorn, which is typical of both long-day and short-day spring-planted crops, is shown in Figure 49. The growing period becomes longer from very late planting of summer crops because of cool weather in the fall.

Other Crops. Corn is a warm weather crop that generally utilizes the full season. In Nebraska, early planting in a normal season insured earlier maturity, lower moisture content, and higher viability when exposed to low temperatures.[41] Under Colorado conditions[73] corn was better in both yield and quality when planted early, light frosts doing less damage than delayed planting.

Three planting dates for cotton, i.e., early, medium, and late, were studied under Georgia conditions.[24] Late-planted cotton (late

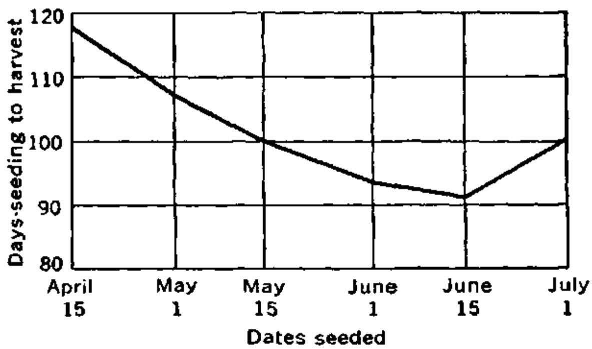

FIG. 49. Effect of planting date on the growing period of broomcorn.

May) yielded only about one-half as much lint per acre as that planted in March and April. Stands were poorest on the earlier-planted cotton and thickest in the May planting. In Texas experiments, early-planted cotton had a longer period of development before being attacked by root rot (*Phymatotrichum omnivorum*), but development of the disease was more rapid in early than in late plantings. The greatest losses were sustained by early plantings.[14]

Perennial legumes may be seeded either in spring or fall. When fall sown, they should be seeded early enough to permit satisfactory root development before the ground freezes, or else so late that the seeds do not germinate until spring.

In many crops, it is a safe practice to seed at heavier than normal rates when seeding has been delayed materially beyond the optimum time determined for the region.

RATE OF SEEDING

The objective in spacing crop plants is to obtain the maximum yield on a unit area without sacrificing quality. The rate of seeding is governed by the ultimate stand desired. Most crops are seeded at lighter rates under dryland than under humid or irrigated conditions. Small short-season varieties of corn require thicker planting than long-season varieties. Corn is generally planted in rows 3 to 4 feet apart, it having been determined in many experiments that rows more widely spaced resulted in lower yields, even under most dryland conditions.[6, 63, 97]

The number of corn plants per hill varies under different conditions from one or two for large southern varieties,[63] to four or five for the small northern varieties. Under semiarid conditions in western Nebraska the highest yields were obtained when single plants were drilled 24 inches apart in the row.[97]

In general, there is a rather definite limit for various regions of the country beyond which heavier seeding rates of small grains fail to produce increased crop yields. However, heavy seeding seldom reduces the yields. Extensive investigations under western conditions showed that the optimum rate of seeding wheat was practically independent of soil type, moisture, locality, date of seeding, cultural treatment, and variety,[57] where rates of 4 to 6 pecks per acre in general produced the highest net yields of both winter and spring wheat. Thin seeding of hard red winter wheat (20 to 30 pounds per acre) is a common practice in parts of the Great Plains. This is feasible for wheat sown early in the season, because of heavy tillering.[35] Irregularity of distribution of barley plants in the drill row may cause only slight variations in yield.[81] Thus American grain drills, when functioning properly, distribute seed of small grains satisfactorily so far as total crop yield is concerned, even though some variation in stand occurs in the drill rows.

The optimum rate of seeding barley may vary over a range of 1 to 3 bushels per acre, depending on variety.[88] An increase in rate of seeding beyond this optimum range caused a great reduction in tillering, length of head, and number of kernels per head. There was also a tendency for grain seeded at the heavier rates to lodge. Most cereals have remarkable ability to adjust themselves to the environment.[33]

Sudan grass, which, in the subhumid regions, is normally drilled at the rate of 22 pounds per acre, was planted at one-fourth normal, one-half normal, normal, twice normal, and three times the normal rate.[70] The yields of hay in tons per acre were: 3.25, 3.96, 4.50, 4.44, and 4.22, respectively.

In millet,[52] as in other grass crops, the closer the plants are in the row within practical limits, the higher will be the yield per row. With a free-tillering variety, thin stands are often compensated by an increase in number of tillers. With a non-tillering variety, thin stands often cause a decrease in yield, even when there is a material increase in plant size.

In cotton, closely spaced plants fruit somewhat earlier than widely spaced ones. The general optimum spacing appears to be from 12 and 16 inches between single plants,[64] although wider spacing may be warranted under certain conditions.[89]

Influence on Crop Quality. Grain quality is affected only to a slight extent by usual variations in seeding rate. In flax differences in plant spacing show no consistent influence on the oil content of the seed.[45] In forage crops in which fineness of stems adds to palatability and reduction in waste when fed, it is desirable to seed more thickly than is necessary to get maximum yields. Ordinarily, the forage will be finer and more leafy without reduction in yield. Sorgo (forage sorghum) can be seeded at rates as heavy as 120 to 150 pounds per acre without reduction in yield. The yield is not materially affected by increases in the seeding rate above 50 pounds per acre, but the quality of hay is improved by having finer stems. For silage purposes, corn may be spaced closer than for grain in order to obtain maximum tonnage of feed. An unduly heavy rate results in no gain in yield, and produces silage containing little grain. In cotton, thick spacing may contribute to decreased size of boll.[89]

DEPTH OF SEEDING

Seeds will emerge from greater depths in sandy soil than in clay soil, and in warm soil than in cold soil. It is customary to plant deep in dry soil in order to place the seeds in contact with moisture. Peas will emerge from a greater depth than will beans when the seeds are the same size, because the bean seedling must push the cotyledons up above the soil surface, whereas the pea cotyledons remain where planted.

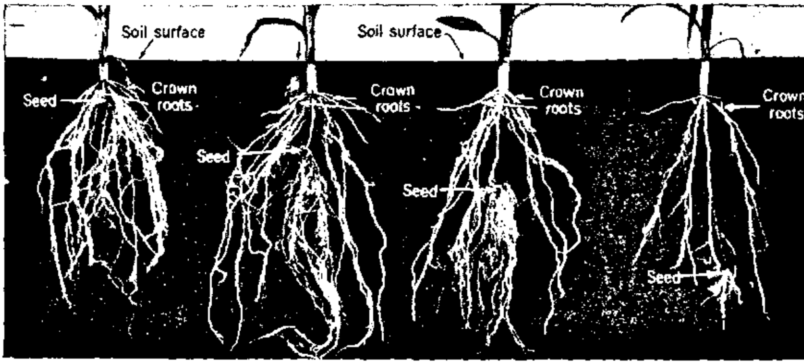

FIG. 50. Corn planted 2, 4, 6, and 10 inches deep. The crown was formed at nearly the same depth regardless of planting depth.

TABLE 3. SEEDING DEPTHS FOR SEEDS OF DIFFERENT SIZES

NORMAL DEPTH OF SEEDING	USUAL MAXIMUM DEPTH FOR EMERGENCE	SEED SIZE	REPRESENTATIVE CROPS
Inches	*Inches*	*Number per pound*	
¼ to ½	1 to 2	300,000 to 5,000,000	Redtop, carpetgrass, timothy, bluegrass, fescues, white clover, alsike clover, and tobacco
½ to ¾	2 to 3	150,000 to 300,000	Alfalfa, red clover, sweet-clover, lespedeza, crimson clover, ryegrass, foxtail millet, and turnip
¾ to 1½	3 to 4	50,000 to 150,000	Flax, Sudan grass, crotalaria, proso, beet (ball of several seeds), broomcorn, and bromegrass
1½ to 2	3 to 5	10,000 to 50,000	Wheat, oats, barley, rye, rice, sorghum, buckwheat, hemp, vetch, mung bean
2 to 3	4 to 8	400 to 10,000	Corn, pea, and cotton
4 to 5		4 to 20 (tubers or pieces)	Potato and Jerusalem artichoke

In general, the larger the seed the deeper it can be planted and still emerge from an arable soil (Figure 50). Approximately one-fourth inch in heavy soil and one-half inch in sandy soil is the most satisfactory depth for seeding small-seeded legumes and grasses under optimum conditions.[1, 66] These include alfalfa, sweetclover, red clover, alsike clover, white clover, timothy, bromegrass, crested wheatgrass, reed canarygrass, and Kentucky bluegrass. Satisfactory emergence of reed canarygrass was obtained from a 1-inch depth and bromegrass from a 2-inch depth on all soil types. A reduction in the stand of soybeans followed seeding deeper than 2 inches in fine sandy loam and 1 inch in a clay soil.[84] However, satisfactory stands were secured at depths up to 4 inches in loam and 2 inches in clay soil. Depth of planting may be an important factor determining the seedling emergence of many grasses and small-seeded legumes.[66]

The seeding depths for seeds of different sizes under field conditions are shown in Table 3.

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8 HARVEST OF FIELD CROPS

Small Grains and Other Seed Crops

STAGE OF HARVEST FOR SMALL GRAINS

Grains cease growing and gaining in dry weight when they reach about the hard dough stage, or when the moisture content of the grain drops below about 40 per cent.[17, 39, 58] Further ripening consists of desiccation unaccompanied by transport of nutrients into the kernel. Ripening is not entirely uniform among different heads or different grains within a head. Consequently, growth may continue until the average moisture content is appreciably below 40 per cent.[8] Small grains are generally harvested with a binder when the grain is in the hard dough stage, which corresponds roughly to a moisture content of 25 to 35 per cent. The heads then are usually light yellow, while the kernels are too firm to be cut easily with the thumbnail.

Premature harvest reduces both yield and quality even when rust is damaging the grain.[49] Underdeveloped grains are low in test weight, starch content, and market value.[2]

Grain or seed crops may be harvested seven days or more before they are dead ripe under cool humid conditions, and three to four days early under warm, dry conditions, without appreciable loss in yield or quality.[1] Briggs[6] in 1895, and others since that time, have reported that wheat grain draws material from the straw after it is cut when nearly ripe. Considerably more growth has occurred when immature barley grains were left to dry in the head than when they were threshed immediately.[18] However, others[2] have found no significant transfer of material from the straw to the grain during the curing process.

Effects of Delayed Harvest. When harvesting with a combine, the small grains must stand in the field for 5 to 10 days past the period of normal binder harvest or until the moisture content of the grain has dropped to 14 per cent or less, a necessity for safe storage without artificial drying. When wheat grain has a moisture content of 13 per cent or less, the rachis of the wheat spike breaks readily, and the straw will burn freely. Losses from delayed harvest are caused by shattering, crinkling, lodging, and leaching.

Cereal stems are likely to crinkle down or break over soon after maturity, especially in damp weather.[44, 34, 47] Oats are more susceptible than barley to crinkling, while barley is more susceptible than wheat or rye. Most tall-stalked grain sorghums go down soon after maturity or after a frost, whereas flax stands erect for long periods.

Weathered or sun-bleached grain is unattractive and often brings a lower price on the market. In Utah, Kanred wheat was cut at 10-day intervals from the time it was ripe to 50 days afterwards to determine the deterioration of uncut wheat in the field.[5] The dry weight of the kernel was unchanged but the weight per bushel and density decreased due to the increased volume of the individual kernels. Baking studies, the final criterion, indicated that this wheat, subjected to alternate wet and dry conditions for 50 days after it was ripe, showed no deterioration in loaf volume or texture of the bread.

In Montana, when bound wheat stood in the shock for several months, the grade was lowered, the color impaired, and the number of damaged kernels increased as the exposure was prolonged.[55] The germination was lowered, but the protein content was practically constant after the initial reduction in the first two months. The loaf volume, color, and texture of bread produced from weathered wheat was practically the same as that from normal wheat.

METHODS OF HARVESTING

In the harvesting of grain the hand sickle, scythe, and cradle were replaced by the reaper which was widely used until the modern binder was put on the market between 1880 and 1890. The header introduced still greater economies in the harvest of small grains.

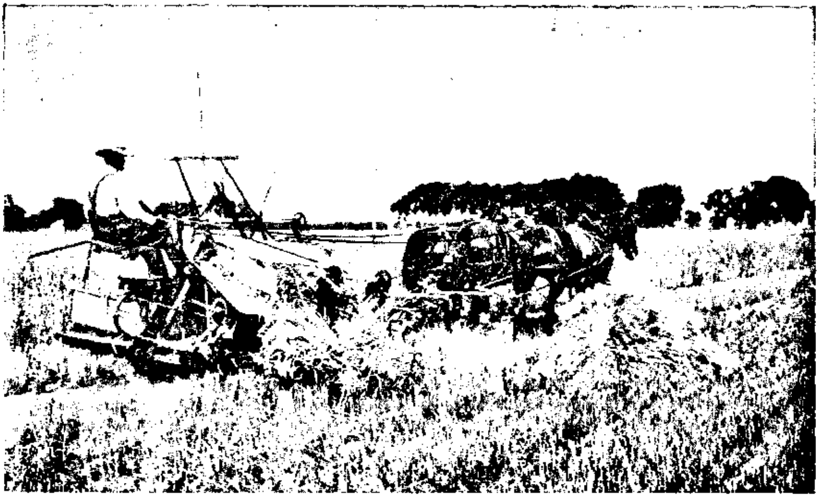

FIG. 51. The binder. (Courtesy Colorado Agricultural Experiment Station.)

Now combines are widely used in the important grain-growing regions of the world.

Binder. Small grain harvested with a binder is tied in bundles and shocked in the field (Figure 51). The bundles of ripe grain in the hard dough stage may be shocked immediately, while those with green grain or weeds should dry for a few hours before being shocked. Shocked grain is ordinarily left in the field for 10 days or more to cure before threshing. When considerable time is to lapse before it is threshed, the bundles may be stacked. About 1½ to 5 pounds of twine (500 feet of twine per pound), are required to bind the 300 to 1000 bundles usually produced on one acre. A ball of binder twine weighs about 5 pounds.

Header. The header formerly was used on large farms in the drier sections of the United States. It cuts off the heads with usually 12 to 16 inches of attached straw, and elevates the material into a header barge, in which it is hauled to a stack or directly to a thresher. The crop should be comparatively free from green weeds, which increase the opportunity for spoilage in the stack. When cut with a header, the grain may contain as much as 15 to 20 per cent moisture if it is to be stacked, but less than 14 per cent when it is threshed immediately.

Combine. The combine or combined harvester-thresher has been used in the Pacific coast states for the harvest of wheat and barley since about 1880, and its use spread into the intermountain states somewhat later. It was introduced into the Great Plains states during World War I and is now used in every grain-growing state in the Union. Combines have been used for the harvest of all small grains, grain sorghum, flax, soybeans, cowpeas, and various legumes and grasses for seed.[25] About 62 per cent of the small-grain crop of 1945 in the United States was combined directly or by the windrow-pickup method. A large part of the threshed soybean crop also was combined.

The combine is essentially a threshing machine attached to a header (Figure 52). The larger sizes with 12-foot to 20-foot cutter bars are tractor drawn and equipped with an auxiliary motor to operate the thresher mechanism. The smaller sizes with cutter bars 40 inches to 10 feet in length are often operated with a direct power drive from the tractor used to pull the machine. Self-propelled combines are coming into general use.

On modern machines, the grain is collected in a tank from which it is spouted into a wagon or truck. The straw usually is spread

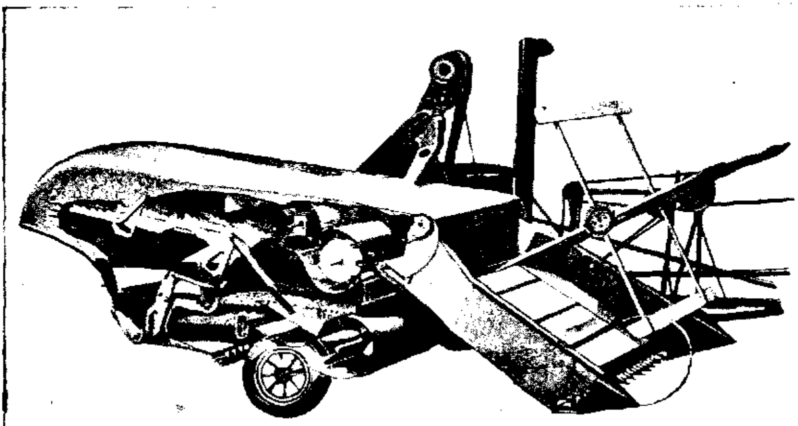

FIG. 52. Sectional view of a small combine having rubber-faced flail bars on the cylinder and rubber block concaves. Other combines may have either rasp-bar or toothed cylinders and concaves. (Courtesy of International Harvester Company.)

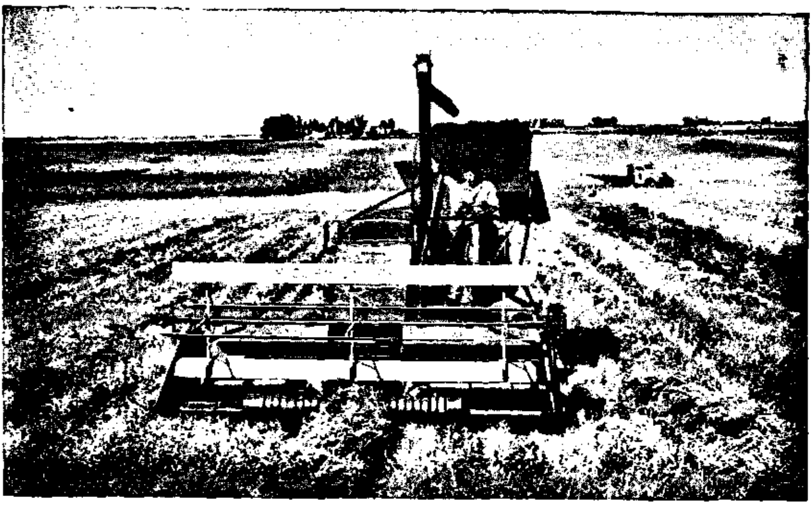

FIG. 53. Self-propelled combine with pickup attachment threshing flax. (Courtesy of International Harvester Company.)

evenly over the ground. Where it is desired to save the straw for feed or bedding, it may be deposited in piles or windrows.

Windrow Pickup Modification. The windrower or swather cuts the crop and places it on the stubble in a windrow. About 10 per cent of the small-grain crop is cut by this method. After drying, the windrow is gathered with a combine which has a pickup device attached to the cutter bar (Figure 53). The most satisfactory stubble height for windrowed grain is about one-third the total length of the straw.[47] The short-stemmed heads will drop to the ground when cutting is too high. A fairly heavy windrow may stay in good condition for 30 days, while a light windrow works down into the stubble and the grain may start to sprout.[56] The windrowed grain is usually dry enough to thresh with a combine with pickup attachment in about five days.

The windrower is used particularly in fields containing green weeds. The weeds dry in the windrow and thus do not increase the moisture content of the grain nor interfere with threshing. In threshing directly with a combine, green weeds increase threshing losses, clog the threshing mechanism, and increase the moisture content of the threshed grain.[48] Usually approximately one-half the moisture in weeds is transferred to the wheat in the first 24 hours of storage and the remainder within seven days.[47] The windrow method also is useful where the grain or seed ripens unevenly, or for early harvesting. In Missouri sweetclover, and red and alsike clover seed were combined successfully when the crop was windrowed.[26]

Binders and separators usually cause greater losses of grain than combines because of the extra handling.[4, 43, 56] However, where cereal stems break over soon after maturity, the losses from combining exceed those from binder harvesting.

Corn Binder and Other Harvesting Machines. The corn binder, or row binder (frontispiece), is used for harvesting corn, sorghum, and other crops growing in cultivated rows. The binder cuts one row at a time and ties the stalks into bundles. The bundles, except of silage crops, are shocked and allowed to dry in the field.

Machine cornpickers are now in wide use on corn belt farms (Figure 54). They require about one-fourth the labor of hand husking. Under unfavorable conditions, machine cornpickers leave more corn in the field than do hand pickers. Losses are usually reduced by growing a hybrid adapted to the machine picker, and by

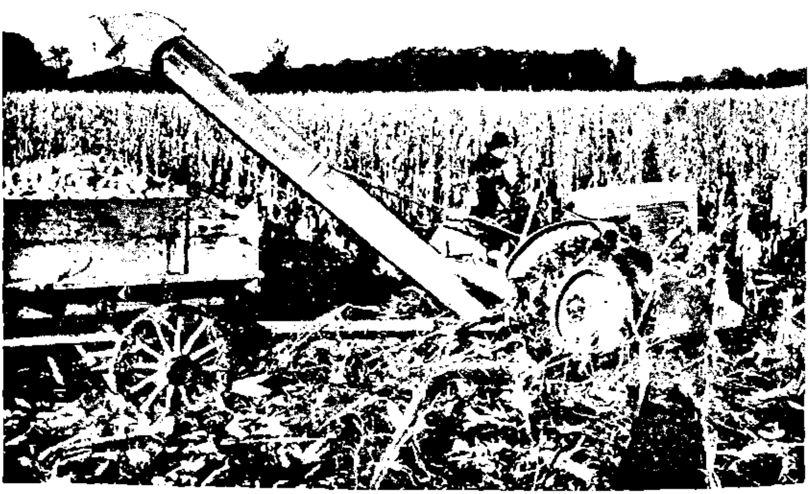

FIG. 54. A two-row tractor-mounted corn picker. (Courtesy Allis-Chalmers Mfg. Co.)

early completion of harvesting, i.e., early in November in the corn belt.

Bean harvesters cut off the roots of beans and similar legumes just below the soil surface and turn the crop from a pair of rows into a single windrow.

Field silage cutters and forage harvesters that cut the standing crop and cut it into short lengths in one operation are now in wide use.

STRAW AND STOVER

Straw comprises the dried stalks or stems and other parts of various crops from which the seed has been threshed in the ripe or nearly ripe stage. About one-sixth of the small-grain straw produced is gathered or saved. Considerable additional quantities are recovered by livestock that graze the stubble fields or have access to straw stacks. When normal small grain is cut with a binder at a height of about 6 inches the straw yields usually range from 1½ to 2¼ times the grain yield in pounds.

Stover is the corn or sorghum plant remaining after the ear or head has been removed. Typical mature corn is 50 to 65 per cent stover, and grain sorghum of different heights ranges from 45 to 75 per cent stover.

Straws and stovers are the least nutritious of all substances commonly used as feed for livestock. Animals maintained on straw alone are scarcely more than kept alive unless considerable waste grain has been left in the straw. However, straw is an important supplement in livestock maintenance. Oat and barley straw are usually considered more valuable for feed than either wheat or rye straw. Corn stover is more digestible than the small grain straws, but the waste is large unless it is shredded. Legume straws have considerable value as feed.

Straw is bulky, and that of small grain is of low manurial value, but it supplies organic matter when returned to the land. One ton of wheat straw contains on the average about 10 pounds of nitrogen, 2.6 pounds of phosphoric acid, and 14.8 pounds of potash.[33] The straws of oats and barley contain slightly more nitrogen and phosphoric acid and about twice as much potash as does wheat straw.

The straws of cowpeas, soybeans, and leguminous crops in general, are comparatively high in nitrogen and calcium, but similar to wheat straw in the other elements. One ton of soybean straw contains 18 pounds of nitrogen, 2.4 pounds of phosphoric acid, and 17.8 pounds of potash. When added to land, fresh or decayed straw should be supplemented with nitrogen and phosphorus for best results. This precludes the depression in yields that often follows in the first crop after a heavy straw application.

In 1924 it was estimated that about 15 per cent of the straw of small grains was burned, chiefly in areas of the United States where the livestock population was small, and where it could not be added to the land advantageously.[33] In the Great Basin, farmers often have burned their straw and stubble before plowing because of the difficulty in disposing of a large volume of straw. At the Nephi Substation in Utah, where the annual rainfall is about 13.33 inches, the wheat yield has not been reduced by burning the straw and stubble, nor has it been increased by plowing the straw under. Burning of straw is not recommended because repeated burning increases a tendency to soil erosion or blowing. Return of straw to the land has been greatly facilitated by use of straw spreaders attached to combines and by use of one-way disk plows and duck-foot and sweep tillage implements to replace moldboard plows on straw-covered lands.

Hay and Hay Making

PRINCIPAL HAY CROPS

The hay and forage crop of the United States usually has a higher annual value than that of any other crop except corn (Figure 55). The most important hay crops rank about as follows on the basis of average tonnage per year: (1) clover and timothy, (2) alfalfa (3) wild hay, (4) soybeans, cowpeas, and peanut vines, (5) small grains, (6) sorgo, (7) lespedeza, and (8) sweetclover. Lespedeza and alfalfa are increasing in importance while timothy and clover, sweetclover, cowpeas, soybean, and wild hay are on the decline.

The production of the leading kinds of hay in the United States in 1947 is shown on page 214.

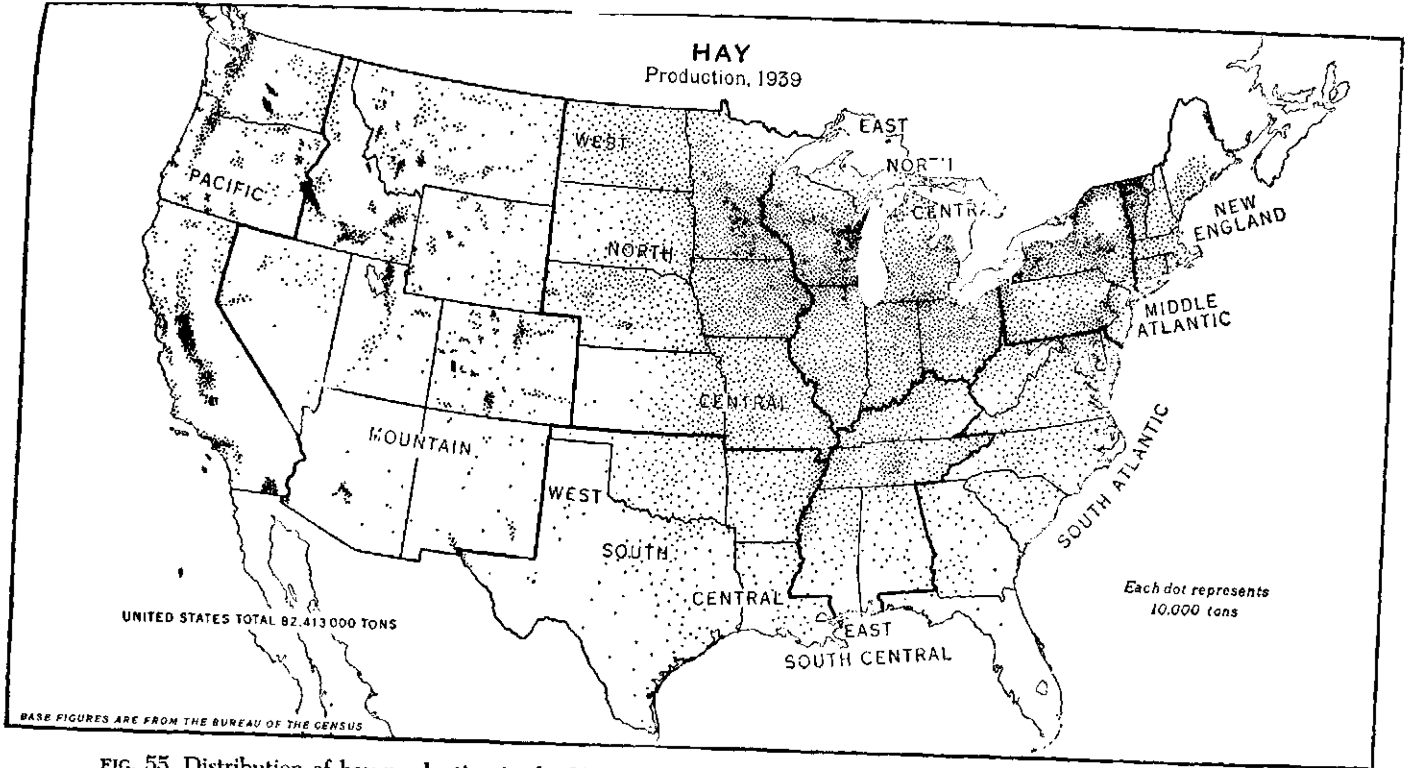

FIG. 55. Distribution of hay production in the United States.

TABLE 1 HAY PRODUCTION (PRELIMINARY ESTIMATES)

KIND	TONS
Alfalfa	33,475,000
Clover and timothy	32,569,000
Miscellaneous tame hay (Johnson grass, Sudan grass, bromegrass, crested wheatgrass, ryegrass, vetch, pea, etc.)	9,476,000
Lespedeza	6,768,000
Grains cut green	3,058,000
Soybean	1,666,000
Peanut	1,421,000
Cowpea	366,000
Sweetclover	395,000
Total tame hay	89,194,000
Wild hay	13,306,000
All hay	102,500,000
Sorghum forage	6,070,000

Hay is by far the most important harvested forage for several reasons: (1) it does not deteriorate rapidly in storage, (2) it can be handled commercially, and (3) it can be made with little cash outlay.

STAGE OF MATURITY FOR HARVESTING

The stage of maturity at which hay crops are cut affects color, leafiness, and other quality factors. It is impossible to produce high quality hay from late-cut grasses and legumes, because lignin (tough fiber) increases as the plants mature.

The more immature a forage crop is when cut, the smaller the yield and the more palatable and nutritious the product. Because of smaller yields and increased labor costs from frequent cutting, some sacrifice of quality must be made in the interest of greater yields. Consequently, plants are harvested for hay at an intermediate stage when neither yield nor quality is at its maximum. The best time to harvest the grasses, clovers, and alfalfa for hay is ordinarily some time between early bloom and full bloom.[61] Sweetclover should be cut in the bud stage to avoid subsequent coarse growth.[52] Crops that are heavy producers of seed, such as cereals, soybeans, and cowpeas should be cut at a later stage. Cereals should be cut for hay when the grain is in the soft to medium dough stage,[48] soybeans when the beans are about half grown, and cowpeas when the first pods are mature. Grasses and alfalfa are sometimes harvested before they bloom when a hay of very high quality is required. Cutting alfalfa in the bud or tenth-bloom stages reduces the vigor and stand as compared with cutting at full bloom.[45] The injury from early and frequent cutting is due to the depletion of organic food reserves in the roots.[15]

Chemical Composition. The composition changes with advance toward maturity. The contents of protein and minerals are higher and that of the less valuable crude fiber is lower in young than in old plants. These changes in alfalfa[28] and in timothy[51] are given in Table 2.

TABLE 2. EFFECT OF STAGE OF MATURITY AT CUTTING ON CHEMICAL COMPOSITION OF ALFALFA AND TIMOTHY HAY

STAGE OF MATURITY	ASH	CRUDE PROTEIN	CRUDE FIBER	NITROGEN-FREE EXTRACT [a]	ETHER EXTRACT (FAT)
	%	%	%	%	%
ALFALFA					
Prebloom	11.24	21.98	25.13	38.72	2.93
Initial bloom	10.52	20.03	25.75	40.67	3.03
One-tenth bloom	10.27	19.24	27.09	40.38	3.02
One-half bloom	10.69	18.84	28.12	39.45	2.90
Full bloom	9.36	18.13	30.82	38.70	2.99
Seed stage	7.33	14.06	36.61	39.61	2.39
TIMOTHY					
No heads showing	8.41	10.18	26.31	50.49	4.61
Beginning to head	7.61	8.02	31.15	49.14	4.07
Full bloom	6.10	5.90	33.74	51.89	2.38
Seed formed	5.54	5.27	31.95	54.12	3.13
Seed all in dough	5.38	5.06	30.21	56.48	2.87
Seed fully ripe	5.23	5.12	31.07	55.87	2.72

[a] Mostly carbohydrates; chiefly starches, hemicelluloses and sugars.

The crude fiber (chiefly cellulose) of young plants as in immature pasture herbage appears to be largely digestible. As the plant matures, a progressively greater proportion of the crude fiber is made up of less digestible lignin, which lowers its net nutritive value. Increased growth of small grains beyond the medium dough stage is more than offset by shattering of kernels, loss of leaves, leaching, and general deterioration of plant structure. Close associations are evident between the contents of fiber and stems; total ash and calcium, and leaves; and of phosphorus, crude protein, and nitrogen-free extract, and heads.[48]

The carotene content, a measure of vitamin A potency, is higher in early stages of leafy growth because the leaves contain more carotene than the stems, and old leaves lose carotene. In alfalfa, clover, and timothy hays, vitamins B and G decrease as the plant matures.[24] In general these vitamins are correlated with the leafiness, greenness, and protein content of the plant. In fact, vitamin D is the only one to show a gain in the sun-cured forage as compared with the green forage.

Cutting hay in late afternoon may avoid the depletion of food materials from the leaves and stems by translocation to the roots and by respiration during the night when photosynthesis is suspended. Practical conditions of curing hay favor morning cutting despite these assumed small losses.

FIELD CURING OF HAY

The aim of the haymaker is to dry the crop to 25 per cent moisture or less with as little loss of leaves, green color, and nutrients as possible. Loss of leaves is more pronounced with legumes than with grasses, especially when the moisture content is 30 per cent or less. The loss of alfalfa leaves begins when the moisture content of the hay drops below 40 per cent.

In the first century A.D., Columella described the curing of hay in a manner which indicates that the principles and practices of hay making have changed very little. He wrote:

"It is best to cut down hay before it begins to wither; for you gather a larger quantity of it, and it affords a more agreeable food to cattle. But there is a measure to be observed in drying it, that it be put together neither over-dry, nor yet too green; for, in the first case, it is not a whit better than straw, if it has lost its juice; and, in the other, it rots in the loft, if it retains too much of it; and often after it is grown hot, it breeds fire and sets all in a flame. Sometimes also, when we have cut down our hay, a shower surprises us. But, if it be thoroughly wet, it is to no purpose to move it while it is wet; and it will be better if we suffer the uppermost part of it to dry with the sun. Then we will afterwards turn it, and, when it is dried on both sides, we will bring it close together into cocks, and so bind it up in bundles; nor will we, upon any account, delay to bring it under a roof."

Most hay is cut with a horse-drawn or tractor mower. It may be cured in the mowed swath, in windrows after raking, in cocks built by hand from the windrows, in bunches made with a rake or buckrake, or it may be hung over a pole or frame set up in the field. Cocking has been a common practice in the humid and subhumid regions. Swath and windrow curing are safe where frequent rain is unlikely to occur during haying. Bunching is practiced with wild hay and sorghum hay in semiarid regions. Curing of coarse legumes, such as cowpeas, on poles or frames is done somewhat in the south where rainfall is heavy, when labor is abundant and cheap.

Hay is gathered into windrows either with a dump rake or side-delivery rake (Figure 56). The latter is superior because it places the hay in a loose windrow that dries quickly. If the hay is wetted by rain while in the swath, it may be stirred with a machine called a tedder. If the windrow becomes soaked through it may be turned over to dry, preferably with a side-delivery rake, after partial dry-

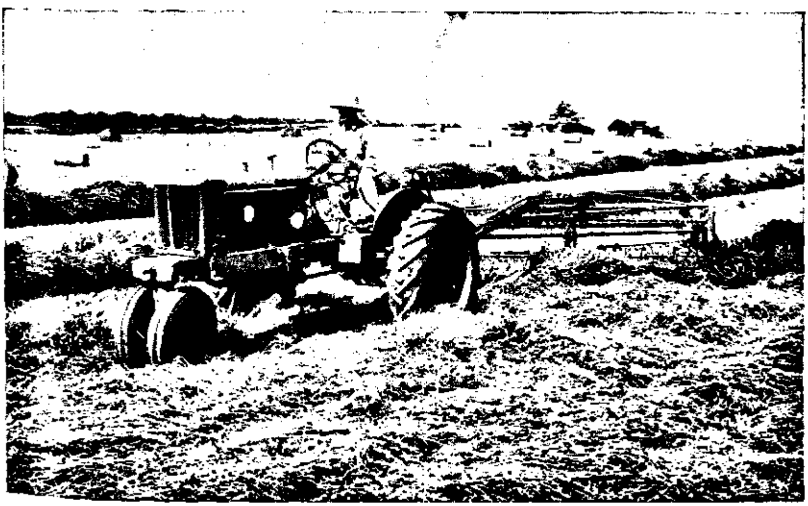

FIG. 56. Side delivery rake. Round bales dropped by the field baler in the background. (Courtesy of Allis-Chalmers Mfg Co.)

ing. Cocks and bunches can be turned by hand or with a dump rake. This permits the bottom portion to dry.

Windrowing and cocking relatively green alfalfa hay materially extends the curing period as compared with swath curing.[29, 30] Prolonged swath curing may result in an undue loss of leaves with a reduction of almost 10 per cent in weight, whereas in hay cured entirely in the windrow, or after 3 to 6 hours initial swath curing, only 1 to 2 per cent loss in leaves may occur. A combination of partial swath curing followed by windrowing seems to be the better practice.[29, 30] Alfalfa can be best cured by windrowing after it is about one-fourth cured in the swath.[20, 21] Legumes should be raked before they become dry enough to shatter, which is sometimes before the hay is dry enough to store.

Function of Leaves in Curing Process. The leaves of alfalfa apparently do not function in the withdrawal of moisture from the cut stems. The moisture loss in alfalfa stems with the leaves attached is about the same as when the leaves are removed.[20, 21, 29, 53] In legumes with large stems, such as sweetclover and soybeans, the leaves may aid in the withdrawal of water from the stems.[21]

ARTIFICIALLY DRIED HAY

To avoid the effects of adverse weather conditions, hay in some parts of the country is artificially dried or dehydrated. The practice is limited by the high cost. In dehydration, hay is put through a drier immediately after cutting or after some sun curing has occurred, but before the leaves are dry enough to shatter.

Most driers require that the hay be chopped or crushed before it is fed into the machine (Figure 57). The desirable length of cutting is 0.25 to 1.50 inches. As cut hay is much more compact than whole hay, it usually must be dried to about 12 per cent moisture for safe storage, whereas 25 per cent moisture is practically always safe for whole hay. Forced air is used almost universally in driers to conduct heat from the burner to the hay.[3, 14] The rotary drum or high-temperature drier with an inlet temperature usually between 1400° and 1500° F. dehydrates the hay in a few minutes. The drum assembly is rotated slowly while the hay is agitated. In the conveyor or low-temperature drier the material dries for some time.

FIG. 57. The Forage Harvester cuts and chops green hay for artificial drying or for silage. (Courtesy Allis-Chalmers Mfg. Co.)

The temperatures permissible range from 250° to 275° F. where the gases contact the driest hay.

Freshly cut alfalfa usually has 75 per cent or more of moisture. This requires removal of 5040 pounds of water at the drier to produce one ton of hay with 12 per cent moisture. When the crop is allowed to dry to 60 per cent moisture in the field, only 2400 pounds of water are removed in reducing the moisture content to 12 per cent, and hauling the extra 2640 pounds of water from the field is avoided. The cost may be reduced materially by greater use of sun curing before the green hay is put through the drier.

The nutrient materials in dehydrated hay are about equal to those in the fresh green material, except for the unavoidable loss of some carotene and the more volatile nitrogen compounds in the drying process. Analyses[3] show that the dehydrated crop is 2 to 2.2 per cent higher in protein and also usually higher in carbohydrates and ether extract than the same crop sun cured. The natural green color, an indicator of carotene content, is retained to a greater extent in artificially dried hay.

The cost of hay dehydration has been high enough to preclude the use of driers by the average farmer. Artificial drying has been confined mostly to farms where a specialty is made of a particularly high class product or as feed for poultry. It has wider uses where the losses of sun curing exceed 25 per cent, especially when hay prices are relatively high.[61] The drying of hay by forcing air through flues built in the mow and covered with hay appears to be a practical method for the typical farmer. Either heated or unheated air may be used.

MOW OR STACK STORAGE

Most of the hay in the subhumid and humid regions is stored in barns. Barn storage allows the hay to become thoroughly cured without continued weathering. The hay is loaded by hand or with a loader, and lifted into the barn with large forks or slings. More recently, considerable hay is gathered in the field and taken to the barn with a sweeprake mounted on a tractor or car chassis. Stack storage is widely used in the semiarid regions of the west because losses from exposure are comparatively low. The percentage of weather-damaged hay is much less in large than in small stacks. The sweeprake is generally used to take the hay from the windrow to the stacks (Figure 58). The overshot stacker is widely used. The swinging stacker, and the boom stacker, which deliver the hay at the points desired, are slower but they save considerable hand pitching on the stack.

Most of the hay sold in commerce is baled, and increasing quantities are being baled for home use. About 40 per cent of the hay crop was baled in 1948. Hay may be baled from the barn, stack, or from the windrow. Windrow pickup balers are the most modern type because of the saving in labor and because of less loss of leaves from shattering (Figure 59). Hay should contain 16 per cent moisture or less at the time it is baled, but most hay baled from the field is higher in moisture than that. The maximum amount of moisture tightly baled hay may contain without special attention to aeration is about 20 per cent. Even at about this moisture the bales become caked, i.e., they remain packed after the bale is opened. Baled hay with as much as 30 per cent of moisture is likely to mold or heat regardless of aeration.[61] Baled hay is compressed to a density such that a ton occupies about 100 to 250 cubic feet.

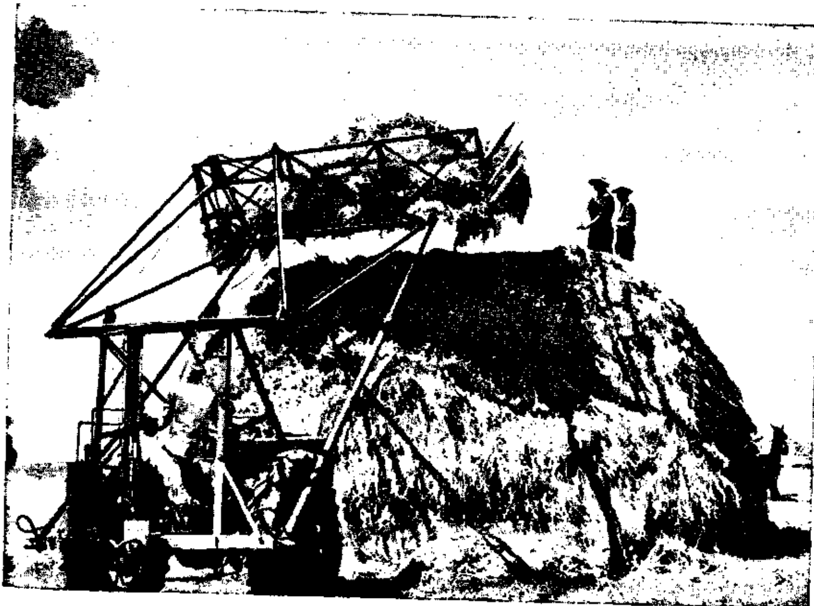

FIG. 58. The combination sweep rake and stacker permits the placing of hay on any side of the stack.

FIG. 59. This one-man pickup field baler ties the "square" bales with twine. (Courtesy of International Harvester Company.)

which is 15 to 50 per cent of the space occupied by loose hay in the stack or mow. Bales vary in size from 45 to 250 pounds, being mostly 60 to 75 pounds with present-day pickup balers. Bales keep best in storage when piled on edge. Some space should be left between tiers to allow air circulation.

MEASUREMENT OF HAY IN THE STACK

Large amounts of hay are bought and sold in the stack, based for convenience upon estimated weights, particularly in the Pacific, intermountain, and Great Plains regions. The volume of a ton of stacked hay, as agreed upon by buyer and seller, usually ranges from 343 to 512 cubic feet, i.e., 7^3 to 8^3. Rules for determination of tonnage by stack measurement are approximations, but the most accurate ones now in use are described below.[23]

Volume of a Hay Stack. The volume of a rectangular stack is equal to its length (L) multiplied by the area of the cross section. The exact area of the cross section is difficult to obtain because an accurate formula is necessary from only two measurements, width (W) and over (O). The over is the distance from the ground on one side to the ground on the other side. Stacks are divided into three different types based on shape, a rule being developed for each shape.[23] The volume determined by these rules averaged the same as the actual volumes, the error never being greater than 5 per cent. The three types of stacks designated were the square flat-topped stacks found in California, the high round-topped stacks common in the Great Basin, and the low round-topped ones common in the Great Plains region (Figure 60).

The rules for determination of the volume in cubic feet are as follows:

(1) Low round-topped stacks: $(0.52 \times O) - (0.44 \times W) \times WL =$ volume in cubic feet.
(2) High round-topped stacks: $(0.52 \times O) - (0.46 \times W) \times WL =$ volume in cubic feet.
(3) Square flat-topped stacks: $(0.56 \times O) - (0.55 \times W) \times WL =$ volume in cubic feet.

To find the number of tons in the stack it is necessary to divide the volume by the number of cubic feet per ton.

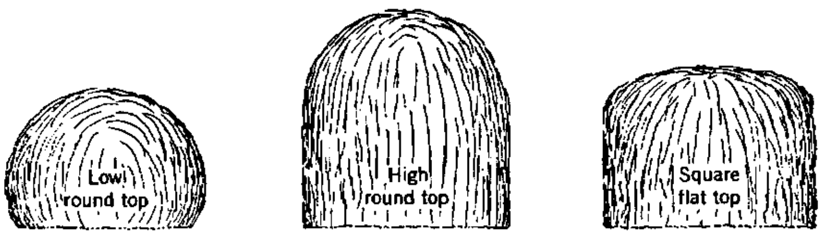

FIG. 60. Hay stack shapes applicable to formulas on page 222.

Cubic Feet per Ton. The amount of hay per cubic foot depends upon the length of time the hay has remained in the stack, moisture in the hay at the time it was stacked, kind of hay, as well as texture and foreign material. Because of these factors, there often is considerable difference in the number of cubic feet per ton in different stacks. The figures below are averages for a large number of stacks: [23]

KIND OF HAY	LENGTH OF TIME IN STACK 30–90 days	Over 90 days
	(*cu. ft. per ton*)	(*cu. ft. per ton*)
Alfalfa	485	470
Timothy and timothy mixed	640	625
Wild	600	450

LOSSES IN FIELD CURING OF HAY

Profound changes in composition occur during the curing of hay in the field.[32, 61] There is an inevitable loss of nutrients when crops are made into hay. Under adverse conditions the loss may be up to 40 per cent, or spoilage may be complete. Under normal weather conditions, the dry matter loss in field curing of hay may be 10 per cent or more in different parts of the country. A loss of 17.6 per cent of the dry matter and 21.5 per cent of the protein has occurred during the ordinary field curing of alfalfa,[32] due to shattering of leaves, pods, seeds, and stems, to leaching and fermentation, and to the respiration that continues in green plants for some time after cutting. Included in the above losses was 30 per cent of the leaves, with a correspondingly large loss of essential minerals including phosphorus and calcium. Curing losses are small when drying is rapid. The leaves are the portion of the plant richest in minerals as well as in protein and vitamins. Different workers have reported the leaf loss in alfalfa to range from 6 to 9 per cent of the weight of the total crop. In cereal hays,[48] the leaves constitute one-fifth the weight of the plant. After the milk stage, cereal leaves contain nearly 50 per cent of the minerals and 40 per cent of the fat of the whole plant.

During curing the carotene starts to decompose at once, due chiefly to oxidation. Alfalfa hay exposed in the swath and windrow for 30 hours in good haymaking weather has lost 60 to 65 per cent of its carotene. The losses in artificially dried hay are less than in sun-cured hay of alfalfa, lespedeza, sorgo, and soybeans. Baled alfalfa, timothy, and clover hays stored in a dark, unheated barn may lose 3 per cent of their carotene per month in the winter, but the losses are much higher with higher temperatures.[27] The percentage rate of loss of carotene was much more rapid than that of the natural green color. Hay exposed to rain loses a considerable proportion of its vitamin G. Synthesis of vitamin D occurs only when alfalfa is cured in the sun, a condition that results in a loss of vitamin A.

The protein content of alfalfa hay exposed to 1.76 inches of rain distributed over a period of 15 days, was only 11 per cent compared with prime hay containing 18.7 per cent protein.[19] Leached burclover hay, oat hay, and naturally cured range forage showed the greatest percentage loss in minerals.[16] The loss of crude protein ranged from 1 to 18 per cent of the total, and of nitrogen-free extract from 6 to 35 per cent of the total according to nature of the forage. Further losses in nutritive value are probably reflected in impairment of palatability and in loss of color.

Spontaneous Heating of Hay. Some heating is likely to occur when hay containing more than about 15 per cent moisture is stored in the stack or mow. Microorganisms, which are able to multiply when the hay is not too dry, consume the material for growth and energy, and release heat and moisture. When this moisture is sufficient to be detectable the hay is said to be going through a *sweat.* Very dry hay and hay in small piles that allow the heat and moisture to be dissipated are not known to sweat. The moisture released by organisms stimulates further microbiological activity and fermentation, and contributes to increased heating and sweating. Loose hay containing less than 25 per cent moisture is sufficiently dry at the time of storage to heat or sweat only moderately, and retains its green color and nutritive value. The storage of alfalfa hay of high moisture content causes heavy losses of organic substances, chiefly fats, sugars, and hemicelluloses. The loss in total weight may be as high as 22 per cent.[22]

Stored undercured hay, or dry hay allowed to become wet after storage, is subject to excessive spontaneous heating. A moisture content somewhat greater than 25 per cent may cause the hay to become brown or black. The green color of hay is destroyed when heating temperatures exceed 122° F.[29] Clean brown hay suitable for feeding was formed at temperatures above 131° F., but below 158° F. The dry matter losses may be very little in brown hay but they may be heavy when the hay becomes black. In Kansas experiments[50] alfalfa hay stacked with 53 per cent moisture sustained a dry matter loss of 39 per cent, and a large proportion became black.

Damp hay stored in large masses may develop temperatures sufficiently high to produce ignition. The steps in the progressive rise in temperature are summarized by LeClerc[32] as follows:

> "It is generally agreed that the initial production of heat in a mass of undercured or wet hay is due mainly to the respiration process of the living cell and to the activity of microorganisms. These agencies are capable of raising the temperature of the hay to as high as 158 degrees F. or slightly higher. Temperatures above this (the death point of microorganisms) cannot be due to biological causes. In the effort to account for the subsequent rapid rise of temperature that is necessary to produce ignition, various and sometimes conflicting hypotheses have been proposed. That of Browne[7] appears to be the most deserving of consideration. It is based on the assumption that microorganisms in the absence of oxygen first produce unsaturated, highly unstable intermediate fermentation products whose subsequent oxidation generates the heat that may ultimately lead to ignition."

The temperature may rise to as high as 374° F. before ignition occurs, often with explosive violence.

GRADES OF HAY IN RELATION TO QUALITY

Quality in hay really means nutritive value. The important physical factors [61] that can be gauged in a practical way are as follows: (1) color, (2) leafiness in legumes, (3) maturity of plants when cut, (4) amount of foreign material, (5) condition, and (6) texture. These factors are generally correlated with palatability as well as chemical composition.

Silage

ECONOMY OF SILAGE

Silage is a moist feed that has been preserved by fermentation in the absence of air. The forage, usually green, is commonly chopped into small sections and stored in a silo. The principal use of the silo is to preserve succulent roughage for winter feeding and to save forages that otherwise would be largely wasted, damaged, or lost. While it is impossible to preserve forage crops as silage as cheaply as in the form of hay, properly prepared silage will preserve a greater proportion of the nutritive value of the green plant.[61]

The modern practice of ensiling green forages traces directly to the process of making sour hay in Germany in the nineteenth century. The green grasses, clover, and vetches were stored in pits, salted at the rate of one pound per 100 pounds, thoroughly trampled, and covered. The first attempt to ensile green maize was made in Germany in 1861.[10] The first American silo was built in Maryland in 1876. The silo became popular and spread to all parts of the country.

CROPS USED FOR SILAGE

Corn (maize) is the principal silage crop in this country, about 4½ million acres or 36 million tons being put up annually. Nearly a million acres of sorghum yielding more than 5¾ million tons are harvested for silage annually. Less than 100,000 acres of other crops are cut for silage. These include sunflowers, small grains, and grasses and legumes ensiled alone or in mixtures. The best silage is made from carbohydrate-rich crops, i.e., those containing more than 2 parts of carbohydrates to one part of protein.

Corn. Corn is nearly the ideal crop for silage. The acre yields of silage range from 4 to 20 tons. A corn crop that produces 50 bushels of mature corn per acre yields 8 to 12 tons of silage.[61] The maximum nutrient value and the largest yield of carotene are generally obtained in corn harvested when the grains are in the glazed stage.[57] The grain types usually are superior to late-maturing "silage" corn, since the nutritive value of corn silage is closely associated with the proportion of grain it contains. Late-maturing varieties yield a greater weight of silage per acre but less dry matter than do the grain varieties.[37] The best silage variety is one that utilizes the growing season to the best advantage in production of dry matter but at the same time reaches, at least 3 years in 5, a stage of maturity that may be loosely described as the dough stage. There is less loss of dry matter in storage when corn is ensiled at the more mature stages.

Sorghum. Sorghum often replaces corn as a silage crop under dry or hot conditions, particularly in the southern Great Plains. The sorgos are more satisfactory from the tonnage standpoint, but grain sorghums make a high quality silage. Sorghum silage appears to be slightly less palatable than corn silage. Cured sorghum and even damp threshed sorghum grain frequently have been ensiled successfully. Water is added to the grain to raise the moisture content to about 30 to 50 per cent, the material is covered, and the usual silage fermentation process begins.

Sunflowers. Sunflowers are grown as a silage crop where the season is too short or too cool for corn or sorghums.[38] Addition of salt at the time of ensiling apparently reduces or eliminates the resinous odor and flavor, and improves the palatability of sunflower silage.[46] The crude protein content of the silage is highest when the seeds are three-fourths mature. Silage from sunflowers harvested at the bud or full-bloom stage is less palatable than that cut at later stages of maturity. The nutritive value increases as the plants approach maturity.

Other Crop Plants. Forage grasses have been used as silage crops in recent years, especially under conditions where it is difficult to make them into good hay. Grasses can be siloed alone or with legumes, almost as readily as can corn, if the crop is dried for several hours before it is put in the silo. The material should be finely chopped, packed to exclude air, and possibly weighted. Timothy and other grasses ensiled in this manner make a highly palatable silage with an agreeable odor without excessive losses of dry matter.

Legumes (alfalfa, soybeans, clover, field peas, and vetch) have been ensiled successfully in recent years. Excellent silage can be made from alfalfa, and palatability tests show it to rank next to corn, but alfalfa produces an insufficient tonnage to recommend its use for this purpose when it is possible to make it into good hay.[54] Sweetclover, while less palatable as silage than alfalfa, is satisfactory when harvested at a more mature stage than for hay. In one experiment sweetclover silage contained 16 per cent of digestible protein and 57 per cent of total digestible nutrients on a dry basis, as compared with 5 per cent of digestible protein and 70 per cent of total digestible nutrients in corn silage.[11]

Sugar beet tops sometimes are made into silage. The chief characteristic of this silage is the enormous crude ash content (ash plus dirt) (Chapter 36) ranging from 20 to 58 per cent on a water-free basis. The composition of dirt-free tops on the basis of percentages in water-free material is: ash, 15; protein, 15; nitrogen-free extract, 49; fat, 3; and fiber, 18.

Weeds and Other Plants. Silages made from wild sunflowers and certain other weeds with a rather strong characteristic odor, such as cocklebur and ragweed, are eaten by livestock with reluctance. Among the silages entirely refused are those made from woody plants with a strong undesirable characteristic odor or taste, such as gumweed and wild sage.[54]

Russian thistles have been used for making silage. They should be harvested when the spines start to feel prickly but while still fairly soft. Analyses have shown Russian thistles to be equivalent to alfalfa in protein and fat content and superior in their carbohydrate-crude-fiber ratio.[12] Russian thistles have a high mineral content with over 8 per cent of potash (K_2O). They are not recommended for silage when reasonably good yields of corn, sorghums, or sunflowers can be obtained. In a majority of cases, weeds prove to be an expensive source of silage.

SILAGE FORMATION

In silage formation the green forage continues respiration until the oxygen is used up in a few hours.[40] It is replaced by carbon dioxide which increases rapidly for 2 or 3 days until it comprises 60 to 70 per cent of the silage gases, the remainder being principally nitrogen. At the same time, the temperature rises and bacteria multiply rapidly.

The second most immediate effect is an increase in temperature, the rise being influenced by the amount of oxygen present. The amount of oxygen depends upon the fineness of chopping, firmness of packing, and the imperviousness of the silo walls to outside air. The temperature rises the highest (140° F. or more) near the surface because of infiltration of air, but elsewhere it seldom exceeds 100° F. The temperature rises for about 15 days, after which it slowly subsides. The silage temperatures are thought to be due to microbial activity.

The sugars are the principal food of the bacteria causing fermentation, but the marked destruction of the pentosans and starches indicates that these substances are also used in part. These carbohydrates are converted through the process of fermentation to alcohols and then to acids, principally acetic and lactic acids.[36] The lactic fermentation is the one most desired.[61] Crops such as corn, sorghums, and small grains have a high content of readily fermentable carbohydrates. Because of their low content of bases, they soon develop an acidity of *p*H 4 or below. Some other crops such as the forage grasses develop less acidity because of a lower amount of soluble carbohydrates and a higher content of basic elements. The legumes develop still less acid because of a small amount of soluble carbohydrates and a very high calcium content. For these reasons, acids or soluble carbohydrates are added to certain crops when ensiled. Since the process of silage formation is one of fermentation, respiration of living plant cells is not essential.

There is a decided change in the bacterial flora with the increase in acidity. For a few days after corn is placed in the silo, there is a large increase in the number of bacteria, chiefly lactic acid organisms. These begin to die after a short time because of unfavorable conditions, and are replaced by types that tolerate and produce more acid.

The proteins in silage also undergo changes, some being converted into the amino form, especially at low acidities. Addition of mineral acids to alfalfa silage may reduce the content of water-soluble amino and ammonia nitrogen.

During the ensiling process in corn there is a change in color and the development of a more or less pleasant aromatic and alcoholic odor and a sour taste due to the formation of acids. These changes are believed to be practically complete after 10 to 12 days.[31]

FACTORS AFFECTING SILAGE QUALITY

Moisture. Corn makes the best silage when it contains about 70 per cent moisture or slightly less.[37] Sorghum silage is best at about 60 per cent moisture (40 per cent dry matter). Hay crops should be allowed to dry down to a moisture content between 68 and 58 per cent,[59] preferably about 65 per cent, before being ensiled. High moisture forages (above 70 per cent) undergo a more undesirable putrefactive fermentation, as well as having greater losses of dry matter, a less agreeable odor, and lower palatability. A moisture content of much below 60 per cent prevents effective packing. Some of the carotene is lost during wilting and partial drying.[61] However, drying is fully as effective and may be less troublesome and expensive than addition of molasses or acids. The proper moisture content for ensiling can be gauged by a simple homemade tester that squeezes out juice at a given pressure[59] (Figure 61). Satisfactory silage can be made from cured corn or sorghum fodder having a moisture content as low as 10 per cent if the proper amount of water is added while filling the silo.

Acidity. Acids influence the character of fermentation, but apparently are not necessary to prevent molding or rotting of the silage.[60] Spoilage is prevented by exhaustion of air from the silage and its subsequent exclusion. Undesirable fermentations yielding butyric acid, and characterized by offensive odors, may take place when the acidity is low. Butyric acid may be formed above about pH 4.4. Acids or soluble carbohydrate material are sometimes added to silage to prevent undesirable fermentations, especially when it is

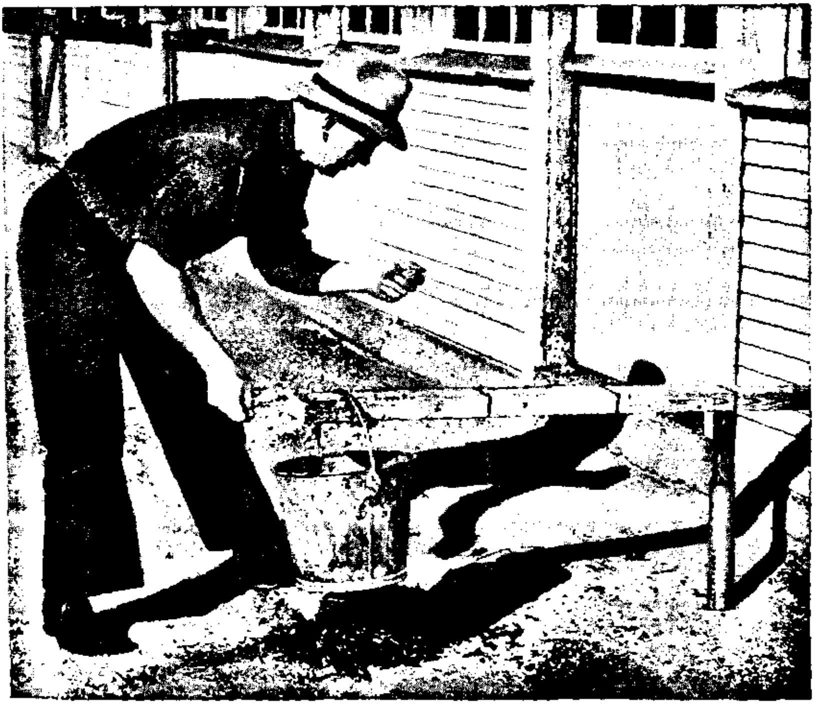

FIG. 61. A simple home-made silage moisture tester. If juice comes out of the holes in the 2-inch pipe filled with legume silage cut in ¼-inch lengths, within one minute or less with a 40-pound per square inch pressure of the plunger, the moisture content exceeds 68 per cent (too wet). If no juice in expressed within a minute with an 80-pound pressure the moisture content is less than 58 per cent (too dry). In the illustration the 32-pound pail of sand hung on the 4-foot mark on the lever gives a plunger pressure of about 40 pounds per square inch.

high in moisture or low in soluble carbohydrates. The addition of molasses increases the acidity slightly, but seldom to a point below pH 4 with grasses and legumes. Molasses improves the odor as well as the palatability of such silages. While mineral acids will increase the acidity of silage, they often impair the palatability.

Molasses has been added to legumes and grasses when they are ensiled, because these crops are deficient in carbohydrates from which the acids for silage fermentation are formed. The first attempt to add molasses to silage was made by Reed and Fitch,[42] who added 5 to 10 per cent to alfalfa. Others [9] recommend addition of 2 per cent

(40 pounds per ton) of molasses to ensiled timothy, and 3 to 4 per cent (60 to 80 pounds per ton) to ensiled alfalfa. Molasses may be allowed to flow directly on the plant material as it travels along the feed table of the cutter, or may be diluted and run into the blower. The addition of molasses serves chiefly to increase the fermentation and the palatability of grasses or legumes ensiled with a high moisture content.

The A.I.V. method of making silage from grasses and legumes was developed in Finland by A. I. Virtanen. The so-called "A.I.V." solution, added at the rate of 17 gallons per ton of fresh material, consists of 5 parts of concentrated hydrochloric acid mixed with one part of concentrated sulfuric acid and then diluted with 4 or 5 volumes of water to bring about an acidity below *p*H 4.

Addition of acids to grasses, or mixtures of grasses and legumes in which the grasses predominate, lowers the palatability of the silage.[60] This is partially compensated for in the slightly more effective preservation of the dry matter and carotene. Dilute acids have lowered the palatability of alfalfa silage and favored preservation of nitrogen and carotene, but had little effect on dry matter losses. There are certain disadvantages to the use of acids, such as (1) the destruction of masonry or concrete structures, (2) troublesome application, and (3) the necessity of neutralizing the acid before the silage is fed. It is doubtful if the acidity should be as much as *p*H 4 to make satisfactory silage. When acid is used, it is pumped into the silo and sprinkled over the chopped material as it enters the silo. Dilute acid at the rate of 5 to 8 per cent of the weight of the crop is necessary to lower the *p*H below 4.0. Phosphoric acid is used to some extent in the United States to preserve silage. It is used at the rate of about 16 pounds (1¼ gallons) to a ton of legume silage. The commercial phosphoric acid is first diluted by pouring one part of the acid into five parts of water.

METHODS OF MAKING SILAGE

The type of silo is unimportant as long as the essential conditions are met. Silage will be preserved effectively if air is excluded and surface or seepage water kept out. Continued tramping while a tower or pit silo is being filled usually is not necessary because the weight of the silage compacts the mass except at the top. In the shallower trench silos the silage usually is packed with a crawler-type tractor or with horses or mules moved back and forth as the silage is dropped in. The upright or tower silo may be constructed of wood, brick, concrete, or tile.[35] The trench silo and circular pit silos are used under semiarid conditions, the former being especially popular. Some trench silos in use have a capacity of 10,000 tons. The general practice in this country has been to harvest the crop, chop it into short lengths, and put it into the silo within a few hours. At the present time, field storage cutters or forage harvesters that cut up the stalks during harvest are coming into wide use. The crops should be chopped fine to make them pack more closely in the silo and thus force out more air.

LOSS IN SILAGE FORMATION

The composition of finished silage approximates that of the fresh material except in being lower in carbohydrates (nitrogen-free extract), (Table 3), and higher in crude fiber and ash.[11, 42] The increases in percentages of other constituents are merely the result of the loss of carbohydrates. The loss of dry matter in making silage should seldom exceed 10 per cent. A direct comparison showed dry matter losses of 7.6 per cent in silage and 15.9 per cent in field-cured corn.[41] The loss of nitrogen-free extract also was approximately twice as great in the field-cured corn. Approximately 10 per cent of the dry matter, 25 per cent of the pentosans, and 25 per cent of the starch contained in corn forage are destroyed after being ensiled 4 months.[40]

TABLE 3. COMPARATIVE COMPOSITION (ON DRY BASIS) OF VARIOUS GREEN CROPS AND OF SILAGE MADE THEREFROM

CROP OF SILAGE	MOISTURE	PROTEIN (CRUDE)	ETHER EXTRACT	FIBER (CRUDE)	ASH	N-FREE EXTRACT
	%	%	%	%	%	%
Sunflower	78.6	9.3	1.5	30.3	9.9	49.0
Sunflower silage	73.8	10.2	2.8	32.6	10.0	44.5
Corn (glazed stage)	62.9	8.1	2.9	16.8	5.1	67.0
Corn silage	69.5	8.3	2.8	22.5	7.1	59.4
Sweetclover (bud stage)	65.2	21.2	2.0	29.6	9.2	38.0
Sweetclover silage	65.2	21.5	3.3	35.7	9.7	29.8

CAPACITY OF SILOS

To estimate the amount of silage in a silo, the computed volume of the silo is divided by the number of cubic feet per ton. The average number of cubic feet per ton of silage settled 30 days or more is about 44. The density is influenced by depth of silage, the moisture present, the proportion of grain to stalk, and the diameter of the silo.[13] The silage density and silo capacities for different depths of corn silage[35] are shown in Tables 4 and 5.

The height of a silo should be 2 to 3½ times the diameter.

A two-inch depth from the top of the silage should be fed each day during cold weather to avoid spoilage.

Silage consumption:	
Cows (900 to 1200 pounds)	30 to 40 pounds per day
Yearling cattle	15 to 20 pounds per day
Sheep	4 to 5 pounds per day
Fattening cattle	25 to 35 pounds per 1000 pounds live weight

TABLE 4. WEIGHT PER CUBIC FOOT OF SETTLED CORN SILAGE

DEPTH OF SILAGE (*feet*)	WEIGHT AT GIVEN DEPTH (*pounds*)	AVERAGE WEIGHT (*pounds*)	DEPTH OF SILAGE (*feet*)	WEIGHT AT GIVEN DEPTH (*pounds*)	AVERAGE WEIGHT (*pounds*)
1	18.5	18.5	21	49.4	35.6
2	20.8	19.7	22	50.5	36.3
3	23.0	20.8	23	51.6	36.9
4	24.9	21.8	24	52.4	37.6
5	26.8	22.8	25	54.	38.2
6	28.5	23.8	26	55.	38.9
7	30.2	24.7	27	56.	39.5
8	31.8	25.6	28	57.	40.2
9	33.5	26.4	29	58.	40.8
10	35.0	27.3	30	59.	41.4
11	36.5	28.1	31	60.	42.
12	38.	28.9	32	60.9	42.7
13	39.5	29.8	33	61.9	43.2
14	40.8	30.6	34	62.8	43.7
15	42.	31.3	35	63.5	44.3
16	43.	32.1	36	64.3	44.9
17	44.5	32.8	37	65.1	45.4
18	45.8	33.5	38	65.9	45.9
19	47.	34.2	39	66.6	46.5
20	48.1	34.9	40	67.4	47.

TABLE 5. SILO CAPACITY FOR SETTLED CORN SILAGE

DEPTH OF SILAGE	CAPACITY WITH AN INSIDE DIAMETER OF										
	10 feet	11 feet	12 feet	13 feet	14 feet	15 feet	16 feet	17 feet	18 feet	19 feet	20 feet
(feet)	*(tons)*	*(tons)*	*(tons)*	*(tons)*	*(tons)*	*(tons)*	*(tons)*	*(tons)*	*(tons)*	*(tons)*	*(tons)*
20	27										
22	30	37									
24	34	41	49								
26	38	46	55	65							
28	43	52	61	72	84						
30	47	57	68	80	92	106	121				
32	51	62	74	87	100	115	131	148			
34	56	67	80	94	109	125	142	161	180		
36		73	86	101	117	135	153	173	194	216	
38			93	109	126	145	165	186	209	233	258
40			100	117	135	155	177	200	224	249	276
42				124	144	165	188	212	237	264	293
44					152	174	198	224	251	279	310
46						184	209	236	265	295	327
48							220	248	279	310	344
50								261	293	326	361

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9 HANDLING AND GRADING MARKET GRAIN AND HAY

Marketing Grain

Grain from the farm is sold mostly to local elevators built at railroad sidings. Sacked grain usually is delivered to a *flat* warehouse. An elevator is equipped with a truck scale combined with a dump that tilts the truck or wagon so that the bulk grain flows out the rear end of the vehicle into a pit. The grain is picked up from the pit by buckets attached to an endless belt and is carried up through a *leg* to the top (cupola) of the elevator, from where it is spouted to bins. It later is spouted into a car from a bin or the cupola. A typical country elevator has a storage capacity of 25,000 to 40,000 bushels divided into 10 to 15 bins holding 500 to 5,000 bushels each. Successful country elevators handle grain equivalent to five or more times the capacity of the elevator during a marketing season, and consequently can store only a small proportion of the total crop.

In Nebraska operating costs ranged from 1.9 cents to 3.5 cents per bushel when the elevator had a turnover of 150,000 bushels or more per season.[14] The usual expected gross margin for handling grain at a country elevator is about 5 cents per bushel. This margin often is reduced somewhat by the purchase of inferior lots of grain at country run prices based upon the average quality for the section.

An elevator may be owned by a farmers' cooperative association, an independent operator, or by a corporation operating several elevators. The three types are commonly referred to as co-op, independent, and line elevators, respectively. The same prices are nearly always paid for grain of a given grade by all elevators at a particular shipping point. The local price is based upon a card price that is received daily from the terminal market to which the grain usually is shipped. The card price is determined by the terminal price for a particular grade and quality of grain on that day, less the freight to the terminal market, less the fees for handling the grain at the local elevator and the terminal market.

The farm price of grain in any region is based on Chicago prices. For example, wheat in the surplus-producing regions brings a lower price as the shipping distance west of Chicago increases. The highest prices are paid in the chief deficiency areas, the south and the Atlantic seaboard states. The lowest prices are in the intermountain states. In the Pacific coast states, prices are higher than in the intermountain states because of the sea outlet.

Before a car is loaded with bulk grain, all cracks and holes are coopered to prevent leakage. Grain doors are nailed on the inside of the car door (Figure 66) up to within 2 or 3 feet of the top of the door. The car is loaded up to the allowable weight, leaving a clearance of about 2½ feet at the top to permit accurate sampling, and the car is sealed. A typical carload of bulk grain is about 1,400 to 1,700 bushels of wheat, rye, or flax, 1,700 to 2,000 bushels of barley, or 2,000 to 2,500 bushels of oats. Usually a carload of bagged grain is somewhat less. A car loaded with two kinds, classes, or grades, of bulk grain separated by a board partition is called a bulkhead car.

The grain is shipped to a commission firm, elevator firm, or cooperative agency at the terminal market. The shipper, using the bill of lading as security, draws a draft upon the consignee for a substantial portion of the expected selling price of the grain. The draft may be payable on sight or when the grain arrives at the market. The consignee sells the grain and remits any balance due after deducting his commission, the weighing and inspection fees, freight, and other charges.

Handling Grain at a Terminal Market

Upon arrival at the market, the cars of grain are sampled by licensed inspectors, and other samples taken by authorized representatives are furnished to the consignee. The latter samples with accompanying grade cards are placed on tables and offered to buyers on a large cash grain trading floor at the Grain Exchange.

At the terminal elevator or mill, the grain is unloaded with a power dragline scoop (Figure 62), or by a dump that tilts up the car until the grain runs out the door into a hopper or pit. The terminal elevators usually are equipped with power windlasses and cables to move cars. Inside the terminal elevator the operations are much the same as in a country elevator except that for the horizontal movement of grain an endless belt about 3 to 5 feet wide (Figure 63) is used in a large terminal elevator, whereas an auger conveyor ordinarily is used in a country elevator. Terminal elevators along a waterfront have marine legs, enclosing conveyor buckets on an endless belt, which are lowered into the hold of a boat to unload bulk grain. Most modern terminal elevators have many large circular bins or silos, each having a capacity of 25,000 to 110,000 bushels. Such an elevator may hold several million bushels of grain (Figure 64). Each bin is equipped with wired thermocouples (usually called the Zeleny System), about 5 feet apart from top to bottom. Temperatures in all parts of each bin thus are measured with a potentiometer located inside the building. Whenever a hot spot (90° F. or more) is detected the grain is moved to another bin so that the moist or heating portion is mixed with the larger bulk of cool sound grain.

FIG. 62. Unloading a car of bulk soybeans at a terminal elevator with dragline scoop.

At a terminal market cash grain usually is sold on the basis of a stated premium above the future price, as described below, of that particular grade of grain. The future price is based upon grain of contract grade, i.e., grain that barely meets the minimum requirements for the particular grade except for a small allowance for variations. Grain received from a country elevator may grade No. 2 because of a test weight per bushel below the requirement for No. 1, but may more than meet the minimum requirements for

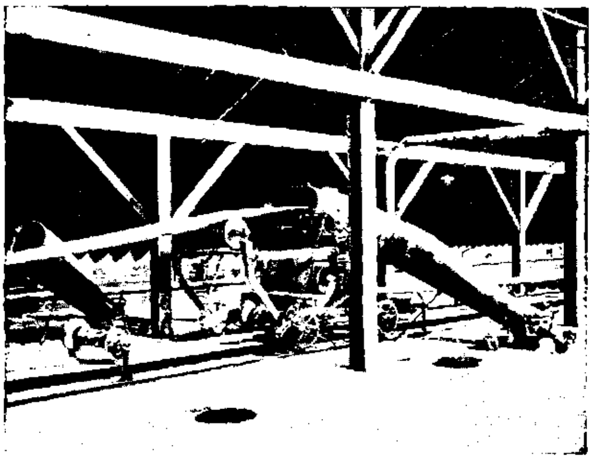

FIG. 63. The "dump" takes grain from the traveling belt and spouts it into a manhole at the top of a bin.

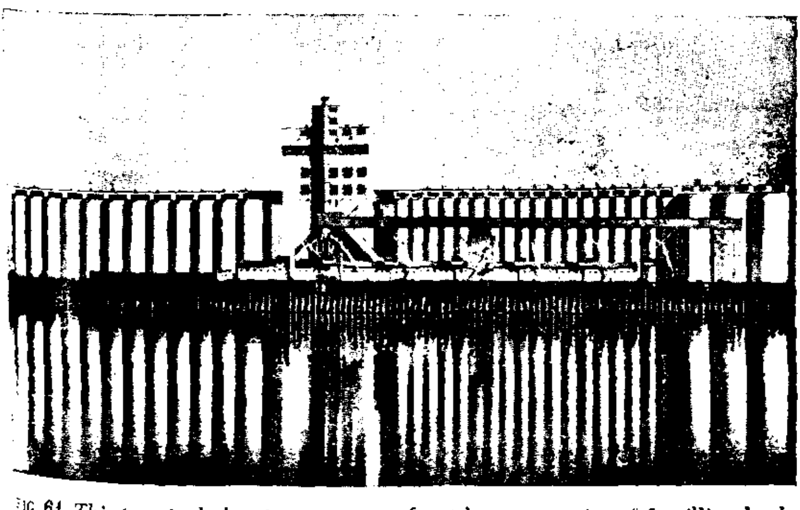

FIG. 64. This terminal elevator on a waterfront has a capacity of 3 million bushels. (Courtesy Archer-Daniels-Midland Company.)

the No. 1 grade with respect to other grading factors such as foreign material, damage, moisture content, and mixtures of grain of other kinds or classes. Consequently such grain commands a premium over the price for contract grain of No. 2 grade. These expected premiums are reflected back in the posted card price at a country shipping point. In a typical transaction, a lot of corn of No. 3 grade may be sold at the terminal market for 5 cents a bushel over the July, September, December, or May future price for that grade. The actual sale price is determined soon thereafter when the hedge is closed by the purchase of futures at the prevailing price.

Hedging

The practice of hedging each day's purchases of grain at a country elevator is widespread.[20] The hedging is done at the terminal market upon wired orders from the country dealer. Hedging consists of selling futures whenever cash grain is bought and later closing the hedge by buying futures when the grain is sold. Losses or gains due to changes in the market price of the actual (cash) grain are thus balanced by corresponding gains or losses in the transactions with future grain when the actual grain is sold. A small fee is charged for the futures transactions. Millers and grain dealers at the terminal markets likewise hedge their purchases and sales of grain and its products immediately. This permits a miller to sell flour for delivery several months later without a speculative risk. Failure to hedge is considered to be gambling and may eventually result in bankruptcy for the operator. Some country elevators sell grain to arrive, instead of hedging, as a means of avoiding speculative losses.

Futures Trading

Dealing in grain futures, which began in Chicago in 1848, is both fascinating and confusing to the layman. Since two futures transactions, a purchase and a sale, occur each time a lot of cash grain changes hands and is hedged, the volume of future trading appears to be very large in proportion to the quantity of grain marketed. Thus a lot of wheat bought successively by a country elevator, a terminal elevator and a mill would involve six futures transactions.

The transactions are conducted in a separate pit for each grain, located in the same room as that in which cash grain is sold (Figure 65). The smallest unit for futures trading of grain usually is 5,000 bushels. With two motions of the arm accompanied by hand signals, a dealer may offer to buy or sell as much as 25,000 bushels of grain at an indicated price. A signal accompanied by a nod indicates acceptance. The shouting around the pit merely helps attract the attention of a buyer or seller. The transactions are conducted under strict rules established by the particular Grain Ex-

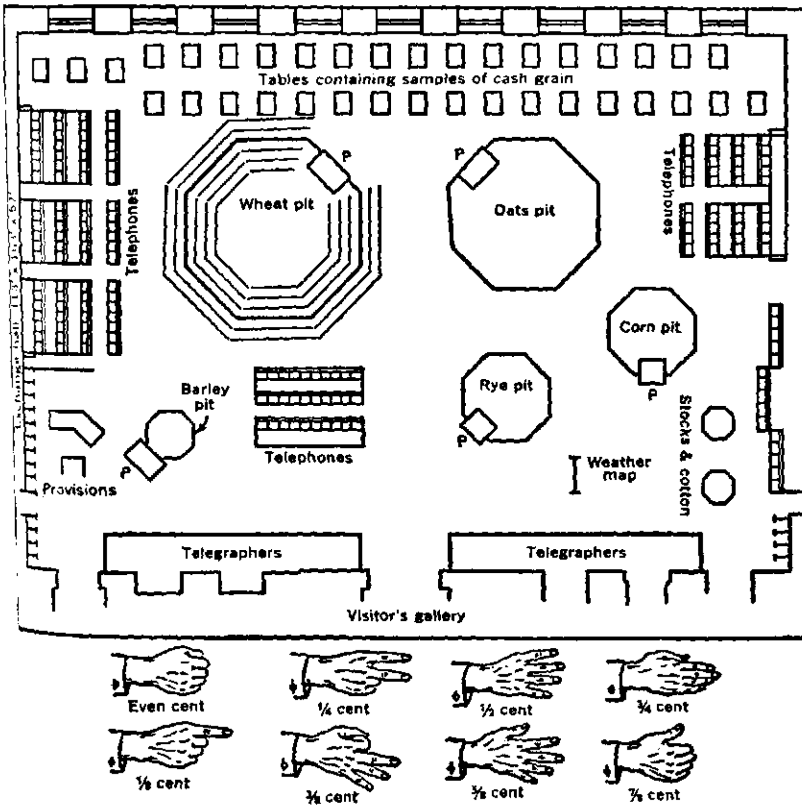

FIG. 65. Diagram of grain trading floor at Chicago, Ill., showing the tables for displaying samples of "cash grain" offered for sale, and the step-bordered pits for grain futures transactions. Changes in price are recorded at the platforms marked "P." Below are shown the hand signals used to indicate the fractional prices in futures transactions. (Courtesy of Chicago Board of Trade.)

change or Board of Trade. These exchanges, which operate the marketing facilities, are subject to federal regulation under the Commodity Exchange Act. Only members of the particular exchange may conduct future trading operations, but members may act as brokers for others. Speculators as well as grain dealers may trade in futures through their brokers. Prices of grain futures fluctuate constantly with changes in present and prospective supplies, demands for the different cash grains, together with changes in the volume and trends in futures trading. The prices of cash grain roughly follow the futures prices.

Although the speculative operations may tend to either disrupt or stabilize the market at any given time, they offer additional outlets for, and lend flexibility to, ordinary hedging operations. Without speculators it might be difficult to hedge large sales of grain for export or processing. A speculator is in a long position when his purchases of futures exceed those that he has sold. In that case he expects the price to rise. When he expects the price to go down he sells short. All sales of future grain are in fact contracts to deliver the grain on or before the end of the month (May, July, September, or December) indicated in the transaction. Only occasionally is delivery called for, cash settlements being much more simple. When delivered on a future sale, the grain nearly always is of a contract grade stored in a terminal elevator. Contract grain frequently consists of varieties or lots of mediocre quality for processing.

The leading terminal grain markets of the United States are Chicago, Kansas City, Minneapolis, and Omaha.

Grain Grading

GRAIN GRADING FACTORS

The purpose of grading grain is to facilitate its marketing, storage, financing, and future trading.[1, 8] It standardizes trading practices and reduces the hazards of merchandising. The factors upon which grades are based determine the quality or market value for the purpose for which the particular grain is generally used. Thus plumpness, which usually is measured by the test weight per bushel, indicates a well-developed endosperm which in wheat may be expected to give a high yield of flour. Plump barley gives a higher yield of malt than does thin barley. In all grains a high test weight indicates a low percentage of hull or bran or both, i.e., a low percentage of crude fiber, and thus an enhanced feeding value.

The test weight of a lot of wheat depends upon its plumpness, shape, density, and moisture content. Plump rounded grain packs together more closely than does wrinkled, shriveled, or angular grain. Dense vitreous kernels are heavier than starchy kernels. In a given lot of wheat, the test weight varies inversely with the moisture content. It may seem odd that dry wheat becomes lighter after it is soaked with water but such is the case when considered on a volume-weight basis. Wetting causes the starch to swell. Furthermore, the wheat grain has a specific gravity of about 1.41 compared with that of water, viz., 1.00. When wetted wheat grains dry out they shrink but not entirely back to their original volume. Each repeated wetting and drying makes the grain lighter in bushel weight. Fully ripe wheat that tests 62 pounds per bushel may test only 55 pounds per bushel when soaked. After several wettings it may test only 59 pounds after it is thoroughly dried, yet have deteriorated only slightly in milling and baking quality.

Other grains likewise swell and decrease in test weight when they are wetted. Flaxseed, on the other hand, increases in test weight as its moisture content increases because it contains no starch to absorb water and swell. Furthermore the 40 per cent of oil in the seed has a lower specific gravity than water, about 0.93, and thus the added water increases the weight of the seed.

The test weight per bushel of any grain is increased by cleaning out chaffy or shriveled kernels and other light material. Thereafter additional cleanings will further increase the test weight of oats and barley by breaking off awn remnants, hairs, and glume tips, which permits closer packing in the test kettle. The test weight of oats is increased merely by transferring the grain from one concrete bin to another, because of the abrasive effects just mentioned. The test weight of clean wheat is not altered appreciably by such handling. With flaxseed, however, each successive cleaning or handling reduces the test weight because the resultant roughening of the originally smooth and glossy seed coat causes the seeds to pack less closely.

In addition to test weight per bushel or plumpness, the chief factors contributing to high quality are soundness, dryness, cleanliness, purity of type, and general condition. Grain that is sour, musty, heated, or moldy is unpalatable, disagreeable in odor, and often unfit for food or feed. Bin burnt, and severely sprouted or severely frosted wheat makes flour of poor baking quality. Dry grain keeps well in storage, whereas wet or damp (tough) grain is likely to spoil. Furthermore, the moisture is valueless and the shrinkage in weight when drying occurs is a complete loss to the purchaser. A lot of grain containing 20 per cent moisture (80 per cent dry matter), when dried down for safe storage to a moisture content of 13 per cent (again on a wet basis), shrinks more than 8 per cent in total weight. Most of the slightly damp grain that reaches the terminal markets is not dried artificially, but is mixed thoroughly with drier grain.

Cleanliness is important except for foreign material in grain that is easily separated and has a value in excess of cleaning costs plus cleaning shrinkage. In grading wheat, barley, rye, flax, and grain sorghum the foreign material removed by dockage testers or appropriate screening devices is considered dockage. The weight of the dockage is subtracted from the total weight of these grains in marketing transactions except when the dockage amounts to less than one per cent of the total weight of the grain. Impurities, i.e., foreign material, that cannot be separated readily may detract seriously from the value of the grain. Certain foreign seeds that often remain in wheat after cleaning, such as garlic, rye, and kinghead affect the quality (color, flavor, or texture) of bread made from the wheat. Stones and cinders the size of grains are particularly objectionable in grain because they are not separated readily by cleaning machines and thus may injure grinding machinery or contaminate the milled products.

Purity of type is important except when grain is used for feed. A mixture of grains of different sizes is difficult to clean without heavy shrinkage losses. Different classes of wheat require different tempering and grinding procedures for milling. Admixtures of inferior-quality varieties lower the quality of the entire lot. In toasted wheat products, which are made from white wheats, red grains present become so dark in color that they appear to be scorched. Mixed barley types do not sprout uniformly during the malting process. Yellow corn mixed with white corn makes an unattractive hominy or meal. Toasted flakes of yellow corn kernels are very dark in color and detract from the appearance of corn flakes made from white corn.

Cracked grain is unsuitable for certain grain products. Bleached, weathered, discolored, or off-colored grain is unattractive. Foreign odors may make grain unsuitable for either food or feed.

GRAIN SAMPLING AND INSPECTION

Grain sampling is the first essential step in grain inspection and grading.[7] A carload of bulk grain is sampled by inserting a trier or probe through the grain to the bottom of the car at five or more places and withdrawing it after it fills with grain (Figure 66). The ordinary probe consists of a 63-inch double brass tube with partitioned slots in the core, and corresponding slots on one side in the outer shell. Turning the core opens or closes the openings. Sacked grain is sampled with a small pointed bag trier. A falling stream of bulk grain from an elevator spout is sampled by cutting across the grain stream at intervals with a dipperlike device called a *pelican*. After a brief examination for quality and uniformity, the probe or trier samples are bulked together. Before grading, all samples are mixed and cut down to a suitable size in a Boerner divider.

At the inspection laboratory (Figure 66) the market class, test weight, and the dockage (Figure 67) (or foreign material in corn and oats), are determined on all samples, and any other factor that seems likely to determine the grade also is analyzed. For example, the moisture content is determined if the grain feels even slightly damp or tough. Likewise, if damaged grains, or foreign material left after the dockage is removed, or grains of other market classes appear to be present in sufficient amount to modify the grade, these factors also are measured. Grain is graded by inspec-

Grade Requirements for Dark Hard Winter, Hard Winter, Yellow Hard Winter

GRADE NO.	MINIMUM TEST WEIGHT PER BUSHEL	MAXIMUM LIMITS OF					
		Damaged kernels (wheat and other grains)		Foreign material		Wheats of other classes	
		Total	*Heat-damaged*	*Total*	*Matter except other grains*	*Total*	*Durum and/or Red Durum*
	lb.	%	%	%	%	%	%
1 [a]	60	2	0.1	1	0.5	5	1
2 [a]	58	4	.2	2	1.0	10	2
3 [a]	56	7	.5	3	2.0	10	3
4	54	10	1.0	5	3.0	10	10
5	51	15	3.0	7	5.0	10	10

Sample grade: Sample grade shall include wheat of the subclass Dark Hard Winter, or Hard Winter, or Yellow Hard Winter, which does not come within the requirements of any of the grades from No. 1 to No. 5, inclusive; or which contains more than 15.5 per cent of moisture; or which contains inseparable stones and/or cinders; or which is musty, or sour, or heating, or hot; or which has any commercially objectionable foreign odor except of smut or garlic; or which contains a quantity of smut so great that any one or more of the grade requirements cannot be applied accurately; or which is otherwise of distinctly low quality.

[a] The wheat in grades No. 1 and No. 2 of this class may contain not more than 7 per cent, and the wheat in grade No. 3 of this class may contain not more than 10 per cent, of shrunken and/or broken kernels of grain and other matter that will pass through a 20-gauge metal sieve with slotted perforations 0.064 inch wide by ⅜ inch long.

OATS

Grade Requirements for the Classes White Oats, Red Oats, Gray Oats, Black Oats, and Mixed Oats

GRADE NO.	MINIMUM LIMITS OF		MAXIMUM LIMITS OF		
	Test weight per bushel	Sound cultivated oats	Heat-damaged kernels (oats, other grains, and wild oats)	Foreign material	Wild oats
	lb.	%	%	%	%
1 [a]	32	97	0.1	2	2
2 [b]	30	94	.3	3	3
3 [c]	27	90	1.0	4	5
4 [d]	24	80	3.0	5	10

Sample grade: Sample grade shall include oats of any one of the classes White Oats, Red Oats, Gray Oats, Black Oats, or Mixed Oats, which do not come

Mixed Wheat. Each of these classes, except Class III, is further subdivided into two or more subclasses based upon differences in texture or variety.

Summarized tabulations of the grades of Hard Red Winter Wheat, corn, and oats are shown on pages 252 and 253.[2]

within the requirements of any of the grades from No. 1 to No. 4, inclusive; or which contain more than 16 per cent of moisture, or which contain stones and/or cinders; or which are musty, or sour, or heating, or hot; or which have any commercially objectionable foreign odor except of smut or garlic; or which contain seeds of wild brome grasses of a character and in a quantity sufficient to cause the grain to be of low quality for feeding purposes; or which are otherwise of distinctly low quality.

[a] The oats in grade No. 1 White Oats may contain not more than 5 per cent of oats of other classes, of which not more than 3 per cent may be black cultivated oats.

[b] The oats in grade No. 2 White Oats may contain not more than 5 per cent of black cultivated oats.

[c] Oats that are slightly weathered shall not be graded higher than No. 3.

[d] Oats that are badly stained or materially weathered shall not be graded higher than No. 4.

CORN

Grade Requirements for Yellow Corn, White Corn, and Mixed Corn

GRADE NO.	MINIMUM TEST WEIGHT PER BUSHEL	MAXIMUM LIMITS OF			
		Moisture	Cracked corn and foreign material	Damaged kernels	
				Total	*Heat-damaged*
	lb.	%	%	%	%
1	54	14.0	2	3	0.1
2	53	15.5	3	5	.2
3	51	17.5	4	7	.5
4	48	20.0	5	10	1.0
5	44	23.0	7	15	3.0

Sample grade: Sample grade shall include corn of the class Yellow Corn, or White Corn, or Mixed Corn, which does not come within the requirements of any of the grades from No. 1 to No. 5, inclusive; or which contains stones and/or cinders; or which is musty, or sour, or heating, or hot; or which has any commercially objectionable foreign odor; or which is otherwise of distinctly low quality.

Storage and Drying of Grain

DETERIORATION OF GRAIN IN STORAGE

Threshed or shelled grain is commonly stored in a sizable bulk in comparatively tight bins from which little moisture can escape and in which adjustment of temperature to that of the outside air takes place slowly. The temperature in the center of a full 1,000-bushel bin 14 feet in diameter lags 1 to 2 months behind the temperature of the outside air.[18] Consequently, the keeping quality of grain depends largely upon its condition when placed in storage.[16] Binned grain containing more than 13 to 14 per cent moisture is likely to go out of condition in warm weather. Grain that deteriorates in storage may heat, become musty or sour, or get sick.

During heating, grain usually reaches a temperature of 90° to 160° F., and at the higher temperatures acquires a browned or mahogany bin-burnt color and a burned taste. At still higher temperatures approaching spontaneous combustion it acquires a charred appearance and taste. Formerly it was believed that the initial heating was caused entirely by the respiration of the embryo of the living grain. Recently it has been observed that moist grain heats at about the same rate when dead as it does when viable (alive). This suggests that much of the heating in grain is caused by the respiration of living and growing fungus or mold organisms always present on and in the grain. Damp dead grain does not heat if it is sterile.

The presence of live weevils and other stored-crop insects also causes grain to heat. Both molds and insects respire, and in doing so they release heat, moisture, and carbon dioxide. This released heat and moisture continues to accelerate the heating of the grain. When the temperature increases to about 130° F., the insects are killed and bacteria and molds are largely inactivated, but spore-forming organisms are not all killed. Enzymes are inactivated at about 140° to 150° F. Heating beyond that point must result from molecular oxidation of organic materials in the grain.

Grain may become musty or moldy when it contains enough moisture for the growth of molds but not enough to cause heating, or when the heat is dissipated rapidly by exposure to air. For example, grain can become musty in the shock or stack before threshing or in sacks or shallow piles or bins from which heat escapes readily. Grain of very high moisture content may become sour from fermentation similar to that occurring in a silo where alcohol and then organic acids are formed. A barrel of grain soaked for hog feed sours in a few days. Wet shelled corn that contains as much as 24 to 30 per cent moisture is likely to sour.

Wheat becomes sick when the moisture content is about 14 to 16 per cent or slightly above that necessary for good keeping quality. It occurs in deep bins usually in terminal elevators where the oxygen supply becomes depleted by respiration of the grain and of the fungi and bacteria on the grain. The oxygen content of the air in such bins may drop to 5 or 10 per cent while the carbon dioxide content rises from an initial 0.3 per cent up to 10 or 12 per cent.

The growth of anerobic bacteria may be the cause of sick wheat in bins.[9] Anerobic organisms thrive in the absence of air because they are able to obtain oxygen by breaking down the carbohydrates in the grain. Sick wheat has a dull lifeless appearance with the germs dead and discolored. Such grain has a high acidity caused by the breaking down of the fats of the embryo into fatty acids. Sick wheat is unsuitable for breadmaking. Damaged corn that shows similar germ injury is not called sick.

DRYING GRAIN

The material used in the construction of the bin has little effect on the keeping quality of grain.[18] Metal bins both absorb and radiate heat from the sun more rapidly than do wooden or masonry bins. Insulated and underground bins retard the absorption of summer heat, but they also retain heat that should be dissipated from warm grain in cool weather. Ventilated steel bins either with perforated sides or bottoms or containing perforated pipes or screen-covered flues are sometimes used for storing grain on farms.[19] The moisture content of grain that is slightly damp or tough may drop 1 to 3 per cent during several months of storage in a ventilated bin, and the grain will remain cool and sound. Grain having a moisture content of 2 per cent or more above that essential for good keeping quality is likely to go out of condition in a ventilated bin. The most effective type of ventilated bin is one with a wind-pressure cowl at the top.[17] The cowl or funnel is attached to a vane so that the flared opening always faces the wind, and air blows down into the grain and passes out through the perforations in the sides or bottom of the bin. Suction-cowl ventilated bins that draw air from the grain are less effective.

Any type of ventilated bin permits the grain to absorb moisture during driving rains or even in damp weather. Forced draft ventilation will dry grain when the relative humidity is below 60 per cent, but this cannot be expected regularly except in dry regions. Heated forced air dries grain quickly.

Natural drying before threshing or shelling is most economical

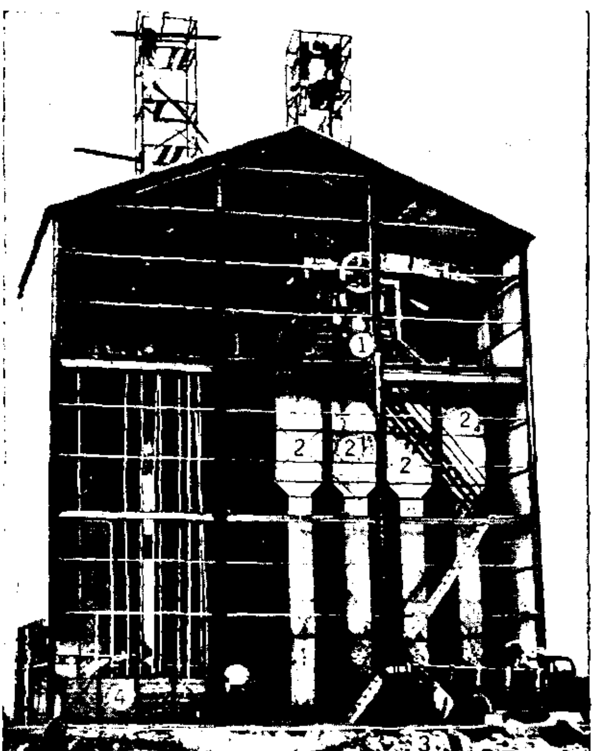

FIG. 68. A modern rice drier: (1) cleaning machinery, (2) drying units, (3) dump pit, (4) hot-air fan.

for the farmer. Damp grain often is sold to buyers who can mix it with dry grain or dry it artificially. Some grain is dried by spreading it out in shallow piles on a barn or bin floor or on the ground outside. Farm grain driers are common in the rice-producing regions and these driers usually are large enough to handle the crop from several farms (Figure 68).

Drying of grain is done by blowing heated air into chambers between thin layers of grain that are passing down over baffles or through screen-covered flues. Rotary driers similar to hay dehydrators also are used. The germination of damp grain (25 per cent or higher) is likely to be damaged when the temperature of the heated air that contacts the grain is much above 110° F. After the grain becomes drier, a temperature as high as 180° F. is safe.[16]

Small grain produced in the dry interior sections of the Pacific coast states where summer rainfall is infrequent is likely to be extremely dry, i.e., with a moisture content of only 7 to 10 per cent. When such grain is moved to the more humid seaport sections and stored in bags in open tiers during the rainy winter season it may absorb water from the surrounding atmosphere until it reaches a moisture content of some 12 per cent. Since this additional quantity of naturally acquired moisture is not detrimental to quality or grade, the resultant increase in weight represents a gain to the holder of the grain. On the other hand deliberate addition of water to market grain is illegal adulteration.

TURNING GRAIN IN BINS

In elevators it is customary to turn grain during cold weather by conveying it from one bin to another. This exposure to cold air may lower the temperature of the grain 20 degrees or more (Figure 69). The moisture content occasionally may be lowered as much as 0.25 to 0.50 per cent by turning when the atmosphere is dry. Often little or no change in moisture content results from turning. Cooling of the grain retards respiration, heating, and insect damage. Cold grain absorbs more moisture than does warm grain at a given relative humidity or vapor pressure. This is accounted for by the greater capacity for surface adsorption at low temperatures. Cold grain spouted from a bin through warm air takes up moisture.

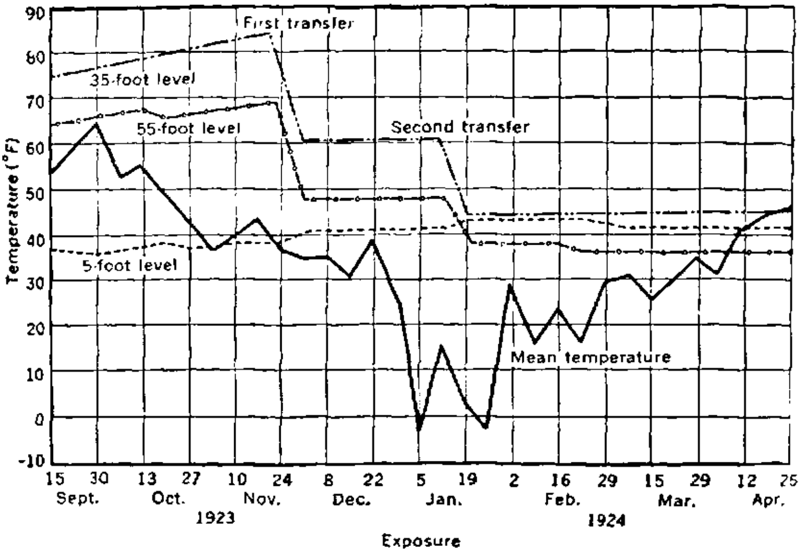

FIG. 69. Temperature of wheat in a 60-foot bin before and after it was transferred (turned) during cold weather.

CLEANING GRAIN

Most grain ultimately requires cleaning before use for any purpose except feed. Market grain rarely is cleaned on the farm because the loss from shrinkage and the cost of cleaning usually exceeds the value of the screenings or the dockage deduction. Very little market grain is cleaned at a country elevator except where it is desired to reduce the dockage content to just below one per cent so the grain can be sold on a dockage-free basis. Such partial cleaning is done to a considerable extent in Canada. Screenings have little sales value in a surplus grain area. Many screenings cannot be shipped without processing them, because of weed laws. Screenings have a substantial value at a terminal grain market where the edible ingredients can be added to ground mixed feeds sold on a guaranteed chemical analysis basis without specifying the individual ingredients. The value of the dockage is taken into consideration in making an offer for cash grain at the terminal market.

Terminal elevators usually have suitable equipment for separating the different seeds. Wild oats screened from wheat or barley formerly found a good market for mule feed in the southeastern states where wild oats are not a weed pest. They were sold in carload lots under the designation of mill oats. Seed of mustard and Frenchweed have a market value for oil extraction when separated from screenings (Chapter 39).

Shrinkage losses of grain in cleaning usually range from 2 to 5 per cent, in addition to the foreign material removed, even when the best equipment is used. The invisible loss, that is, dust, moisture evaporation, spilled grain, and grain lodged in the equipment during cleaning in an elevator is likely to be about 0.25 per cent. Appreciable cleaning losses are avoided only when the operation is a mere scalping to remove excess dockage. The moving of oats or barley through elevator machinery knocks off portions of the glumes or awns that then become screenings, foreign material, or dockage. Wheat grains lose hairs and bran, and suffer cracking during handling.

Types of cleaners. Separations of different grains, seeds, and foreign material are made mechanically on the basis of differences in length, thickness, shape, or specific gravity.[6] The most common cleaning device is the fanning mill found on many farms. This consists of two or more screens to sift out particles or grains both larger and smaller than the particular grain being cleaned, together with an air blast that blows out the material lighter than the desired clean grain.

Larger machines similar to the fanning mill, often called receiving separators, are found in many elevators and in all mills and seed warehouses. These machines, which use suction rather than an air blast to remove light or chaffy material, make more accurate separations than is accomplished with a fanning mill. Such machines are excellent for removing trash, chaff, certain fine seeds, and cracked or shrunken grain, but they are not satisfactory for separating grains or seeds of similar diameter or specific gravity. For example, oats and wild oats can be separated from wheat, rye, or barley only in part with a screen cleaner because their diameter is much the same and the differences in specific gravity are too small. Vetch seed has almost the same diameter and specific gravity as wheat and cannot be separated with a fanning mill. Mustard seeds will pass through fine screens or sieves that grain cannot penetrate but many of them roll rapidly down the sloping screen of the cleaner and are discharged with the cleaned grain. On the other hand, the triangular wild buckwheat seeds, which are appreciably larger than mustard seeds, are screened out readily because they do not roll. A sample of oats cleaned once on a good screen cleaner may still contain 100 to 300 mustard seeds per pound of oats.

Disk and cylinder cleaners (Figure 70) remove nearly all mustard seeds. These more difficult separations often are made in pocketed disk or indented cylinder cleaners that separate grains or seeds differing in length. The pockets on revolving disks, or indentations inside a slowly revolving cylinder, pick up short particles or grains that can be held in shallow pockets or indentations while they reject the longer ones. The separated fractions are discharged into different spouts. Such machines have a series of disks or cylinders with different-sized pockets or indentations which permit of several excellent separations. Thus cockle seed (Figure 71) can be separated from wheat because of its shorter length, and oats and barley are separated from wheat because of their greater length. A fair separation of mixtures of two varieties of even the same kind of grain can be made when the grains differ appreciably in length. Large cleaners of the screen, disk or cylinder types may have a capacity of 300 to 600 bushels per hour.

Ring graders are equipped with rotating spaced spring steel rings to separate grains differing in diameter. With these machines, oats can be separated from barley, and thin barley kernels can be separated from plump grains. Accurate separations are accomplished by different spacings between rings. The needles machine makes similar separations by allowing the grain to flow over a series of baffles bearing the needles (fine spring rods), for slender grains to fall between. A machine called a spiral separator separates globular seeds, e.g., wild peas, from wheat. The round seeds roll over the ides of an inclined spiral trough while the seeds of other shapes merely slide to the bottom.

Two other interesting types of machines, called gravity and magnetic separators, are used especially for cleaning small-seeded legumes such as alfalfa and clover. The gravity separator is used also to remove the lighter Angoumois moth-infested grains from sound seed corn. The gravity machine has a shaking table with air blowing up through numerous small openings in the table top which *floats* the seeds and material differing in specific gravity over into different compartments or spouts. Moist sawdust added

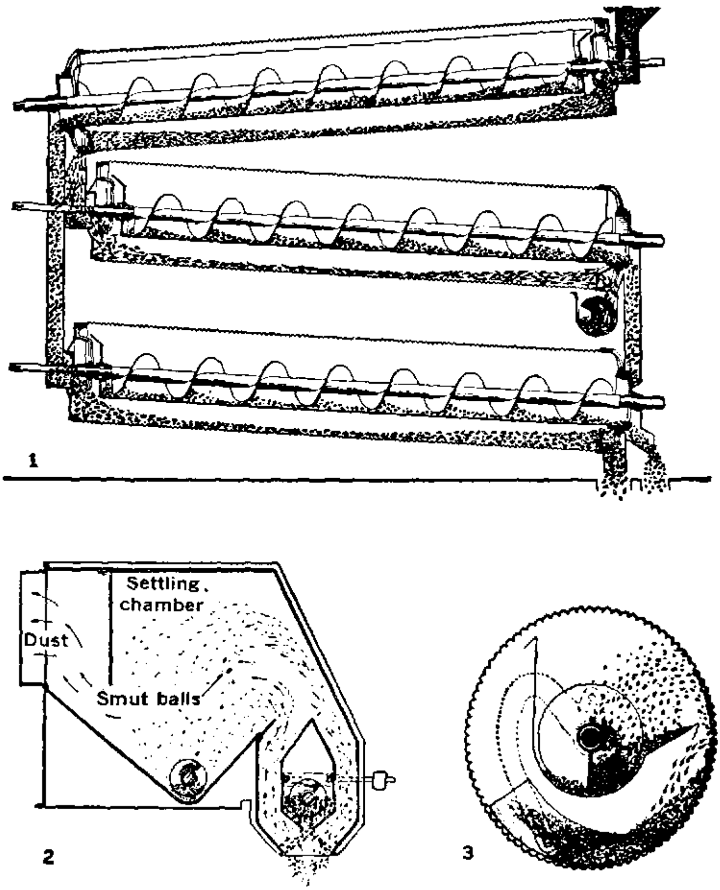

FIG. 70. (1) A cylinder cleaner. The cylinders have round indentations on the inside walls that pick up short seeds and reject long ones. The upper cylinder has medium-sized indentations that reject all the oats and barley in wheat. The middle cylinder with large indentations salvages the fraction of longer wheat kernels from the oat-barley mixture. The lower cylinder picks up short, fine and broken seeds out of the wheat. (2) Aspirator on cylinder cleaner. (3) Cross-section of cylinder.

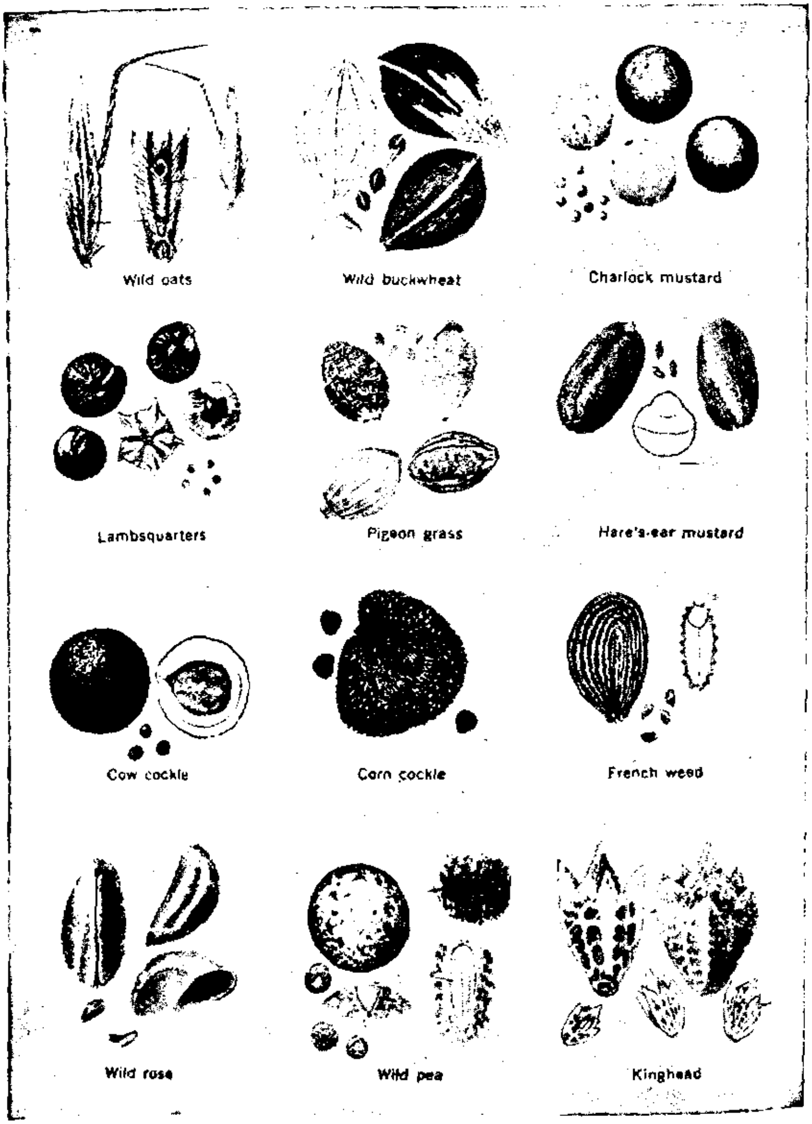

FIG. 71. Weed seeds (enlarged and comparative sizes).

to clover seed sticks to the mucilaginous seed coats of buckhorn seeds, and a gravity separator removes the sawdust particles from the clover seed, taking with them the above otherwise inseparable weedseeds. Dodder seeds have a very rough surface to which small steel or iron filings will cling (Figure 72). Filings are mixed with clover seed containing dodder and a magnetic separator is then used to draw out the metallic-coated dodder seeds. Another type of magnetic separator equipped with powerful electromagnets is placed in grain and seed spouts to catch any pieces of iron or steel scrap in a moving stream of grain and thus prevent damage to grinding or other machinery, and also reduce the hazard of fires that might start from accidental sparks arising from striking metals.

STORED-GRAIN INSECTS

Grain in storage is subject to damage from the attack of several species of insects.[4] The chief stored-grain insect pests are the rice weevil (*Sitophilus oryzae*), the granary weevil (*Sitophilus granarius*), and the Angoumois grain moth (*Sitotroga cerealella*). The lesser grain borer or Australian wheat weevil (*Rhizopertha dominica*) is destructive to grain in elevators, but is not often present in farm bins. The Indian meal moth (*Plodia interpunctella*) damages corn and sometimes other grains also. The cadelle (*Tenebroides mauritanicus*) not only consumes stored grain but also burrows into the walls of wooden bins. Other insects, including beetles, moths, and mealworms, that are found in grain, but which subsist largely on broken grains and milled products, are popularly referred to as bran bugs. Among the more common bran bugs are the saw-toothed grain beetle (*Oryzaephilus surinamensis*), the flat grain beetle (*Laemophloeus minutus*), the confused flour beetle (*Tribolium confusum*), and the red flour beetle (*T. castaneum*).[11]

The rice weevil, broad-nosed grain weevil, Angoumois grain moth, flour beetles, and certain other insects often fly to the field and attack grain while still standing in the field. When harvest or threshing is delayed, the grain may be heavily infested by the time it is placed in storage. The granary weevil has no wings under its wing covers and therefore is unable to fly.

The rice weevil and granary weevil are snout beetles that deposit

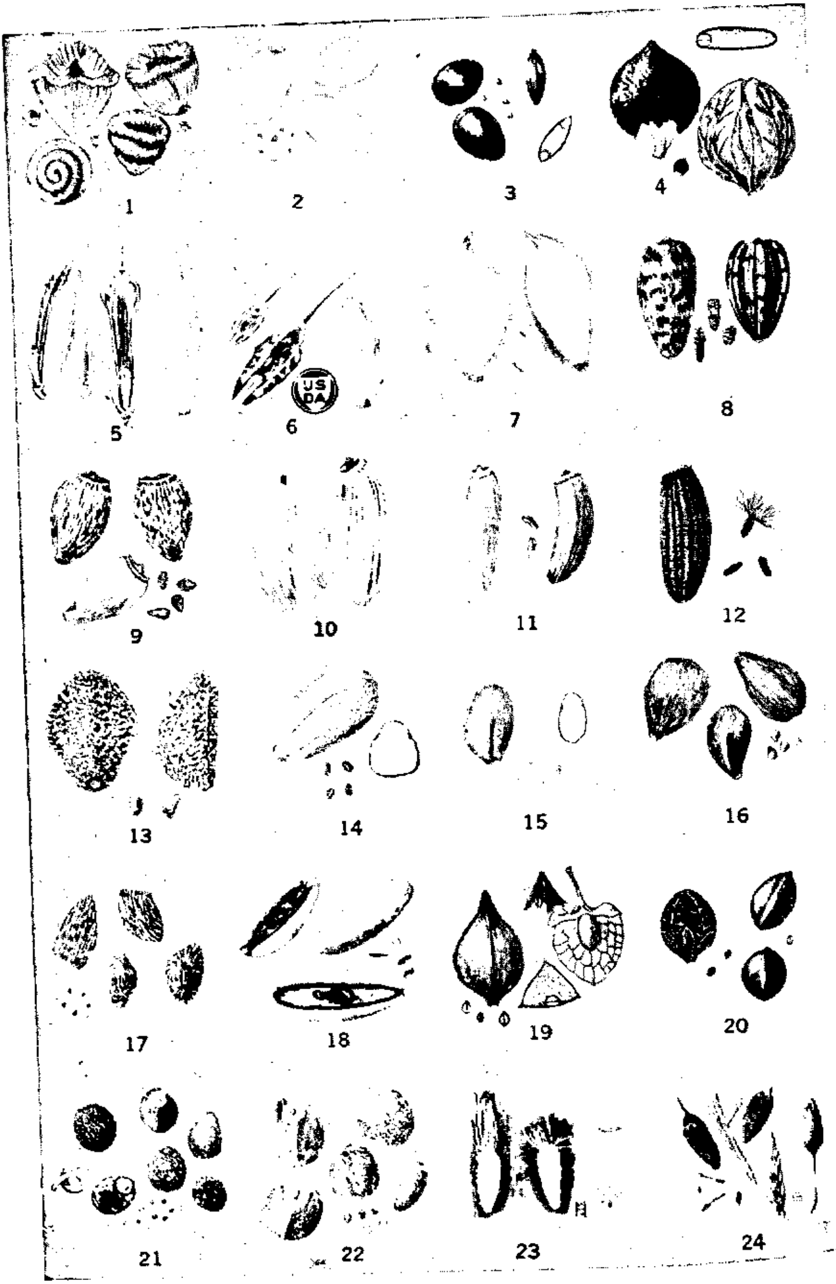

FIG. 72 (See facing page).

eggs in small borings in the kernels. The Angoumois grain moth deposits eggs on the surface of the kernels. When the larvae of these insects hatch, they bore inside the kernels, consume the contents, pupate, and then emerge as adults. The grain borers have similar feeding habits. Other insects such as the cadelle, square-necked grain beetle (*Cathartus quadricollis*), and the Indian meal moth eat the germ out of the grain.

Temperature is the chief factor determining the abundance of stored-grain insects in a region,[11] and the greatest precautions to protect grain from stored insects are necessary in the south where temperatures are high. The rice weevil is dormant at 45° F. or below, and the granary weevil at 35° F. and below. These insects will die at prolonged temperatures below 35° F. For this reason, grain is moved (or run) to another bin during cold weather in order to break up hot spots due to insect infestation.

Damp grain is very subject to insect injury. Grain-infesting insects either die or fail to multiply when the moisture content of the grain is below 9 per cent.

Control of Stored-grain Insects. Grain for storage should be cleaned to remove cracked material and live insects and then placed in clean bins free from insects. The empty bins can be fumigated or the walls and cracks can be sprayed with contact insecticides. Solutions or emulsions containing 2 to 5 per cent of D.D.T. are toxic to stored-grain insects. D.D.T. is safe on bin walls but not on grain for food or feed. Another contact spray[11] is as follows:

Dormant-tree spray oil,	1 gallon
Lye,	3 ounces
Water,	9 gallons

FIG. 72. Seeds of common weeds.

1. Russian thistle
2. Tumbling mustard
3. Rough pigweed or redroot
4. Pennsylvania smartweed
5. Chess or Cheat
6. Darnel
7. Wild garlic or onion
8. Wild sunflower
9. Star thistle
10. Bull thistle
11. Canada thistle
12. Perennial sowthistle
13. Field bindweed
14. Peppergrass
15. Whiteweed
16. Poverty weed
17. Broad-leaved plantain
18. Buckhorn or narrow-leaved plantain
19. Curled dock
20. Sheep sorrel
21. Clover dodder
22. Field dodder
23. Horseweed
24. Nutgrass

Stored grain should be fumigated when it becomes infested with insects. One of the best fumigants is a mixture of 3 parts by volume of ethylene dichloride and 1 part of carbon tetrachloride applied as a coarse spray to the surface of the grain. This fumigant is sold under various trade names, and home mixture should not be attempted. The vapor from this mixture is heavier than air and settles downward through the grain to the bottom of the bin. A dosage of 6 to 8 gallons of the mixture per 1,000 bushels of grain is recommended. The operator should apply the spray from outside the bin because the vapors are toxic to man. The dosage may be reduced to 2 gallons if 10 per cent by volume of methyl bromide is added to the above mixture but methyl bromide is not recommended for general farm use because it is too dangerous to humans.

Reinfestation of fumigated corn stored in a tight metal bin can be prevented by spraying the surface of the grain, using 2 quarts of white refined oil for a 1,000-bushel bin.[11]

Carbon bisulfide (high-life) can be used to fumigate grain in an isolated bin, but a fire or explosion will result if a spark or flame contacts this gas. A safe and effective mixture is 1 part of carbon bisulfide to 4 parts of carbon tetrachloride. This mixture is sold under various trade names, and home preparation should not be attempted.

Closed-top tight elevator bins can be fumigated with 3 pounds of granular calcium cyanide (containing 25 per cent hydrocyanic acid) per 1,000 bushels of grain. A special applicator is used to run the fumigant into the grain as the bin is filled. After 24 to 36 hours, the bin is ventilated to allow the gas to escape. Cyanide fumigants must be handled with extreme caution [13] because hydrocyanic acid is fatal to man and animals in very small doses.

Hydrocyanic acid gas, methyl bromide, or chloropicrin (tear gas) are used for fumigation of flour mills.

Precautions to be followed in handling various fumigants are described by Cotton et al.,[11, 12, 13] and by Back and Cotton.[5] Unless handled properly their use will prove distressing, injurious, or even fatal to the operator. A gas mask is advisable when handling any of the more toxic materials.

Heating grain in a dryer at 130° to 140° F. for 30 minutes will kill all insect life.

Marketing Hay

Much of the hay marketed in the western range states is sold in the stack to range livestock raisers or feeders.[15]

Baled hay is sold at the farm, trucked to markets, or shipped to commission dealers. A carload of hay weighs about 12 tons. At the market hay is sold in the car, often with a *plug* of 20 to 30 bales unloaded to facilitate examination.[10] Smooth uniform bales of a suitable size are preferred. When hay is consigned to a commission firm, it is customary to draw a draft for about 80 per cent of the expected selling price, which is honored upon its receipt (sight) or when the hay arrives at the market.

The chief users of market hay are producers of market milk, and owners and breeders of horses. The Elkhorn Valley of Nebraska, the Platte Valley of Nebraska, Wyoming, and Colorado, the mountain parks of Colorado, the Imperial Valley of California, the Salt River Valley of Arizona, and the Tipton Valley of southwestern Oklahoma are important sources of market hay. The dry sunny climate in the irrigated valleys of the west are favorable to the quick curing of bright green hay. The black belt of Alabama has produced large quantities of Johnson grass hay for the market.

The market price of hay depends upon palatability, nutritive value, and appearance. Hay of a bright green color has been cut before it was too ripe, was cured promptly, and is high in carotene. Leafy legume hay containing 40 to 50 per cent or more of its weight in leaves is high in protein. Hay leached by rain loses water-soluble carbohydrates and amino acids, which lowers its nutrient value. Foreign material may be offensive, inedible, of low nutrient value, or even injurious to livestock. Hay cut when too ripe contains seeds that may be rejected or lost by shattering. Seed development withdraws nutrients from the leaves and stems, making the latter less valuable. The stems of overripe hay usually are coarse, woody, and high in crude fiber. Coarse stems usually are rejected, especially by cattle. Horses may eat the coarser stems but refuse shattered seeds and leaves.

Grading Hay

The grading of hay for shipment in interstate commerce is optional, i.e., when one or more parties interested in the hay request an official inspector to grade it and issue a grade certificate. Contracts for the purchase of hay of a given grade require official grading. The grading is done by licensed inspectors operating on a fee basis at primary and terminal markets.

The chief factors in the grading of hay are leafiness (for legume hays), color, foreign material, maturity, and fineness. Hay that contains more than a trace of injurious foreign material, or has an objectionable odor, or is undercured, heating, hot, wet, musty, moldy, caked, badly broken, badly weathered, badly overripe, or very dusty, is placed in Sample grade in the Official Standards for Hay. Hay containing more than 35 per cent of foreign material or 35 per cent moisture is not even classed as Hay. Peanut straw, *i.e.*, peanut vines from which the peanuts have been removed, is classed as Hay. Standards had been established for 11 groups of hay up to 1944 as follows: Group I, Alfalfa and Alfalfa Mixed Hay; Group II, Timothy and Clover Hay; Group III, Prairie Hay; Group IV, Johnson and Johnson Mixed Hay; Group V, Grain, Wild Oat, Vetch, and Grain Mixed Hay; Group VI, Lespedeza and Lespedeza Mixed Hay; Group VII, Soybean and Soybean Mixed Hay; Group VIII, Cowpea and Cowpea Mixed Hay; Group IX, Peanut and Peanut Mixed Hay; Group X, Grass Hay; and Group XI, Mixed Hay.[3] Each group of hay includes one or more classes which are based upon the kind of hay or mixture of various kinds. Three numerical grades (1, 2 and 3), in addition to Sample Grade, are provided for each group or class. Special grade designations in addition to the numerical grades are provided for certain groups and classes. These include Extra Leafy, Leafy, Extra Green, Green, Fine, and Coarse.

GRADES OF HAY

The standards for Group I, Alfalfa and Alfalfa Mixed Hay and for Group III, Prairie Hay, taken from the *Handbook of Official Hay and Straw Standards*, of the U. S. Department of Agriculture, effective September 1, 1944, are shown below.

In prairie hay, the so-called Upland grasses include bluestem (*Andropogon* species), grama grasses (*Bouteloua* spp.), (*Paspalum* spp.), wheat grasses (*Agropyron* spp.), prairie June grass (*Koeleria cristata*), Indian grass (*Sorghastrum nutans*), and other grasses which grow commonly in virgin upland prairie meadows. Midland grasses are slough grass or prairie cordgrass, *Spartina pectinata*, bluejoint (*Calamagrostis* spp.), and sprangletop (*Fluminea festucacea*). The types acceptable under Group X, Grass Hay, include, in addition to some of the above grasses, redtop, Kentucky bluegrass, Canada bluegrass, crabgrass, smooth bromegrass, ryegrass, barnyard grass, Bermuda grass and also, when cut early, wildrye (*Elymus* spp.), certain annual bromegrasses such as cheat (*Bromus secalinus*), pigeongrass (*Setaria viridis* and *S. glauca*), broomsedge (*Andropogon virginicus*), and certain sedges (*Cyperaceae* spp.), and rushes (*Juncaceae* spp.).

Injurious foreign material consists of species with awns, seeds, or leaves that cause punctures, lacerations, or abrasions on the membranes of livestock. It includes squirreltail grass (*Hordeum jubatum*), and mature ripgut or broncho grass (*Bromus rigidis*), needlegrasses (*Stipa* spp.) and three-awn grass (*Aristida oligantha*).

ALFALFA AND ALFALFA MIXED HAY (GROUP I)

Class and Class Requirements

CLASS	MIXTURE PERCENTAGE
Alfalfa	Alfalfa with not over 5 per cent grasses
Alfalfa Light Grass Mixed	A mixture of alfalfa and grasses with over 5 per cent but not over 20 per cent grasses
Alfalfa Heavy Grass Mixed	A mixture of alfalfa and grasses with over 20 per cent but not over 60 per cent grasses
Alfalfa Light Timothy Mixed	A mixture of alfalfa and timothy with over 5 per cent but not over 30 per cent timothy
Alfalfa Heavy Timothy Mixed	A mixture of alfalfa and timothy with over 30 per cent timothy
Alfalfa Clover Mixed	A mixture of alfalfa and clover with over 10 per cent but not over 50 per cent clover and not over 10 per cent grasses
Alfalfa Light Johnson Mixed	A mixture of alfalfa and Johnson grass with over 5 per cent but not over 30 per cent Johnson grass
Alfalfa Heavy Johnson Mixed	A mixture of alfalfa and Johnson grass with over 30 per cent alfalfa and over 30 per cent Johnson grass
Alfalfa Light Grain Mixed	A mixture of alfalfa and grain hay with over 5 per cent but not over 20 per cent grain hay and not over 10 per cent grasses
Alfalfa Heavy Grain Mixed	A mixture of alfalfa and grain hay with over 40 per cent alfalfa and over 20 per cent grain hay and not over 10 per cent grasses

Grade and Grade Requirements for all Classes of Alfalfa and Alfalfa Mixed Hay

U. S. GRADE NO.	LEAFINESS OF ALFALFA (MINIMUM PER CENT OF LEAVES) [a]	COLOR (MINIMUM PER CENT OF GREEN COLOR)	MAXIMUM PER CENT OF FOREIGN MATERIAL
1 [b]	40 [c]	60	5
2	25	35	10
3	10		15

Sample grade: Hay which does not come within the requirements of any of the numerical grades; or which contains more than a trace of injurious foreign material; or which has any objectionable odor; or which is undercured, heating, hot, wet, musty, moldy, overripe, or very dusty; or which is otherwise of distinctly low quality.

[a] Does not apply in the classes Alfalfa Heavy Grass Mixed Hay, Alfalfa Heavy Timothy Mixed Hay, Alfalfa Heavy Johnson Mixed Hay, and Alfalfa Heavy Grain Mixed Hay.

[b] Grade No. 1 shall not include hay in which a majority of the alfalfa stalks bear brown and/or black seed pods.

[c] Hay to meet this leafiness requirement must have at least one-fifth of the alfalfa leaves clinging to the stems.

Special Grades for Alfalfa and Alfalfa Mixed Hay

EXTRA LEAFY HAY

Definition. Extra Leafy hay shall be hay of any of the grades of the classes Alfalfa, Alfalfa Light Grass Mixed, Alfalfa Light Timothy Mixed, Alfalfa Clover Mixed, Alfalfa Light Johnson Mixed, and Alfalfa Light Grain Mixed in group I in which the leafiness of the alfalfa is 50 per cent or more with most of the leaves clinging to the stems, but shall not include hay in which a majority of the alfalfa stalks bear brown and/or black seed pods.

Grades. The words "Extra Leafy" shall be added to and made a part of the grade designation. Example, U. S. No. 1 Extra Leafy Alfalfa Hay.

LEAFY HAY

Definition. Leafy hay shall be hay of any of the grades lower than grade No. 1 of the classes Alfalfa, Alfalfa Light Grass Mixed, Alfalfa Light Timothy Mixed, Alfalfa Clover Mixed, Alfalfa Light Johnson Mixed, and Alfalfa Light Grain Mixed in group I in which the leafiness of the alfalfa is 40 per cent or more with at least one-fifth of the leaves clinging to the stems, but shall not include hay in which the leafiness of the alfalfa meets the requirements for Extra Leafy Hay nor hay in which a majority of the alfalfa stalks bear brown and/or black seed pods.

Grades. The word "Leafy" shall be added to and made a part of the grade designation. Example, U. S. No. 2 Leafy Alfalfa Hay.

EXTRA GREEN HAY

Definition. Extra Green hay shall be hay of any of the grades of any of the classes in group I which has 75 per cent or more green color, but shall not include hay in which a majority of the alfalfa stalks bear brown and/or black seed pods.

Grades. The words "Extra Green" shall be added to and made a part of the grade designation. Example, U. S. No. 1 Extra Green Alfalfa Light Grass Mixed Hay.

GREEN HAY

Definition. Green Hay shall be hay of any of the grades lower than grade No. 1 of any of the classes in group I which has 60 per cent or more but less than 75 per cent green color, but shall not include hay in which a majority of the alfalfa stalks bear brown and/or black seed pods.

Grades. The word "Green" shall be added to and made a part of the grade designation. Example, U. S. No. 3 Green Alfalfa Light Timothy Mixed Hay.

COARSE HAY

Definition. Coarse hay shall be hay of any of the grades of any of the classes in group I in which the alfalfa stalks are hard and round and of which more than 30 per cent of the stalks have diameters equal to or greater than the diameter of No. 11 steel wire (approximately twelve one-hundredths of an inch), by W & M standard wire gage standards.

Grades. The word "Coarse" shall be added to and made a part of the grade designation. Example, U. S. No. 2 Coarse Alfalfa Hay.

PRAIRIE HAY (GROUP III)

Class and Class Requirements

CLASS	MIXTURE PERCENTAGES
Upland Prairie	Upland grasses with not over 10 per cent legumes
Midland Prairie	Midland grasses or a mixture of midland grasses with upland, timothy, and or other grasses, with over 40 per cent midland grasses and not over 10 per cent legumes
Upland-Midland Prairie Mixed	A mixture of upland and midland grasses with over 10 per cent but not over 40 per cent midland grasses and not over 10 per cent legumes

Grade and Grade Requirements for all Classes of Prairie Hay

U. S. GRADE NO.	COLOR (MINIMUM PER CENT OF GREEN COLOR)	MAXIMUM PER CENT OF FOREIGN MATERIAL
1 [a b]	50	10
2 [a b]	35	15
3 [b]		20

Sample grade: Hay which does not come within the requirements of any of the numerical grades; or which contains more than a trace of injurious foreign material; or which has any objectionable odor; or which is undercured, heating, hot, wet, musty, moldy, caked, badly broken, badly stained, badly weathered, badly overripe, or very dusty; or which is otherwise of distinctly low quality.

[a] Grades No. 1 and No. 2 shall not include hay that is stained.

[b] Hay of the class Upland Prairie in which one-third or more of the Upland grass stalks bear seed heads and/or jointed stems to meet the requirements of grade No. 1 shall have 65 per cent or more green color; grade No. 2 shall have 50 per cent or more green color; and grade No. 3 shall have 35 per cent or more green color.

Special Grades for Prairie Hay

EXTRA GREEN HAY

Definition. Extra Green Hay shall be hay of any of the grades of any of the classes in group III which has 65 per cent or more green color, but shall not include hay that is stained or hay of the class Upland Prairie in which one-third or more of the upland grass stalks bear seed heads and/or jointed stems.

Grades. The words "Extra Green" shall be added to and made a part of the grade designation. Example, U. S. No. 1 Extra Green Upland Prairie Hay.

GREEN HAY

Definition. Green Hay shall be hay of any of the grades lower than grade No. 1 of any of the classes in group III which has 50 per cent or more but less than 65 per cent green color, but shall not include hay that is stained or hay of the class Upland Prairie in which one-third or more of the upland grass stalks bear seed heads and/or jointed stems.

Grades. The word "Green" shall be added to and made a part of the grade designation. Example. U. S. No. 2 Green Upland-Midland Prairie Mixed Hay.

Crop Judging

Exhibition of crop products has considerable educational, cultural, and recreational value. In awarding premiums for the best products, consideration is given chiefly to appearance, uniformity, size, and trueness to type, based upon weighted point scores adopted by exhibit officials or the judges. Such scores usually reflect market values for the particular crop commodity, but have little if any relation to productivity or to the inherent value of the variety or type being shown. Prize-winning crops usually indicate two things: (1) favorable environment for plant development, and (2) meticulous selection and preparation of the exhibit material. The best plants often are found where thin stands have permitted optimum individual plant development at the expense of yield per unit area of land. However, good cultural conditions and freedom from disease and insect injury are essential to the production of acceptable crop exhibits.

Standards of excellence in crop products are largely arbitrary, and in some cases are based upon characters that actually are deleterious to crop yield or quality. For example, deep rough kernels of corn indicate late maturity, slow drying, and susceptibility to kernel rots. Compact heads of sorghum favor worm damage and moldy grain. Tall corn stalks make harvesting difficult. Certain varieties of wheat known to be of inferior breadmaking quality regularly take the prizes at local, state and international exhibits merely because the grain has a high test weight, and plump, vitreous, and smooth kernels. The substitution of utilitarian or quality standards does not fully remedy this incongruous situation. The merits of a crop or crop variety are determined by comparative experimental tests and by established performance on farms and in markets and processing plants. Experimental facts outweigh the opinions of the best crop judges, examining a few selected exhibit samples. However, it is incumbent upon crop students to learn to judge and exhibit crops because the present type of agricultural fair will continue in vogue for many years. People adore a contest. Furthermore, the judging of exhibits develops skill in the appraisal, identification, and grading of crop products.

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10 PASTURES AND PASTURAGE

Importance of Pastures

According to the census of 1945, about one-half the American farm land, or 529 million acres, is in pasture (Figure 73). Of this, about 109 million acres are tillable and the remainder is rough, wooded, cutover, or marshy land. In addition to the 683 million acres of privately owned pasture land, 369 million acres of public-owned lands are grazed. More than 5 million sheep and 1¼ million cattle are grazed on 83 million acres in the National Forests each year. Large numbers of livestock also are grazed on the 204 million acres controlled by the Department of the Interior. The total area of range land in the west is about 728 million acres. About 1052 million acres grazed at least part of each year in the United States furnish 35 per cent of the livestock feed.

Development of improved methods of pasture management and a better realization of the value of pasturage have been responsible for an intense interest in the establishment and maintenance of productive pastures since about 1925. In addition, national agricultural policies have favored grassland farming for erosion control.[29] This situation has encouraged renovation of old pastures by tillage or mowing to destroy less desirable plants, followed by application of fertilizers and reseeding with productive palatable species. On unplowable pastures the land may be worked with a disk or spring-tooth harrow or other implement. In some sections a cutaway disk implement called a *bush-and-bog* is used for this purpose. The use of improved pastures may involve replacement of Kentucky bluegrass and white clover, which are persistent under heavy grazing, with more productive taller-growing crops such as alfalfa, sweetclover, bromegrass, orchard grass, and timothy. Timothy, brome-

FIG. 73. A typical farm pasture (*above*). Mountain summer sheep range (*below*). (Courtesy of Colorado Agriculture College.)

grass, and young orchard grass are more palatable than Kentucky bluegrass, and Dallis grass is more palatable than carpet grass and does not become a pest in cultivated fields as does Bermuda grass.

The declining market for cash crops before World War II, and the protracted drought in the Grain Plains region from 1933 to 1940, caused retirement of large areas of land from cultivation. Much of this land has reverted to pasture. Millions of acres of sod were plowed up for crop production in the semiarid Great Plains between 1910 and 1930. The more unfavorable sites were soon abandoned and eventually reverted to grassland. The natural process of range restoration on plowed land may require 25 to 40 years,[28] although good grazing may be available after 8 or 10 years.[38] Artificial reseeding restores the range quickly, but it is more costly, and frequently results in failure except in favorable wet seasons. Recent improved methods of establishing perennial grasses offer much hope of range improvement in the drier areas.*

Much of the grassland in the drier sections of the southwestern Great Plains region was plowed up during the period from 1924 to 1930. During World War I, extensive areas of grassland in more humid sections were plowed up for production of wheat and other grains. Much of this land in the east was reseeded to pastures a few years later. Extensive soil drifting occurred in 1933–39, mostly on western lands broken either before or after World War I.

Advantages of Pastures

The chief object of good pasture maintenance is to provide green succulent feed for livestock during the entire grazing season. Livestock kept on pastures are more comfortable and sanitary than those kept in drylots. The animals harvest the crop at a minimum cost. Pastures produce about two-thirds as much dry matter as the same area in cultivated crops.[29] In Virginia experiments the yield of pasturage was 40 to 65 per cent that of the same crops allowed to mature and then cut for hay.[40] However, the dry matter of immature grasses is higher in protein and vitamins, and is more digestible than that from mature grasses harvested for hay. Conse-

* For more complete information on pastures in United States see "Grass," U. S. *Dept. Agr. Ybk.*, 1948.

quently, pasturing produces about three-fourths as much in digestible nutrients as the same crops cut for hay [29] (Table 1).

TABLE 1. DIGESTIBLE NUTRIENTS IN HARVESTED CROPS AND PASTURAGE

CROP	YIELD ROUGHAGE	TOTAL DIGESTIBLE NUTRIENTS	
	Per acre	*Harvested*	*Grazed*
	(*tons*)	(*lb.*)	(*lb.*)
Alfalfa	2.61	2793	2067
Clover—red, alsike, and crimson	1.46	1504	1113
Sweetclover	1.82	1867	1382
Lespedeza	1.82	1170	866
Clover and timothy mixed	1.40	1393	1030
Timothy	1.26	1210	895
Grains cut green	1.31	1292	956
Annual legumes	1.02	1102	815
Millet, Johnson grass, and Sudan grass	1.23	1225	906

Kinds of Pastures

TAME PASTURES

Tame pastures are lands once cultivated that have been seeded to domesticated pasture plants and are used chiefly or entirely for grazing by livestock. The principal kinds of tame pastures are as follows:

(1) *Permanent pastures* are grazing lands occupied by perennial pasture plants or by self-seeding annuals which remain unplowed for long periods (5 years or more).

(2) A *rotation pasture* is a field used for grazing which is seeded to perennials or self-seeding annuals, but which forms a unit in the crop rotation plan, and is plowed within a 5-year or shorter interval.

(3) *Supplemental pastures* are fields used for grazing when the permanent or rotation pastures are unproductive or do not supply enough feed for the livestock kept on the farm. Such pasture may be provided by the aftermath of meadows, small-grain stubble, seedling small grains, annuals such as Sudan grass, lespedeza, and crimson clover, or biennials such as sweetclover.

(4) *Annual pastures* are seeded each year to take the place of permanent pasture wholly or in part. Such pastures may include a series of crops such as winter rye, Sudan grass, soybeans, and rape.

(5) *Renovated pastures* are those restored to former production by tillage, mowing, reseeding, or fertilization.

NATURAL OR NATIVE PASTURES

Natural or native pastures are uncultivated lands occupied wholly or mainly by native or naturally introduced plants useful for grazing. The chief types are as follows:

(1) A *range* is a very extensive natural pasture.*

(2) *Brush pastures* are covered largely with brush and shrubs, where a considerable portion of the feed obtained by livestock comes from browsing woody plants.

(3) *Woodland pastures* are wooded areas with grass and other edible herbage growing in open spaces and among trees.

(4) *Cutover* or *stump pastures* are lands from which the merchantable trees have been cut, but on which there are stumps and usually also some new growth.

Permanent Pastures

PASTURE AREAS

The United States can be divided into the five fairly definite pasture regions shown in Figure 74. Because of the response of pasture plants to temperature and rainfall differences, the northern and southern sections of these regions are rather different. Most of the area in the eastern half of the United States as well as the Pacific coastal section originally was in forest, and as the trees were removed, the pastured land was occupied by introduced plants. The western portion of region 1 was prairie land comprising the so-called tall-grass region.

CLIMATIC AND SOIL CONDITIONS

The 60° annual isotherm marks approximately the northern limit of usefulness of southern pasture plants. The exceptions to this are

* The plants occurring on the western ranges are well described and illustrated in the book entitled *Range Plant Handbook*, prepared by the Forest Service, U. S. Dept. of Agriculture. The carrying capacity of different range types is shown in *U. S. Dept. Agr. Ybk.*, 1939, pp. 925–955. A complete report, entitled *The Western Range,* prepared by the United States Forest Service in 1936, was issued as *Senate Document 199.*

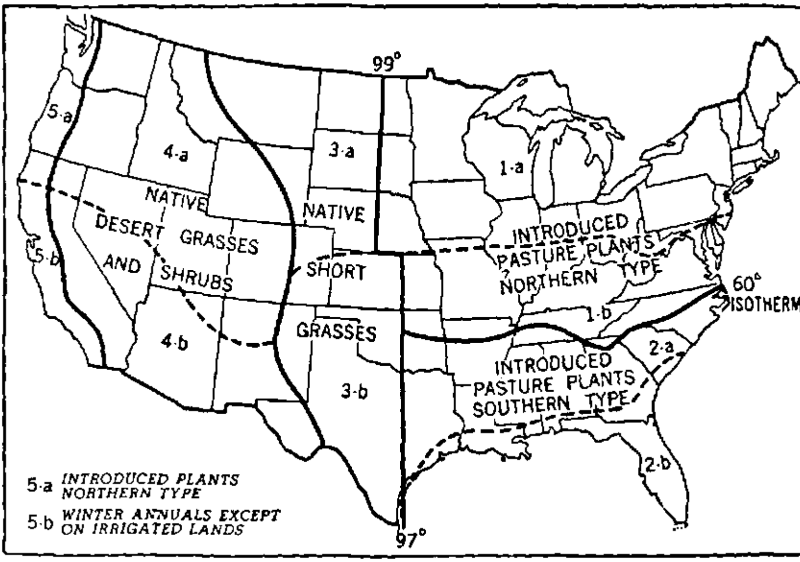


FIG. 74. Pasture regions of the United States.

mostly annuals such as lespedeza and Sudan grass.[83] North of this line, southern grasses are subject to winter injury, while to the south bluegrass, orchard grass, timothy, redtop, and the clovers are unable to thrive during the long period of high temperatures. This temperature effect is particularly important in the humid regions (1, 2, and 5a).

Rainfall differences largely determine the flora in the Great Plains and intermountain area (Regions 3 and 4). The 99th meridian in the north and the 97th meridian in the south mark the western limit where introduced pasture plants in general are more productive for grazing than native plants. In region 4, the annual precipitation is so low that desert or semidesert conditions prevail except in the extreme northern part and at higher altitudes in the mountains. The northern half of region 5 has a fairly abundant winter rainfall and a mild climate due to the Japan Current.

Although mountain valleys, parks, and clearings furnish considerable pasturage (Figure 73), the higher mountain slopes are unimportant from the national pasture standpoint, because in most sections they are rather completely forested or are composed of

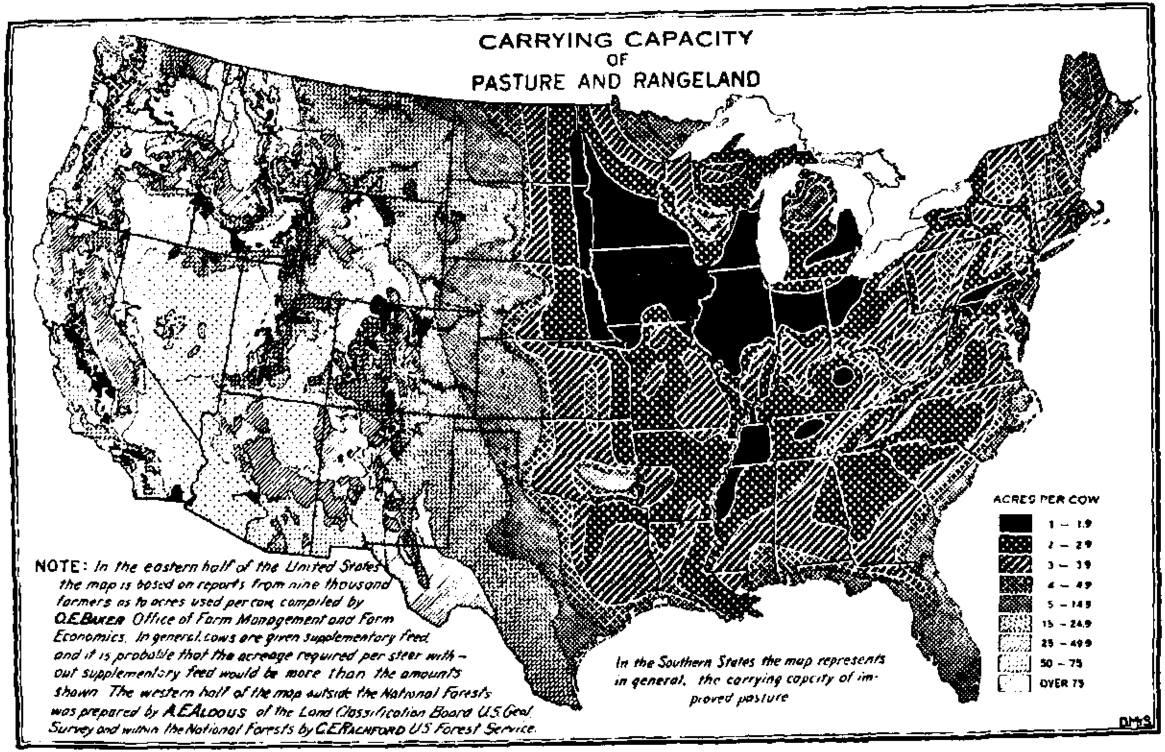


FIG. 75. Carrying capacity of pasture and rangeland.

rock masses with very little productive soil. The most valuable grazing lands are level or rolling areas, particularly those in the corn belt. The level grass lands of the Great Plains are also good pasture but are less productive than those in the corn belt, due to limited rainfall (Figure 75).

Next to climate and topography, soil characteristics have the most influence upon the type of pasture plants that occupy the land. Legumes are most abundant on soils of limestone origin, with a few exceptions.

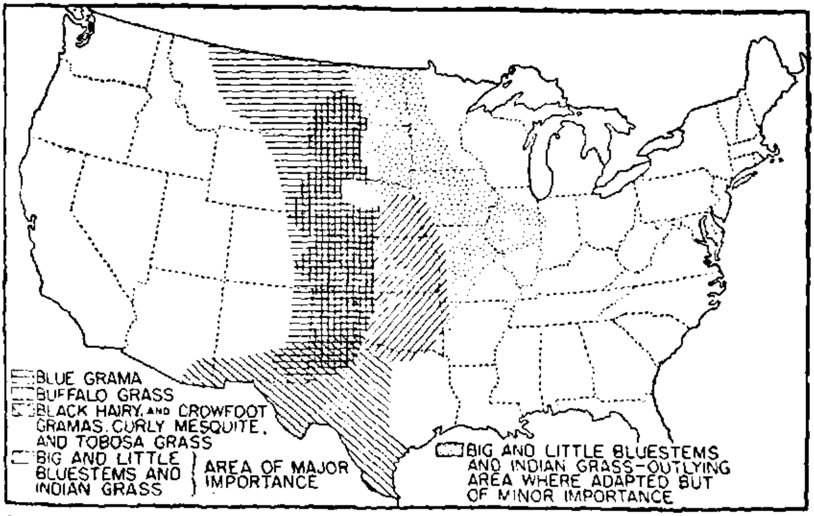
Adapted Pasture Species

Introduced grasses and legumes are the most important pasture plants in regions 1, 2, and 5.

In region 1, on the whole, Kentucky bluegrass (*Poa pratensis*) is the most important pasture grass. In mixtures with white clover it is nearly always present on productive soils in permanent pastures. Other grasses important in this region are Canada bluegrass (*Poa compressa*), redtop (*Agrostis alba*), timothy (*Phleum pratense*), orchard grass (*Dactylis glomerata*), smooth bromegrass (*Bromus inermis*), and several fescues (*Festuca* species). In section 1b, the lespedezas are becoming more and more abundant in pastures, due to their ability to furnish grazing during the summer months.

In section 2b, carpet grass (*Axonopus compressus*) on moist sandy soils and Bermuda grass (*Cynodon dactylon*) and lespedeza on loam, silt, and clay soils supply a large percentage of the pasturage. Dallis grass (*Paspalum dilatatum*) and Johnson grass (*Sorghum halepense*) also furnish a great amount of pasturage. Improved grasses in section 2b are largely carpet and Bermuda grasses. Others found there are Bahia (*Paspalum notatum*) and Para (*Panicum purpurascens*) grasses.

A large proportion of the pasturage on the Great Plains (region 3) is supplied by native short grasses (Figure 76). The principal grass association in the northern Great Plains consists of blue grama (*Bouteloua gracilis*), green needlegrass (*Stipa viridula*), and western needlegrass (*Stipa comata*) with a small admixture of June grass (*Koeleria cristata*). Seeded crested wheatgrass may have twice the grazing value of native grasses.[38] The central Great Plains has a very typical association of buffalo grass (*Buchloë dactyloides*)



Sections of the United States where native short grasses and prairie grasses are well adapted and are of primary importance.

FIG. 76. Leading native pasture grasses in the Great Plains and prairie regions.

and blue grama. Farther south below the Texas Panhandle, the black grama (*Bouteloua eripoda*) and curly mesquite (*Hilaria belangerii*) are the most important pasture plants. Just east of this region is the tall-grass region with the bluestems (*Andropogon furcatus* and *A. scoparius*), switchgrass (*Panicum virgatum*), dropseeds (*Sporobolus* species), sideoat grama (*Bouteloua curtipendula*) being among the predominating species.

The intermountain area (region 4) has the lowest production per acre of pasture because the rainfall is low. In the northern part, thin stands of wheatgrass (*Agropyron spicatum*), little bunchgrass (*Festuca idahoensis*), and Sandberg bluegrass (*Poa sandbergii*) are found. In the central portion of the region (Utah and Nevada) there exists a true desert shrub vegetation characterized by large sagebrush (*Artemisia tridentata*) and shadscale (*Atriplex confertifolia*). During rainy periods, the introduced annual bromegrass (*Bromus tectorum*) and similar plants spring up to furnish some grazing. Associated with shadscale is the winterfat (*Eurotia lanata*), one of the most valuable grazing plants in the Great Basin. In the southern part of the region, the best grazing lands are found in western New Mexico and eastern Arizona. Drouth-resistant grasses grow among the shrubs, among them being galleta grass (*Hilaria jamesii*), tobosa grass (*Hilaria mutica*), black grama (*Bouteloua eripoda*), and wild ryegrass (*Elymus* species).

Abundant rainfall and a mild climate in section 5a makes possible establishment of permanent pastures of introduced plants. Among the grasses that thrive there are Kentucky bluegrass, orchard grass, tall oatgrass, timothy, meadow fescue, meadow foxtail, reed canarygrass, the ryegrasses, and the bent grasses. All the clovers, particularly Ladino clover, do well in this area. The rainfall in section 5b is much lower, with the result that most of the pastures in the interior valleys are irrigated. Among the pasture plants used are alfalfa, Dallis grass, Italian ryegrass, Ladino clover, orchard grass, tall fescue, and meadow fescue.

Characteristics of Pasture Plants

Short young herbage low in fiber content is eaten in preference to old, tall, stemmy, and highly fibrous herbage. All grasses are palatable when closely clipped.[30] They become unpalatable when growth stops. A dense sward with a height of about 4 inches approaches the ideal.[19] Animals exercise a choice between species when the grass is 4 to 6 inches high, but show little discrimination when it is 2 to 4 inches high.[5] Perennial ryegrass leaves grow fast enough and long enough to have a long period of palatability.[30] Orchard grass leafage grows very rapidly and is very palatable while in active growth, but is unpalatable when growth ceases. Hairy and scabrous plants tend to be unpalatable. The more mature a leaf, the more these conditions are accentuated. Timothy, bromegrass, and Italian ryegrass are regarded as most palatable, followed by white clover and orchard grass. Timothy may be almost suppressed in a pasture because of its extreme palatability. In one test in Massachusetts, cattle selected herbage in the following order: white clover, timothy, redtop, and Kentucky bluegrass.[5] In another test, their preference was: timothy, redtop, Italian ryegrass, English ryegrass, tall oatgrass, meadow fescue, red fescue, and reed canarygrass in descending order.

The high palatability of big bluestem and little bluestem causes these tall grasses to be replaced by the less palatable but more persistent short buffalo grass under heavy grazing in the Great

Plains region. Where the land is protected from grazing these palatable species are restored and the grass again grows "as high as a horse's belly" as pioneers reported having first found it.

Basic Principles of Plant Behavior

Certain important principles of pasture plant behavior are listed below: [30]

(1) A plant excessively grazed will have its leaf development and root system reduced proportionally. Moreover, the new leaves are reduced in size, with the result that their functional efficiency is lowered. Sod blocks of seven prairie grasses in Nebraska clipped every 2 weeks produced only 13 to 47 per cent as much dry matter as did the unclipped sods.[6] Plants weakened by clipping renewed growth slowly.

(2) Plants can withstand defoliation in proportion to their ability to develop side shoots and tillers in spite of defoliation. Clipped plants may fail to produce new rhizomes.[6]

(3) Plants suffer punishment in direct proportion to their yielding capacity.

(4) Other things being equal, plants are grazed in proportion to their erectness and accessibility.

(5) Plants with an erect growth habit usually are less efficient than prostrate plants in the production of side shoots and tillers.

(6) Severe defoliation when the plants are commencing active growth is more harmful than at other times of the year. Consequently, plants that start active growth exceptionally early in the spring are most subject to damage. The clipping of seedling grass plants [25] has resulted in a decrease of 80 to 96 per cent in dry weight of forage.

Plants in Pasture Mixtures

For reasons given below it is seldom desirable to seed land intended for permanent pasture to a single species.[29]

(1) Legumes in pastures tend to maintain the nitrogen content of the soil.

(2) Mixtures result in a more uniform stand and higher production because several soil conditions are often represented in a pasture.[24]

(3) Mixtures provide a more uniform seasonal production because the growth and dormancy periods vary among different plants.

(4) Mixtures of grasses and legumes provide a better balanced ration since legumes are richer in both proteins and minerals.[31]

Addition of wild white clover to a seeding of Kentucky bluegrass increased the yield of herbage more than 500 per cent in New York experiments.[19] The protein content of Kentucky bluegrass grown alone averaged 18 per cent while the same grass grown in association with wild white clover averaged 25 per cent.

The number of pounds of the different seeds in a mixture determine only in part the percentages of the different species that emerge or the relative stands that result later, owing to differences in the size of seeds, the percentage of live seeds, and the plant competition.[17, 18]

Rates of Seeding

The rates of sowing grasses and legumes in pastures are shown in Table 2.

TABLE 2. RATES OF SEEDING GRASSES AND LEGUMES IN PASTURE MIXTURES

GRASS	RATE (*pounds per acre*)	GRASS	RATE (*pounds per acre*)
Cool Weather Grasses		Weeping lovegrass	½
Timothy	3–6	Galleta grass	5
Orchard grass	5–8	Sand dropseed	½–1
Bromegrass (awnless)	4–10	Harding grass	2–4
Mountain bromegrass	2–6	Carpet grass (seeds naturally)	
Reed canarygrass	3–10	Bermuda grass (roots)	
Tall oatgrass	3–4	Big bluestem	5–6
Meadow fescue	8–10		
Kentucky bluegrass	1–10	*Cool Weather Legumes*	
Canada bluegrass	1–3	Alfalfa	2–10
Bulbous bluegrass	1–2	Ladino clover	1–4
Redtop	2–10	White clover	1–3
Perennial ryegrass	6–10	Red clover	3–10
Crested wheatgrass	4–11	Alsike clover	2–6
Slender wheatgrass	2–5	Strawberry clover	2–6
Russian wild rye	5	Sweetclover	2–10
Warm Weather Grasses		Birdsfoot trefoil	4–6
Dallis grass	4–10	*Warm Weather Legumes*	
Blue grama	4–8	Lespedeza (Korean and common)	5–15
Sideoat grama	3–4	Low hop clover	1–3
Rothrock grama	3–4	Persian clover	1–3
Buffalo grass	1–2	California burclover	2–8
Lehman lovegrass	½	Black medic	3
Boer lovegrass	⅓		

Pasture Mixtures for Different Regions

The rates of seeding of pasture mixtures, the adapted pasture plants, and some of the recommended mixtures for different regions and conditions in the United States are shown below. Detailed recommendations are found in "Grass," *U. S. Dept. Agr. Ybk.*, 1948.

REGION	ADAPTED PASTURE PLANTS
Northeast (20–25 pounds per acre)	Timothy, orchard grass, bromegrass, reed canarygrass, meadow fescue, Kentucky bluegrass, redtop, perennial ryegrass, Ladino clover, red clover, alsike clover, alfalfa, birdsfoot trefoil, white clover, Korean lespedeza.

Recommended mixtures:

(1) General use: Timothy, orchard grass, or bromegrass and Ladino clover, or red clover.
(2) Poorly drained land: Reed canarygrass, meadow fescue, or redtop and alsike clover, or Ladino clover.
(3) Poorly-controlled grazing areas: Kentucky bluegrass and white clover included with No. 1.

North central (10–23 pounds per acre)	Biennial sweetclover, timothy, meadow fescue, bromegrass, Ladak alfalfa, Ladino clover, orchard grass, red clover, alsike clover, white clover, redtop, Kentucky bluegrass, Canada bluegrass, Korean lespedeza.

Recommended mixtures:

(1) Alfalfa (6 to 10 pounds), bromegrass (5 to 10 pounds).
(2) Biennial sweetclover (8 to 12 pounds), meadow fescue or orchard grass (6 pounds).
(3) Timothy (2–6 pounds), Kentucky bluegrass (2–7 pounds), red and alsike clover (3–6 pounds), Ladino or white clover (1–2 pounds).
(4) For poorly-drained soils: Timothy (5 pounds), redtop (5 pounds), reed canarygrass (2–6 pounds), alsike clover (3 pounds).

Northern Great Plains	
Eastern portion (12 pounds per acre)	Crested wheatgrass, intermediate wheatgrass, bromegrass, alfalfa, wild rye, feather bunchgrass.
Western portion (10 pounds per acre)	Crested wheatgrass, sweetclover, blue grama, sideoat grama, buffalo grass, western wheatgrass, Russian wild rye, Mandan wild rye, feather bunchgrass.

REGION	ADAPTED PASTURE PLANTS
Northern intermountain irrigated (16–25 pounds per acre)	Bromegrass, meadow fescue, orchard grass, timothy, alsike clover, Ladino or white clover, yellow sweetclover, alfalfa. Strawberry clover, alsike clover, redtop, timothy, and reed canarygrass for wet lands.
Northwestern irrigated (16–25 pounds per acre)	Bromegrass, Kentucky bluegrass, timothy, orchard grass, tall oatgrass, fescues, alfalfa, and red, alsike, Ladino, white and strawberry clover, sweetclover, birdsfoot trefoil, big trefoil.
Southwestern irrigated (13–30 pounds per acre)	Orchard grass, perennial ryegrass, meadow fescue, Ladino clover, alfalfa, burclover, Dallis grass, Rhodes grass, bromegrass, Harding grass, yellow sweetclover.
Western range lands (5–13 pounds per acre)	Crested wheatgrass, bluestem wheatgrass, slender wheatgrass, bromegrass, tall oatgrass, sand dropseed.
Southwestern range lands (8–10 pounds per acre)	Crested wheatgrass, western wheatgrass, bromegrass, galleta grass, yellow sweetclover, Indian rice grass, domestic ryegrass, weeping lovegrass, subterranean clover, Harding grass, alfilaria, burnet.
Pacific northwest Coastal wetlands (12–20 pounds per acre)	Seaside bent, Astoria bent, redtop, velvetgrass, white clover, Alta fescue, reed canarygrass, meadow foxtail, birdsfoot trefoil, big trefoil.
Humid uplands (14–20 pounds per acre)	Perennial ryegrass, orchard grass, tall oatgrass, Alta fescue, Chewings fescue, creeping red fescue, Astoria bent, highland bent, white clover, sub clover, big trefoil, birdsfoot trefoil.
Great Basin semiarid	Crested wheatgrass, western wheatgrass, slender wheatgrass, bromegrass.
Southern Great Plains (9–19 pounds of unprocessed seed per acre)	Blue grama, buffalo grass, sideoat grama, sand lovegrass, sand bluestem, switchgrass, Indiangrass, little bluestem, weeping lovegrass.

REGION	ADAPTED PASTURE PLANTS
Southeast	Bermuda grass (preferably coastal Bermuda), carpet grass, Dallis grass, Bahia grass, common and Kobe lespedeza, Korean lespedeza, white clover, low hop clover.

Recommended mixtures:

(1) Coastal plain: Dallis grass (10 pounds), redtop (2 pounds), lespedeza (15 pounds), white clover (1 pound).
(2) Georgia piedmont: Bermuda grass, hop clover, lespedeza.
(3) Mountain: Kentucky bluegrass (5 pounds), redtop (5 pounds), orchard grass (5 pounds), Ladino or white clover (1 to 2 pounds), lespedeza (15 pounds).
(4) Florida (wet sandy acid soils): White clover (3 pounds), Persian clover (1 pound), redtop (5 pounds). Carpet grass establishes itself naturally.

Establishment of Permanent Pastures

Since most of the plant species used for permanent pastures have small seeds, it is necessary to prepare a firm seedbed. The use of good seed of small-seeded grasses and legumes is important in providing good pasture coverage relatively free from weeds. The seed should be drilled rather than broadcast, and should be seeded not over 1¼ inches deep. A general practice is to seed the grasses and legumes with a small grain as a companion crop. The pasture plants are more productive the first year when seeded alone,[29] and, when grazed properly, provide a larger net return than the grain crop and may offset the grazing value of the companion crop. Under irrigation, it is necessary to keep the soil surface moist until the seedings are well started. This may require irrigation every 7 to 10 days. Dryland grass seedings succeed only during favorable moist periods.

In general, it is advisable to sow cool-weather grasses in the fall. Warm-weather species should be seeded in the spring. Small-seeded legumes should be sown on the surface in the spring. It is often difficult to get in the fields early in the spring in the northern states. Early spring seeding is advisable in the southern states where the permanent grasses are distinctly summer grasses. Early spring seeding is advisable also in the northern states on extremely heavy soils where heaving causes a severe loss of seedlings during the winter. Clovers and other legumes should be broadcast or drilled on the grass seedings in late winter or very early spring. Disease-resistant varieties of alfalfa such as Ladak should be used in order to prolong the stand.

Several grasses adapted to Florida are established by vegetative methods—root or stem cuttings, or sod pieces. These include Napier, Bermuda, Para, St. Augustine, Pangola, and centipede. Carpet grass establishes itself without seeding.[7]

A new pasture should be grazed lightly the first season. The young plants must have time to develop a good root system so as to withstand drought, and the strain of grazing.

Pasture maintenance or improvement may be brought about by reseeding, fertilization, and good grazing management.

Fertilization of Pastures

Most pasture lands in the humid regions of the country are deficient in calcium, phosphorus, nitrogen, and sometimes potassium. The minerals calcium, phosphorus, and potassium must be applied before much response can be expected from application of commercial nitrogen.[29] Pastures on soils of fair natural fertility, particularly those that have been neglected several years, can be improved by fertilization. An application of 400 to 600 pounds of a 6–12–6 fertilizer gave the best increases in south Georgia.[31]

Applications of superphosphate alone generally give the greatest response because they encourage the legumes that supply nitrogen to the grasses. When added to a pasture that had been unfertilized for 40 years, all fertilizers increased the nitrogen content of the herbage.[9] The averages for each year were about the same for the phosphorus-lime as for the phosphorus-nitrogen treatments. In Ohio, run-out bluegrass and white clover pastures have been treated with superphosphate, lime being added where the pH was below 5.5.[4] In the case of lime deficiency, it may be desirable to replace certain pasture plants with others not sensitive to acid soils. For this purpose lespedezas may be used in place of clovers in areas where they are adapted.

Applications of nitrogen usually increase the protein content of herbage. It has increased the crude protein of bluegrass-white clover herbage as much as 12 per cent.[34] Nitrogen may promote growth enough so that pastures will be ready for grazing as much as 3 weeks earlier than those without such applications. Nitrogen applications often discourage the growth of legumes. Nitrogen is relatively ineffective on Ohio sods with a high clover content.[11]

Mineral fertilizers, limestone, and barnyard manure can be applied in the fall, winter, or early spring. Commercial nitrogen should be applied at least two weeks before increased growth is desired. Applications of nitrogen are rarely effective except in the presence of adequate soil moisture. For this reason, the returns for midsummer applications are often unsatisfactory.

Renovation and Reseeding

Cultivation of pastures to secure improved grazing is of little value unless accompanied by reseeding or application of fertilizers, or both.

PRACTICES IN HUMID REGIONS

Cultivation in connection with reseeding and fertilization resulted in improved pastures in Vermont and Iowa by elimination of weeds, covering the seed, and mixing the fertilizer in the soil. Grasses and clovers that make a quick growth may be seeded on old pasture sod that has been well disked and fertilized.[12] In Wisconsin,[14, 15] run-out bluegrass pastures can be improved by the scarification of the sod with a disk or spring-tooth harrow, after which legumes such as alfalfa, sweetclover, and red clover are seeded in the thinned pasture sod. As an average of 27 different pasture renovations the total weed population (mainly ragweeds and horseweeds) was reduced 85 per cent after 2 or 3 years. Reseeding alone may be desirable in some instances in connection with the improvement of old pastures, but it is seldom a complete remedy.

Revegetation of Range Lands

The return of abandoned cultivated land to grass is a difficult problem on the Great Plains as well as in other areas of moisture[27] shortage. From 20 to 50 years are required for buffalo grass to become reestablished naturally on abandoned farm land. In recent years, the seeding of blue grama, buffalo grass,[37] and other species has been fairly successful. Seedings of cultivated grasses (smooth brome, slender wheatgrass, and crested wheatgrass) thrived on areas where the original native vegetation consisted of grama and fescue grasses.[16] The land was disked, the seed sown broadcast early in the spring, and the field protected from grazing the first season.

Artificial range reseeding in the native sod generally has been unsuccessful in the semiarid region unless the seeding was favored by unusual rainfall. Range grasses have been restored by reseeding on depleted mountain meadows, alluvial bottoms, and the better sites of mountain slopes where soil moisture conditions were above average. For cultivated grasses, an annual rainfall of 18 inches or more appears to be essential.

An overgrazed oak-brush range in Utah was seeded successfully with crested wheatgrass, smooth brome, and mountain brome.[23] White and yellow sweetclover seedings resulted in poor to no stands. The best stands were obtained from seed broadcast on plowed furrows spaced approximately 3 feet apart, the seed being covered with a brush drag. During a period of 7 years this method resulted in an increase of 360 to 900 per cent in grazing capacity compared with open-grazed unseeded areas. Some degree of soil preparation was necessary to assure successful reseeding. Unless moisture and other conditions are unusually favorable, 2 or 3 years are required to establish a new range. When livestock are kept off for such a period, scattered seedlings have an opportunity to spread, and dormant seeds germinate and produce new seedlings to help increase the ground cover.

Grazing Systems

The capacity of native pastures has been increased as much as 50 per cent by good grazing management. Controlled grazing is necessary to give the palatable species an opportunity to recuperate and to produce seed. Persistence of vegetation through a dry summer and a cold winter is directly related to root development. Overgrazing has resulted in poor root growth with very little food accumulation, with the result that the plants are likely to die either from drought or cold.[35] Large decreases in weight of roots have followed overgrazing.[30] The total decrease from the early to the late stage of grazing was from 2.17 to 0.95 tons of roots per acre in the 0 to 4-inch depth, and from 0.86 to 0.34 ton in the 4- to 12-inch depth on upland Nebraska soil.

INFLUENCE OF GRAZING ON SPECIES

One of the first signs of an overgrazed range is that the most palatable grasses such as bluegrass, needlegrass, June grass, wheatgrass, bromegrass, and the fescues become less vigorous, produce less forage, and become reduced in numbers. The less palatable plants, such as gumweed, snakeweed, mountain sage, sand hill sage, cactus, and poisonous plants increase in numbers. As the condition becomes more severe, annual weeds tend to replace perennial weeds and shrubs. The last stage is bare spots which gradually increase, and this in turn causes an increase in soil erosion. After the perennial grasses have perished and erosion started, a long time may be required to restore the range to its original productivity.

For maintaining the vigor of blue bunchgrass and slender wheatgrass, two valuable range species in Montana, they should not be utilized beyond 60 to 70 per cent of their foliage production by early summer, or more than 80 or 85 per cent at the close of the summer grazing period.[10] The higher the successional stage of the vegetation, the greater the value of the range for grazing. As shown in Table 3, the range tends to take on the characteristics of a more arid type as it becomes depleted. The higher successional stages were characterized by greater density of stand, a higher percentage of grass in the stand, and greater grazing capacity.

Grazing management influenced the composition of cultivated grasses grown in mixtures in the British Isles [20] in a pasture composed

TABLE 3. PRODUCTIVITY OF SUCCESSIONAL TYPES OF RANGE VEGETATION

ITEM	BLUE BUNCHGRASS	SLENDER WHEATGRASS	PORCUPINE GRASS	RABBIT BRUSH
Density of vegetation (%)	60 to 80	40 to 60	30 to 50	20 to 40
Grasses (%)	75	65	85	25
Weeds (%)	20	25	10	50
Browse (%)	5	10	5	25
Palatable (%)	62	54	49	25
Surface acres to feed 1 cow 1 month	2	3	4	11

of perennial ryegrass, rough-stalked meadow grass, and wild white clover. The plot grazed heavily in March, April, and May had white clover as the most important constituent of the pasture by the middle of the third season. Another plot was made grass-dominant by deferring grazing until April 15. The perennial ryegrass became more vigorous, while the white clover was considerably checked. A third plot not grazed before April 15, but completely pastured down at each subsequent grazing and then rested for a month, maintained a good balance between perennial ryegrass and white clover.

DEFERRED AND ROTATION GRAZING

On the western range, the problem is to maintain the important palatable native range plants. Ranges may be injured more by too early grazing than by any other faulty practice. Grasses grazed too early in the spring may be pulled up by the roots or damaged by trampling in a wet soil. In the spring, when the new grasses commence their growth, the water content of the herbage may be as high as 85 per cent, with a low feeding value. Excessive early grazing each year may delay satisfactory development of the palatable plants by as much as 6 weeks. It is desirable to delay grazing until the important forage plants have reached a height of 6 inches or, in the case of the shorter grasses, until the flower heads are in the boot.[10] Normal stand and vigor of bluestem pastures in eastern Kansas were maintained when grazing was deferred until June 15.[3] Such a period of protection every 2 or 3 years seemed sufficient. The deferred system gave an increase of approximately 25 per cent in carrying capacity.

Rotation grazing consists in grazing two or more pastures in regular order with intervening rest periods for each pasture.[25] An experimental area on the Jornada Reserve, moderately grazed under the deferred system, was more than four times as valuable as the outside range heavily grazed yearlong.[10] As applied to western ranges, the system of deferred rotation grazing provides for reservation until after seed maturity of about one-fourth or one-fifth of the entire area used by the herd. Then that area is grazed. A different area is so reserved each year. The result is an increase in carrying capacity of the range, a chance for improvement when the range is depleted, and better growth of animals without losses through nonuse of feed. Continuous grazing is superior to the rotation of range pastures at approximately monthly intervals.

THE HOHENHEIM SYSTEM

An intensive plan of grassland management, known as the Hohenheim system,[13, 22, 41] was developed in Germany in 1916. This method may prove feasible in the northeastern states where summer climate favors the growth of grass. The system is designed to supply a luxuriant growth of grass rich in protein so as to make it possible for the animals, especially dairy cattle, to obtain from the pasture all the feed necessary.

The Hohenheim system involves: (1) division of the pasture into from 4 to 8 paddocks, about equal in size; (2) heavy applications of fertilizers, especially nitrogen; (3) separation of the herd into two groups, producers and nonproducers; and (4) frequent rotation of these groups. Usually 1 to 2 acres is allowed per 10 cows, so that with 30 cows, each of the paddocks would have an area of about 3 to 5 acres. The cattle are moved progressively to other paddocks at intervals of about one week, or whenever the grass reaches a height of 4 or 5 inches. Young stock and dry cows kept separate from the milk cows, follow on each paddock as the milkers are advanced. After they have moved on, the paddock may be harrowed to scatter the droppings. Additional nitrogen is applied at this stage when needed. The grass is mowed when the animals are unable to keep it down.

The Hohenheim system has been investigated in the United States since 1928. The effect of the heavy fertilizer applications was pronounced in Massachusetts. In Wisconsin the completely fertilized areas of a bluegrass pasture produced about three times as much herbage as the unfertilized areas during the first year.[13] The fertilizers used were 100 pounds per acre each of phosphates, potash, and nitrogen. The turf was greatly thickened, the weeds largely disappeared, and white grub injury was practically eliminated. In Ohio, treatment doubled the carrying capacity and lengthened the grazing season by about 15 per cent.[4] At Beltsville, Maryland, rotation grazing increased the yield of total digestible nutrients by 10.4 per cent, heavy fertilization increased the yield 16.4 per cent, and both combined increased the yield 28.6 per cent.[41] Heavy fertilization failed to improve the uniformity of carrying capacity throughout the grazing season. Midsummer applications of nitrogen were poorly utilized.

Burning Grasslands and Brush

Burning of grasslands has been practiced for many years particularly in the southeast, but authorities differ as to its effectiveness in grassland improvement. Those who advocate burning claim that it: (1) brings about an earlier growth of vegetation; (2) results in more palatable vegetation than that from unburned areas; (3) increases the productivity of the soil through liberation of the lime phosphoric acid, and potash contained in the ash; (4) improves the character of the herbage by control of weeds and brush; (5) controls chinch bugs.

Such benefits if realized are more likely to occur in humid regions. Burning frequently has detrimental effects particularly in the west. Some of these effects are: (1) removal of the extra vegetative material that would add humus and nitrogen to the soil. (2) Destruction of old vegetation in the soil which functions to increase the water-holding capacity. (3) Injury to the living vegetation.

In Kansas, continued annual burning of native bluestem pastures decreased the total production of grass.[2] Yields from burned and unburned areas are given in Table 4.

Other conclusions were that burning should be carried out in early spring after hard freezing weather is over, but before the native grasses start growth, and that burning should be practiced

TABLE 4. EFFECTS OF BURNING ON BLUESTEM PASTURES IN KANSAS

DATE OF ANNUAL BURNING	6-YEAR AVERAGE YIELDS PER ACRE *Grasses and Weeds* (*tons*)	*Weeds* (*tons*)
Late fall (December 1)	1.02	0.20
Early spring (March 20)	1.12	0.15
Medium spring (April 10)	1.18	0.18
Late spring (May 5)	1.48	0.03
Unburned	1.68	0.14

only in occasional years when an excess amount of dry material is on the pasture from the previous season. Burning had very little effect on control of weeds unless done late in the spring. Burning stimulated early spring growth due to a warmer soil.

Burning also is detrimental to the vigor of short grasses in the west,[16] the total yield for the season usually being less on burned areas. Shallow-rooted grasses like bluestem and the fescues may be killed by a single burning. The dry forage left protects the young growth from too close grazing

On the other hand, burning is practically necessary in the Gulf coast region as long as the land is used for both grazing and lumbering, particularly when only the native grasses and legumes are grazed.[29] Burning increases the number of legumes and grasses by destruction of the heavy ground cover of pine needles and leaves from other trees.

In Kansas, buckbrush (*Symphoricarpos* species) was seriously injured when burned late in the spring.[1] Sagebrush has been eradicated from range lands when burned in the late fall when it was dry.[16] Removal of the sagebrush permitted grasses such as the fescues, wheatgrasses, and arid bluegrasses to become more productive. Some pastures increased their foliage two to five times from this practice. It took several years for the sagebrush to become reestablished. Burning was equally damaging to grasses and sand sagebrush in western Oklahoma.[28]

Mowing and Spraying Weeds and Brush

Mowing was an effective method of suppressing sand sagebrush (*Artemisia filifolia*) in pastures in western Oklahoma.[28] This species is not large and woody like the big sagebrush (*A. tridentata*), common to the intermountain plateau region, so that a heavy-duty power takeoff mower with some extra-heavy equipment will cut it satisfactorily. Such mowing has more than doubled the beef production per acre on sagebrush pastures. Best results were secured from mowing in June when the food reserves in the sagebrush roots were most depleted. The sagebrush required removing after a year, cutting in the opposite direction to get many prostrate plants and branches that had been passed over the first time. The experiments showed that livestock should be kept off the pasture from June until September during each of the 2 years.

Buckbrush and sumac were eradicated when cut in the flower stage, i.e., about May 10 and June 8, respectively, in Kansas.[1] In Connecticut experiments [8] July was the best time to mow brush consisting of soft maples, alders, white birches, and blackberries. In the northern regions the critical period for destroying the brush appears to be when the roots contain the smallest amount of starch. generally when the plants are in blossom. In the southern states woody shrubs must be grubbed out or killed with poisons.

Spraying with mixtures of diesel oil and 2,4–D is preferable to either mowing or burning for destroying sand sagebrush, skunkbrush, and certain other pasture shrubs.

Stock-Poisoning Plants *

Poisonous plants cause estimated losses of 4 per cent per year to range livestock. Animals usually eat poisonous plants in harmful quantities only when the more nutritious and palatable plants are inadequate to meet their feed requirements.

Poisonous plants vary greatly with respect to (1) the condition under which animals are poisoned by them, (2) the portion of the plant that is poisonous, (3) changes in the toxicity of the parts of the plant during growth and drying, (4) the susceptibility of different species of animals to being poisoned by them, and (5) the effects on the poisoned animals.

Some of the important poisonous plants are: Arrowgrass (*Triglochin maritima*), death camas (species of *Zygadenus*), horsetail (species of *Equisetum*), larkspur (species of *Delphinium*), loco (species of *Oxytropis* and *Astragalus*), lupine (species of *Lupinus*), whorled milkweed (*Asclepias galioides* and *A. mexicana*), poison vetch (some species of *Astragalus*), water hemlock (species of *Cicuta*), white snakeroot (*Eupatorium urticaefolium*), crazyweed (species of *Oxytropis*), and sneezeweed (species of *Helenium*).

Poisonous principles found in these plants include: cyanogenetic

* For a more complete discussion of poisonous plants see W. C. Muenscher, *Poisonous Plants of the United States,* The Macmillan Company, New York, 1940, pp. 1–266.

glucoside in arrowgrass; an alkaloid, zygadenine, in death camas; an alkaloid, equisetin, and aconitic acid, and fungi in horsetail; alkaloids (delphinine and others) in larkspurs; a toxic base, locoine, in loco weeds; alkaloids (lupinine and others) in lupines; an alcohol-soluble resin in whorled milkweed; selenium in *Astragalus* species; a resinlike substance, cicutoxin, in water hemlock; and a higher alcohol, tremetol, in white snakeroot.

Several of the poisonous plant species can be killed with 2,4-D sprays.

Crops for Temporary or Annual Pastures

The growth of perennial grasses and legumes stops or is greatly retarded, and the carrying capacity is reduced each season when the temperature becomes too hot or too cold for the particular species. It is often desirable to grow annual or biennial crops to supplement permanent pastures during unproductive periods. Temporary pastures should not be planted on steep slopes because of the erosion hazard while the land is bare. A suitable succession of annual crops may provide pasturage for a long season in nearly all parts of the country. Some of the advantages of annual pastures are greater production per acre, a longer grazing season, less trouble from internal parasites, better maintenance of the productivity of the soil, and less danger from noxious weeds. Among the disadvantages are the greater labor requirement, the cost of seed, greater danger of erosion, impracticability of grazing such crops on clay soils in wet weather, and frequent inability to obtain good stands.

In many of the humid sections of the north clover and alfalfa may be pastured temporarily by sacrificing one cutting of hay. Other temporary pasturing schemes include Italian ryegrass in early spring; winter or spring small grains from April to July; rape, field peas, or vetch in early summer; and soybeans or Sudan grass from midsummer to fall. Sweetclover may be pastured in the fall in its first year and in early spring of its second year. Some of these crops have two to four times the carrying capacity of comparable permanent pastures in the early spring, midsummer, or late fall.

An example of an effective arrangement of annuals, for southeastern North Carolina, to provide pasturage for dairy herds is as follows:[29] (1) Abruzzi rye, sown in September and grazed from November 15 to March 15; (2) crimson clover and hairy vetch sown August 15 to September 1 and grazed from March 1 to May 15; (3) Sudan grass sown April 1 and grazed from May 15 to November 15; and (4) Biloxi soybeans sown March 15 and grazed from June 1 to November 15.

Also in the south, legumes such as lespedeza can be maintained in association with Dallis grass but cannot compete satisfactorily with carpet grass and Bermuda grass. White clover, a cool weather perennial legume, formerly considered only for the north, provides excellent early pasture in the south where it is maintained largely as a winter annual. Fall-sown grains provide excellent grazing during the fall, winter or early spring in the south. Winter oats sown with crimson clover or burclover are now being recommended for winter pasture. More pasturage is secured when one of the improved rust-resistant varieties of oats is sown. A mixture of Italian ryegrass and crimson clover also provides excellent winter pasture. Pearl (cat-tail) millet furnishes abundant summer pasture in the south.

In the drier parts of the Great Plains a sequence of annuals has given the most satisfactory cultivated pastures. In eastern Colorado rye may be sown from August 15 to 30. This will furnish late fall and early spring pasture until the rye reaches the jointing stage which is approximately June 1. In the spring (May 20 to 30), Sudan grass is sown in an adjacent field in close drills, and can be grazed from about July 1 until frost. A third field may be planted either to a spring small grain or to a spring-sown winter wheat for grazing from June 1 to July 1, but native grass pastures usually are used to carry the animals over this period. Oat pasturage is more palatable than barley, and barley is more palatable than wheat or rye.

Winter Wheat for Pasture

Winter wheat is pastured extensively in the late fall and again in the spring in the central and southern Great Plains states. About 65 per cent of the winter wheat acreage in Kansas is pastured at least to some extent in favorable years. From 60 to 120 days of grazing are available during the period from November to April. Native pasture in late spring, early summer, and late fall, and

Sudan grass from July to September provide grazing for the remainder of the season. Moderate grazing causes little or no reduction in grain yield in fields of winter wheat well established and well supplied with soil moisture. Yields have been reduced from 5 to 50 per cent by heavy grazing or by grazing when the wheat growth was scanty and soil moisture was limited. Wheat pasture experiments were conducted in western Kansas for 5 years on both fallowed land and on land previously cropped to wheat.[32] The grain yields are shown in Table 5.

TABLE 5. EFFECT OF PASTURING WINTER WHEAT ON GRAIN YIELD, 1926 TO 1930

METHOD PASTURED	TIME PASTURED	AVERAGE GRAIN YIELDS PER ACRE	
		Fallow Land (*bu.*)	*Wheat Land* (*bu.*)
Fall pasturing	October 15 to December 15	29.6	25.3
Moderate seasonal pasturing	October 15 to December 15 and March 1 to April 15	28.9	25.0
Check (unpastured)	———	26.6	26.2
Spring pasturing	March 1 to April 15	25.6	23.5
Severe seasonal pasturing	October 15 to December 15 and March 1 to April 15	23.5	21.3
Late spring pasturing	April 15 to May 1	20.4	——

Moderate and timely grazing of the rank growth of wheat on fallowed land even improved the grain yield. Spring grazing may be started when growth is resumed in the spring, but should be discontinued when the plants start to grow erect just previous to jointing. The wheat plants may be injured by grazing at any time after their growing points are above the ground line.[21] Permanent injury resulted when the culm tips were grazed, as severed culms never produced heads. The sowing of an additional peck of seed per acre is recommended where grazing is contemplated.[32] Moderate pasturing is especially beneficial where wheat has been sown very early or has made an excessive growth. Pasturing checks rank growth and tends to prevent lodging.

Samples of wheat taken late in the fall contained 27 to 28 per cent protein and 12 to 15 per cent ash. The high protein content accounts for the high nutritive value of wheat pasture. Rather rarely, animals are poisoned on wheat pasture from an unknown cause. It has been suggested that the wheat may contain an excess of potassium nitrate absorbed from very fertile soils, or that some other factor affects the calcium balance in the animal body. Wheat poisoning, which is called grass tetany, often is relieved by intravenous injections of calcium lactate. Grass tetany is believed to occur less frequently among animals that have access to supplemental roughages and concentrated feeds.

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11 WEEDS AND THEIR CONTROL*

Economic Importance

Weeds cost the farmers of America more than 2 billion dollars annually in crop losses and in the expense of keeping them under control. Much of the cost of intertillage of row crops, and of the maintenance of fallow, and an appreciable portion of the seedbed preparation and seed cleaning costs are chargeable to weed control. Suppression of weeds along highways, and railroad right of ways, and in irrigation ditches and navigation channels, yards, parks, grounds, and home gardens is another expensive item. Ragweed pollen (Figure 77) is a source of annual periodic distress to several million hay fever sufferers. Poison ivy, poison oak, poison sumac, nettles (Figure 78), thistles, sandburs, and puncture vine bring pain to other millions. The barberry bush which spreads the black stem rust to grains and grasses can be regarded as a weed. Also weeds serve as hosts for other crop diseases and for insect pests. The total cost of weeds to the nation has been estimated at 3 billion dollars a year.

In some locations, however, weeds are beneficial in checking soil erosion, supplying organic matter to the soil, and in furnishing food and protection to wild life.

Types of Farm Weeds

A weed is a "plant out of place," but a better definition is "plant that does more harm than good and has the habit of intruding

* For more complete information on weeds and their control, see:

W. C. Muencher, *Weeds*, The Macmillan Company, New York, 1942.

W. W. Robbins, M. K. Bellue, and W. S. Ball, *Weeds of California*, California State Dept. of Agriculture, Sacramento, Calif., 1941.

W. W. Robbins, A. S. Crafts, and R. N. Raynor, *Weed Control*, McGraw-Hill Book Co., Inc., New York and London, 1942.

FIG. 77. (A) Giant ragweed or kinghead, *Ambrosia trifida;* (B) common ragweed, *A. elatior* (*artemisifolia*).

FIG. 78. Horsenettle (*Solanum carolinense*), a perennial.

where not wanted."[20] Some plants, e.g., Canada thistle, are always considered weeds, whereas red clover would be considered as a nuisance under some circumstances but hardly a weed at any time. Nevertheless, more than 30 American crop plants frequently have been listed as weeds. Among the more troublesome crop plants that get out of place are Johnson grass, cheat, sweetclover, Bermuda grass, sesbania, vetch, rye, black medic, burclover, hemp, black mustard, chicory, and kudzu.

Annual weeds live for a single year, mature seed, and die. Most of the common farm weeds belong to this group, among them being pigweed, ragweed, fanweed (Figure 79), Russian thistle, wild oats, mustard, lambsquarters, pigeon grass (Figure 80), and peppergrass.

Biennial weeds require two seasons to complete their growth. They grow from seeds and devote the first season to food storage, usually in short fleshy roots. During the next spring they draw on the stored food to produce a vigorous vegetative growth and to mature seeds. Among the biennial weeds are burdock, bull thistle, mullen, and wild parsnip.

Perennial weeds live for more than two years. The majority of simple perennials possess root crowns that produce new plants year after year, being supported by a fleshy taproot, e.g., dandelion, or by means of fibrous roots. Plants of this type depend upon production of seed for their spread, except in a few instances. Creeping perennials propagate by means of underground parts and often also by seeds. Field bindweed, Canada thistle, perennial sowthistle, leafy spurge, and whitetop spread by horizontal roots. Quackgrass and Johnson grass spread by rootstocks (rhizomes).

Weeds also may be classified as common and noxious. Common weeds are annuals, biennials, or simple perennials that are readily controlled by ordinary good farm practices. Noxious weeds are those which are difficult to control because of an extensive perennial root system or because of other characteristics that make them persistent.

FIG. 79. Fanweed or Frenchweed (*Thlaspi arvense*).

FIG. 80. Pigeon grass, yellow bristlegrass or yellow foxtail (*Setaria lutescens*).

FIG. 81. The corn has been killed in the thick bindweed spots. Note mature Russian thistles in right foreground.

Losses Caused by Weeds

Weeds may cause losses in several ways: [24]

(1) Decrease in crop yields. Weeds decrease yields by removal of moisture needed by crop or pasture plants (Figure 81). Most weeds require as much water to produce a pound of dry matter as do the cereal crops. In addition, weeds compete with crop and pasture plants for light and soil nutrients.[24] Yields of close-drilled sorghum on bindweed-infested land and on clean land averaged 2.06 and 3.92 tons per acre, respectively, in a Kansas experiment. Barley produced an average acre yield of 7.5 bushels on infested land and 21.5 bushels on land free from bindweed.[26]

(2) Impairment of crop quality. The presence of weed seeds in small grains may materially lower the quality. In threshed grain green weed pieces raise the moisture content so that it may not keep in storage. Weeds such as wild garlic, mustard, fanweed, yarrow, chicory, or ragweed consumed in hay or pastures impart undesirable flavors to dairy products.

(3) Harbor plant pests. Many weeds act as hosts to organisms that carry plant diseases. Curly top, a serious virus disease of the sugar beet, is carried from such weeds as the common mallow,

chickweed, and lambsquarters to the sugar beet by the beet leafhopper which breeds upon these weeds. The sugar beet webworm prefers to deposit its eggs on the Russian thistle and similar weeds. Weeds of the family Solanaceae contribute to the spread of such pests as the Colorado potato beetle.

(4) Increased irrigation costs. Weeds on ditchbanks and growing in the ditches may seriously impair the efficiency of irrigation channels. Windblown weeds often obstruct headgates and diversion boxes. As a result, ditches must be cleaned every year.

(5) Injury to livestock. Some poisonous weeds described in Chapter 10 may cause illness or death to livestock. Mature plants of sandbur, three-awned grass, porcupine grass, downy bromegrass, and squirreltail grass may cause mechanical injury to stock that eat them.

(6) Decreased land values. Land values may be reduced by the presence of weeds, particularly noxious weeds.

Persistence of Weeds

Weeds usually are able to survive in competition with crop plants because of a wide range of adaptability as well as effective means of propagation, such as by underground parts.

Many weeds produce large amounts of seeds per plant. The number for several species is as follows: [22] fanweed 7,040; pigweed 117,400; Russian thistle 24,700; lambsquarters, 72,450; green foxtail 34,000; perennial sowthistle 9,750; and tumbling mustard 80,400. Seeds of some weeds escape notice because they are so small.

Many weed seeds remain viable in the soil for many years. Some weed seeds including bindweed, wild oats, and cocklebur may exhibit dormancy. Their prolonged viability in the soil explains the sudden appearance of certain weeds after years of good cultural practices.

Dissemination of Weeds

NATURAL AGENCIES

Seeds with barbs and hooks may become attached to animals and carried long distances. Weed seeds eaten by birds and animals may pass through the digestive tract uninjured. Cactus is spread principally by jack rabbits which eat the fruits containing indigestible seeds. Seeds equipped with tufts of hair, e.g., Canada thistle, bull thistle, or sowthistle, may be disseminated by wind for distances of 2 to 15 miles. Weed seeds are often carried to other locations by rains or in streams. Tumble weeds of various species, e.g., Russian thistle, tumbling amaranth, tumbling mustard, may roll in the wind for long distances, scattering seeds as they go. Weeds with horizontal roots or rootstocks spread from one to several feet each year. Bindweed patches may double their area every 5 years.

MAN-MADE AGENCIES

Weeds are widely spread in impure farm seeds. Some of the most serious weed pests have been introduced from foreign countries in wheat, alfalfa, clover, sugar beet, and other crop seed. Hay, straw, and other forages have contributed to the spread of weed seeds.

In irrigated sections seeds of weeds that grow on the banks of reservoirs, canals, and ditches may fall in the water and be carried to cultivated fields. Several million weed seeds comprising 81 species floated down a 12-foot irrigation ditch in Colorado in one day.[9]

Farm machinery may spread weed seeds. Plows, harrows, and cultivators may drag roots or seed-bearing portions of perennial plants to other parts of a field.

Spreading of fresh barnyard manure on cultivated fields may disseminate weed seed. In one experiment[10] 6.7 per cent of the weed seeds fed to farm animals were viable when recovered in the fresh manure. After burial for 1 month in manure, velvet weed, bindweed, and whiteweed seeds were still viable. Practically all seeds were dead after being buried in manure for 3 months.

Control of Common Farm Weeds

Crop seeds of high purity and free from noxious weed seeds should be sown. An important control method is early and frequent cultivation of the land. Row crops should be grown on the land periodically to permit intertillage. Weeds are killed most easily when they are seedlings. The greatest benefit of bare fallow in the semiarid region is prevention of weed growth. Another important feature in controlling growing annual weeds is to keep them from going to seed by early mowing, especially in pastures, and along fences, ditches, or roadsides where cultivation is impracticable or impossible. Weeds that mature seeds should be burned to kill the seeds, when they collect in irrigation ditches, drains, fence corners, and waste places.

Crop rotation is a valuable aid in weed control because many weeds are associated with certain crops. Continuous culture to one crop makes the control of these associated weeds difficult. For example, dodder (Figure 82) and Russian thistles may be troublesome in alfalfa, but are readily eliminated in cultivated crops. Wild oats and the mustards become serious pests on land cropped continuously to small grains. Corn cockle and cheat are commonly associated with wheat growing, while green foxtail is often troublesome in flax and corn fields. A properly planned crop rotation that includes cultivated, small grain, and grass or legume sod crops will restrict weed populations materially.

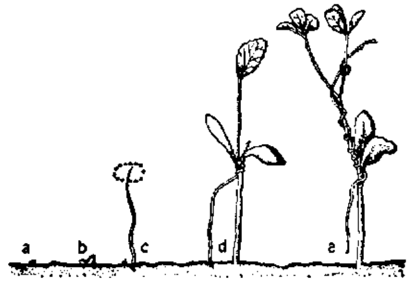

FIG. 82. A dodder or "lovevine" (*Cuscuta* species), seedling comes up and sways around until it encounters a host plant which it entwines. Haustoria or suckers penetrate the stem of the host and take up nutrients. Then the lower stem of the dodder dies.

So-called smother crops have the ability to make a rapid growth that shades out other plants. Their effectiveness depends upon maintenance of a thick stand. Common smother crops are alfalfa, foxtail millet, buckwheat, rye, sorghum, and Sudan grass.

All types of community farm machinery, particularly small grain separators, combines and hay balers, should be cleaned before they are brought to the farm.

These practices also will aid in the control of noxious weeds, although additional methods may be required to eradicate them. Klamath weed (St. John's-wort) is being controlled with parasitic beetles imported from Australia.

CLEAN CULTIVATION FOR NOXIOUS WEED CONTROL

Clean cultivation or bare fallow is a common means for the eradication of perennial noxious weeds having horizontal roots or rootstalks, especially on large infested areas. This practice is based on the principle of root starvation. The new shoots are cut off before they replace the food reserves utilized in their growth.

Ordinarily, the weed area should be plowed in the spring or early summer as a preparation for subsequent frequent cultivation to prevent top growth. Often the best time for plowing is when the weeds are in flower because root reserves are low at that time. Repeated cultivation reduces the food materials stored in the roots, as indicated in Table 1.[3]

TABLE 1. PERCENTAGE OF CARBOHYDRATES IN ROOTS OF BINDWEED

CULTURAL TREATMENT	DEPTH OF ROOTS 0–12 *inches* (%)	12–24 *inches* (%)
Uncultivated	53.75	57.36
Cultivated every 3 weeks	30.89	34.83
Cultivated every 2 weeks	27.45	27.41
Cultivated weekly	27.32	28.32

Allowance of some top growth for 6 to 8 days after the shoots emerge before starting cultivation aids in bindweed eradication.[15] Cultivations every 2 weeks at a depth of 3 inches throughout the growing season are desirable.[3, 5, 21] While there is little advantage to be gained from more frequent and deeper cultivation, failure to cultivate at the proper time will prolong the eradication period.[17] Clean cultivation for 2 years involving 20 to 25 cultivations is generally required for complete eradication of bindweed. Low-priced land scarcely justifies the expense involved in this practice.

The duckfoot cultivator with sweeps or shovels that overlap 3 to 4 inches has been used extensively for clean cultivation but a straight blade set at right angles to the direction of cultivation may be a more efficient implement.[24] Such a blade, sharpened on one edge, may be bolted on a cultivator with the front edge dipped slightly. The shovel-type cultivator, disk harrow, and spring-tooth harrow are generally ineffective as clean cultivation implements. A possible exception is the use of the spring-tooth harrow for quackgrass control.

A combination of clean cultivation and smother crops may either weaken or eliminate perennial weeds. Land clean cultivated until about July 1, followed by a smother crop of sorghum or Sudan grass, and repeated for several successive seasons has resulted in almost complete control of bindweed. Winter rye and winter wheat have been used as smother crops in some regions, with the land clean cultivated between harvest and seeding. A smother crop is most effective when it follows a full season of clean cultivation.

Pasturing land with sheep sometimes is an effective method of controlling certain weeds. Sheep are able to suppress field bindweed on land seeded to Sudan grass for pasture. They eat the bindweed in preference to the Sudan grass but they make good gains on the latter after eating down the weeds.

FLAMING

Railroad companies have suppressed weeds extensively along the right of way by burning with oil burners. Annual weeds are killed when the flame merely sears or wilts the plants without burning. The leaves of small weeds in the row can be killed by a quickly-passing flame that does not injure the larger thicker-walled stalks of crop plants. A flaming implement has been used to kill weeds in a cotton field.[19] The flaming is started a month after planting when the cotton plants are large enough, i.e., with a stem diameter of $^{3}/_{16}$ inch or more, to escape injury from the flame. The weeds are held in check during the first month by cultivation and hoeing, but thereafter may be controlled satisfactorily by flaming without injury to the cotton. Flaming machines and methods of using them are undergoing rapid development, and offer promise of largely eliminating the hand hoeing and possibly much of the cultivation in the growing of sugarcane, cotton, and probably other row crops. Several hundred flaming machines were in use in the south by 1945.

CHEMICAL CONTROL

In recent years, the control of perennial weeds through the use of chemical herbicides has expanded remarkably. The ideal herbicide is one that is nonpoisonous, easily applied, effective in the control of various species at a minimum expense, and without permanent injury to the soil. Previous to 1945 complete chemical eradication of weeds was advisable only on small areas or those inaccessible to cultural implements. The most effective chlorate treatments cost 4 to 8 times more than the better tillage treatments.[23] Among the most widely used herbicides for controlling perennial weeds, are 2,4–D, sodium chlorate, common salt, arsenicals, carbon disulfide, and ammonium sulfamate.

2,4–D. This chemical, 2,4-dichlorophenoxyacetic acid, kills many species of broad-leaved weeds in concentrations of the pure chemical of as low as 0.1 per cent to 0.2 per cent in a water solution or emulsion. About ¼ to 2 pounds of the 2,4–D acid per acre kills most broad-leaved annual weeds. It is effective also against many biennial broad-leaved weeds, and at these low applications usually does not hurt most grasses appreciably.[18] Spraying small grain fields with ¼ to ¾ pound per acre when the plants are 5 to 6 inches high, kills mustard and other annual weeds with only slight injury to the crop. Corn may be sprayed with ½ to ¾ pound per acre after it is 8 inches high and before tasseling, with little injury. Two sprayings will kill most of the weeds such as ragweed, cocklebur, wild mustard, and pigweed without cultivation. Black nightshade, buffalo bur, corn cockle, cow cockle, purslane, and weedy grasses are resistant to 2,4–D. When 2,4–D is sprayed at a rate of 2 pounds per acre on the soil immediately after large-seeded crops such as corn and soybeans are planted it kills most of the emerging weed seedlings including those of grasses. The larger crop plant seedlings which have germinated at lower depths come up through the treated soil. Such pre-emergence treatment controls the weeds for a time without cultivation or additional spraying, but is successful only on well-prepared soil with few clods or stones. Occasionally corn is injured by this treatment.

The effect of 2,4–D on certain noxious perennial weeds is promising. It seldom kills such weeds completely in one spraying, but the damage may be sufficient to prevent their injuring the current crop or going to seed. Furthermore, the weeds may be so retarded that additional sprayings or supplementary smother crop control practices may be effective. The 2,4–D appears to be ineffective against Russian knapweed and it does not prevent recovery of Canada thistle. Whitetop is damaged by 2,4–D applied in early spring, on warm days (if any). Leafy spurge may be severely damaged but only by heavy applications of 3 to 5 pounds per acre. Nutgrass (Figure 83) has been greatly retarded with 2,4–D. Field bindweed can be killed with 2,4–D in humid regions where the roots are shallow. In deep-soil semiarid regions, 2,4–D is helpful in control when preceded by a period of cultivation, followed by spraying the emerged shoots, and followed in turn by seeding a close-drilled crop.

FIG. 83. Nutgrass (*Cyperus rotundus*).

The use of 2,4–D to control pasture weeds has some limitations because it damages or destroys most legumes. White clover, however, usually survives moderate 2,4–D sprays. Horsenettle and milkweed are not killed by 2,4–D sprays. The 2,4–D is not poisonous to livestock. Sold under many trade names and in different dilutions, 2,4–D has been used widely for killing dandelions, plantains, docks, wild onion, and other weeds in lawns. It is highly toxic to most garden flowers and vegetables and many ornamental trees and shrubs. It kills wild honeysuckle and some weedy vines but does little damage to wild blackberries.

Three kinds of 2,4–D are on the market: the sodium salt, the amine salt, and the ester. The sodium salt is the least expensive, but the least active. The ester is the most expensive but it is active and less is required per acre. The amine salt is intermediate between these two in weed killing power, but it is the least volatile and thus less damaging to nearby plants. Recommended rates are based upon the content of pure 2,4-D acid in these compounds. These chemicals are cleaned out of a sprayer with difficulty.

Formerly 75 to 200 gallons of spray seemed necessary to cover an acre of crop plants adequately. However, with the distribution obtainable with recently developed field-sprayers, small-orifice nozzles, 1½ to 10 gallons per acre are sufficient. When applied as an aerosol with good airplane sprayer, satisfactory coverage with 2,4-D can be obtained with even smaller quantities of liquid. Dusts containing 2,4-D are effective against weeds but are hazardous to nearby sensitive crops because of the drifting of the dusts, especially when distributed from an airplane. Application of 2,4-D dusts from an airplane is now prohibited.

Sodium Chlorate. Sodium chlorate is highly effective against nearly all weeds. Plant tissues are killed whenever chlorate ions come in contact with them in sufficient concentration. At least 2 years are required for complete eradication of difficult noxious perennials with sodium chlorate. The soil will be rendered more or less unproductive for one or more additional years.

Sodium chlorate should be applied from July to November at the rate of 3 to 6 pounds per square rod. The larger amounts are required on fertile soil. Large vigorous roots are harder to kill than small ones. The entire amount should be applied in a single application,[24] and the spots that are missed, or where new growth appears, should be treated later. The dry chemical is applied to the soil broadcast by hand or with a mechanical spreader. A grain drill should not be used because of damage to the machine. The soil should be moist at the time of application. The chlorate is absorbed by the roots after it enters the soil solution. The dry treatment sometimes is slightly less effective than the spray treatment in control of bindweed, probably due to less thorough coverage.[2, 15]

Sodium chlorate applied as a spray to the foliage is absorbed by the leaves and translocated down to the roots through the xylem.[7] The chemical is dissolved in water at the rate of 1 to 3 pounds per gallon, the concentration being immaterial so long as the proper amount is applied per unit of area. The best control of bindweed is obtained when the plants are sprayed after the full bloom period.[16] The plants usually are sprayed in July or later, further applications being made as often as regrowth makes them necessary. Some type of pressure sprayer is required. Plant growth should be undisturbed before and after treatment. Good weed kills follow spray treatments made when there is sufficient humidity to produce dew at night.[1]

Sodium chlorate applied as a spray presents a serious fire hazard. After being impregnated with chlorate, dried organic materials become highly combustible. The operator is advised to wear rubber boots and to wash clothes that come in contact with the spray solution. The chemical should be kept in metal containers, mixed in the open, and never applied close to wooden structures. Commercial products that combine with sodium chlorate to reduce the fire hazard also reduce the effectiveness of the chlorate. The only possible advantage of spraying is uniform application. Labor, safety and equipment costs favor the dry treatment. It can be applied uniformly in the dry state. Sodium chlorate has been used [24] to control bindweed, Canada thistle, Russian Knapweed, whiteweed, perennial sowthistle, quackgrass, blue lettuce, and poverty weed. The effectiveness of the treatments increases as the plants approach maturity. Two or three spray applications control Johnson grass when the rate of application is 100 gallons per acre with 1 pound of sodium chlorate in each gallon.[11] The spray should be applied to the second growth when it is 12 to 18 inches high. Bindweed is eradicated by chlorates more effectively than is Canada thistle or perennial sowthistle.[23] Whiteweed is resistant to chemical herbicides but in Idaho has been killed with 6 pounds of sodium chlorate per square rod applied in October, and by two spray applications made at 10-day intervals at the bloom stage, the same total amount of chemical being used.[14] Additional treatments have been required in other states.

Barley and sunflowers are very sensitive to sodium chlorate applied to the soil, while flax and oats are among the most tolerant crops. Wheat, followed by rye, are next to oats in degree of tolerance. Soybeans are resistant in the early stages but invariably became susceptible later to a marked degree.[13] Tolerant crops should be planted on treated soil.

Common Salt. Common salt (sodium chloride), applied at the rate of 1 pound per square foot, or 20 to 25 tons per acre, will kill all vegetation including noxious weeds. It can be applied dry or wet. Applications of salt to western soils renders them unproductive for an indefinite period. One salted area in Kansas was barren after 17 years,[26] but such lands will return to production in a relatively shorter time with cultivation and addition of manure. Heavy rains or irrigations tend to leach the salt from the soil. The use of salt is limited to small areas where no vegetation is desired, as around fences and barns.

Arsenicals. Sodium arsenite has had some use as a herbicide, and many commercial weed killers are composed at least partly of this compound. It is available in solution form that contains the equivalent of about 4 pounds of arsenic trioxide per gallon. Sodium arsenite can also be obtained as a white powder that contains about 80 per cent sodium trioxide. The equivalent of 4 pounds of arsenic trioxide per square rod will sterilize the soil for several years, but it may not greatly affect deep-rooted perennials. Arsenicals are very poisonous to animal life and thus are not generally recommended. However, they are widely used along railroad tracks and on driveways and factory yards.

The acid-arsenical method was developed in California.[6, 8] The stock solution, an arsenical compound, is added to 200 parts of water in a spray tank, and this is stirred slowly while five parts of concentrated sulfuric acid are added. The spray should be applied to plants that are mature but still carrying considerable foliage, when the humidity is high and the soil is dry. The acid-arsenical method has been most successful in the control of Russian knapweed, intermediate on bindweed, and a complete failure on whiteweed.

Carbon Disulfide. Carbon disulfide, a highly explosive, volatile liquid, has been used with considerable success in eradicating bindweed and whiteweed on high-priced land where a residual effect on the soil is not permissible.[14] It is poured into holes in the soil where it volatilizes and spreads laterally to kill the root. The penetration is faster at high temperature and in dry soil. A special applicator[2] is used to place 2 ounces of the chemical 6 to 8 inches deep. The holes are made about 18 inches apart and the openings are closed with soil to prevent evaporation into the air. Since carbon disulfide is effective only under certain soil conditions and is expensive, the method is practical only on small areas.

Tetrachlorethane. Tetrachlorethane applied by the same method and at the same rate as carbon disulfide will kill field bindweed, and the toxicity in the soil disappears by the spring following a late fall application. Its cost is about the same as that of carbon disulfide.

Ammonium Sulfamate. Ammonium sulfamate kills many weeds, and is especially effective on poison ivy and certain weedy shrubs. It is used in a concentration of 12 to 16 ounces to a gallon of water. On field bindweed, it has not been so effective as sodium chlorate.

Sinox. Sodium dinitro-ortho-cresylate (proprietary name Sinox) has been used for controlling broad-leaved annual weeds in cereals, flax, onions, alfalfa, and field peas, and in roadsides and pastures. It is applied with a field sprayer or airplane.[17, 25] About 1 gallon or more of Sinox per acre is used for mustard and similar weeds, applied in 15 gallons of water with a sprayer.

Another proprietary compound, Dow selective weed killer, the ammonium salt of dinitro-ortho secondary butyl-phenol is used for purposes similar to those described for Sinox.

Other Herbicides. Borax can be used to replace sodium chlorate as a herbicide, but 1,000 to 2,000 pounds per acre are required for good weed control. It is more effective against leafy spurge than is sodium chlorate.

Sulfuric acid, also a top-killer, has been used to kill weeds in small grain fields.[4]

Ammonium thiocyanate applied at the rate of 10 pounds per square rod sterilizes the soil for about 4 months.[12] Later, it serves as a fertilizer. It shows promise for controlling certain weeds, but it may stimulate subsequent weed growth because of its fertilizer value.

Description of Some Serious Noxious Weeds

The most serious noxious weeds in the country probably are quackgrass, Canada thistle, bindweed, leafy spurge, whiteweed (white top), perennial sowthistle, Johnson grass, Russian knapweed, and nutgrass. These species, serious weed pests in several states, are found in cultivated fields, pastures, and meadows.[24]

FIELD BINDWEED (*Convolvulus arvensis*)

This plant, a member of the morning-glory family, is a perennial that propagates by seeds and by lateral creeping roots from which rhizomes and then new stems and roots arise. The roots may grow 1 inch a day and penetrate to a depth of 12 to 20 feet or even more. The lateral roots, which can spread several feet in a year, often are found mostly at a depth of 12 to 30 inches. The stems are smooth, slender, slightly-angled vines that spread over the ground or twine around and climb any erect crop plant (Figure 84). The vines may be 1 to 6 feet in length. The leaves are 1 to 2 inches long, more or less arrow-shaped, round-pointed at the tip, and with pointed or blunt lobes at the base. The flowers are bell-shaped, white or pink, and ¾ inch to 1 inch broad. The fruits are small round capsules and normally 4-seeded. The seeds are usually dark brown, rough, and somewhat pear-shaped but usually flattened on two sides with a third convex side. The seeds may remain in the ground for several years and then germinate and produce new seedlings.

Field or European bindweed is distributed throughout the United States. It is a serious pest in Iowa, South Dakota, Minnesota, Nebraska, Kansas, Colorado, Utah, Idaho, Washington, and California.

WHITEWEED (*Lepidium draba*)

Whiteweed, a member of the *Cruciferae* or mustard family, is also known as perennial peppergrass, hoary cress, and whitetop. Whiteweed is a perennial that propagates both by seed and creeping roots. The plant is erect, 10 to 18 inches high, and grayish white in color. The leaves are oval or oblong, with toothed or almost smooth margins, and ½ to 2 inches long with blunt ends. The flowers are numerous, white, and small. The seed pods are heart-shaped, and contain small reddish-brown seeds about the size of alfalfa seed. Two other species, very similar to *L. draba* and known by the same common names, are *L. repens* (or *L. draba* variety *repens*), and *Hymenophysa pubescens*.

Whiteweed makes a vigorous growth on the irrigated, alkaline soils of the west. It is a serious pest in the Rocky Mountain region

FIG. 84. Field bindweed (*Convolvulus arvensis*) climbing up barley and oat plants.

and on the Pacific coast. Whiteweed is very resistant to chemical eradication.

CANADA THISTLE (*Cirsium arvense*)

Canada thistle, classified in the compositae or thistle family, is a perennial that propagates both from seed and creeping roots (Figure 12). The stems are erect, hollow, smooth to slightly hairy, 1 to 4 feet tall, simple, and branched at the top. The leaves are set close on the stem, slightly clasping, typically green on both sides, sometimes white hairy beneath, deeply and irregularly cut into lobes tipped with sharp spines, or sometimes entire or nearly so. The typical thistle flowers occur in numerous heads about ½ inch broad and ¾ inch long, usually rose-purple, sometimes white, all flowers on a plant usually being either male or female. The seeds are tan, about ⅛ inch long, slightly flattened and curved, with a white downy tuft easily detached. Canada thistle is widely distributed in the northern half of the United States. A smooth-leaved type of Canada thistle that is more difficult to control is spreading rapidly in various sections.

RUSSIAN KNAPWEED (*Centaurea picris*)

Russian knapweed also belongs to the thistle family. It is a perennial that reproduces both by seeds and black creeping roots. The plant is erect, rather stiff, branched, and 1 to 3 feet high. The young stems are covered with soft gray hairs. The lower leaves are 1 to 2 inches long with toothed margins that become narrower, smaller, and with entire margins as they approach the top of the plant. The flowers are in heads, like thistles, about one-half inch in diameter, and lavender to whitish in color. The seeds are chalky white or grayish, oblong, small, and have a bristly tuft. Russian knapweed is generally distributed in the western states.

PERENNIAL SOWTHISTLE (*Sonchus arvensis*)

Perennial sowthistle, a member of the compositae family, spreads both by seeds and creeping roots. The stems are erect, smooth, 2 to 5 feet high, and unbranched except at the top. The leaves are light green, the lower ones being 6 to 12 inches long, deeply cut, with the side lobes pointing backwards; the upper leaves are smaller, clasping, with margins slightly toothed, and prickly (Figure 85). All parts are filled with a milky juice. The flower heads resemble those of the dandelion, being bright yellow and 1 to 2 inches broad. The seeds are small, brown, flattened, ridged, and crowned with a tuft of fine white hairs. This weed is found throughout northern United States.

LEAFY SPURGE (*Euphorbia virgata*)

Leafy spurge, a member of the Euphorbiaceae or spurge family, is a perennial that propagates by seeds and creeping roots. The plants are pale green, erect, 1 to 3 feet high, and unbranched except for flower clusters. The leaves are long and narrow with smooth margins (Figure 86). The flowers are small, greenish yellow, and occur in small umbrellalike clusters at the top of the stem. The

FIG. 85. Perennial sowthistle (*Sonchus arvensis*).

FIG. 86. Leafy spurge (*Euphorbia virgata*).

pods are 3-seeded, the seeds being light gray, smooth, and about twice as large as alfalfa seeds. The plant is characterized by a milky sap. It is rather widely scattered throughout the country.

QUACKGRASS (*Agropyron repens*)

Quackgrass is a perennial that propagates by seed as well as by long, jointed yellow rhizomes or rootstalks (Figure 87). This grass is erect, 1 to 3 feet high, with slender stems. The flat, narrow leaves are rough above but smooth beneath. The seed is borne in spikes 3 to 7 inches long.

Quackgrass is found throughout the northern half of the United

FIG. 87. Rhizomes of quackgrass (*Agropyron repens*) bearing shoots.

States. While it has forage value, quackgrass becomes a very bad weed because of its persistence. It is related to and resembles some of the native wheatgrasses which are valuable forage and pasture plants.

JOHNSON GRASS (*Sorghum halepensis*)

Johnson grass is a perennial that propagates by seeds and rootstocks. It is an erect plant, 5 to 6 feet tall. The stems are smooth, pithy, and stout. The leaves are 12 to 18 inches long, narrow, smooth, and flat. The inflorescence is a loose purplish panicle. It is closely related to sorghum and Sudan grass. Johnson grass is widespread throughout the southern states. The most economical control method is heavy pasturing or frequent mowing to starve the rootstocks followed by plowing and the planting of a clean cultivated crop.

NUTGRASS (*Cyperus rotundus*)

Nutgrass, also called coco grass, is a perennial sedge (but not a grass) that propagates by deepset rootstocks and by small tubers (*nuts*) borne on the rootstocks. The nuts are ¼ to ¾ an inch in diameter. Very little viable seed is produced. The culms are slender, 6 to 18 inches tall, and have the 3-sided structure typical of the sedges. The culms are leafless except for three or four involucral bracts at the summits. The flowers are borne in umbels (Figure 83. Nutgrass is widely distributed, especially from Virginia to Kansas and southward, and is one of the most serious weed pests in the south.

General Control Procedures

(1) Clean seed, clean cultivation to kill weeds while young, rotation of crops, including an intertilled crop and a sod crop, and mowing when necessary to prevent the weeds from going to seed. Some of the more common weeds controlled by such methods are:

Annuals: wild oats, pigeon grass, witch grass, canary grass, crab grass, barnyard grass, darnel, wild barley, mustards, lambsquarters, Frenchweed, pigweeds, smartweeds, Russian thistle, peppergrass, summer cypress, black medic, vetch, puncture vine, mallow, false flax, wild buckwheat, ragweeds, horseweed, bachelor's button, prickly lettuce, purslane, corn cockle, cowcockle, and sunflower.

Biennials: burdock, bull thistle, sweetclover, and wild carrot.

Perennials: dandelion, milkweeds, curled dock, sheep sorrel, wild rose, blue vervain, chicory and buckhorn plantain.

(2) Clean fallow, alternating with smother crops and clean tillage between cropping periods; herbicide application to small patches. Noxious perennials: field bindweed, leafy spurge, poverty weed, whitetop, sowthistle, quackgrass, horsetail, bracken fern, Russian knapweed, Johnson grass, nutgrass, and St. Johnswort.

(3) Spraying with Sinox, Dow Selective weed killer or 2,4-D in fields of small grain.

Annuals: mustards, pigweeds, lambsquarters.

(4) Mowing of pastures.

Annuals: sunflower, broomweed.

Perennials: sagebrush, rabbitbrush, buckbrush (*Symphoricarpos*).

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PART II CROPS OF THE GRASS FAMILY

12 INDIAN CORN OR MAIZE*

Economic Importance

Indian corn † or maize is the premier crop of the United States, occupying a fourth of the crop land.

Corn ranks with wheat, rice, and oats in the world production of cereal crops. More than one-half the total world crop of corn of approximately 5 billion bushels is grown in this country. Other important producing countries are Argentina, China, Brazil, Rumania, Yugoslavia, U.S.S.R., Italy, Hungary, Manchuria, India, and Union of South Africa. Argentina is the largest exporting country. Locally maize is a highly important food plant in Mexico, Central America, and most of South America.

In the United States, from 1937 to 1946, the average area harvested was 90 million acres, the production 2,840,000,000 bushels, and the yield was 31.5 bushels per acre. Production exceeded 3 billion bushels in 4 of the last 5 years of this period, and the acre yield was more than 32 bushels in each of the years from 1942 to 1946. The value of the 1944 corn crop was about 3½ billion dollars. The leading states in corn production are Iowa, Illinois, Indiana, Minnesota, Ohio, Nebraska, Missouri, and Wisconsin (Figure 88). About 60 per cent of the acreage and 75 per cent of the total pro-

* For more complete discussions of corn, see H. A. Wallace and E. N. Bressman, *Corn and Corn Growing*, 4th ed., John Wiley and Sons, Inc., New York, 1937, pp. 1–436; and J. Burtt-Davy, *Maize—Its History, Cultivation, Handling and Uses*, Longmans, Green and Co., New York, 1914.

† The word corn merely means grain to the British, Germans, and many other nationalities, and often is used to designate the predominant grain in a country or section. The name corn usually refers to wheat in England, oats in Scotland, barley in North Africa, grain sorghum locally in southern California, broomcorn in the vicinity of Lindsay, Oklahoma, but to maize in most of the United States.

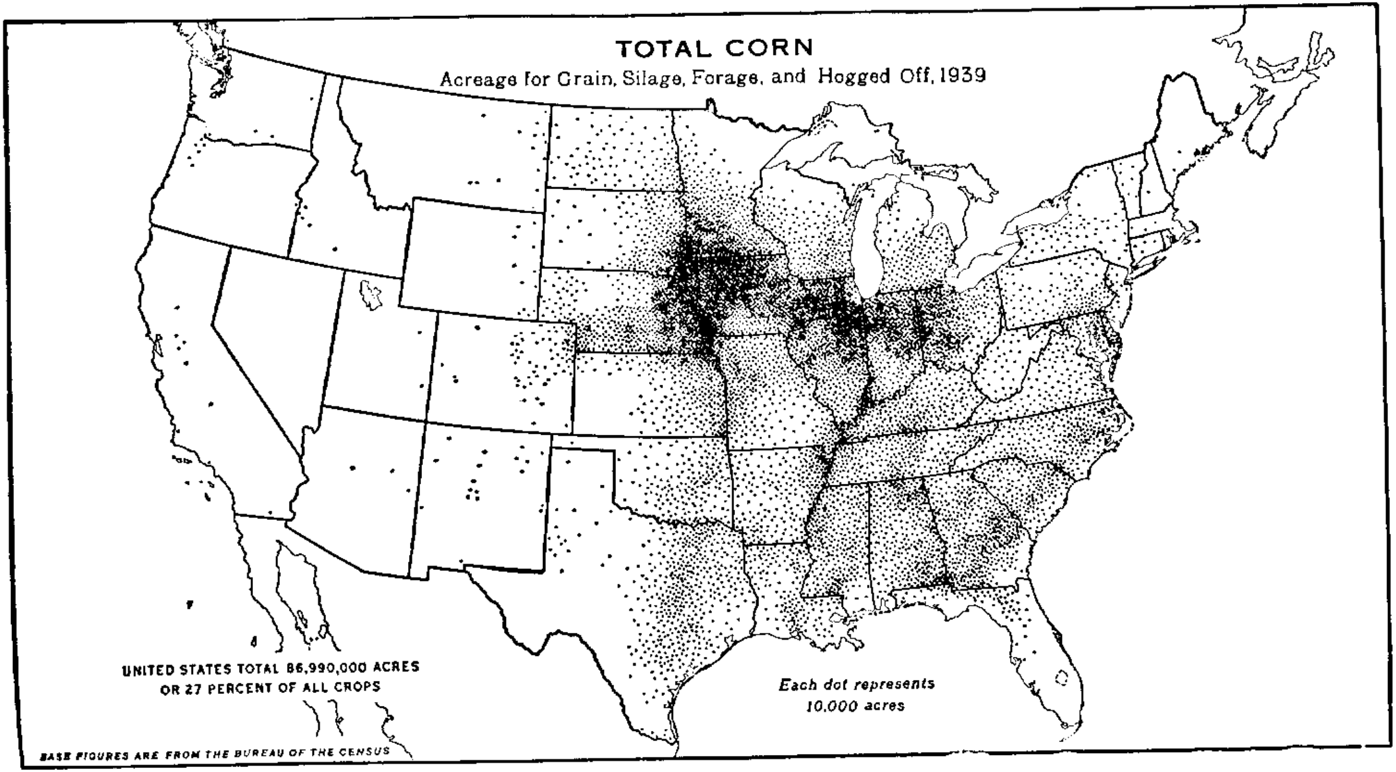

FIG. 88. Distribution of corn in the United States.

duction is in the corn belt states. Corn is grown in every state in the Union, and in 1946 only six states failed to produce more than a million bushels. Corn is grown on about 4 million farms, or approximately two-thirds of all farms in the United States. Iowa produces more than one-sixth of the crop. The production in Iowa alone exceeds that of any foreign country. The Iowa corn crop of more than 660 million bushels in 1946 would fill a crib 5 feet wide, 6 feet deep, and about 10,000 miles long.

Corn supplies three-fourths of the nutrients derived from feed grain and 90 per cent of that from silage fed in the United States. The processing of corn furnishes some 3 million tons of human food, 60 million gallons of beverage alcohol, and many industrial products.

The popcorn crop supplies 50,000 tons of food. The commercial production of popcorn increased from an average of 77 thousand acres from 1935–1943 up to 300,000 acres in 1945. The average yield of popcorn exceeds 1300 pounds of dry ears per acre. Iowa, Illinois, Indiana, Ohio, Nebraska, Oklahoma, Texas, and Kansas lead in the production of popcorn (Figure 100). Before 1930 most of the commercial popcorn was produced in two counties in western Iowa and one county in central Nebraska.

An average of about 400,000 acres of sweet corn for canning and freezing was grown from 1936 to 1945. The average yield was about 2.3 tons of fresh ears per acre. The leading states in the production of canned corn are Minnesota, Illinois, Wisconsin, Indiana, Iowa, and Maryland. About 3 to 6 pounds of canned corn per capita is packed each year. The sweet corn crop provides 300,000 tons or more of canned and frozen corn. Perhaps 1 to 2 billion *roasting ears* are gathered from the fields and gardens each year. Yields average 5000 marketable ears per acre.

Origin and History

Maize (*Zea mays*) is perhaps the most completely domesticated of all field crops. Its perpetuation for centuries has depended wholly upon the care of man. It cannot exist as a wild plant. Corn was seen by Columbus in Cuba on November 5, 1492, on his first voyage to America. The explorations of the sixteenth and seventeenth centuries showed that corn extended from Chile to the Great Lakes.[96] Fragmentary histories of the early migrations of the aboriginal tribes, and the evolution of the vocabulary related to maize, indicate a single origin, probably Mexico or Central America. Other more direct evidence suggests that maize originated in South America.

The closest botanical relatives of maize, *Euchlaena* (teosinte) (Figure 89), and *Tripsacum* (gamagrass), may have contributed

FIG. 89. Teosinte plant (A), ear (B) and seeds (C).

to modern types of maize. Many writers since 1875 have considered teosinte to be the progenitor of maize. Luther Burbank and others have claimed to have produced maize from teosinte by continuous selection for several years. More careful investigators have shown that the plants from which maize can be selected are in fact natural crosses of maize and teosinte, which are found frequently in Mexico and Central America.

Mangelsdorf and Reeves [58] visualized a wild pod corn (*Zea mays*) that originated on the South American continent from a remote *Andropogonaceous* ancestor and continued growing on as a wild plant until the Asiatic migrations brought man to America perhaps 25 thousand years ago. Man domesticated maize and finally carried it northward. Recently discovered maize remnants unearthed in ancient debris in a New Mexico bat cave indicate that early man developed the crop from a primitive, podded popcorn, with ears 2½ inches long, into a non-podded flint corn with 7-inch ears. This development occurred during some 3,000 years, beginning possibly about 2500 B.C. There is no evidence that these prehistoric maize specimens were derived from teosinte. Flour corn, dent corn and sweet corn apparently were produced later.

"This is not to say that the problem of the origin of maize has been solved; indeed problems of this nature are seldom susceptible to a complete and final solution. The most that can be expected is that certain important facts will become established beyond a reasonable doubt." [59] A recent proposal is that maize originated in Asia from a cross between two grass species, but there seems to be no authentic evidence of the existence of maize in Asia before the pre-Columbian era, and no traces of it were left behind.

Adaptation

Maize has a remarkable diversity of vegetative type, with the result that sorts adapted to a wide range of environmental conditions are in cultivation. From 58° north latitude in Canada, the culture of maize passes without interruption through the tropical regions and on to the frontier of agriculture in the southern hemisphere (35° to 40° south latitude). It is grown from sea level to 10,000-foot altitudes. Some small early sorts only 2 feet tall and bearing eight to nine leaves are able to mature grain in 50 days, while others with 42 to 44 leaves and growing 20 feet tall require as many as 330 days to come to maturity. This shows how corn has been modified to meet the conditions of many environments. The phenomenon has been well described by Jenkins[34] who states:

> "The greatest plant-breeding job in the world was done by the American Indians. Out of a wild plant, not even known today, they developed types of corn adapted to so wide a range of climates that this plant is now more extensively distributed over the earth than any other cereal crop. Modern breeders are carrying on this work and making important discoveries of their own."

In the United States, corn varieties grown in the northern states are 3 to 8 feet tall, mature in 90 to 120 days, and may develop several tillers. In the central and southern corn belt, the varieties may grow 8 to 10 feet tall, mature in 130 to 150 days and usually have few, if any, tillers. Occasional fields of tall corn, up to 17 feet, are difficult to harvest. Varieties in the south Atlantic and Gulf states may grow to a height of 10 to 12 feet on fertile soils and require 170 to 190 days to reach maturity. They often tiller profusely and produce two or more ears per stalk.

The region of greatest production of corn in the United States has a mean summer temperature of 70° to 80° F., a mean night temperature exceeding 58° F., and a frost-free season of over 140 days.[34] An average June–July–August temperature of 68° F. to 72° F. seems to be most favorable for maximum yields. Corn flowers and ripens more quickly at 80° F. Very little corn is grown where the mean summer temperature is less than 66° F., or the average night temperature below 55° F. The minimum temperature for the germination and growth of corn is 50° F. or slightly below. Corn plants will withstand a light freeze in the seedling stage up to the time when they are 6 inches tall. Thereafter, a light freeze will kill the plants except those of certain hardy strains. Prolonged low temperatures below 45° F. but above freezing will kill many strains of corn. Corn is grown extensively in hot climates, but yields are reduced where the mean summer temperatures are above about 80° F.

The annual precipitation where corn is grown ranges from 10 inches in the semiarid plains of Russia to more than 200 inches in the tropics of India. In the United States, the best corn regions have an annual precipitation of 24 to 40 inches, except where the crop is irrigated. General corn production is limited to sections having an annual precipitation of 15 inches or more, and a summer (June to August) precipitation of 8 inches or more. A heavier precipitation is required in southern latitudes and low altitudes. Some corn is grown at high altitudes where the summer precipitation is less than 6 inches. Indians of New Mexico and Arizona grow corn where the annual precipitation does not exceed 8 inches by planting in widely-spaced hills in dry sandy washes that receive extra water whenever a rain is heavy enough to cause runoff.

The corn plant utilizes about one-half its seasonal intake of water during the 5 weeks following attainment of its maximum leaf area, which is at about the tasseling stage.[40]

Corn is a short day plant, i.e., flowering is hastened and vegetative growth retarded by a short length of day. Long days increase the leaf number, plant size, and length of growing period of corn. Northern varieties moved southward where the days are shorter mature quickly with a reduced plant growth. Southern varieties moved to the north make a large vegetative growth but do not reach the silking stage until the short days of autumn. A variety becomes progressively one day earlier or later for about every 10 miles it is moved southward or northward, respectively, where the altitude is the same. The varieties that succeed best in any region are those fitted to the particular length of day. Quick-maturing varieties are grown in the north. Progressively longer-season varieties are grown to the southward.

Adapted types from 43 states, when grown in Nebraska, showed wide variations in vegetative characters. In maturity, the extreme variation was 155 days for Mexican June from New Mexico, to 96 days for Northwestern Dent from North Dakota. There was a marked transition from large late types to small early types from south to north across the country. This was associated with a progressively shortened frost-free season and increased maximum length of day from south to north.[41, 44] The number of leaves on the main stalk is the most reliable measure of the length of season

Botanical Characteristics

Maize (*Zea mays*) is a coarse annual grass, classified in the tribe Maydeae which has separate staminate and pistillate inflorescences.[36] Among other members of the Maydeae tribe, teosinte (*Euchlaena mexicana*), a native of Mexico, is an annual rank-growing grass grown in the southeastern part of the United States as a forage crop.[58] A perennial species of this genus (*E. perennis*) also is known. Gamagrass (*Tripsacum dactyloides*) is distributed over eastern and southern United States and is a useful pasture and meadow grass. Other species of Tripsacum occur in Mexico and Central America. Teosinte and gamagrass spikes break up into sections upon threshing with a seed enclosed in the thick hulls of each section. Job's tears (*Coix lachryma-jobi*), from southern Asia is grown in the United States as an ornamental. The fruits are used as beads. Thin-hulled strains have been grown in the Philippine Islands and South America as a cereal under the name of adlay.

VEGETATIVE CHARACTERS

Culms or Stalks. The culm or stalk of maize ranges in length from 2 to 25 feet and in diameter from one-half inch to 2 inches in different regional types. The internodes are straight and nearly cylindrical in the upper part of the plant, but alternately grooved on the lower part. A bud occurs at the base of each internode except the terminal one, usually in the groove. When the buds develop, they produce ear shoots. Buds below the soil surface develop the tillers. The outside of the culm is protected by an epidermis that renders it fairly impervious to moisture. Inside the epidermis is the cortex and pericycle (rind) containing many vascular bundles. The stem inside the rind is filled with ground tissue (pith) in which vascular bundles are interspersed (see sugarcane stalk, Figure 11).

Tillers contribute to grain formation on the main stalk.[15] Removal of tillers often may injure the plant and reduce the yield.

Commercial strains and inbred lines of corn vary considerably in lodging. Lodged stalks are considered as those that break over or lean 30 degrees or more from the vertical. Most commercial corn hybrids are rather resistant to lodging. Increases in percentages of broken stalks occur when they are infected with diseases such as *Diplodia, Gibberella,* or *Cephalosporium,* or when starchy seed susceptible to scutellum rot is planted.[49] Corn has stood more erect when planted at the rate of two kernels per hill than when three kernels per hill were planted. Much of the lodging in corn is due to weak roots. Erect plants have about twice as large a root system as lodged plants.[22]

Corn stalks contain about 8 per cent of sugar before the grain is formed, and as much as 10.5 per cent sugar when pollination fails or is prevented.[88]

Leaves. The leaf consists of the blade, sheath and a collarlike ligule. The leaf blade tapers to a point at the tip and also tapers from the central midrib to the thin edges. At the base of the blade, the two edges extend to form two auricles. The sheath clasps the culm.

A typical leaf of a corn plant grown at Ithaca, N. Y.,[79] was about 80 cm. long, 9 to 10 cm. wide, with an average thickness of ¼ mm., and contained more than 140 million cells.

The structure of the leaf blade[79] is similar to that of the sugarcane leaf (Figure 9). The upper surface bears scattered hairs and has large stomata. The lower surface is free from hairs and has smaller but more numerous stomata. A cross section of the leaf shows both the upper and lower epidermis to consist of single layers of cells. Between the upper and lower epidermal layers are five or six layers of mesophyll cells, and within the mesophyll are occasional fibro-vascular bundles containing both the strengthening and conducting tissues of the leaf. At intervals along the upper epidermal layer are groups of large bulliform or hygroscopic cells. Whenever evaporation from the leaf appreciably exceeds the water intake, these bulliform cells shrink and the leaves roll up, thus reducing the surface area exposed to evaporation. When water becomes more abundant, the bulliform cells absorb water, swell, and flatten out the leaf blade again. In the sorghum leaf, in contrast, the bulliform cells are concentrated chiefly in large groups near the midrib, so the drying leaf usually folds up like butterfly wings instead of rolling.

The reduction in yield resulting from the loss of leaves during storms or otherwise becomes progressively less with advances in the development of the plant.[14]

Roots. The corn plant has three types of roots, viz., (1) seminal, (2) coronal or crown, and (3) brace, buttress or aerial roots. The *seminal* roots, usually 3 or 5, grow downward at the time of seed germination (Figure 45). Shortly after the plumule has emerged, the coronal roots form at the nodes of the stem, usually about 1 to 2 inches below the soil surface (Figure 50).

These coronal roots, which are ultimately 15 to 20 times as numerous as the seminal roots, develop at the first 7 or 8 nodes at the base of the stem. Brace roots arise from the nodes above ground, but their function is similar to that of the coronal roots after they enter the soil.

The usual spread of the main roots is approximately 3.5 feet in all directions from the stalk.[26, 97] The lateral spread is practically all attained by midseason when the plants are about 4 feet in height, the later-season growth being in depth. Although most of the lateral roots are found in the first and second feet of soil, some may extend downward as far as 7 to 9 feet. The seminal root system may live to maturity of the plant and penetrate 5 or 6 feet deep. The size of the root system increases with that of the top growth. Compared with a small type, a large type of corn may have a 50 per cent greater spread, 10 per cent deeper penetration, 65 per cent more functional main roots, 92 per cent greater combined length of main roots per plant, 311 per cent greater root weight, and 29 per cent larger diameter of main roots.[98] The rate of root growth as well as top growth is approximately the same for all types until the small varieties tassel. Thereafter, continued vegetative growth causes the medium and large types to surpass small early types. Similarly, as the medium types commence tasseling, their vegetative development is exceeded by that of the large type.

INFLORESCENCE

The corn plant is normally monoecious, i.e., the staminate and pistillate flowers are borne in separate inflorescences on the same plant. The staminate flowers are borne in the *tassel* at the top of the stalk, while the pistillate flowers are located in spikes which terminate lateral branches arising in the axils of lower leaves. The mature pistillate inflorescence is called the *ear*. Occasionally, off-type plants produce seed in the tassel.

The central axis of the staminate panicle is the continuation of the main vegetative stem. The branches of the panicle are spirally arranged around the axis. The spikelets are usually arranged in pairs, one sessile and the other pediceled.[96] Groups of three or four may be found occasionally. The spikelet is completely enclosed by two firm, more or less pubescent, ovate glumes. There are two florets per spikelet, the upper being the more advanced in development. Each floret contains three stamens, 2 lodicules, and a rudimentary pistil. Each anther produces about 2500 pollen grains or approximately 15,000 for a single spikelet. Thus a tassel containing 300 spikelets produces 4,500,000 pollen grains to fertilize the 500 to 1,000 silks produced on an ear.

The pistillate inflorescence, or ear, is a spike with a thickened axis (Figure 15). The pistillate spikelets are borne in pairs in several longitudinal rows.[57] This paired arrangement explains the customary even number of rows of grains on the ear. An occasional ear with an odd number of rows has lost one member of the pair. The individual spikelet is two-flowered, only one floret ordinarily being fertile. When the second flowers of the spikelet also are fertile, the crowding of the kernels destroys the appearance of rows. The result is an irregular distribution of kernels as seen in the Country Gentleman variety of sweet corn (Figure 90).

The two thick and fleshy glumes are too short to enclose the other

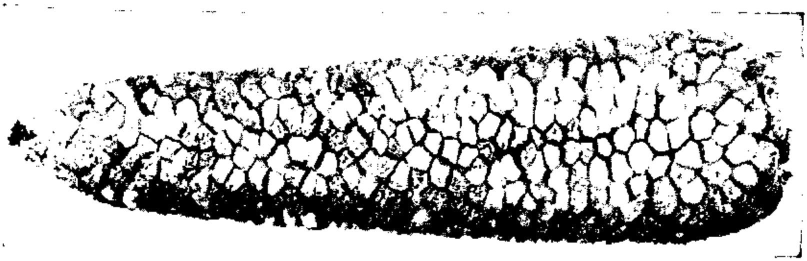

FIG. 90. Country Gentleman sweet corn showing irregularity of the rows of seed. Note several large smooth white-capped kernels that resulted from pollination with field corn.

parts of the spikelet. The lemma and palea, which together constitute the *chaff*, are thinner and shorter than the glumes. The single ovary in a fertile floret bears a long style or "silk" which is forked at the tip (Figure 15). The silk has a sticky stigmatic surface and is receptive to pollen for about two weeks and throughout its length (Figure 16). The remnant of the silk is evident on the crown of each mature kernel. The silks ordinarily are 4 to 12 inches in length. Unfertilized ears may produce silks 20 to 30 inches long.

POLLINATION

Corn is normally cross-pollinated,[41] being well adapted to wind pollination by bearing the male flowers at the top of the plant and the female flowers about midway up the stalk.

Cold wet weather retards the shedding of pollen, while hot dry conditions tend to hasten it. The emergence of the silks is delayed by drought. Protandry is the shedding of pollen before the appearance of the silks and protogyny is maturation of the stigmas first. Corn is somewhat protandrous, but pollen shedding and the receptivity of the silks overlap sufficiently to permit some self-pollination.

In the fertilization of the maize flower[63, 78] the pollen grain germinates and establishes a pollen tube within 5 to 10 minutes after it falls on the silk. The pollen tube enters the central core of a hair on the silk and passes down through the silk (Figure 17). The two sperm nuclei migrate into the pollen tube and pass down to the embryo sac. Fertilization is accomplished within 15 to 36 hours after pollination, the slower rates occurring at low temperatures and when the silks are long. One of the two sperm nuclei unites with the egg cell to produce the embryo, while the other unites with first one and then the other of the two polar nuclei of the embryo sac to give rise to the endosperm. The union of sperm nuclei with both the egg cell and the polar nuclei is called double fertilization. The endosperm often shows certain characteristics of the pollen parent because it develops directly from the endosperm nucleus after union with the male nucleus. The pericarp on the other hand, does not display characters derived from the pollen parent that season. Any effects are shown when a new plant develops the next season. The immediate effect of the pollen parent on the characteristics of the endosperm, embryo, or scutellum is called xenia (pronounced zēēn'ĭ ȧ). Xenia occurs when a sweet corn ear is pollinated with flint corn and the kernels are smooth and starchy instead of wrinkled and sugary. Also, when pollen from a plant with yellow endosperm fertilizes a plant with white endosperm, the kernels have a yellow endosperm because of the Mendelian dominance of yellow over white. When yellow corn is pollinated by a white corn, the kernels are yellow but are lighter in color and often white capped.

Pollen of dent on sweet corn silks may cause a 25 per cent increase in average kernel weight because of the formation of a starchy instead of a sugary endosperm [41] (Figure 90). The effect on kernel size is negligible when one commercial variety of dent corn is crossed on another.[42] However, hybrid kernels on pure line ears have increased as much as 11 per cent in weight.

The flowers near the middle of the ear develop the silks early, and usually are pollinated first. The flowers in the lower third of the ear develop at about the same time but because of their remote position take more time to extend the silks out of the husk. Those at the tip of the ear are last to develop. Under unfavorable conditions the earlier-pollinated kernels appear to take precedence over the others in food supplies, and the tips and butts of the ears are filled very poorly and bear smaller grains.

DEVELOPMENT OF THE CORN KERNEL

In the development of the corn kernel or caryopsis, the ovary wall grows by cell division and cell enlargement to form the pericarp of the kernel.[35, 78] The endosperm and the entire kernel grow rapidly in length and diameter during the period of 10 to 20 days after pollination. This is followed by a correspondingly rapid growth of the embryo during the period from 20 to 40 days after pollination. The embryo grows and differentiates until the various rudimentary structures of a new plant are apparent. The endosperm cells divide rapidly and nearly fill the space within the growing ovary wall within 18 days after pollination. The endosperm cells at first divide in all directions. Later, cell divisions occur largely

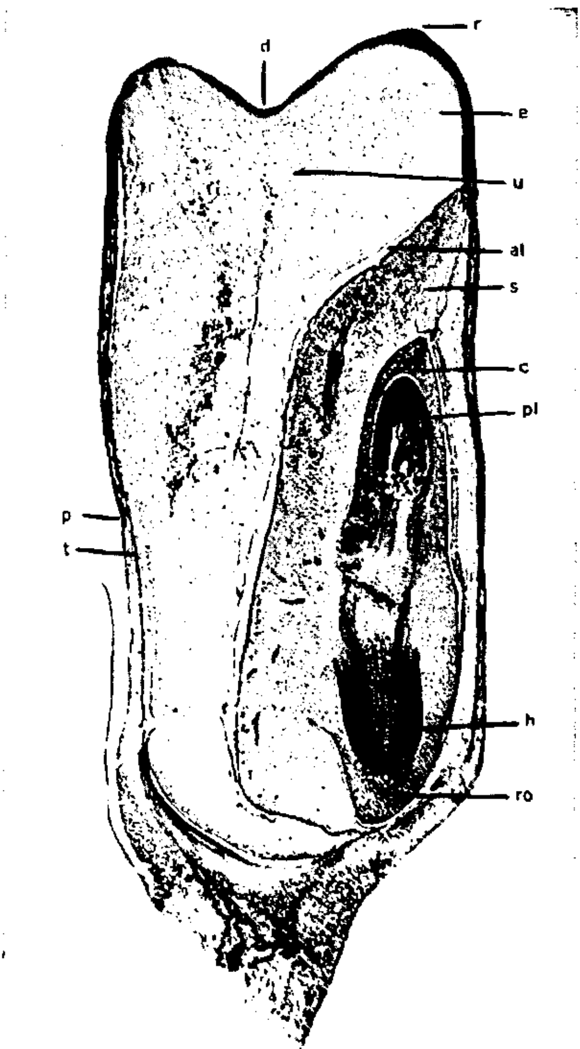

FIG. 91. Half of a nearly mature dent corn kernel showing the dent (d), remnant of style (r), endosperm (e), unfilled portion of immature endosperm (u), aleurone (al), scutellum (s), plumule (pl), hypocotyl and radicle (h), testa or true seed coat (t), and pericarp (p). The germ comprises the entire darker area to the right including the scutellum and the plumule and hypocotyl and other embryonic tissues, and including the coleoptile (c) the rootcap (ro).

around the periphery, and rows of cells are forced inward. Final endosperm growth is due chiefly to cell enlargement. The mature endosperm is 50 times as long and wide as it is in the initial stages of its observable formation.

The endosperm cells at first contain simple sugars but later the sugars are converted to starch.

The testa, or often-called nucellar layer, arises just inside the pericarp where the cells of the integuments and nucellus of the embryo sac have degenerated.

The kernel ceases growth about 45 days after pollination. The shape of the individual kernel is determined in part by the degree of crowding on the ear. Isolated grains and many of those at tip and butt usually are somewhat rounded. Grains in crowded rows on the ear are often angular in outline.

FIG. 92. Horny starch, soft (white) starch and germ of dent corn. A portion of the pedicel is shown at the base of the kernel at the upper right.

About 1,200 to 1,400 kernels of typical dent corn weigh one pound. The kernels usually range from ¼ to ⅜ inch wide, ⅛ to ¼ inch thick, and ⅜ to ⅝ inch deep. The kernels of Cuzco corn from Peru are about ⅝ inch wide.

The parts of the corn kernel as shown in Figures 91 and 92 include a pedicel or tip cap over the closing layer of the hilar orifice at the end of the kernel where it is attached to the cob.[28] The embryo (germ) lies near one face of the kernel. The outer rim of the embryo is the scutellum. The remainder of the kernel inside the testa is occupied by the endosperm. The outer layer of cells of the endosperm is the aleurone which comprises about 8 to 12 per cent of the kernel and is high in nitrogenous substances. The aleurone may be red or purple in certain varieties. In dent corn the endosperm may be partly corneous (horny) and partly soft or starchy white. The corneous portion may be a tenth to a fourth higher in protein. The germ, comprising about 11 per cent of the kernel, contains $\frac{5}{6}$ of the oil, $\frac{3}{4}$ of the ash, and $\frac{1}{5}$ of the protein in the kernel.

Outside of the aleurone is the testa or true seed coat, and this in turn is surrounded by the pericarp. The hull (pericarp and testa), comprising about 6 per cent of the kernel, is high in cellulose and hemicelluloses.

THE EAR

The normal ear contains 8 to 28 rows of grains, each regular row containing 20 to 70 grains. An occasional freak ear may have only four rows when other rows are aborted. Ears with 14, 16, 12, and 18 rows predominate among American varieties of dent corn. A large ear of corn may contain about 1,000 kernels, but ordinary good ears contain about 600.

The average well-dried ear of 50-bushel per acre corn belt corn weighs about 6 to 7 ounces and contains about 400 grains. About 9,000 to 9,500 such ears are produced by planting 3 seeds per hill in 3,556 hills, spaced 42 inches apart each way, or 10,668 seeds (8 pounds) per acre. The shelling percentage of dry well-filled ears averages about 80 to 85 per cent. In average dry corn, 70 pounds of ears yield 56 pounds (1 bushel) or 80 per cent of shelled corn. In volume, 70 pounds of ear corn occupy 1½ heaping bushel measures or nearly two level bushels.

Groups of Corn

Corn is often classified into seven groups or types, based largely upon endosperm and glume characteristics. These are dent, flint, flour, pop, sweet, waxy, and pod corns (Figure 93). The Latin names listed are presented because the different types sometimes have been regarded as distinct botanical subspecies. The use of botanical subspecies names is no longer valid in the light of our knowledge of corn heredity. The sweet, waxy, and pod types each differ from dent corn by only a single hereditary factor, and the

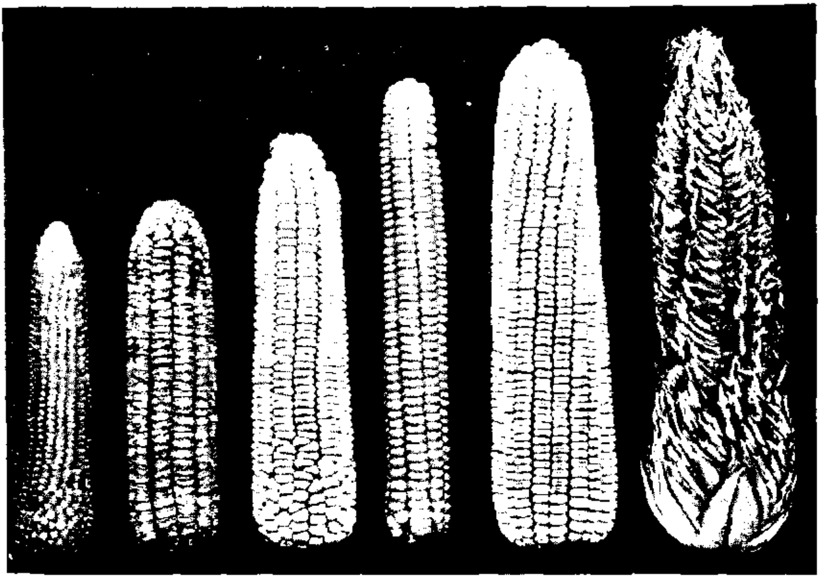

FIG. 93. Ears of (left to right) pop, sweet, flour, flint, dent and pod corn.

flint, flour, and pop types may differ by relatively few hereditary factors.

DENT CORN (*Zea mays indentata*)

Both corneous and soft starch are found in dent corn, the corneous starch being extended on the sides to the top of the kernels. When the grain dries, a pronounced wrinkle or dent forms on the top of the kernel because of the shrinkage of the soft starch. Dent corn is the most widely cultivated type, being by far the most important one in the United States and almost the only type in the corn belt. The kernels have a wide range of colors, but are yellow or white in most commercial varieties.

FLINT CORN (*Zea mays indurata*)

The endosperm of flint corn usually is soft and starchy in the center, but completely enclosed by a corneous outer layer. The kernels are usually rounded at the tip. Most flint corns grown in the northern part of this country have eight rows of kernels on the ear, and are early in maturity. They also are grown in sections where the season is short. The ears of the tropical flint corns of Louisiana and Florida usually have 12 or 14 rows of kernels.

FLOUR CORN (*Zea mays amylacea*)

Kernels of flour corn are composed almost entirely of soft starch. They are shaped like flint kernels because they shrink uniformly as they ripen. All colors exist, but white, blue, and variegated are the most common. Flour corns are grown by some of the American Indian tribes and by many growers in Central and South America. In the United States, the variegated flour types are usually called squaw corn.

POPCORN (*Zea mays everta*)

This group is characterized by a very hard corneous endosperm and small kernels. There are two subgroups of popcorn: rice, with pointed kernels, and pearl, with rounded kernels. The grains may differ greatly in color and size.

SWEET CORN (*Zea mays saccharata*)

The kernels of sweet corn are translucent and more or less wrinkled at maturity. Sweet corn, before it is ripe and dry, has a sweeter taste than other types because the endosperm contains sugar as well as starch. It lacks the ability to produce fully developed starch grains.

WAXY CORN

The kernels of waxy corn have a uniformly dull rather soft endosperm, showing neither white-starchy nor corneous-translucent layers. The endosperm breaks with a waxlike fracture. The starch in waxy corn consists of amylopectin, which has a branched-chain molecular structure and a high molecular weight (50,000 to 1,000,000). The starch, which resembles tapioca starch, is used for making special adhesives. The endosperm starch and also the pollen of waxy corn ar · stained red by an iodine-potassium iodide solution. Starch of ordinary corn, which stains blue in the iodine test, consists of about 78 per cent amylopectin and 22 per cent amylose. The latter substance has a straight-chain molecular structure and a molecular weight of 10,000 to 60,000.[24]

POD CORN (*Zea mays tunicata*)

In pod corn, each kernel is enclosed in a pod or husk. The ear formed is also enclosed in husks as in other types. Pod corn may be dent, sweet, waxy, pop, flint, or flour corn in endosperm characteristics. It is merely a curiosity and is not grown commercially.

The typical present-day podded ear as described never breeds true. When planted, half the crop is pod corn, a fourth is normal without pods, and the remaining fourth are long-podded ears containing no grain but a few seeds may develop in the tassel. Thus, pod corn is genetically a heterozygous plant, the progeny of which segregates in a typical 1:2:1 Mendelian ratio with the podded character dominant. Pod corn formerly was regarded as the primitive type of corn from which other types arose.

Open-pollinated Varieties

An unknown number in excess of 1,000 varieties of corn were grown in the United States before the recent spread of corn hybrids. They originated through hybridization, segregation, and selection, either natural or controlled. Many are now about to disappear.

Varietal names of corn mean less than those of almost any other crop. All are heterozygous. Selection and local adaptation have produced numerous strains and types within varieties. Frequently there are larger differences among strains within varieties than between the varieties. Two strains of Boone County White differed in yield 18 bushels per acre in one comparison in Iowa.[30] Two strains of Reid Yellow Dent were compared at Lincoln, Nebraska, one adapted at Lincoln and the other to conditions 100 miles farther north. The northern strain matured 7 days earlier, the plants were 12 inches shorter, the stalks averaged 118 grams lower in weight, and the yield of shelled corn per acre was 15.4 bushels less.[41] Ordinarily, locally adapted strains, regardless of variety name, will produce the highest yields. In contrast, a given corn hybrid should have the same yielding capacity regardless of where the seed is grown, if it is sound.

A list of varieties recommended for different states is given by Jenkins.[32] In general the prolific varieties that produce more than one ear per stalk have been grown in the southern states, among them being Cocke Prolific, Douthit Prolific, Mosby Prolific, Hastings Prolific, Whatley Prolific, Garrick Prolific, Thompson Prolific, and Neal Paymaster. These are all white corn varieties. A yellow variety, Jarvis Golden Prolific, is grown to some extent. A Creole Yellow Flint variety is grown in Louisiana, and a Cuban Yellow Flint variety is grown in Florida.

From Virginia westward to the Mississippi Valley, Boone County White, Johnson County White and Reid Yellow Dent were recommended. In the latitude of Pennsylvania the yellow varieties, Lancaster Surecrop, Clarage, Leaming, and Reid Yellow Dent have been popular varieties. In the northeast, King Phillip Flint (red pericarp) and the yellow varieties, Longfellow Flint, Golden Glow, Cornell 11, and West Branch Sweepstakes were recommended.

The varieties of the Great Lakes region include Golden Glow (yellow), King Phillip Flint (yellow), Longfellow Flint (yellow), Minnesota 13, and Northwestern Dent. The latter variety is mostly red-kernelled. Reid Yellow Dent and Krug (yellow), Johnson County White and Silver King (white), and the yellow dents, Clarage and Leaming, are among the well-known varieties of the main corn belt. St. Charles White has been recommended in Missouri, Arkansas, and Kentucky. From Arkansas and Mississippi westward to Arizona, a white variety called Mexican June and a similar strain called Laguna have been widely grown. This large-stalked corn is adapted to late planting in June, and it appears to withstand heat and drought much better than do the typical corn belt varieties. Other popular varieties in Texas and Oklahoma included Surcropper (white), and Ferguson Yellow Dent. Midland Yellow Dent and Pride of Saline (white) thrive in eastern Kansas and some adjacent areas. Hays Golden (yellow) is popular in western Kansas and Oklahoma. Under the short-season conditions of northern Minnesota, North Dakota, Montana, Wyoming, and Utah, quick-maturing varieties are needed. These include Minnesota 13 (yellow), Falconer Semi-Dent (yellow), Northwestern Dent (red mixture), Gehu Yellow Flint, Dakota White Flint, Rustler White Dent, and Minnesota 23 (white-cap yellow). California formerly produced one variety, called King Phillip Hybrid, on most of the acreage of the state. This is an open-pollinated variety, with reddish-yellow flinty kernels.

The Indian tribes maintained their own strains of corn, to a large degree, for many decades. Their chief problem has been elimination of contamination by unadapted varieties brought in by well-wishing white men from their own home communities. Many of the Indian varieties are a colorful mixture of red, purple, yellow, and white kernels, mostly of the flint and flour types.[5] Such mixing helps to avoid the deleterious effects of inbreeding.

A characteristic of varieties grown in the south is a long husk on the ear. Long husks partly protect the ears from the corn earworm, weevils, moths and birds.

Corn Hybrids

State agricultural experiment stations, the United States Department of Agriculture, and a considerable number of commercial firms are engaged in the development of new corn hybrids.[9] Probably several hundred different corn hybrids are being grown on a commercial scale. These are being produced from a large number of inbred lines. However, certain outstanding lines enter into the pedigrees of a large percentage of the hybrids that have gone into production. Among the more popular inbred lines are those designated as WF9, 38–11, Hy, R4, L317, L289, Kys, 187–2, A, Os420, Os426, C11, C14, Cornell 11, I205, CC4, CC8, CC1, Tr, 90, 540, and Pr. These inbred lines were selected largely from some of the most productive open-pollinated varieties. Many of the varieties that contributed these lines had been carefully selected for many years. Many good lines came from Reid Yellow Dent and its derivatives, Black, and Osterland. Leaming, Lancaster Surecrop, Clarage, Golden Glow, Rustler, Minnesota 13, Boone County White, Neal Paymaster, Bloody Butcher, and Dakota White Flint also contributed valuable lines.

The leading corn hybrid in the United States is U. S. 13. This double cross is produced by a combination of four popular inbred lines. Its pedigree is (WF9 x 38–11) x (Hy x L317). On the basis of supplies of certified hybrid seed available for planting in 1948, U. S. 13 was the leading hybrid in Iowa, Illinois, Indiana, Kansas, Missouri, Nebraska, New Jersey, West Virginia, Maryland, Pennsylvania, and Virginia. Other important hybrids include Iowa 939, Iowa 306, Iowa 4316, Indiana 608, Indiana 844, Ohio C38, Wisconsin 464, Wisconsin 279, Wisconsin 416, Minhybrid 404, Kentucky 103, Missouri 8, Missouri 148, Cornell 29–3, Tennessee 10, Tennessee 15, Texas 8, and Colorado 152. Commercial hybrid seed corn producers often designate their hybrids by their own firm numbers. without disclosing the pedigrees. However, many of the commercial hybrids are produced entirely or in large part from well-known inbred lines, and some of the popular hybrids listed above are being merchandised under various firm designations.

Popcorn and Sweet Corn Varieties

The varieties of popcorn and sweet corn grown in the United States have shorter and more slender stalks, smaller ears, and are earlier in maturity than the field corn varieties and hybrids typical of the corn belt. Because of this smaller size and also because of the premature harvesting of sweet corn, planting usually is at a thicker rate than for planting field corn.

The leading varieties of popcorn include South American (Dynamite or South African), with large yellow kernels having a mushroom shape after popping. Supergold, also called Sunburst and Yellow Pearl, has smaller yellow kernels of high popping expansion. The white-kerneled varieties White Rice and Jap Hulless formerly were the leading popcorns in the United States. White Rice has pointed white kernels. Jap Hulless has short thick ears having 30 to 40 irregular rows of slender pointed kernels. Two novelty varieties of popcorn are the white-seeded pearl type Tom Thumb, with miniature ears 1½ to 2 inches long, and Strawberry with deep red kernels and equally short ears. The White Pearl and Queen Golden varieties formerly were of considerable importance.[7]

The first hybrid popcorn, Minhybrid 250, was released in Minnesota in 1935. In 1946 about two-thirds of the commercial popcorn crop of the United States consisted of hybrids. The leading hybrids are produced from 5 yellow inbreds developed from the Supergold and South American varieties by the Indiana and Kansas agricultural experiment stations and the United States Department of

Agriculture. The most popular hybrids are Purdue 31, K 4 (Purdue 32), and Purdue 38. These hybrids, which are three-way crosses, outyield all open-pollinated varieties, and may have a popping expansion of 31 volumes.

Numerous varieties of sweet corn have been grown in the United States. The most popular open-pollinated varieties include Country Gentleman, Stowell's Evergreen, Crosby, and Golden Bantam. The latter is an early yellow-kerneled variety. Black Mexican, with dark purple grains, is grown occasionally in gardens (Figure 94). Two long-husked varieties, Honey June and Golden June, are grown in Texas and other southern states where worm infestation is common. These varieties were selected from crosses between sweet corn and Mexican June field corn.

Much of the sweet corn consists of yellow hybrids having in their parentage a phenomenal inbred line from the Golden Bantam variety known as Purdue 39.[77] This line is resistant to the bacterial wilt (Stewart's disease) of corn, has an extremely high quality, and is much more productive than the open-pollinated parent variety. Golden Cross Bantam is a single cross of Purdue 39 and another inbred line, Purdue 51. This widely grown hybrid is the leading yellow canning corn in the United States. Other popular hybrids involving Purdue 39 or its derivatives, include Purgold, Indigold, Marcross, Spancross, Whipcross, and Carmelcross.

Hybrid sweet corn is especially advantageous to growers of corn for the cannery because of its more uniform growing period. Since the ears usually are gathered from the field at a single picking, this uniformity of maturity permits a larger portion of the ears to be picked while in prime condition.

Fertilizers

Barnyard manure is commonly applied to land to be planted to corn when the manure is available and not needed for more intensive crops such as potatoes or sugar beets. A large proportion of the corn land in the northeastern states, nearly one-half that in the Great Lakes states and western irrigated regions, and about 15 to 30 per cent of that in the central corn belt is manured. Of the entire domestic crop, nearly one acre in six receives an application of

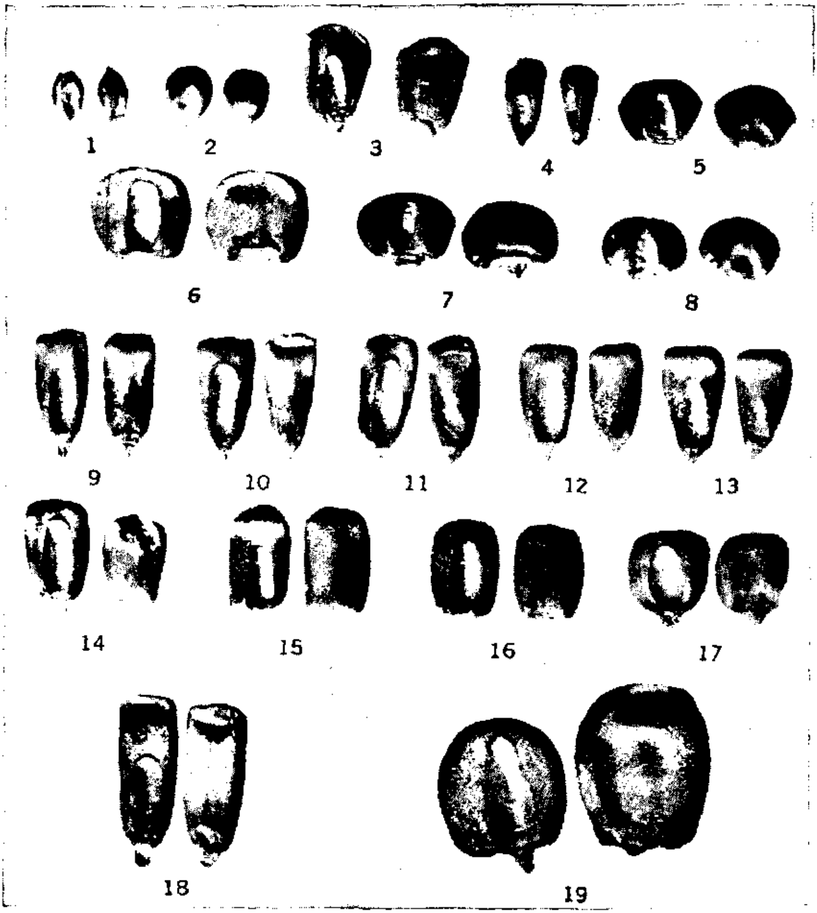

FIG. 94. Paired kernels of 19 varieties of corn: (1) Rice pop corn; (2) Pearl pop corn; (3) Stowell's Evergreen sweet corn; (4) Country Gentleman sweet corn; (5) Black Mexican sweet corn; (6, 7, 8) 3 varieties of flint corn; (9 to 17) 9 varieties of dent corn; (18) horsetooth or shoepeg dent corn; (19) Cuzco corn from Peru. All slightly less than natural size.

barnyard manure. In Ohio, 8 tons of manure per acre increased the yield of corn about 12 bushels on land that produced 30 bushels of corn without manure.[87] Oats following the manured corn crop yielded 31 bushels per acre compared with 25 bushels following unmanured corn.

As shown in Table 1 of Chapter 6, the typical fertilizer application for corn land has an analysis approximating a 3–8–3 or 4–8–4 mixture in most states and a 2–12–6 combination in other states, including Indiana and Ohio. Average rates of application ranged from 100 to 300 pounds per acre in 1938. More than half of the nitrogen fertilizer used for corn in the south is applied as a side dressing after the corn has started growth. On very sandy soils, additional side dressings may be needed after periods of heavy rains. In experiments in Ohio, an application of 500 pounds per acre of fertilizer gave corn yields of 42 to 46 bushels per acre when half or more of the total fertilizer was applied in the hill, compared with 31.5 bushels when all the fertilizer was broadcast.

Cultural Methods

CROP ROTATIONS

The chief rotations in the corn belt are: [81] a 2-year rotation of corn and small grain; a 3-year rotation of corn, small grain, and clover; a 4-year rotation of corn, oats, wheat, and clover; and a 4-year rotation of corn, corn, small grain, and clover. Soybeans are often substituted for one of the corn crops in the latter rotation. Most rotations in the irrigated regions of the western states include alfalfa and small grain, with corn, sugar beets, or potatoes as cultivated crops. Under dryland conditions, alternate corn and wheat, or corn with occasionally barley or oats replacing wheat, appear to be most satisfactory. Corn usually shows a relatively small response to the extra moisture provided by fallow. In much of the south, corn ranks second only to cotton in acreage. Since these two crops do not supplement each other well, it is advisable to grow soybeans with corn, followed by some crop such as rye or winter peas to be turned under for green manure as a preparation for cotton. In a Rhode Island experiment corn was grown continuously over a 40-year period in a comparison of cover crops versus no cover crops.[70] Clovers as legume cover crops were the most effective in maintenance of corn yields. However, winter rye seeded at the last cultivation of corn in the fall increased the average annual yield by 6 bushels over the adjacent no-cover-crop plot for a 34-year period. Small grains usually yield well following corn.

SEEDBED PREPARATION

Land is either plowed or listed as the first step in seedbed preparation for corn. In the north and in the corn belt, where the ground is frozen over winter, land can be plowed equally well in the fall or spring where a cultivated crop has been grown the previous season. Fields that have been in alfalfa, clover, or pasture should be fall-plowed to permit the sod to decay. Fall plowing for corn is inadvisable in the south because it promotes water erosion.

In the subhumid prairie region, early fall plowing tends to overstimulate the crop, rendering it more susceptible to drought injury.

The final preparation of plowed land usually consists of pulverization of the surface 4 inches so as to provide a soil free from large air spaces in which to plant the seed. This should be done immediately before the crop is planted in order to suppress weeds. Frequently the land can be put in condition to plant by double disking and harrowing. The corrugated roller is sometimes used on heavier soils to break clods and firm the seedbed. Sometimes a plank drag is used to smooth the surface for the planter.

Under semiarid conditions, the land often is listed in the winter or early spring. The lister furrows intercept drifting snow and soil.

PLANTING METHODS

Corn usually is planted in rows 36 to 44 inches apart with either a surface or lister planter. Sometimes furrow openers are attached to the surface planter so as to plant in shallow furrows. Surface-planted corn usually is planted in hills or check-rows to permit better weed control by cross cultivation, while listed corn is drilled in the row with cultivation possible in only one direction.

In the corn belt most of the corn is surface-planted in check rows. Checked corn generally yields more than surface-drilled corn because it is practically impossible to control the weeds in the latter without hoeing. Jenkins [31] compared the surface, furrow, and lister methods on a silt soil in Iowa, with weeds kept under control. The yields were not significantly different, but the listed corn tasseled and silked somewhat later than the surface-planted corn.

In Nebraska surface planting gave slightly higher yields than listing.[46] Because of lower production cost and essentially equal yields, listing is regarded as highly practical. The chief advantage of listing is in more economical weed control.

Experiments in Kansas indicate that the listing method is adapted to regions with limited rainfall and light soil types, with the surface-planting method more suitable for areas with abundant precipitation and heavy soil types.[86] Listed corn is better protected from spring frosts. In a 2-year comparison, 9 per cent of the plants were killed by frost in listed corn, and 63 per cent in surface-planted corn. The retarded early growth of listed corn is advantageous in a dry season because the soil moisture is less likely to be exhausted before the silking period is reached.

In the Great Plains, lister planting is a common practice. On listed land the corn may be planted by splitting the ridges with a lister planter. Often the ridges are leveled and the furrows *nosed out* with a lister at the time the corn is planted.

In the south corn is usually planted in drills. On poorly-drained soils, it is customary to list up the plowed land into beds the width of the corn row, the corn being planted on the top of the beds. This is sometimes called listing, the furrows between the beds being left to drain the excess water.

TIME OF PLANTING

Corn planting begins about February 1 in southern Texas and progresses northward through the eastern two-thirds of the country at an average rate of 13 miles per day (Figure 95). In the corn belt the planting season is at its height about May 15. At a corresponding latitude, planting may be somewhat later in the western third of the country because of cooler weather at the higher elevations. There are two general periods of corn planting in much of the cotton belt, one early and one late. The early date corresponds closely to that for planting cotton, while the late period begins in June after the cotton has been chopped. Some varieties respond to summer planting better than others. In Arkansas Mexican June proved superior to three other varieties that were standard for the early (April 15) period.[60] In Texas the highest yields are obtained when corn is planted at the average date of the last spring frost.[56]

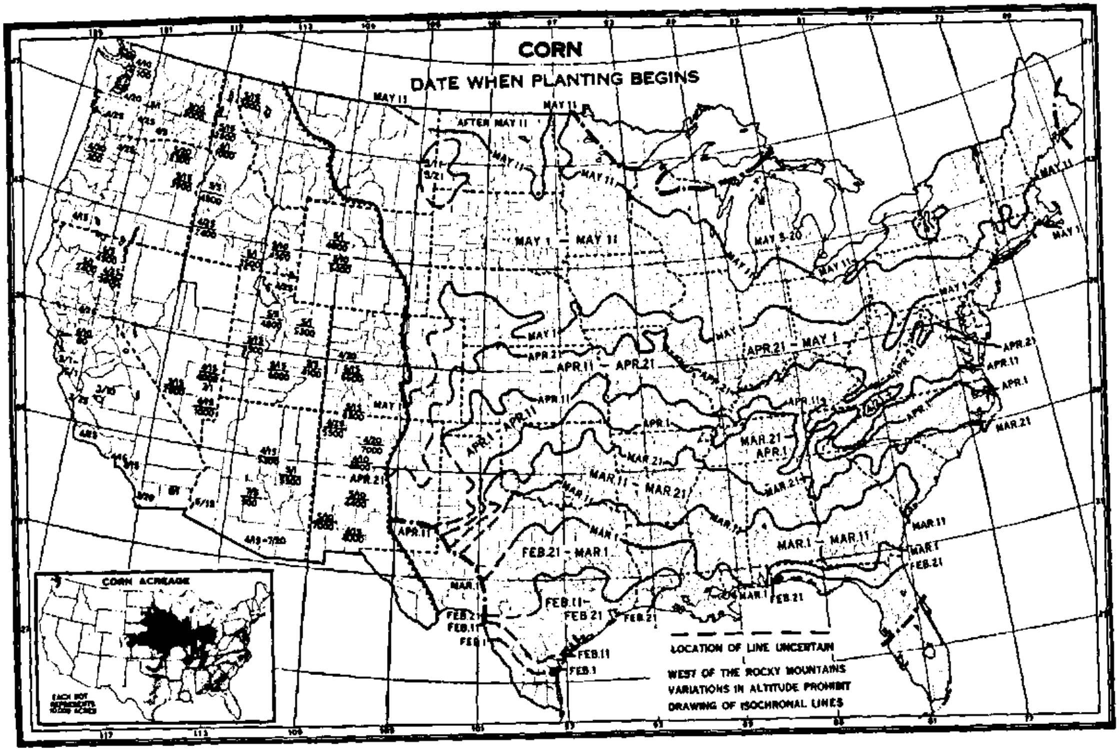

FIG. 95. Date when corn planting begins.

In western Kansas planting in June permits the corn to tassel and silk after the extreme midsummer drought and heat are past, and this results in higher yields.

The number of days from planting to maturity decreases as the date of planting is delayed.[66] A variety that required 150 days to mature when planted April 1 in Tennessee matured in 113 days when planted on June 1.

Corn can be planted earlier on sandy soil than on the heavier clay soils. It is futile to plant corn early in a cold, poorly prepared seedbed. In Colorado corn planted in cold soil April 20 emerged about the same time as that planted May 1.[85] The popular idea of the Indians not to begin planting corn "until the oak leaves are as big as squirrels' ears" is a fairly safe rule to follow. However, it is unnecessary to delay planting until all danger of spring frosts is past. Permanent frost damage to early-planted corn is infrequent.

RATE OF PLANTING

The typical spacing of corn ranges from about 3 square feet per plant in the northern corn belt to 18 square feet on the poorer soils in the south. The number of plants per acre ranges from about 2,400 to more than 14,000.

The average rate of planting corn in the United States, including that used for replanting, is about 9½ pounds per acre. Fodder corn is planted thicker. The usual rate in the corn belt is about 8 pounds per acre (7 acres per bushel of seed). Large long-season varieties adapted to the southern states produce maximum yields at thinner rates than do smaller varieties of the north. Furthermore, corn can be planted thicker on fertile than on infertile soils. In the Great Plains area, frequent moisture shortage necessitates thin rates of planting in spite of the productive soils.

In the south, corn is often grown two stalks to the hill with the rows spaced 4 or 6 feet apart on the poorer soils. Comparisons in Arkansas showed that less than 3,500 plants per acre (about 1 plant per hill) produced the highest yields on light upland soils.[72] Under more favorable conditions, the yields increased up to 2.5 to 3.0 plants per hill in 44-inch rows. In Tennessee tests, higher yields were obtained from 1 or 2 kernels per hill than from three.[65] In both cases, small early varieties yielded more at the higher rates of planting than did large late varieties.

The standard corn belt rate of planting is three kernels per hill in 40- or 42-inch rows. Thicker planting of productive hybrids on good well-fertilized land is becoming common. In northern and north central Iowa, larger average yields were obtained where five kernels per hill were planted instead of four, three, or two kernels. In the south central fourth of the state, the highest yield was obtained from four kernels per hill, while in the southern fourth the three-kernel rate produced the maximum yields.[30] The varieties grown in the southern part of the state are of larger size than those grown in the northern part, hence the superiority of the thinner rate. In Nebraska, in checked corn with hills spaced 3.5 feet apart, stands of 1, 2, 3, 4, and 5 plants per hill yielded at the respective rates of 36.8, 45.4, 48.7, 46.0 and 42.9 bushels per acre as a 12-year average.[46] In eastern Kansas, two to three kernels per hill, or 16 to 18 inches apart in the drill row, resulted in the largest yields.[86]

In the northern states, as well as under favorable western conditions, thick rates of planting have resulted in the highest yields. In northern Colorado, four or five plants per hill produced more corn per acre than the three-plant rate on fertile soils with ample irrigation water. Yields of 83.1, 88.8, and 87.2 bushels per acre of Golden Glow corn were obtained for the three, four, and five-plant rates, respectively.[53] The highest grain yields for drilled corn there were obtained when the plants were spaced 6 to 9 inches apart in rows of 3.5 feet apart. The thickest rates tend to produce weak stalks.

Under semiarid conditions, the rate is adjusted to the limited moisture available. At the Akron, Colorado, Field Station the highest average yield of ear corn, 13.3 bushels per acre, was obtained from plants spaced 24 inches apart in 44-inch rows.[6] The yield from double-spaced, or 88-inch rows, was 28 per cent less. The double-spaced rows decreased yields markedly in years of good production and did not increase the sureness of production in poor years. In Arkansas, 3,000 to 3,500 plants per acre in double-width rows produced 66.6 per cent of the yield of the same rate in ordinary rows.[72] In Nebraska the yield from double-width rows was reduced 23 per cent when the stand of plants per row remained the same, and 14 per cent when the number of plants per row was doubled so as to provide the same number of plants per acre.

Sweet corn and popcorn often are planted in rows 30 to 40 inches apart and thick enough in the row so that the number of plants per acre ranges from one-fourth more to twice as many as the usual spacing for field corn. Popcorn usually is planted at a rate of 3 to 6 pounds per acre and sweet corn at 8 to 16 pounds per acre.

CULTIVATION

The principal reason for the cultivation of corn is to control weeds (Chapter 5), as shown by many experiments in which corn from cultivated plots and from plots merely scraped with a hoe to control weeds, have been compared. Extensive experiments have shown no important differences in favor of deep cultivation. Root pruning has frequently resulted from cultivation deeper than 3 inches.[69] Weeds are controlled economically early in the season with such implements as the harrow or rotary hoe, which can be used without damage to the corn plants until they are some 4 inches high. Subsequent cultivation can be done satisfactorily with ordinary cultivators, frequent enough to control weeds but shallow enough to avoid injury to the corn roots. Cultivation of corn in listed furrows saves subsequent labor by burying the small weeds in the row.

HARVESTING

About 89 per cent of the corn acreage of 1944 and 1945 was harvested for grain, 5 per cent was cut for silage, and 6 per cent was hogged down, grazed, or cut for fodder.

Of the total corn acreage harvested for grain in 1945 about 53 per cent was husked or snapped from the standing stalk by hand, about 33 per cent was husked with a corn picker (Figure 54), and 14 per cent was cut and shocked before husking. Of the latter, about 11 per cent was husked from the shock by hand and 3 per cent was husked with a husker-shredder. Husking from the standing stalk is the prevailing method in the corn belt. In 1945 about 80 per cent of the corn harvested for grain in Illinois was gathered with a mechanical corn picker. For the entire United States 40 per cent of the total production of corn was gathered with the corn picker. Labor scarcity and high wage rates during the war encouraged use of corn pickers on a custom basis. In the south, most of the corn is snapped from the standing stalk with the husk left on. Most of the snapped corn is husked after drying at the time it is fed or shelled. Combination huskers and shellers are used to some extent. Cutting and shocking has been the prevailing method of harvesting corn in the east central states. Nearly half of this is cut with a corn binder (frontispiece) and the remainder is cut by hand or with cutting sleds.

PICKING OR SHUCKING

Corn is picked, husked (or shucked) from the standing stalks, usually after it has dried out sufficiently for safe storage in cribs. Mechanical corn pickers do very satisfactory work where the plants stand erect in the field and when the husks are slightly damp. The picker may be wasteful where the plants are lodged. Most strains of hybrid corn have strong root systems and stand well for mechanical picking.

In field hand husking of good corn in the corn belt, skilled workers husk 60 to 90 bushels a day, and an average worker husks an acre of corn in about 5½ to 6½ hours, or about 6 bushels per hour. Contest champions can hand husk 25 to 30 ears per minute. With a two-row corn picker, corn is harvested and cribbed with about 2 man-hours of labor per acre. In the south the ears are snapped, thrown in piles, and then gathered and hauled at the rate of about an acre in 4 to 5½ hours.[35]

When corn is gathered from the field the grain usually contains 16 to 30 per cent moisture. Corn can be shelled when it contains 25 per cent moisture or less, but the shelled grain cannot be stored safely in bins unless it contains less than 13 to 14 per cent moisture. Consequently, most of the ears are stored in cribs until dry enough for safe storage of the shelled grain. Most cribs are 4 to 10 feet wide, about 8 to 10 feet high, and of any convenient length.[39] Often two cribs are covered by one roof, with a driveway between that can be used for emergency corn storage. The recommended maximum width for corn cribs for the corn belt ranges from 6 feet in the northern part to 9 feet in the southwestern part.[90] Corn cribs have slatted sides and ends to provide free circulation of air. In the Great Plains region much of the corn is stored in temporary outdoor cribs constructed of woven wire fencing or a picket snow fence. Wet corn containing more than 30 per cent moisture is likely to spoil when ears in cribs or piles are more than 2 feet from the open air. For cribs wider than 4 feet, drying is aided by inserting A-shaped or rectangular ventilators in the middle of the crib and extending its full length.

Damp corn usually should be dried artificially for safe keeping. Under corn belt conditions, corn containing 25 to 30 per cent moisture placed in ordinary cribs is likely to spoil when the weather turns warm in the spring. The screening out of shelled grain and the blowing out of husks and silks improves the circulation of air through the crib and hastens drying. Cleaning, combined with the use of crib ventilators, usually takes care of corn containing 25 to 30 per cent moisture. When the grain has dropped to a moisture content of 20 per cent the cobs may still contain more than 30 per cent moisture.

When corn is killed by freezing before the grain is mature, and while it is high in moisture, the damaged damp grain is referred to as *soft* corn. Even after soft corn is dried so that it will keep in storage it is low in test weight per bushel, and shrunken or chaffy. However, such corn is nearly equal in feeding value (pound for pound) to plump sound corn. The lower starch content of soft corn makes it undesirable for processing. The best utilization of soft corn is to feed it promptly to avoid spoilage or the expense and labor of drying it.

Considerable corn is sold in the ear for feeding purposes before it is dry enough for shelled corn bin storage. Such damp corn will not yield the 56 pounds of dry shelled corn normally obtained from 70 pounds of dry ear corn. Consequently the corn is sold on the basis of an agreed-upon number of pounds of ear corn to constitute a bushel. The relation between the moisture content of the grain and the number of pounds of ear corn required to produce 56 pounds of shelled corn of 15 per cent moisture content as reported

TABLE 2. WEIGHT OF EAR CORN REQUIRED TO PRODUCE 56 POUNDS OF SHELLED CORN AT 15 PER CENT MOISTURE CONTENT

MOISTURE IN GRAIN (%)	EARS FOR 1 BUSHEL OF SHELLED CORN AT 15 PER CENT MOISTURE (*lb.*)	MOISTURE IN GRAIN (%)	EARS FOR 1 BUSHEL OF SHELLED CORN AT 15 PER CENT MOISTURE (*lb.*)
15	70	45	108
20	75	50	120
25	80	55	132
30	85	60	149
35	92	65	170
40	100		

by the Missouri Agricultural Extension Service is shown in Table 2.

Sweet corn is ready to harvest for the market or for canning when the grain is in the late milk stage and contains about 70 per cent moisture,[13] 5 to 6 per cent sugar, and 10 to 11 per cent starch. That stage is reached about the time the silks become brown and dry, which usually is about 21 days after silking. The corn remains in prime condition only about 2 days in hot summer weather and 5 days in cooler autumn weather. After that, the sugar content decreases, the starch content increases, the appetizing flavor is lost, and the pericarp becomes tough.[11]

Corn Stover

The leaves and stalks contain about 30 per cent of the total nutrients in the corn plant.[38] Stover from corn husked or snapped from the standing stalk usually is utilized only for pasture. Most of the stover from corn cut and shocked is used either for feed or bedding. The best utilization of corn stover is obtained by putting the stalks through a husker-shredder. This practice is followed on less than one-fourth of the shocked corn. The coarse parts of the unshredded stalks are not consumed, but they furnish bedding and can be returned to the soil mixed with manure. Even where all the corn stalks are returned to the land they do not maintain the soil organic matter.

Corn Fodder

About 2.2 per cent of the corn acreage was cut for fodder and fed without husking in 1943. About 0.6 per cent of the acreage was cut and fed green. Larger proportions are used for fodder in dry years when more of the corn fails to develop ears. The feeding of corn fodder is popular in the northern border sections where corn often fails to mature. Such stalks are more palatable than when they have produced mature ears.

About 3.8 per cent of the total corn acreage is stripped or topped, chiefly by small operators in the south who need additional forage and are not pressed for time. In stripping, the leaves are pulled from the stalks by hand, tied in bundles with leaves for a band, and hung on a corn stalk to cure. In topping, the stalks are cut off just above the ear and then cured in small shocks. Either stripping or topping before the kernels are mature checks their development and reduces grain yields. Stripping a ton of cured leaves requires 2 or 3 days labor, whereas a ton of cured tops can be gathered in a third of the time.

Corn Silage

The most complete utilization of the corn plant is as silage, cut when the ears are in the glazed stage before serious loss of leaves occur. Up to two-thirds of the digestible nutrients of corn silage is in the grain. Corn that fails to produce grain because of drought should be allowed to mature in the field as completely as possible without undue loss of leaves. About 90 per cent of the corn for silage was harvested with a binder or by hand and hauled to the silage cutter in 1943, but the field silage cutter and forage harvester are increasing in popularity.

Harvest by Livestock

About 3.8 per cent of the corn acreage was hogged or grazed in 1943, most generally in the northern Great Plains. Corn may be pastured by cattle, sheep, or hogs, but cattle usually waste a large amount of corn unless they are followed by hogs. Corn is usually harvested more efficiently by the other methods, but often a poor crop or a shortage of labor makes it advantageous to pasture the crop.

Seed Corn

Seed corn should be placed where it will start to dry the day it is gathered from the field. A free circulation of air is essential to avoid danger of molds and to prevent heating when the moisture content is high. Small quantities of seed may be dried satisfactorily on various types of hangers or racks designed so that the ears do not touch each other.[33] The crop is dried artificially by a forced draft of heated air by most large growers of hybrid seed corn. The room must be well ventilated where heat is employed. A reduction in the moisture content of the seed to 12 or 13 per cent at a temperature range of 105° to 110° F. does not reduce the viability.[4]

High-moisture corn exposed to freezing is likely to be reduced in viability. Death from freezing is directly related to the moisture content of the corn kernel and the duration of the exposure to cold.[48] Corn that matures in a natural way becomes tolerant to freezing progressively as the moisture content diminishes. Corn with 10 to 14 per cent moisture will stand the most severe winter temperatures without injury to germination.

Well-matured seed corn kept dry retained its viability satisfactorily up to 4 years under Nebraska conditions.[44] Old seed should be tested for germination before it is planted. In Illinois second-year seed was equal to the first but the yield from three-year-old seed dropped 7.8 per cent, and the decline in yield from seed more than six years old was extremely sharp. The decreased yields from old seed were due to weak plants as well as to low germination.[17]

SEED SELECTION

The ideas of the earlier corn growers differed widely as to what constituted the best ear type to save for seed. This dilemma is eliminated when hybrid seed is used because all ears in a pure hybrid have the same inherent productive capacity, if they are sound, viable, and free from disease. When corn shows came into prominence about 1900, judges formulated the corn score card as a guide to excellence. The ear was logically regarded as a thing of beauty but unfortunately characteristics associated with beauty were erroneously regarded as important from the production standpoint. As a result, much futile attention was devoted to the fine points of score-card selection. The conclusion of investigators[54, 71] is practically unanimous that physical differences among good seed ears such as number of kernel rows, weight per kernel, ratio of tip to butt circumference, shelling per cent, and filling of tips and butts are valueless as indications of relative productivity. However, yield sometimes is associated with weight of ear and length of ears.[30, 34] In general, ears that are heavy because they are long are more likely to be productive than are heavy ears of a large circumference. Ears with heavier cobs, fewer rows, heavier kernels with rounded corners and smoother indentation are more productive than the old standard show type.[8] Extremely rough, starchy ears are more susceptible to the rot diseases than the smoother, more flinty types.

Close selection for a particular set of characters of a uniform type tends to reduce yields because of a decrease in vigor similar to that obtained by inbreeding.[20]

Field selection of seed ears from the standing stalks at about the average date of the first fall frost appears to be the most practical method for yield maintenance or improvement of an open-pollinated variety. Seed ears should be selected from healthy vigorous plants that have produced sound ears. That is about all that needs to be done by the growers of the remaining 20 million acres of open-pollinated corn.

Corn improvement by ear-to-row tests of selections was introduced by C. G. Hopkins at the Illinois Station in 1897 in experiments designed to modify the protein and fat content of the corn kernel. Later extensive experiments failed to show yield increases by ear-to-row selection, particularly where practiced continuously.[41]

HYBRID SEED CORN

About 64 million acres or 75 per cent of the corn acreage of the United States was planted to hybrid corn in 1948. Practically 100 per cent of the main corn belt acreage was hybrids. The proportion of hybrid corn is increasing rapidly in other areas as suitable hybrids become available. In 1933 only 0.2 per cent of the corn acreage was of hybrids. This increased to 14.9 per cent by 1938, and the expansion since that year has been rapid.

First-generation hybrid seed for growing the hybrid crop must be obtained each year. Yields are reduced when seed is saved from the hybrid crop. The yield of the second generation of double crosses is about 84 per cent of that of the first generation, or about the same as open-pollinated corn.[68, 83]

The chief concern of the hybrid corn grower is to obtain seed of the hybrid best suited to his conditions. The published results of state yield tests are a valuable guide in making the proper selection. "Corn hybrids are as specific in their adaptation to the soil and climate as open-pollinated varieties and will perform in a satisfactory manner only when grown under the conditions to which they are suited."[32] The first four hybrids released by the Iowa Agricultural Experiment Station yielded 11 to 26 per cent more than the average of open-pollinated varieties in the tests from 1935 to 1940.[92] In Minnesota, hybrids yielded 9 to 12 per cent more than the check variety.[23] The better recommended hybrids distributed for commercial production have given yield increases that range from 15 to 35 per cent above open-pollinated varieties. Many superior hybrids are also outstanding for their strength of stalk and lodging resistance.

The advantages from the use of hybrid seed are greatest where yields are high. For example, a 20 per cent increase above a 75-bushel yield is five times as valuable as the same percentage increase above varieties grown where they yield only 15 bushels an acre. On poor soils open-pollinated varieties sometimes outyield available hybrids.[16] Likewise, hybrids often make a relatively poor showing under dry conditions. Hybrids that shed their pollen during a hot dry period may give very low yields whereas open-pollinated varieties, which are irregular in pollen shedding, may partly escape the adverse weather period and produce a better yield. Most corn hybrids were developed under favorable growing conditions. Hybrids designed especially for adverse conditions may be expected to extend the adaptation of hybrid corn.

Producing Hybrid Seed. Production of hybrid seed corn requires the use of some 200,000 acres to produce the 10 million bushels of hybrid seed for planting 60 million acres. The sale value of the seed is 70 to 100 million dollars annually. Some 40,000 workers are employed for a period of 2 to 3 weeks to detassel the seed-producing rows. Large high-framed motor-propelled carriers have been devised on which the crews ride along the rows while they pull out the tassels before they shed pollen. Four to eight rows are thus detasseled in one trip across the field.

The general methods of developing and producing corn hybrids [82] consist essentially in (1) isolation by self-fertilization and selection of lines that breed more or less true for certain characters, (2) determination of the inbred lines with best combining ability, and (3) utilization of these selfed lines in double cross hybrids.

Inbred lines are produced by self-pollination of plants selected from among varieties or hybrids. In self-pollinating or selfing the pollen from the tassel is placed on the silks of the same plant under controlled conditions. This is done by first placing paper bags over the tassels (Figure 28). The ear shoots also must be covered with small bags before the silks extrude from the husks, and usually the silk is trimmed so that it will grow out as a uniform brush. Usually one or two days later the pollen is jarred into the tassel bag and then poured on the silks and the ear shoot then covered with a large tassel bag. The seed from the better selfed ears is planted in progeny rows. Self-pollinations are then made on several plants in each row, and selection is continued. The vigor of these selfed lines is much less than that of the parent field variety, but the inbreeding process reveals many undesired abnormalities that can be eliminated.[18] Such abnormalities include sterility, dwarf habit, suckers, tassel ears, silkless ears, susceptibility to diseases, and lethal seedlings. After 5 to 7 years of repeated self-pollination and selection the inbred lines breed relatively true for most plant characters.

Frequently after one to three years of inbreeding, some of the seed of each line is planted in a special crossing block with every fourth, third, or alternate row planted to an adapted corn variety or hybrid to be used as a pollen parent. The tassels are removed from all of the inbred rows before they shed pollen so that all plants are pollinated by the one parent variety. This so-called top-crossed seed produced on each row is planted separately to determine which inbred lines have the best combining ability, i.e., are likely to produce the highest yields in subsequent crosses. The better lines as shown by the top-cross test are retained and inbred until uniform. Most of the inferior inbred lines meanwhile have been discarded.

Small groups of 10 to 15 high combining lines are then intercrossed in all possible single cross combinations. A total of 45 single crosses * is obtainable with 10 lines, and 105 with 15 lines. These single crosses are tested thoroughly for yield, grain quality, and other characteristics. The performance of all possible double crosses may be predicted from the performance of the single crosses.† Seed of only the best predicted double crosses is then produced for field testing.‡ The double-cross hybrids which prove most productive and otherwise desirable are made commercially available for farm use.

A single cross involves a cross of two inbred lines, for example, A × B. Single crosses (Figure 96) of field corn are not widely used commercially because the seed yield is low and the seed often is small. The three-way cross is made from a single cross and an inbred line, i.e., (A × B) × C. The double cross is a cross between two single crosses, for example, (A × B) × (C × D). The commercial field corn hybrids now in production are either double crosses or three-way crosses.

For commercial hybrid seed production the single crosses or inbred lines are grown in alternate rows or groups of rows in isolated fields. In these crossing fields all the plants of the seed (or female) parent strain are detasseled before they shed any pollen. The male or pollen parent rows are not detasseled, and the ears are not gathered for seed. The ratio of male to female rows depends upon the region and the cross to be made, and particularly on the abundance of pollen produced by the male parent. Inbred lines are usually low pollen producers. When they are used to supply the pollen, one row of the male parent is generally planted to every two rows of the female parent. When single-cross plants supply the pollen, either one row of male parent to three or four

* This number is determined by the formula $n(n-1)/2$ in which n is the number of inbred lines.

† The methods used in predicting the yields of double crosses are described by Hayes, H. K. and Immer, F. R., *Methods of Crop Breeding*, McGraw-Hill Book Co., Inc., New York, 1942.

‡ The number of possible double crosses is too large to permit field testing of all of them. The number, which is 630 for 10 inbred lines and 4095 for 15 inbred lines, is computed by the formula: $n(n-1)(n-2)(n-3)/8$, in which n equals the number of inbred lines.

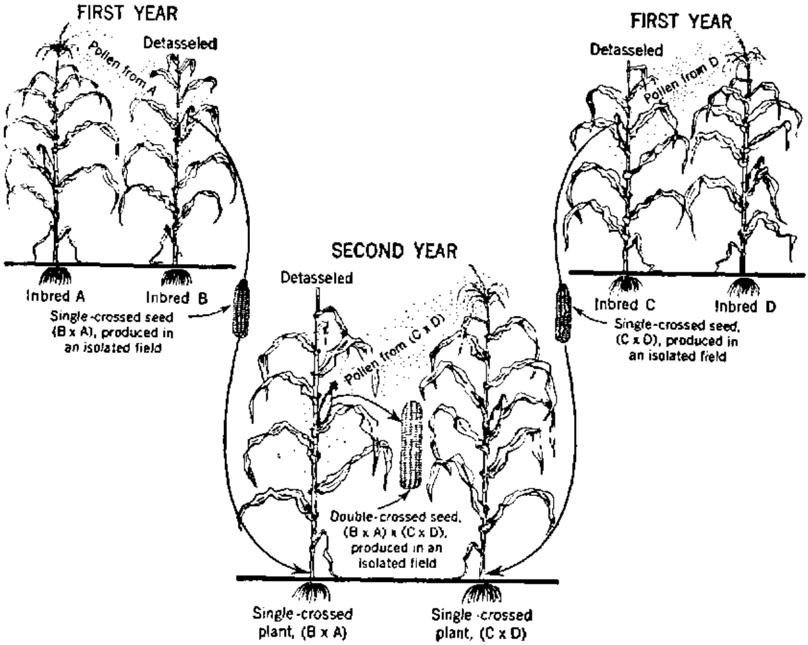

FIG. 96. (*Top*) Steps in producing hybrid seed corn. (*Bottom*) Production of double cross hybrid seed corn. Every fifth row was planted to the pollen parent and the four intervening seed parent rows have been detasseled.

rows of female parent (Figure 96), or a two- and six-row combination is satisfactory under favorable climatic conditions.

Inbreeding experiments with maize were started by E. M. East and G. H. Shull before 1905. In 1908 Shull suggested use of hybrids between inbred lines as a basis for practical corn improvement. The use of double crosses, or crosses between crosses, was advocated by D. F. Jones in 1918. The first commercial production of double cross hybrid corn was in 1921.

Uses of Corn

About 80 per cent of the corn crop is kept on the farms on which it is produced for use as feed, food, and seed. Fully half of that sold, counting equivalent by-products, also is used for feed. The approximate utilization of field corn in recent years was as follows:

Use	*Percentage of total*
Hog feed	40.0
Cattle feed	24.0
Poultry feed	15.0
Horse and mule feed	8.5
Sheep feed	0.7
Farm household use	1.0
Seed	0.5
Exports	0.3
Dry milling (corn meal, hominy grits, etc.)	3.0
Wet milling (starch, oil, feed)	5.0
Distilling and fermenting industries	1.6
Breakfast cereals	0.4

Large quantities of damaged corn were used for the manufacture of industrial alcohol in 1945.

About 16 million bushels of seed corn are required annually for planting some 90 million acres of corn. About one bushel of corn is retained on farms for food for each member of the American farm household.

Exports of corn are extremely variable and very small in recent years. Corn has been imported in years of scarcity chiefly from Argentina.

A minor but interesting use of the corn plant is the manufacture of some 30 million corncob pipes a year. Much of this industry is localized near Washington, Missouri, where a special variety, Missouri Cob Pipe corn, is grown for its large thick cobs. In this case the grain is the by-product.

At times large quantities of corn stalks have been used in manufacturing cellulose products including plastic panels. This industry provides a market for the corn stalks but deprives the land of needed organic residues. Pulverized corn cobs are used extensively as a mild abrasive for removing the carbon from airplane motors. Corn cobs are used for home fuel and for other purposes.

The consumption of corn and other grains for food in the United States is shown in Table 3.

TABLE 3. HUMAN CONSUMPTION OF GRAIN AND GRAIN PRODUCTS IN THE UNITED STATES (POUNDS PER CAPITA FOR CIVILIAN POPULATION, AVERAGE 1940–1944)

PRODUCT	WHEAT	CORN	BARLEY	OATS	RYE	RICE
Flour	155.5				2.7	
Meal		22.6		4.0		
Breakfast food	3.7	2.4				
Sirup		11.4				
Sugar		4.6				
Starch		1.5				
Other			1.4			6.3
Total grain used	218	67	22	8	4	10

White corn only is used for toasted breakfast foods made from corn because the yellow endosperm pigments turn too dark upon heating to make an attractive product. The production of white corn has decreased to such an extent that processors pay a substantial premium for white corn of suitable quality. This shift from white to yellow corn occurred after the discovery of the higher vitamin A value of the latter type. A majority of the consumers in the north long ago showed strong preference for corn meal from yellow corn [1] because it "looks richer." This choice has been further enhanced since the discovery of the difference in vitamin values a quarter of a century ago. Consumers in the south on the other hand use white corn meal almost exclusively because it "looks purer," although they consider yellow corn very appropriate for feeding hogs.

Corn meal has never been a generally acceptable food to a majority of Europeans even in times of food scarcity. This long standing attitude is shown by the following description of corn written by Lyte in his *New Herbal* published in 1616.[57]

> "There is as yet no certain experience of the naturall vertues of this corne. The bread that is made thereof is drye and hard, having very small fatnesse or moysture, wherefore men may easily judge, that it nourisheth but little, and is evill of digestion, nothing comparable to the bread made of Wheat, as some have falsly affirmed."

Milling of Corn

Before milling, the grain is cleaned by aspiration, sieving, and by electro-magnetic removal of any foreign metal fragments. Dry milling is of two types called (1) new process, and (2) old process or water ground.[1] In the milling by the new process the grain is cracked or ground between a series of steel rolls accompanied by sifting to remove the hull or bran, the germ, and the flour. The degermed grain may be used for hominy or else ground further into grits or cornmeal. The bran is used for feed. The germ is pressed to extract the corn oil and the residue used for feed. Grits are used mostly for food and in brewing. The fine particles of corn flour, which come mostly from the soft part of the endosperm, are used for food or industrial purposes. A bushel of corn yields about 29 pounds of grits and meal, 4 pounds of flour, 1.6 pounds of oil, and 21 pounds of feed.

Old process cornmeal is ground between rolls or stone burs usually in small mills, many of which formerly were, or still are, run by water power. The coarser bran particles sometimes are sifted out but most of the germs remain in the cornmeal. Many people relish the flavor of this old-fashioned product but its keeping quality is impaired by the presence of the oil in the germ which becomes rancid after prolonged storage. Two bushels (112 pounds) of corn yield about 100 pounds of old process cornmeal.

Most hominy now is made from corn that is soaked until soft, then broken in a degerminator and then separated from the germ and bran. Large particles of endosperm are called samp or pearl or cracked hominy. When coarsely ground it is called hominy grits.

Lye hominy is made by a process learned from the Indians. The grain is soaked in hot water containing lye or a bag of wood ashes until the hulls are loosened. The hulled grains are washed to remove the alkali.[1]

In wet milling the grain is steeped for about 2 days in warm water that has been treated with sulfur dioxide to prevent fermentation.[80] Then the softened grain is passed through degermination mills that crack the kernel and loosen but do not crush the germ. The mass then passes into germ separation tanks where it is flooded with *starch milk,* and the light loosened germs floated off. The remainder of kernel is then ground fine and the particles of hull are sifted out. The starch is separated from the protein (*gluten*) by letting the mixture suspended in water flow down long tables. The particles of starch, being heavier, are freed from adhering bits of gluten as they roll over and over, until they finally settle out and come to rest on the bottom of the table, while the gluten passes on over the end. The starch from the tables is washed, filtered, and then dried in kilns. The gluten is dried and used mostly for feed. Zein, a purified alcohol-soluble protein of corn, is used in making certain plastics and paints.

The corn starch is used directly largely for food, textile and paper sizing, laundry starch, dextrines, and adhesives. Some corn starch is used in making cores for foundry molds. Large quantities of starch are hydrolized into glucose (corn sugar), corn sirup, and dextrines, by heating in a dilute solution of hydrochloric acid and then blowing the converted solution into a neutralizing tank containing sodium carbonate. The glucose is crystallized out of the solution much as cane and beet sugar are crystallized. A bushel of corn (56 pounds) containing 16 per cent moisture yields in the wet-milling process about 1.6 pounds of oil and 35 pounds of starch (or 27.5 pounds of glucose or 40 pounds of sirup). The starch of waxy corn is used for making adhesives such as the gums applied to stamps, envelopes, gummed tape, corrugated paper boxes, and plywood. It can be substituted for tapioca starch for food purposes.

Recently, corn steep water has been used in the culture medium for growing *Penicillium notatum,* the organism that produces the drug penicillin.

Making Corn Whisky

In making alcohol or whisky from corn the grain is cleaned and then either ground or exploded by steam, and the germ then removed. The remaining mass, mixed with water to form a slurry, is heated with steam to gelatinize the starch. The resulting material is cooled to a mashing temperature of about 145° F. and malt (usually barley malt) is added. The diastase in the malt converts the starch to sugar. The solution (wort) is drawn off, yeast is added, and fermentation allowed to proceed. The resulting alcohol (or whisky) is recovered by successive distillations. Whisky is aged in oaken barrels that often are charred on the inside. During aging objectionable substances are absorbed by the wood or charcoal, whereas the whisky absorbs colors and flavors from the wood. Bourbon whisky is made largely from corn, rye whisky from rye, and Scotch whisky chiefly from barley. Other grains or potatoes may supply part of the starch for any type of whisky.

The dried residue known as distillers grain is used for feed. Distillers' slops or distillers solubles likewise may be dried and used for feed.

Popping and Canning Corn

When popcorn grain containing 10 to 15 per cent moisture is heated sufficiently, this moisture, which is confined in the colloidal protein matrix in which the starch grains are imbedded, is converted into steam. The steam pressure finally is released with explosive force and the grain "pops" as the starch grains expand. Good popcorn expands 24 volumes or more in popping. Poorer lots may show an expansion as low as 15 volumes. Popcorn containing less than 8 per cent or more than 15 per cent moisture gives only about one-half as large a volume on popping as that containing 12 to 13 per cent moisture.[99] Corneous types of grain sorghum also can be popped.

The ears of sweet corn for canning are snapped closely so as to leave little or no shank. The ears usually are snapped in the morning and hauled to the cannery as promptly as possible, because sweet corn deteriorates rapidly after picking.[4, 18] The grains may lose one-half their sugar and much of their flavor within 24 hours. Piles or truck loads of fresh corn will heat unless they are handled soon. At the cannery the corn is husked mechanically, sorted, trimmed, and cleaned. The whole kernels may be cut from the cobs by mechanical knives or they may be cut across and the contents remaining scraped out, leaving part of the pericarp on the cob. The latter method produces Maine style or cream style canned corn. A ton of ears yields about 750 (600 to 900) pounds of cut corn. The residues consisting of husks, cobs, shanks, and silks usually are chopped and made into silage either at the cannery or back on the grower's farm. Most of the cannery crop is grown under contract, with the cannery supplying the seed and notifying the grower when his corn is ready to be gathered and processed. At the stage for best canning quality the dry weight of the kernels is not more than one-half that of mature sweet corn.

Composition of the Corn Kernel

The average composition of the corn kernel is approximately as follows:

SUBSTANCE	PER CENT		
Water	13.5		
Protein	10.0		
Oil	4.0		
Starch	61.0		Carbohydrates
Sugars	1.4		Carbohydrates
Pentosans	6.0		Carbohydrates
Crude fiber	2.3		Carbohydrates
Ash	1.4		
Potassium		0.40	
Phosphorus		.43	
Magnesium		.16	
Sulfur		.14	
Other minerals		.27	
Other substances (organic acids, etc.)	0.4		
Total	100.0		

The germ contains about 35 per cent oil, 20 per cent protein, and 10 per cent ash.

The comparative vitamin content of yellow corn and wheat is about as follows:

VITAMIN	MILLIGRAMS PER POUND	
	Yellow Corn	Wheat Grain
Vitamin A	1990.00	86.00
Thiamin	2.06	2.25
Riboflavin	.60	.51
Niacin	6.40	27.34
Pantothenic acid	3.36	5.83
Vitamin E (as alpha tocopherol)	11.21	16.88

White corn has the same general composition as yellow corn except in being practically devoid of vitamin A. Corn is relatively low in niacin (nicotinic acid), the vitamin that checks pellagra. This disease, which causes a dermatitis (inflamed skin), occurs in the south among people living on a restricted diet, but one that includes considerable quantities of cornmeal and hominy grits. Consumption of large quantities of corn may leave symptoms of niacin deficiency even with an abundance of supplemental niacin in the diet because of the deficiency of the amino acid, tryptophane, in corn. Corn is higher in oil and somewhat lower in protein than is wheat grain. The two grains are very similar in nutritive value.

In general, about 500 pounds, or 9 bushels of corn produces 100 pounds of pork when fed to growing pigs. There is a close relationship between the prices of corn and hogs. Under average free-market conditions the price of 100 pounds of hog is about equal to the cost of 11.4 bushels of corn. When the price of corn rises so that the hog price per 100 pounds will purchase less than 11 bushels of corn, hog feeding soon decreases.

The relative nutritive value of corn and other grains is indicated in Table 4.

The true feeding value of corn is not evident from the figures shown, because corn is higher in fat than the other grains. The fats have a calorific value about 2¼ times as high as do carbohydrates, because of a reduced oxygen content. Aside from this difference the caryopses of the grains are similar to corn in composition and feeding value. Barley, buckwheat, proso, oats, and rice

TABLE 4. NUTRITIVE VALUE OF CORN AND OTHER GRAINS

TEST ANIMAL	PER CENT OF TOTAL DIGESTIBLE NUTRIENTS IN								
	Barley	*Buckwheat*	*Corn*	*Grain sorghum*	*Proso or millet*	*Oats*	*Rice (rough)*	*Rye*	*Wheat*
Cattle			78	78		72			
Sheep	77	62	74	79	69	76	71	79	76
Swine	74	69	80	77	74	74			73
Poultry	68	65	80	81	72	62	65	60	73

grains are enclosed in hulls composed chiefly of celluloses, lignin, silica, and other constituents of limited nutritive value.

The hull constitutes approximately 13, 22, 22, 28, and 20 per cent, respectively, of barley, buckwheat, proso, oats, and rice.

Diseases

The diseases of corn have been described by Ullstrup,[94] and Koehler and Holbert.[50, 51]

CORN SMUT

Corn smut, caused by the fungus (*Ustilago maydis*) is the most widely recognized disease of corn. The disease is widespread but probably is most generally present in the west central Great Plains. It causes complete barrenness of many plants[19] and reduced grain development in others. The average yield reduction from smut was 30 per cent in experiments in Minnesota.[36] Galls on the ear are most destructive while those on the stalk or leaves above the ear are more damaging than when they attack the lower portion of the plant.

The disease appears as galls of various size on the aerial parts of the corn plant. The galls are whitish at first but become dark with the development of the black smut spores inside the white membrane. At maturity the galls break and scatter the powdery spores. Galls may appear almost any place where meristomatic tissue occurs, but commonly they are found near the midribs of the leaf or at the nodal buds on the stem and on the ears. Vigorously-growing plants are most likely to be attacked. The smut is not poisonous to livestock. In fact, young galls cooked and eaten form a palatable substitute for mushrooms. Indians made this discovery.[5]

The smut organism lives over in the soil, and consequently seed disinfection is ineffective except for preventing the spread of the disease to new localities. Future infection may be reduced by systematic destruction of smut, by crop rotation, and by refraining from applying infested manure to land that is to be planted to corn. Smut resistant inbred lines have been developed, and some hybrids involving these lines partly escape smut injury. Doubtless highly-resistant hybrids eventually will be developed.

HEAD SMUT

Head smut is a distinct disease that produces galls on the ear and tassel, entirely destroying these parts. The disease occurs in local areas of the southwest and Pacific coast states and rather rarely elsewhere. The fungus *Sphacelotheca reiliana* lives over in the soil or on the seed. It enters the young plant and grows into galls in the developing ears or tassels. The galls break and discharge the powdery spores in the wind. The disease can be controlled if infested land is not planted to corn for two years and the seed is treated so that the disease is not carried to new fields.

ROOT, STALK, AND EAR ROT DISEASES

Corn rots may bring about reductions in field stand, reductions in vigor of plants that survive, chlorosis, barrenness, general blighting of the plant, and rotting of ears in the fields.[25] Among the organisms that cause seedling blights are the ear rot fungi *Gibberella zeae*, *G. fujikuroi* (*Fusarium moniliforme*), and various species of *Aspergillus*, *Penicillium*, and *Pythium*. Root rots are caused by *Pythium arrhenomanes*, *Gibberella zeae*, *G. fujikuroi*, and *Diplodia zeae*. Stalk rots are caused by *Diplodia zeae*, *Gibberella zea*, *Macrophomina phaseoli* (*Sclerotium bataticola*), and occasionally by *Gibberella fujikuroi*, and *Nigrospora sphaerica* (*Basisporium gallarum*), and by the bacterium *Phytomonas dissolvens*. Ear rots are caused chiefly by *Diplodia zeae*, *D. macrospora*, *Gibberella fujikuroi*, *G. zeae*, *Nigrospora sphaerica*, *Rhizoctonia zeae*, and various species of *Penicillium* and *Aspergillus*.

The ear-rot fungi may continue to grow and damage corn after it is harvested. Molding of corn in storage may result from the growth of *Penicillium, Aspergillus,* and *Fusarium* species if the moisture content of the grain exceeds 14 per cent. A rot and darkening of the germ caused by species of *Penicillium* causes the condition called blue eye. Nearly all of these organisms are carried in the soil or on decaying corn residues. Most of them also are carried on the seed. The molds are evident on the ears. The dark fruiting bodies of certain stalk and root rots are often seen either on the outside or inside of old corn stalks.

Diplodia develops abundantly on infested kernels, and weak infected plants die following the rotting of roots at the crown. The subcrown internodes of plants grown from *Diplodia*-infected seed usually appear dry and brown in contrast to the white tissues in normal plants. There is little evidence that this fungus advances up the stalk from the rotted roots and rotted crown. Ears may be infected through the shank, and may be reduced to a charlike mass. Ears conspicuously rotted with *Fusarium* may be recognized by the characteristic pinkish color of the kernels. *Gibberella* causes both root rot and seedling blight. Charcoal rot (caused by *Macrophomina phaseoli*) destroys the pith in the roots and the lower part of the stalks, leaving the fibrous strands carrying black spores. This disease, which kills the stalks prematurely and causes them to fall down, is most serious under dry-soil conditions.

The seedling diseases and some of the rots are best controlled by the use of sound, undamaged, disease-free seed and by seed treatment. The corn should be planted after the soil is warm. Some of the stalk rots are checked when the soil nutrient elements are properly balanced with suitable fertilization. The planting of resistant hybrids reduces damage from these diseases.

Chemical seed corn disinfectants, such as Semesan Jr., often increase the yield, stand, and vigor through control of the rot diseases when damaged or infested seed must be planted.[27] Dust treatments, particularly with organic mercury compounds, frequently are beneficial in the northern part of the corn belt. Especially favorable results from seed treatment have been obtained on early planted corn which often rots in cool, water-logged soil before it can germinate. Much of the value from dust treatments seems to result from the control of *Diplodia* or *Gibberella* seedling blights.

West of the Missouri River where conditions are drier, and rotting organisms less prevalent, significantly increased stands or yields as the result of seed treatment usually are not obtained.[43, 61, 62]

LEAF DISEASES

The chief leaf diseases are bacterial wilt or Stewart's disease, caused by *Bacterium stewarti*, and *Helminthosporium* leaf spots caused by *H. turcicum* and other species. Corn rust caused by *Puccinia sorghi* attacks the leaves, and brown spot caused by *Physoderma zeaemaydis* attacks both leaves and sheaths.

Insects

EUROPEAN CORN BORER

The European corn borer (*Pyrausta nubilalis*) which causes losses of 20 to 40 million dollars a year, is one of the most serious pests of corn in the United States. The yields of hybrid corn are reduced about 3 per cent for each borer per plant.[75] Losses to market sweet corn are about 8 per cent per borer per stalk. From 1917, when it was first observed in Massachusetts and New York, to 1946 the European corn borer had migrated as far as Kansas, Nebraska and the Dakotas. The larvae bore within the stalks, tassels, cobs, and ears of corn, eating as they go.[10] The mature larvae are about one inch long, with a brown head, a grayish to pinkish body with two dark brown spots on the back of each body segment (Figure 97). The insect overwinters as a full-grown larva in the stalks, stubble, and cobs of corn or in the stalks of other coarse-stemmed crop or weed plants. The larvae begin to pupate from April to July and emerge as moths 2 or 3 weeks later. The period of pupation is early in central latitudes and progressively later to the north. Also the multiple-generation strain of the borer pupates earlier than does the single-generation strain. The moths choose the larger plants upon which to deposit the eggs.

Control measures include complete destruction of all waste plant materials around the corn fields and plowing so as to cover all plant residues in the fields. Planting as soon as the soil is warm enough to permit rapid growth improves the vigor of the plants and helps

FIG. 97. European corn borer in ear of corn. Most of the damage comes from boring in the stalk.

them to survive corn borer attack. Extremely early or late planting should be avoided. Locally adapted stiff-stalked, nonlodging, disease-resistant hybrids should be planted.

Sweet corn or hybrid corn can be protected by 3 or 4 applications at 5-day intervals of a spray consisting of ½ pound of DDT (or 4 pounds of derris or cube powder, containing 4 per cent or more of rotenone), in 100 gallons of water plus a very small amount of spreading agent, beginning when the first eggs start to hatch.

SOUTHWESTERN CORN BORER

The southwestern corn borer (*Diatraea grandiosella*) is a serious pest of corn under some conditions.[12] The damage is similar to that produced by the European corn borer. Stalks containing several borers often break over and may fail to produce ears. A native of Mexico, the present range of this insect extends from Arizona to eastern Kansas. It has spread rapidly eastward and northward during recent wet years.

The larva of the southwestern corn borer is about an inch long and is nearly white, with brown spots scattered over the back. The winter form that occurs on corn roots in the winter is creamy without the brown spots.

The best method of avoiding loss from this insect is to replace corn with grain sorghum which suffers much less injury. Late planting of corn avoids some damage. Plowing in the fall or winter followed by thorough tillage on a community scale will control the insect but that is feasible only in the irrigated regions. This practice is not adapted to dry land regions because of the probability of soil blowing nor to humid sections where water erosion is likely to occur.

CHINCH BUG

The chinch bug (*Blissus leucopterus*) is so destructive that in some cases entire fields are destroyed.[73] The greatest injury occurs when the corn is planted late adjacent to a field of barley or other small grain. The bugs breed in the small grains and migrate into the corn on foot in June or early July when the small grains ripen and lose their succulence. A creosote-posthole barrier line between the small grain and the corn field will serve as a repellent and trap during the migration period. A furrow is made between the fields and a line of creosote about one-half inch wide is then poured near the top of the ridge on the side nearest the infested field. The line must be renewed daily or as often as necessary to maintain its effectiveness during the migration period. Postholes dug at intervals of 20 to 30 feet along the creosote line will trap the insects where they may be killed. Barriers are ineffective where the bugs reach maturity in the small grains and fly into the corn or sorghum fields. A delay in harvesting, as when wheat is cut with a combine, may give the bugs time to develop wings before they are forced to migrate.

The growing of resistant varieties or hybrids will retard damage from chinch bugs. The corn varieties from eastern and central Kansas and Oklahoma where chinch bugs usually are abundant tend to be more resistant than those from the eastern corn belt. Spraying with chlordane offers promise of chinch bug control.

CORN EARWORM

The corn earworm (*Heliothis obsoleta*) causes more direct damage to the ear of corn than does any other insect. About 2 per cent of the corn crop is destroyed annually by this pest. It occurs throughout the United States wherever corn is grown but is most destructive in the southeastern states. This insect also causes considerable damage to compact-headed grain sorghums. Under the name cotton bollworm it is a serious enemy of cotton. As the tomato fruitworm it eats into the nearly ripe fruits of the tomato plant. It also feeds on many other crops.

The number of generations of the corn earworm per year ranges from one in the extreme north and two to four in the central states to as many as seven generations in the extreme south.

The corn earworm lives over winter in the pupal stage in burrows 1 to 9 inches deep in the soil.[76] The moth (or adult) emerges from these burrows in the spring and the female deposits about 1,000 eggs on the leaves of corn or other plants. The larvae hatch in 2 to 8 days and begin feeding. The larva attains full size in 13 to 28 days during which time they molt (shed their skins) about five times, as they enlarge. The full-grown larva is about 1½ inches long, of various colors, and often with conspicuous stripes. The eggs usually are deposited on the silks of corn. The young larvae eat their own way down to the ear.

The corn earworm devours developing kernels, and fouls the ear so that molds develop. Their tunnels permit weevils to gain access to the ear within the husk. The larvae also feed on leaves, tassels, and silks of corn, and often destroy the young growing point or *bud* of the corn stalk.

The best prevention of corn earworm damage consists of growing varieties or hybrids with long heavy husks. Good husk covering retards or prevents the young larvae from reaching the ear. The best corn varieties grown in the south commonly have husks extending 4 to 6 inches beyond the tip of the ear on many of the plants. Early planting permits corn partly to escape damage before the corn earworms become numerous. Early plowing destroys the burrows in which the pupae are hibernating and prevents emergence of many moths. Market sweet corn, because of its high value, can be protected feasibly by applying insecticides after the silks have wilted. A satisfactory insecticide is a squirt in the tip of each ear of ¼ teaspoon of white mineral oil (2 gallons per acre) containing 0.2 percent pyrethrins from pyrethrum extract.[3]

CORN ROOTWORM

Three species of the corn rootworm attack corn in the United States. These are: (1) the southern corn rootworm or 12-spotted cucumber beetle, *Diabrotica 12-punctata,* which occurs in the south, the east and the central states, (2) corn rootworm, *D. longicornis,* of the Great Plains, and (3) the Colorado corn rootworm, *D. virgifera,* of the mountain states. The larvae bore into bases of seedling plants and ruin the bud or growing point. They also feed on the roots of older corn, causing the plants to fall over. The southern corn rootworm cannot be controlled once it gets into the corn. The other two species can be kept under control by crop rotation with at least two years intervening between crops of corn on a particular field.[91]

GRASSHOPPERS

Several species of grasshoppers feed on the foliage of the corn plant. When grasshoppers are very abundant they devour large plants, leaving only the bare stalks or sometimes only the stub in the field. The chief method of controlling grasshoppers has been with poisoned baits, chiefly bran mash containing sodium fluosilicate or an arsenic compound.[74] Spraying or dusting the crop with 1 pound of chlordane per acre also is effective. When a heavy outbreak of grasshoppers is expected it is well to substitute a resistant sorghum for corn where sorghum is well adapted.

WEEVILS

Weevils and other pests of stored corn and other grain were discussed in Chapter 9. The rice or black weevil (*Sitophilus oryza*) and the Angoumois grain moth or fly weevil (*Sitotroga cerealella*) attack corn in the field as well as after it is gathered and stored.[2] These two insects breed in stored grain most of the year but in the south the adults fly to the field and attack the grain when the corn is about in the roasting ear stage.

The best protection against weevil damage to corn is to grow varieties with long heavy husks (Figure 98). The Angoumois grain moth cannot penetrate the husk to deposit eggs on the grain. The

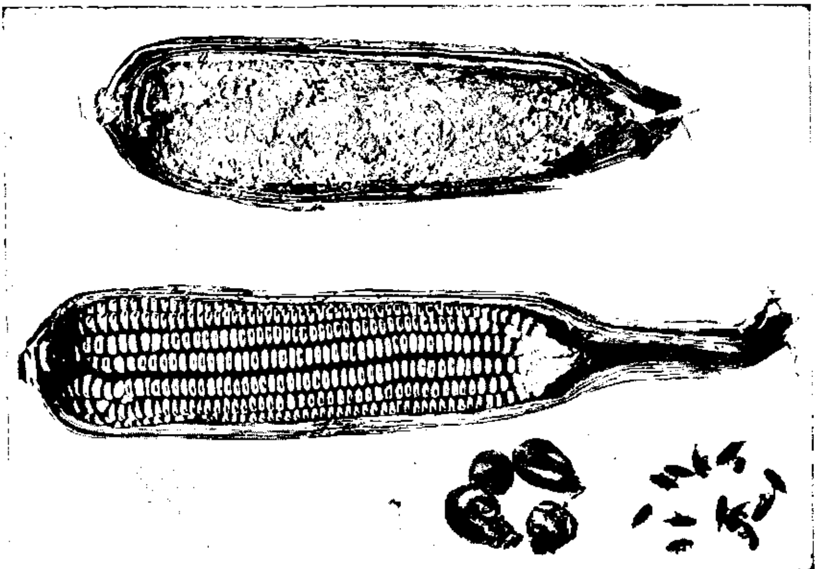

FIG. 98. The short-husked ear (*top*) was destroyed by weevils. Long husks protected the other ear from the weevils. Weevil-bored popcorn kernels (*lower*), and rice (or black) weevil adults (*lower right*).

rice weevil usually does not eat through the husk but attacks ears that have a poor husk covering or those with husks damaged by the corn earworm. In the south, corn usually is snapped at harvest and stored in the husk until time to feed the grain. Good undamaged husks offer effective protection against the spread of weevils from infested to sound ears. Repeated fumigation of all grain in storage will keep down the number of insects available to attack corn in the field.

CUTWORMS

Various species of cutworm larvae attack corn. The chief damage results from the cutting off of the culm of young plants near the soil surface. The common cutworms are nocturnal feeders. They are controlled by spreading poisoned bran mash in the field in the late afternoon. The pale western cutworm (*Agrotis orthogonia*) is controlled by the use of clean summer fallow which starves the larvae.[91]

ARMY WORMS

The army worm (*Cirphis unipuncta*) is widely distributed throughout the central latitudes where corn is important. The fall army worm (*Laphygma frugiperda*) occurs generally in the south, and the moths frequently migrate far to the north where the larvae damage late-planted corn. Both of these pests devour the leaves of corn and the fall army worm often attacks the growing point or bud of the plant.

Poisoned baits spread in the late afternoon will destroy the army worm and also the fall army worm. A common method of checking the moving hordes of both pests when on the march is to plow out a deep furrow and drag a log through the furrow to smash the trapped worms.[95]

CORN ROOT APHID

The corn root aphid (*Anuraphis maidi-radicis*) is a small bluish-green insect found on the roots of corn and usually attended by small brownish ants.[86] The injury is evidenced by weakened plants that turn yellow. The corn root louse (aphid) can be controlled by late fall plowing, which destroys the nests of the attendant ants, or by rotation. Where these insects are present, corn should not be grown for more than 2 years in succession on the same field.

OTHER INSECTS

Among the numerous other insects attacking corn [91] may be mentioned the corn leaf aphid (*Aphis maidis*), maize billbug (*Sphenophorus maidis*), corn flea beetle (*Chaetocnema pulicaria*), desert corn flea beetle (*C. ectypa*), larger cornstalk borer (*Diatraea zeacolella*), rough-headed cornstalk beetle (*Euetheola rugiceps*), white grubs (*Phyllophaga* species), corn root webworm or budworm (*Crambus caliginosellus*), maize billbug (*Calendra maidis*), seed corn maggot (*Hylemyia cilicrura*), wireworms, webworms, and the Japanese beetle. The Japanese beetle chews off the silks of corn, thus preventing pollination. The corn flea beetle acts as a carrier (vector) of the bacterial wilt disease organism. Several Ohio corn hybrids, 160. 487, and 418 are resistant to the corn leaf aphid.[29]

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13 SORGHUMS

Economic Importance

Sorghum was harvested on an average of about 15,650,000 acres annually in the United States in the 10-year period, 1937 to 1946. Of this, approximately 55 per cent was harvested for forage or for bundle feed (grain and forage together), 37 per cent was harvested for grain, 6 per cent was cut for silage, and 1.4 per cent was crushed for sirup. Broomcorn was harvested on an average of 276,000 acres during the 10-year period. Sudan grass was harvested for seed on some 150,000 acres, and nearly 3,000,000 acres annually were sown for pasture, hay and green manure. In 1945 the combined acreage of sorghum, broomcorn, and Sudan grass exceeded the national barley acreage and nearly equalled the acreage of cotton. The acreage, production, and yield of each of the above classes of sorghum is shown in Table 1.

TABLE 1. SORGHUM PRODUCTION IN THE UNITED STATES

TEN-YEAR AVERAGE—1937 to 1946

	Grain sorghum	*Forage and hay*	*Silage*	*Sirup*	*Broomcorn*	*Sudan grass (seed)*
Acreage (Thousands)	6,135	8,413	907	192	276	144
Production (Thousands)	98,130 bushels	11,992 tons	5,300 tons	11,500 gallons	42 tons	54,000 pounds
Acre yield	15.6 bushels	1.4 tons	5.9 tons	60 gallons	300 pounds	375 pounds

In general, sorgo (sweet sorghum) is grown for forage, silage, and sirup, while grain sorghum is grown for grain. However, approximately 40 per cent of the sorghum harvested for forage and

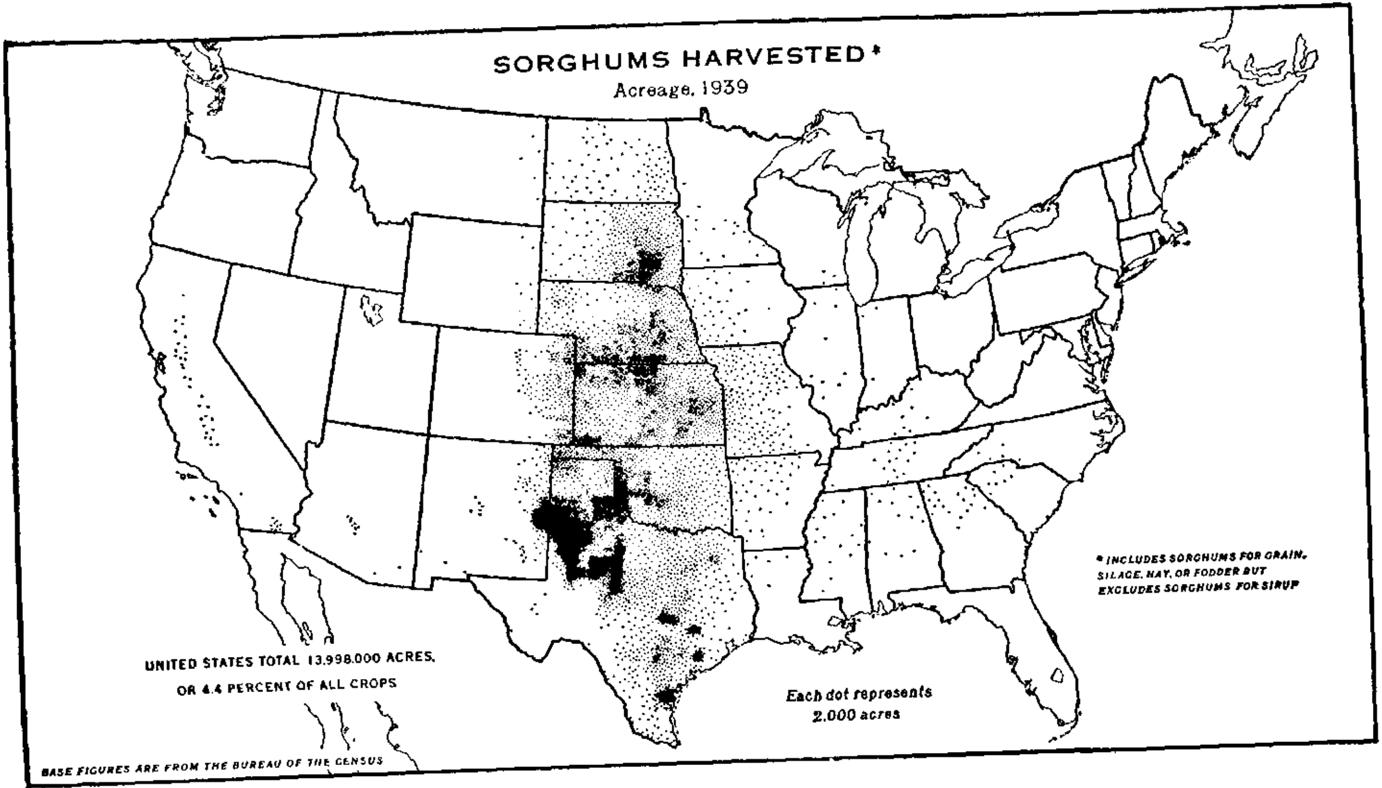

FIG. 99. Sorghum acreage in the United States.

hay and possibly one-fourth of the silage acreage, consisted of dual-purpose types of grain sorghum. Some sorgo is threshed for grain or seed. The acreage of sorgo was about two-thirds that of grain sorghum. The proportion of sorgo has declined considerably since 1941. Texas, Kansas, Oklahoma, and Nebraska, in the order named, lead in production of sorghum for forage and bundle feed. Texas, Kansas, Oklahoma, and California lead in production of threshed grain sorghum, and Kansas, Texas, Nebraska, and Missouri, again in the order named, lead in production of sorghum silage (Figure 99). Sorgo sirup is produced chiefly in Alabama, Mississippi, Georgia, and Tennessee. Broomcorn is produced almost entirely in Oklahoma, Colorado, Illinois, New Mexico, Texas, and Kansas (Figure 100).

California, Texas, New Mexico, Colorado, and Kansas lead in production of Sudan grass seed. Sudan grass is used for pasture or hay in nearly all states. It is the leading temporary summer pasture crop in the north central and south central states. It is particularly important in Texas, Oklahoma, Kansas, New Mexico, Colorado, and Nebraska. Prior to 1942, it was planted extensively for soil improvement on land withdrawn from cotton production.

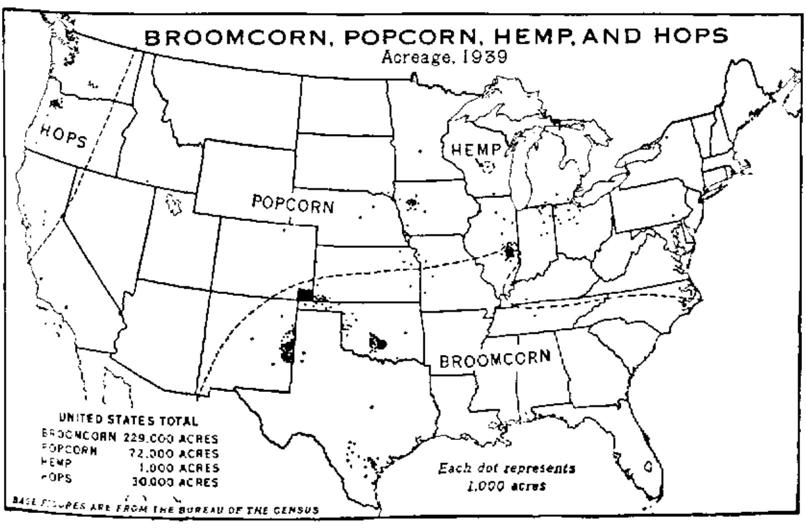

FIG. 100. Acreage of broomcorn, popcorn, hemp and hops in the United States.

Sorghum is the basic feed crop for grain, hay, roughage, cultivated pasture and silage in the southern half of the Great Plains where corn production is hazardous because of drought and heat.

Statistics on the world production of sorghum are very inadequate, but the total area devoted to the crop is about 80 million acres. It is a chief food grain in much of Africa and parts of India, Manchuria, and China. It also is grown in nearly all countries in the southern half of Europe and Asia, and in Central America, South America, and Australia. As a world food grain, sorghum ranks third. being exceeded by wheat and rice.

Adaptation

Sorghums are grown most widely in the semiarid region of the southwest, but they also are grown extensively in the northern Great Plains, the south, and the hot irrigated valleys of Arizona and California.

The most favorable mean temperature for the growth of the plant is about 80° F. The minimum temperature for growth is 60° F. Consequently, only a part of the frost-free season is available to produce the crop. The sorghum plant seems to withstand extreme heat better than other crops, but extremely high temperatures during the fruiting period reduce the seed yield.[38] Sorghum is a short-day plant.

The sorghums are well adapted to regions of limited rainfall where the average annual precipitation is only 17 to 25 inches.[16] However, sorghum is highly productive also on irrigated land and in humid sections. The plants remain practically dormant during periods of drought but resume growth as soon as there is sufficient rain to wet the soil. This characteristic accounts in large part for the success of sorghum in a dry season and is the reason why it has been called a crop camel. As compared with corn of similar seasonal requirements, sorghum has more secondary roots and a smaller leaf area per plant. Sorghum leaves and stalks wilt and dry more slowly than those of corn,[12] enabling sorghum to withstand drought longer. A waxy cuticle apparently retards drying.

Sorghum is grown successfully on all types of soil. In moist seasons the highest yields are obtained on heavy soils, but in dry seasons it does best on sandy soil. Sorghum will tolerate considerable quantities of alkali, or salts, fairly well.

Its resistance to drought, heat, grasshopper, rootworm, and corn borer injury accounts for the growing of sorghum instead of corn. Most farmers prefer to grow corn where it succeeds even though the yields are one-third lower than from sorghum. The chief drawbacks of sorghum as compared with corn are lower yields of succeeding crops, greater uncertainty in getting stands, the necessity of prompt harvesting, greater difficulty in storing the grain, the greater necessity of grinding the grain before feeding, and the usually lower feeding and market value.

Origin and History

Sorghum apparently is a native of tropical Africa. It was grown in Assyria before 700 B.C. The first sorgo or sweet sorghum was introduced into the United States from France in 1853. The most important single shipment of sorgo was that of 16 varieties from Natal, South Africa, in 1857. These were the progenitors and probably the identical types of several of the varieties grown widely today.

At least two varieties of sorghum called chicken corn and Guinea kafir were introduced by slaves from Africa, but these never were widely grown. The earliest grain sorghums fully established in this country were Brown durra and White durra which reached California from Egypt in 1874. Kafir was introduced from South Africa in 1876, milo from Africa between 1880 and 1885, shallu from India in 1890. Feterita was introduced from the Anglo-Egyptian Sudan region of Africa in 1906, while hegari and Sudan grass came from the same region in 1908.[15, 34]

The introduction of broomcorn culture in the United States in the 18th century has been credited to Benjamin Franklin.[15] Broomcorn was grown in Europe before 1596.

Botanical Description

Sorghum belongs to the family *Gramineae*, tribe *Andropogoneae*. *Sorghum vulgare* includes the annual sorghums with 10 pairs of chromosomes, viz., grain sorghum, sorgo, broomcorn, and Sudan grass. Sudan grass is further classified into the subspecies *sudanense*.[26] *Sorghum halepense* (Johnson grass) is perennial in habit, produces rhizomes, and has 20 haploid chromosomes.

Closely related to Sudan grass is Tunis grass (*Sorghum virgatum*) which has been tested but not grown in this country commercially because it shatters its seeds. Other related species of sorghum such as *S. versicolor*, which has only five haploid chromosomes, are found in Africa.

THE SORGHUM PLANT

Sorghum is a coarse grass with culms 2 to 15 or more feet in height.[39] The culms are similar to those of corn, being grooved and nearly oval. The peduncle (top internode) is not grooved. The grooves alternate from one side to the other on each successive internode. Sorghum plants can be distinguished readily from corn plants because of the presence of saw-teeth on the margins of sorghum leaves. Some varieties have sweet juicy pith in the stalks, others are juicy but not sweet, while still others are deficient in both sweetness and juiciness. A dry-stalked variety has a white midrib in the leaf. A juicy-stalked variety has a dull or cloudy midrib caused by the presence of juice instead of air spaces in the pithy tissues. A leaf arises at each node, the blades being glabrous with a waxy surface. The surface of the culms, sheaths, and leaves is glaucous. Buds at the nodes of the culm often give rise to side (axillary) branches. Crown buds give rise to tillers. The total number of leaves on the main stalk, including those formed during the seedling stage, averaged 16 to 27 per stalk in 21 American varieties.[29] The first 10 (more or less) of the small leaves arise from the crown nodes underground. Early-maturing varieties have few leaves and consequently are limited in plant yield.

The sorghum inflorescence is a loose to dense panicle, having many primary branches borne on a hairy axis, bearing paired ellipsoidal spikelets. The sessile spikelet of each pair is perfect and fertile, while the pedicellate spikelet is either sterile or staminate. Two pedicellate spikelets accompany the sessile spikelet at the end of each panicle branch. The two glumes of the fertile spikelet are usually indurate (leathery). There are two florets in the fertile spikelet, the lower sterile and the upper fertile. The lemma and palea are thin and translucent. The lemma may be awned or awnless. Some sorghums have seeds fully covered by the chaff even after being threshed, while others are more than half exposed and thresh out completely free from the chaff. The position of the panicle is usually erect, but may be recurved. Recurving is the result of heavy thick panicles being forced out the side of a too-narrow sheath while the peduncle is too flexible to support the panicle in an erect position. Later the peduncle stiffens (becomes lignified) in the recurved condition.[13] Erect varieties have slender panicles during the boot stage. A well-developed panicle of certain varieties may contain as many as 2,000 seeds or 2 ounces of seed. Average panicles contain about 1¼ ounces. The number of seeds in a pound is about as follows: milo, 12,000 to 15,000; kafir, 18,000 to 20,000; sorgo, 20,000 to 30,000; and broomcorn, 22,000 to 30,000.

Sorghums are about 95 per cent self-pollinated in the field,[28] but they will cross readily with other varieties of sorghum, broomcorn, or Sudan grass, and frequently with Johnson grass also, grown in close proximity.

The pigments of colored sorghum seeds are found in the pericarp, or the subcoat (testa), or both. When the pericarp only is pigmented, the seeds are yellow or red. When the pericarp is white and a testa is present, the seeds are buff-colored as in Sourless sorgo or bluish white as in feterita and hegari. With a colored pericarp and a testa present, the seeds usually are dark brown as in the Schrock variety or reddish-brown as in Darso and Sumac. The seeds of some sorghums such as Cody, Club, and feterita varieties have a thick starchy mesocarp in the seedcoat. Such seeds take up water quickly and are subject to invasion by seed-rotting fungi.

Although considered an annual and usually grown as such, sorghum can survive as a perennial where the temperature is mild and soil moisture is available. It has lived for at least 6 years in the field in southern California, and 13 years in a greenhouse.

Each new culm arising from crown buds develops its own root system and a new series of crown buds but remains attached to the old crown.[14] A culm dies after it has flowered and after all active buds at the culm and crown nodes also have elongated into stems. Then its roots also die and decay. In the meantime, new culms have grown alongside the original culm. This process continues as long as conditions are favorable for vegetative reproduction.

Prussic Acid Poisoning

The young plants and leaves of sorghum, Sudan grass, and Johnson grass contain a glucoside called dhurrin, which upon breaking down releases a poisonous substance known as prussic acid or hydrocyanic acid (HCN). Some losses of cattle, sheep, and goats occur each year from sorghum poisoning when they graze upon the green plants. Silage and well-cured fodder and hay usually may be fed with safety.[35] Silage may contain toxic quantities of prussic acid, but it escapes in gaseous form while the silage is being moved and fed. The prussic acid content of sorghum hay and fodder decreases during curing so that it is dangerous only occasionally.

The prussic acid content decreases as the plant approaches maturity.[19] Small plants, young branches, and tillers are high in prussic acid. The prussic acid content of the leaves is 3 to 25 times greater than that of the corresponding portions of stalks of plants in the boot stage. Heads and sheaths are low in prussic acid. The upper leaves contain more prussic acid than the lower leaves. The amount of prussic acid varies in different sorghums. Sudan grass contains about two-fifths as much as many sorghums grown under the same conditions. Sudan grass rarely kills animals unless contaminated with sorghums or sorghum-Sudan grass hybrids, except occasionally in the northern states. Even there it usually is safe after the plants are 18 inches high. Freezing does not increase the prussic acid content of sorghum but it causes the acid to be released quickly from the glucoside form, thus making frosted sorghum very dangerous until it begins to dry out. An abundance of soil nitrates causes sorghum to be high in prussic acid. Drought-stricken and second-growth plants are dangerous because they are small and consist largely of leaves, which are high in prussic acid.

Since a mere half-gram of prussic acid can kill a cow, 18.6 pounds of Sudan grass containing 0.0066 per cent HCN or 7.6 pounds of sorghum with 0.0164 per cent HCN likewise can be fatal. Sheep seem to be slightly less susceptible than are cattle, while horses and hogs apparently are not injured.

Sorghum is unsafe for pasturing except after the plants are mature and no new growth is present. Individual animals differ in their susceptibility to sorghum poisoning. Poisoning is less likely to occur if the animals eat some ground grain before they are turned into the pasture. The growing of Rancher and 39–30–S sorgo and certain strains of Sudan grass that are low in dhurrin content should reduce losses from poisoning.

The remedy for cyanide poisoning is intravenous injection of a combination of sodium nitrite and sodium thiosulfate. For cattle, 2 to 3 grams of sodium nitrite in water, followed by 4 to 6 grams of sodium thiosulfate in water, and for sheep, up to 1 gram of sodium nitrite and 2 to 3 grams of sodium thiosulfate are recommended.

FIG. 101. A head of Leoti sorgo.

Sorghum Groups

The sorghums originally introduced into the United States could be classified into rather distinct groups. Many of the varieties now grown, however, were derived from crosses between different groups, and represent recombinations of group characters. Sorgo or sweet sorghum (often called *cane*), includes the Orange, Amber, and Sumac groups in addition to many miscellaneous varieties. The leading grain sorghum groups are kafir, hegari, milo, feterita, durra, and shallu. Most of the grain sorghum now grown consists of varieties derived from kafir-milo crosses. These include Early Kalo and the combine types Martin, Plainsman, Westland, Midland. Miscellaneous varieties such as Coes, Bonita, Darso, Schrock, and Grohoma were derived from two or more groups.

The sorgos [39] are characterized by abundant sweet juice in the stalks, which usually range in height from 5 to 10 feet. The seed of some varieties remains enclosed in the glume after threshing. The heads (panicles) may be loose or dense, and the lemmas awned or awnless, and black, brown, or red, depending upon the variety. The seeds are small or medium-sized and are either white or some shade of brown (Figure 101).

Grain sorghum stalks usually are either fairly juicy or comparatively dry at maturity, and the stalk juice is not sweet or is at most only slightly sweet. Grain sorghums, in general, have larger heads and seeds and shorter stalks, and produce more seed in proportion to total crop than do the sorgos. The stalks of American grain sorghums usually range from 2.5 to 6.0 feet in height. The seed threshes free from the glumes.

Among the grain sorghums, the kafirs in general have thick and juicy stalks, relatively large flat, dark-green leaves, and awnless cylindrical heads (Figure 102). The seeds are white, pink, or red,

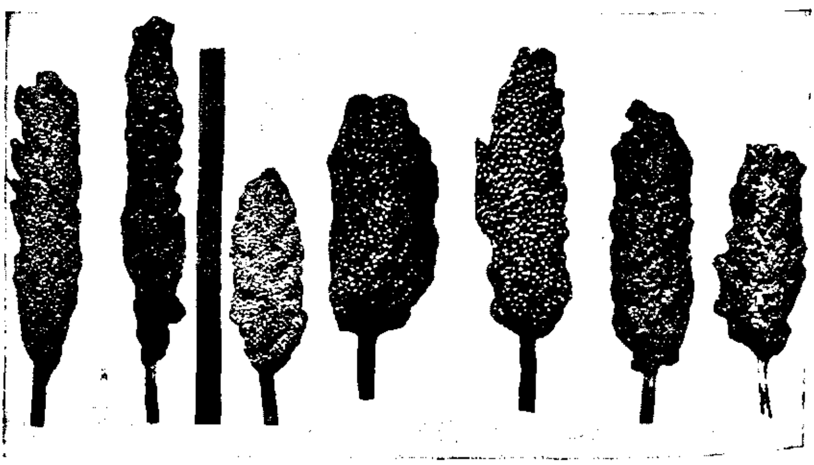

FIG. 102. Heads of several groups of grain sorghum. *Left to right:* Blackhull kafir, Red kafir, hegari, milo, feterita, darso, Schrock.

FIG. 103. Spikelets (*left*) and seeds (*right*) of 10 sorghum varieties (1½ times natural size). (1) Blackhull kafir, (2) hegari, (3) Yellow milo, (4) darso, (5) shallu, (6) White durra, (7) Kansas Orange sorgo, (8) Sumac sorgo, (9) Black Amber sorgo, (10) Evergreen Dwarf broomcorn.

and of medium size (Figure 103). The chaff is either black or straw-colored. Kafirs are grown for both grain and forage. Hegari is similar to kafir in appearance except that the heads are more nearly oval, the seeds are a chalky or starchy white, and the more abundant leaves and sweeter juice make it more prized for forage.

Milos have somewhat curly light-green leaves and slightly smaller leaves and stalks than kafir, and are less juicy. The leaves have a yellow midrib containing carotene. The heads of the true milos are bearded, short, compact, and rather oval in outline, with very dark brown chaff. The seeds are large and are yellow or white.

The plants tiller considerably, and in general are earlier and more drought-resistant than those of kafir. Milo is grown strictly for grain, and the stover usually is not utilized for pasture.

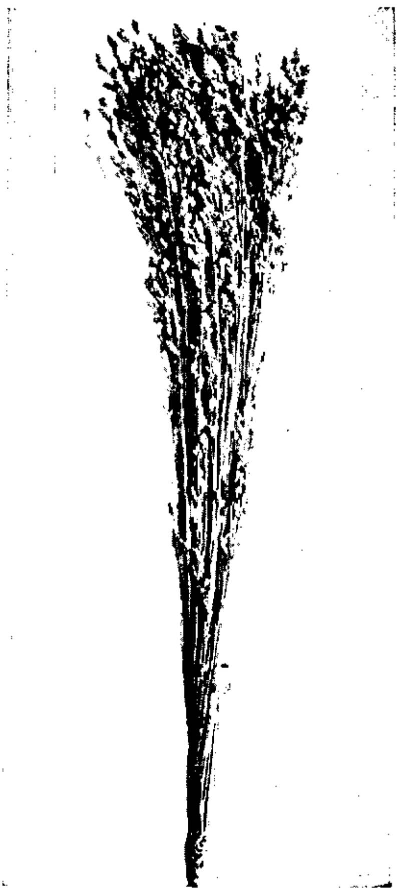

FIG. 104. A panicle of broomcorn.

Feterita has few leaves, slender, relatively dry stalks, rather oval, compact heads, and very large chalky white seeds. Its earliness permits it partly to evade drought and makes it suitable for later planting than kafir. It is grown chiefly as a late-planted catch crop for grain.

Durra has dry stalks, flat seeds, very pubescent glumes, and either compact and recurved or loose and erect panicles. Durra is the chief type in North Africa and the near east, and is important in India.

Shallu has tall slender dry stalks, loose heads, and pearly white seeds. It is relatively late in maturity and is grown largely for grain. The loose heads dry out quickly, do not harbor worms, and make it difficult for birds to roost on the slender branches and eat the grain. Shallu is widely grown in India.

Kaoliang has dry, stiff, slender stalks, open bushy panicles with wiry branches, and rather small brown or white seeds. Kaoliang is the sorghum grown almost exclusively in China, Manchuria, Korea, Japan, and southeastern Siberia, but is rarely grown in the United States or other countries except those mentioned.

Broomcorn produces heads with fibrous seed branches, 12 to 36 inches long (Figure 104), that are used for making brooms and

FIG. 105. Sudan grass plant.

whisk brooms. The stalks range from 3 to 14 feet in height and are dry, not sweet, and of limited value for forage. The lemmas are awned with small brown seeds enclosed in tan, red, or dark-brown, very pubescent glumes.

Sudan grass has slender leaves and stalks and loose heads with

FIG. 106. Seeds, enlarged and natural size of Sudan grass (*left half*) and Johnson grass (*right half*). Note that the swollen tips of the pedicels of the Sudan grass seed at extreme left are broken off but they remain on the corresponding Johnson grass seed.

small brown seeds (Figure 105). Johnson grass is similar to Sudan grass except that it is perennial with underground stems, and the seeds are different (Figure 106).

Varieties

A classification of some of the leading sorgo and grain sorghum varieties, based upon their principal or best utilization is given below:

A. *Grain Types.* With dry or semijuicy stalks
   1. Combine or extra-dwarf varieties. Martin, Plainsman, Westland, Midland, Caprock, Bonita, Double Dwarf 38, Colby, Day, Wheatland, Beaver, Dwarf White durra and Double Dwarf White Sooner
   2. Medium-tall grain varieties. Texas and Sooner milo, feterita, shallu, durra, and Early Kalo
   3. Waxy varieties. Cody

B. *Dual-Purpose Grain and Forage Types.* Juicy and sometimes sweet stalks
   All varieties of kafir and hegari, Schrock, Darso, Atlas, and Norkan sorgo, Coes.

C. *Forage Types.* Juicy and sweet stalks
   Sumac, Atlas, Norkan, Leoti, Fremont, Red Amber, Dakota Amber,

Rancher, Sourless, and Honey sorgo especially, but all other sorgos also

D. *Sugar Types.* Juicy and sweet, with high content of crystallizable sucrose

Colman, Collier, Straightneck, and Folger

E. *Sirup Types.* Juicy and very sweet, but sugar not easily crystallized

Honey, Sugar Drip, Rex, Rox, Kansas Orange, Sapling, Silvertop, White African, Planter, Gooseneck, and Hodo

The time of maturity is the most important factor determining the adaptation of a sorghum variety to a particular locality.[1, 34] However, choice of a sorghum variety for any region is based largely upon its intended use and method of harvesting.[8, 18, 22] Differences in yield, if not too large, are a secondary consideration provided the variety possesses the other characteristics desired. It is essential that a variety reach maturity before it is killed by frost. Consequently, as the average frost-free period becomes shorter, progressively quicker-maturing varieties are grown.

The later-maturing varieties have large leafy stalks and are suited to regions with short days and a long growing season. They fail to head under the long days in northern latitudes. Quick-maturing varieties are best adapted to long-day conditions. In the south they mature very quickly with limited vegetative growth and do not utilize the full growing season.

The sorghum zones of the United States, based upon growing season and day length, are shown in Figure 107.

Region 1. Gooseneck, Hodo, and Honey sorgos: Japanese sugarcane and Napier grass are more productive than sorghums for forage. Shallu is the leading grain sorghum.

Region 2. Sumac, Silvertop, Honey, Gooseneck, White African, Sugar Drip, Rex, Colman, and Sapling Sorgos. Grain sorghums: hegari, Schrock (Sagrain), Darso, Blackhull kafir, Martin, Plainsman, Caprock, and Bonita.

Region 3. Sumac, Atlas, Kansas Orange, and Sourless (African Millet) sorgos. Hegari, Early hegari, Martin, Bonita, Plainsman, Caprock, Westland, Blackhull kafir, Darso, several strains of dwarf Blackhull kafir, Hydro kafir, Red kafir, Pink kafir, Sunrise kafir.

Region 4. West of the ninety-eighth meridian. Sorgos: Early Sumac, Norkan, Leoti, and Sourless. Grain sorghums: Early Kalo, Midland,

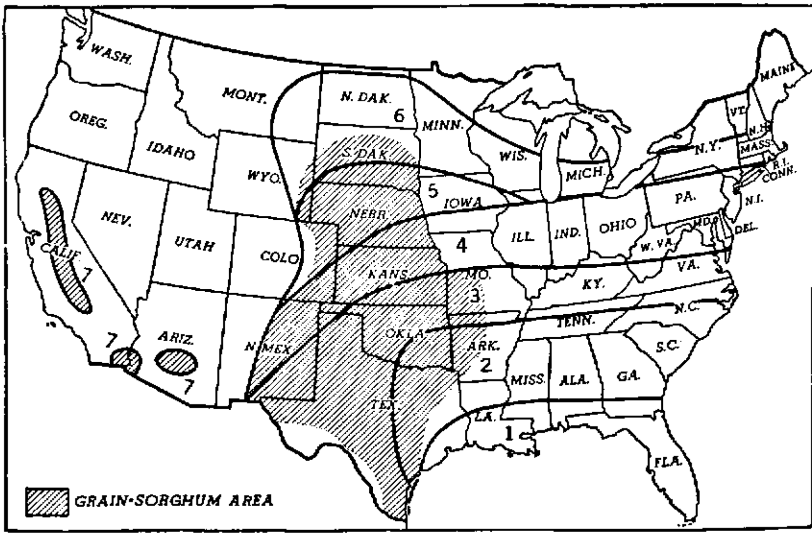

FIG. 107. Zones of sorghum production in the United States.

Westland, Pink kafir, Dwarf (Western) Blackhull kafir, Sedan kafir. Sooner, and Freed. East of the ninety-eighth meridian: Atlas and Kansas Orange sorgo, Blackhull kafir, Pink kafir, Red kafir.

Region 5. Sorgos: Leoti, Fremont, Black (Early and Minnesota) Amber, Rancher, Early Sumac, Red Amber, Dakota Amber, Atlas, Kansas Orange. Grain sorghums: Coes, Early Kalo, Day, Midland, Colby, Sedan kafir, Sooner, and Highland.

Region 6. Sorgos: Black (Early and Minnesota) Amber, Dakota Amber, Rancher, 39–30–S, Red Amber, Fremont. Grain sorghums: Coes, Sooner, Day, Colby, Sedan kafir.

Region 7. Sorgos: Honey, Atlas, Gooseneck. Grain sorghum: hegari, Double Dwarf 38 milo, Dwarf White durra.

Two varieties of standard broomcorn are grown rather widely in this country, viz., White Italian (Evergreen) and Black Spanish. Evergreen is the most productive variety in humid regions, while Black Spanish is popular in the Washita Valley of Oklahoma, and in southeastern Colorado. The Western Dwarf broomcorns, Scarborough, Fulltip, and Evergreen Dwarf are grown in western Oklahoma, eastern New Mexico, and southwestern Kansas.

Nearly one-half the Sudan grass grown is the unselected commercial type similar to that originally introduced in the United

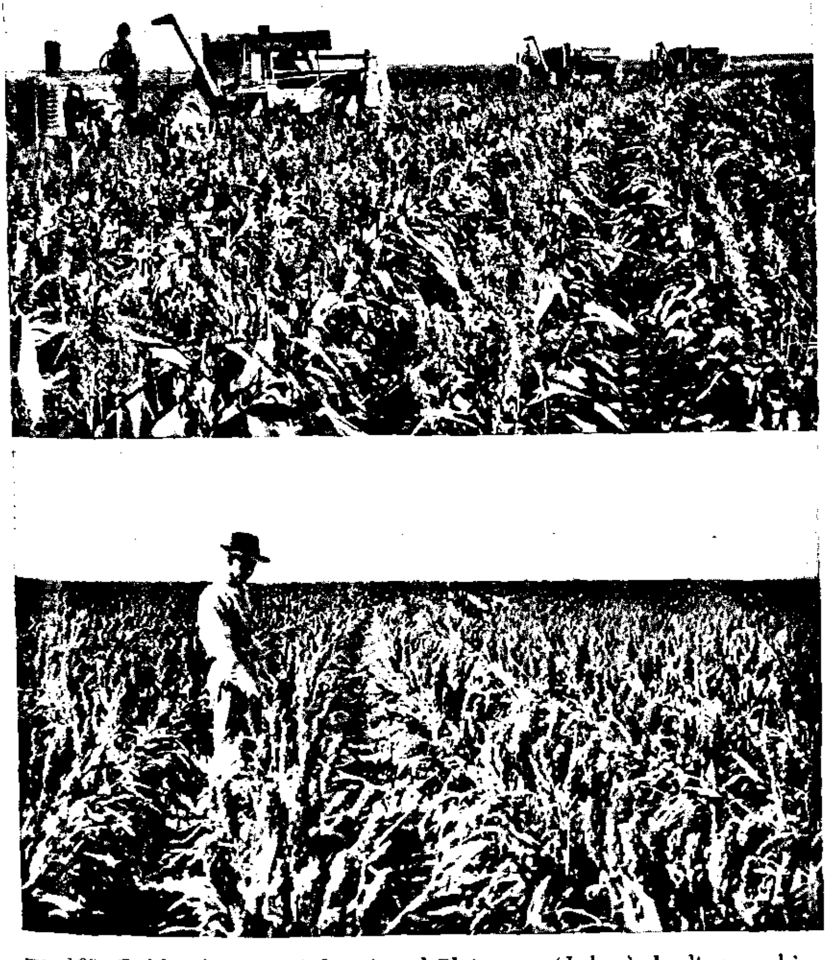

FIG. 108. Fields of Martin (*above*) and Plainsman (*below*), leading combine types of grain sorghum. (Courtesy of W. P. Martin and W. H. Cunningham.)

States, and most of the remainder is Sweet Sudan. Sweet and Tift are resistant to bacterial leaf spots, and the latter is resistant also to *Helminthosporium* and other fungus leaf spots. Sweet Sudan is juicy and sweet and consequently very palatable as pasturage. Cal-approved 23 is a high-yielding late-maturing variety.

The breeding and distribution of new sorghum varieties has

FIG. 109. A field of Atlas sorgo being harvested for silage.

effected marked changes in production since 1928.[17] The development of varieties such as Martin, Westland, Midland, Plainsman (Figure 108), Double Dwarf 38, and Bonita have made it possible to harvest the crop successfully with a combine and at the same time eliminate losses from root rot. Thus grain sorghum production has been adapted to large-scale mechanized methods. The development of quick-maturing varieties such as Coes, Early Kalo, Day, Colby, Midland, and Sedan kafir has extended the grain sorghum belt into Nebraska, South Dakota and northeastern Colorado. Breeding of the Rancher and 39–30–S varieties has reduced hazards from sorghum poisoning. Breeding of the stiff-stalked Atlas variety with palatable seeds has made sorghum a popular as well as productive silage crop (Figure 109).

Rotations

Sorghum follows other crops readily, but care should be exercised in the choice of a crop to follow sorghum. Grain sorghum often is grown continuously or is alternated with sorgo, Sudan grass, broomcorn, or corn. In northwestern Kansas an occasional rotation is sorghum, spring barley, winter wheat. A 3-year rotation of sorghum, fallow, and wheat is popular where fallow is a desirable preparation for winter wheat.[18] In the southern Great Plains grain sorghums usually produce more after fallow, winter small grains, cowpeas, or cotton than in continuous culture. Milo responds well to the additional moisture conserved by fallow, the yields on fallow in western Kansas being 75 per cent higher than from land continuously in sorghum.[25]

Sorghum is supposed to be hard on the land, the effect being particularly noticeable when small grains follow immediately. At Hays, Kansas, average wheat yields were 4.1 bushels per acre lower after sorghum than after corn.[9] Some of the injurious after-effects of sorghum can be explained by the persistence of the sorghum plant that keeps it growing until killed by frost. Sorghum thus depletes the soil moisture to a greater extent than do other crops.

Sorghum injury to subsequent crops under irrigation, where soil moisture is ample, has been attributed to the high sugar content of sorghum roots and stubble.[2] The sugars in roots of different varieties of sorghum at maturity have ranged from 15 to over 55 per cent on a dry matter basis. Corn varieties ranged from less than 1.0 to about 4.5 per cent.[4] These sugars furnish the energy for soil microorganisms which multiply and compete with the crop plants for the available nitrogen in the soil and thus retard the crop growth. This condition lasts for only a few months, or until the sorghum residues have decayed. Ground sorghum roots added to the soil have depressed nitrate accumulation and bacterial development more than have corn roots.[42] In the irrigated areas of southern California and Arizona, the sorghum crop usually follows either wheat or barley in the same season.

The injurious after-effect of sorghum on irrigated land may be overcome with nitrogenous fertilizers such as barnyard manure, or by planting inoculated legumes.[3] Both alfalfa and fenugreek made practically normal growth after sorghums in California. The detrimental influence of sorghum on dry land may be avoided by fallowing the next season. Another means of avoiding this effect is to plant spring crops after sorghum, especially those planted in May or June. By that time available nitrates will have accumulated, while much of the soil moisture deficiency caused by the sorghums will have been overcome with normal precipitation.

Fertilizers

In the Great Plains, where the larger part of the sorghum acreage is located, very little fertilizer is used on sorghum or any other crop. The limiting factor in this region is moisture and not soil fertility; the use of fertilizers does not pay. Even barnyard manure has been of little benefit to grain sorghum on most soils in the Great Plains.

In the southeastern states any fertilizer beneficial to corn locally may be expected to be equally beneficial to sorghum. Where forage is the chief consideration it is desirable to have the nitrogen content of the fertilizer rather high. In the cotton belt it has been common practice to apply 200 to 300 pounds of cottonseed meal per acre to land that is to be planted to sorghum.

In experiments at the Alabama Agricultural Experiment Station, the highest yields of sorghum silage were obtained from a complete fertilizer analyzing 6–10–4 or 6–20–4. Phosphorus was most effective in increasing yields followed by nitrogen, potassium, and lime.

For Sagrain sorghum on the alluvial soils of the Yazoo-Mississippi delta in Mississippi, an application of 150 pounds per acre of ammonium sulphate when the plants are approximately 12 inches high has been recommended.

At the Oklahoma Agricultural Experiment Station small increases in the forage yields of darso and kafir were obtained from application of barnyard manure and phosphates.

Sorghum Culture

SEEDBED PREPARATION

A warm mellow seedbed is essential to good seed germination. Weed control before planting is desirable. Experiments, in general, favor fall or winter seedbed preparation. The common methods of land preparation are plowing, listing, disking, and the use of the one-way. Where the lister is used, the second operation usually is to break or level the ridges or to split them. Plowing is common in the eastern portion of the grain sorghum region. The yields of sorghum may be increased from 25 to 30 per cent by thorough seedbed preparation of medium-heavy soils as compared with ordinary methods.[9]

PLANTING

Sorghum for grain, fodder, or silage is usually planted in cultivated rows, 36 to 44 inches apart. For hay, it is planted in close drills with a grain drill. The lister planter, corn planter, or cotton planter in each case equipped with special sorghum plates, is used for planting in cultivated rows. Sorghum plates usually have holes $\frac{3}{16}$ to $\frac{1}{4}$ inch in diameter. A corn planter, equipped with disk furrow-openers, combines the advantages of planting in warm soil with the better weed control resulting from planting in a furrow.

In recent years some of the combine types have been planted with furrow drills in rows 14 to 21 inches apart sometimes with no subsequent cultivation. One or two harrowings or the use of a field cultivator with suitably spaced sweeps are the usual means of controlling the early weeds.

The amount of seed to plant per acre for a given stand depends upon the condition of the seedbed, seed viability, seed size, and weather conditions at seeding time. A discrepancy between field and laboratory germination of sorghum seed frequently ranges from 30 to 50 per cent when seed of high viability is used.[33] Marked deficiency in field emergence may be expected when the laboratory germination is 85 per cent or lower. The stands are improved by seed treatment.[32]

Spacing between plants in the row for maximum yields depends upon tillering habits of the variety. Oklahoma experiments[30] indicate that the various sorghum groups ranked from the greatest to the least number of tillers as follows: Hegari, feterita, sorgo, milo, kaoliang, kafir, and durra. In general, kafir and most other grain sorghums make the highest yields when the plants are spaced 6 to 8 inches in rows 40 to 44 inches apart.[7, 21]

Milo varieties, such as Texas and Sooner, which tiller vigorously, produce best when spaced 12 to 15 inches between plants in the row. In cultivated rows, about 3 pounds of kafir seed per acre, 1.5 to 2.5 pounds of milo, and 3 to 4 pounds of feterita are usually planted. The dwarf combine types require 3 to 4 pounds of seed per acre under usual conditions. About 5 to 12 pounds per acre usually are planted on rich land under irrigation.

The highest tonnage of forage sorghums planted in 40- to 44-inch rows may be expected when the plants are spaced not more than 4 to 6 inches apart. Sorgo, kafir, and hegari grown for forage should be planted at a rate of 4 to 5 pounds per acre. The yields of sorghum planted in close drills for hay are about the same for all rates of seeding between 15 and 75 pounds per acre. Recommended seeding rates are 30 pounds per acre west of the 100th meridian in the Great Plains, 45 pounds between the 98th and 100th meridians, and 60 to 75 pounds east of the 98th meridian.[22]

The seed of sorghum is generally covered with 1 to 2 inches of soil. The percentage and rapidity of germination is reduced by soil temperatures below 77° F., and slightly reduced by deep planting (2½ inches).[23]

Sorghum yields usually are highest when the crop reaches maturity shortly before the average date of the first killing frost. To achieve this, quick-maturing varieties are planted late and the long-season varieties are planted early.

The date of planting of sorghums should be so arranged that germination and early growth will take place during the period of moderately high temperatures, and the blooming and filling at such a time as to avoid the highest temperatures.[38] In the southern parts of the grain sorghum region, the crop can be planted from March until August with a good chance to mature. In the northern part of the region, the soil does not become warm until after May 15. In general, the best time to plant sorghums is between May 15 and July 1.[18] A safe rule in all localities, except where the sorghum midge is troublesome, is to plant not earlier than about 2 weeks after the usual corn-planting time. The earliest possible safe planting is advisable where chinch bugs are present.

In the southern parts of Arizona and California the best yields are obtained from planting in July.

In the southern Great Plains, general optimum dates for planting grain sorghum varieties where chinch bug injury is improbable, are about May 15 for kafir; June 1 for hegari and milo; and June 15 for feterita, Sooner milo, Bonita, and other quick-maturing types.[18] Medium-late planting results in better stands, taller stalks, larger heads, and shorter growing periods than does early planting. Planting earlier than necessary for safe maturity usually reduces plant growth. Early planting sometimes is desirable to avoid conflicts with other crops at harvest time, or to clear the land in time for seeding other crops.

HARVESTING

Grain sorghum for grain usually is harvested with a combine. Grain sorghum is mature when the seeds are fully colored and have begun to harden. At that stage it may contain as much as 18 to 20 per cent of moisture. For combining, the crop should be allowed to dry until the grain contains 13 per cent or less of moisture unless provision is made for drying the grain. The cheapest method of drying is to dump the threshed grain in long low tiers or piles on a clean, dry, sodded area. Artificial drying is practiced frequently in south Texas.

The combine, used to harvest well-manured, dwarf, erect grain sorghum, saves seven-eighths of the labor in harvesting and threshing as compared with hand heading. A few days of dry weather after a severe freeze usually will reduce the moisture content of the grain to the point where it can be combined at a moisture content low enough for safe storage.

Threshing of harvested heads or bundles is done either with a combine or grain separator. Cured heads contain about 70 per cent grain. Grain sorghum bundles are topped with a special vertical-bladed sickle attached to a combine that is pulled up to each shock at threshing time.

The seed of sorghum should be fairly mature before the crop is cut for forage,[22] for the reasons listed below: (1) The largest tonnage of dry matter is obtained from mature plants, (2) the feed is more palatable, (3) the plants contain less prussic acid, (4) the fodder does not sour in the shock so easily, and (5) the silage made from mature sorghum is drier and thus less acid. The total dry weight of the plants may increase about 40 per cent between first heading and maturity.

For silage, sorghum is best harvested with a field silage cutter. For bundle feed or fodder, sorghum in rows is usually harvested with the row (or corn) binder,[5, 18, 20] but the wheat binder is more efficient for light crops of short-stalked varieties. Usually 2 to 3 months of curing in the shock are necessary before the fodder is dry enough for stacking.

Drilled sorgo is cut for hay with a mower. Because of the thick juicy stems, it takes a long time to cure sorgo sufficiently for stacking. The crop is often allowed to lie in the swath for a day or two, then raked into windrows, where it is left for 4 or more days for curing, and then usually is bunched with a buckrake or hay rake. There it is left for 2 weeks or longer. Drilled sorgo should be allowed to form seed before it is harvested, except when it has been severely injured by drought and will not head.

Sudan Grass Culture

Sudan grass will endure considerable drought but, like all sorghums, is sensitive to low temperatures.

The crop is grown much the same as other sorghums, being planted after the soil has become warm, usually about 2 weeks after corn is planted. The date of planting varies from April 1 to July 1 from the extreme south to north.[36] Sudan grass is often planted in close drills for hay production but in the southwestern semiarid region, it is planted in rows for all purposes. Since the plant tillers profusely, the final weight of stems per unit area usually is about the same for rates of seeding ranging from 15 to 40 pounds per acre. The usual rate for close drills under humid conditions is 20 to 25 pounds per acre, while the rate under semiarid conditions is generally 15 to 20 pounds. When planted in rows 36 to 44 inches apart, 2 to 4 pounds of seed per acre will produce a good stand.

Sudan grass is commonly cut for hay when the first heads appear, being more palatable at this stage than when cut later. Usually two crops are harvested for hay, although three or even four may be cut under favorable conditions. For seed production, the second crop usually is saved for seed, the first crop being cut rather early for hay. Sudan grass grown for seed usually is cut with a corn binder, shocked, and threshed like wheat. It should be cut after the greatest amount of seed appears to be ripe, and before it shatters. The straw is about as valuable for feed as is prairie hay.[6]

Broomcorn Culture

Broomcorn can be grown wherever the temperatures are high enough for dependable corn production.

Seedbed preparation for broomcorn is the same as for other sorghums.[24] The crop is planted in rows 3 to 3½ feet apart. In the humid regions, the plants should be spaced about 3 inches apart in the row. A thinner spacing of plants, 6 to 9 inches apart in the row, is desirable in the western broomcorn areas because the moisture supply is likely to be limited. The quantity of seed required usually ranges from 2 to 4 pounds per acre. Broomcorn is planted between April 1 and July 15, generally from May 1 to June 15, or after the soil has become warm. June planting is generally advocated in the western areas. Two or three periods of planting are helpful in spreading the harvest period.

Broomcorn brush turns from pale yellow to green before maturity. It should be harvested when the entire brush is green from the tip down to the knuckle. The fibers will be weak at the bottom if they are harvested while the lower ends are still yellow. The seeds are about in the milk stage when the brush is ready to harvest. About 4 or 5 days after the proper stage is reached, the brush often begins to redden.

Tall standard broomcorn is tabled before it is cut from the stalk. The tabler walks backward between two rows and breaks the stalks diagonally across each other to form a so-called table of the two rows which is from 2.5 to 3.0 feet high. In the next operation the brush is cut, pulled out of the boot, and placed on the table to dry for a short time. It is usually taken to a curing shed within 24 hours. When dwarf varieties are grown, the heads are jerked or pulled from the stalks. The heads are placed in bunches on the ground or between the stalks to dry somewhat before they are hauled from the field.

Broomcorn may be threshed either before or after curing. It is of better quality when threshed before curing because fewer of the fine branches are knocked off when the brush is moist and flexible. The best quality of broomcorn is cured in 4- to 6-inch layers on efficient for light crops of short-stalked varieties. Usually 2 to 3 months of curing in the shock are necessary before the fodder is dry enough for stacking.

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Market Factors in Broomcorn

High-quality broomcorn brush is pea-green in color, with straight fibers, and free from discoloration. The fibers should be approximately 20 inches long, pliable, and free from coarseness. Brush that is overripe, reddened, or bleached is of poor quality. Defective brush consists chiefly of spikes, crooks, and twisted, coarse, flat, and stemmy fibers.

In hauling, curing, threshing, and baling, the brush is handled in small bunches or armfuls to keep the fibers straight and untangled. These operations and harvesting require 120 to 130 hours of man labor for each ton of shed-cured brush cut from tabled stalks and handled so as to obtain a high-quality product. No feasible method of doing these tasks mechanically has been devised. The present-day costly methods have been followed for 75 years.

Broom factories are located mostly in cities or near large centers of population because it is cheaper to ship broomcorn than brooms. Factories are widely distributed over the United States.

Brooms are made by placing successive handfuls of the fiber around a handle and wrapping these on with fine wire while the handle revolves in a winder (Figure 110). The shoulder of the broom usually is made by winding a bunch of brush on each of two opposite sides with the fibers pointed toward the upper end of the handle and then bending the fibers downward. Then the outer or hurl brush is attached to give the broom a covering of smooth fibers. The fibers are then sewed and trimmed. The brush is first sorted and then dipped in a dye solution and bleached in a chamber in which sulfur is burned. It is then worked into brooms while the fibers are still moist and pliable. A ton of broomcorn brush makes 80 to 100 dozen brooms.

FIG. 110. Making brooms on a home-made foot-treadle machine. Winding the brush on the handle with wire at left. Hand-stitching a broom held in a clamp at right. Power winders and mechanical sorting, trimming, and stitching machines are used in commercial broom factories.

Johnson Grass as a Crop

Johnson grass is such a noxious weed pest that its importance as a pasture and forage crop is often overlooked. Although statistics are not available it probably is the leading perennial hay crop of the south, and furnishes an appreciable portion of the pasture. In some years 150,000 acres of Johnson grass are cut for hay in Texas alone. Johnson grass is widely distributed throughout the south and as far north as the 38th parallel from the Atlantic coast to the Colorado border. It is found even farther northward in the Potomac and Ohio Valleys and in California, Oregon, and Washington. Johnson grass seldom has been sown during the past 50 years except recently in northwestern Texas where it has been seeded for the control of wind erosion and for pasture.

Johnson grass was collected as early as 1696 apparently at Alepo, a town in Syria. It is still known in Europe and North Africa as Alepo grass or Sorgho d'Alep. It is regarded as a native of the Mediterranean coastal countries of Europe, Africa, and Asia extending eastward into India. It was introduced into South Carolina from Turkey in 1830. Ten years later it was popularized by a Colonel Wm. A. Johnson of Selma, Alabama, which accounts for its present name. Despite its weedy habits Johnson grass was recommended as a crop by certain agricultural authorities as late as about 1890, and again about 1935.

Johnson grass is most abundant and vigorous on the richer bottom lands. Where such land is reserved for Johnson grass hay meadow it is often plowed every two or three years to break up and cover the old stubble and clear the land temporarily, which stimulates new growth from the rhizomes. Sometimes winter oats are sown in the fall, harvested in the late spring and the Johnson grass then allowed to grow for hay. When the land is needed for other crops the Johnson grass is pastured heavily or mowed frequently to deplete the food reserves in the roots and rhizomes and retard development of new stalks or rhizomes. The rhizomes that develop under these conditions are mostly rather shallow. The land is then plowed in the spring and planted to a cultivated crop, or is summerfallowed. Under these circumstances the Johnson grass often is eradicated by 6 cultivations at two-week intervals on semiarid land and by 10 to 15 cultivations in humid areas. The rhizomes develop mostly after the plant blooms. Rhizomes (Figure 15) and roots live only about a year.

Johnson grass usually is cut for hay before it blooms in order to avoid the development and dispersal of seeds.[37]

On the seeds of Johnson grass the tip of the pedicel bears a swollen head from which the deciduous pediceled or staminate floret has become detached by abscission. Since the Sudan grass pedicel has no abscission layer the staminate florets become detached by the breaking of the pedicel.

Uses of Sorghum

FEED

Most of the sorghum grain and nearly all of the sorghum forage produced is fed on the farms on which it is grown. Until recently, the proportion of grain sold off the farm averaged less than 15 per cent. More grain sorghum has been grown for the market since 1941 when the distribution of improved varieties for harvesting with a combine made grain sorghum a profitable cash crop. Except for poultry the threshed grain usually is ground before being fed. When the crop is headed by hand, the heads often are ground without threshing, forming "head chops." Grain sorghum bundles may be fed whole or chopped.[18] The grain that goes to market is used mostly in mixed ground feeds or poultry scratch feeds.

INDUSTRIAL USES

At times grain sorghum replaces corn grits in the brewing and distilling industries. During World War II considerable quantities were used in the manufacture of alcohol. Also during that war the grain of waxy varieties, particularly Cody, was used for extraction of starch to manufacture a satisfactory substitute for *Minute* tapioca. The starch is extracted from the grain in a manner similar to that used in the manufacture of corn starch. The most recent large-scale industrial development is the manufacture, from the ordinary nonwaxy grain sorghums, of starch, glucose, sirup, oil, gluten feeds, and other products, similar to those produced in the wet-milling of corn.

COMPOSITION

The composition of grain sorghum (Appendix Table 2) is similar to that of corn except in being slightly higher in protein and lower in fat.[10] In feeding value, grain sorghum usually ranges from 90 to 100 per cent, averaging about 95 per cent of that of corn. In feeding bound grain sorghum (bundle feed) one or two bundles constitutes a single feeding of both grain and roughage for an animal. Sorgo bundles fed in the same manner often require some supplemental grain to balance the higher ratio of roughage to seed. Sorghum silage has about the same composition as corn silage. The comparative feeding value of the two silages varies with the relative moisture content and the proportion of grain they contain. When these two factors are equal, corn silage has a higher feeding value because the grain is softer and more completely absorbed in the intestinal tract.

Sorgo and Sudan grass hay are coarser but similar in chemical composition to other grass hays except in being somewhat higher in protein and ash and lower in fat and crude fiber due to the fact that they usually are cut at an earlier stage of growth.

SIRUP

Sorgo for sirup is cut when the seed is nearly ripe, or at least in the stiff-dough stage. Before cutting, the leaves usually are stripped from the stalks by hand, using a special two-pronged tool, or a lath, paddle, or pitchfork. After cutting, the stalks are topped with a knife to remove the heads, peduncles, and often two or three of the upper internodes. The juice of the upper internodes and peduncle is much higher in starch and mineral matter than that from the remainder of the stalk. The leaves constitute about 10 per cent, and the topped portion 20 to 30 per cent of the total green weight of the stalk.[41] The juice is expressed from the stripped cane by crushing the stalks between revolving fluted iron rolls in a cane mill equipped with three (or occasionally two) rolls (Figure 111). The strained juice that sometimes is allowed to settle for a time is piped to an evaporating pan where it is boiled down to a sirup containing about 70 per cent sugar. During the boiling, the juice is skimmed constantly to remove floating impurities such as chlorophyll, soil, plant fragments, proteins, gums, fats, and waxes (Figure 112). Often the juice, or the partly evaporated semisirup is treated with lime, clay products, or phosphoric acid to neutralize the acid juice and to precipitate impurities. Treatment with malt diastase, an enzyme product, hydrolyzes the starch into glucose and prevents thickening or jellying due to the 0.5 to 3.0 per cent

FIG. 111. Crushing the juice from sorghum stalks.

FIG. 112. Skimming the boiling juice in a sirup pan. Horse-drawn sweep-powered sorghum mill in background.

of starch usually present in the juice. With such treatment a concentrated sirup containing as much as 70 per cent sugar will pour readily. Sometimes a yeast extract containing another enzyme, invertase, also is added to change part of the sucrose (cane sugar) into dextrose (glucose) and levulose (grape sugar), and thus prevent crystallization (sugaring). The juice of a good variety of sorgo grown under suitable conditions contains 13 to 17 per cent sugar, of which 10 to 14 per cent is sucrose.

A good field should yield 15 tons of fresh sorghum or 10 tons of stripped stalks per acre. A ton of stripped stalks should yield 700 to 1200 pounds of juice or 8 to 20 gallons of sirup. However, the average yield of sirup is less than 60 gallons per acre. Sorgo sirup acquires its flavor or tang chiefly from organic acids that are present in the juice. The sirup is rich in iron, particularly so when it has been evaporated in an iron pan or kettle. Sorghum sirup often is referred to as molasses, which is a misnomer, since molasses is a by-product of sugar manufacture. The production of sorgo sirup has declined about 75 per cent since 1920 when the industry reached its maximum.

SUGAR

Attempts to develop a sorghum sugar industry have not been successful thus far because of certain difficulties and limitations that make the sugar more expensive than that from sugarcane or sugar beets. Sorghum sugar was manufactured on a commercial scale under public subsidy in Kansas and New Jersey about 1890. Extensive experiments on sorghum sugar manufacture were made between 1878 and 1893 and again between 1935 and 1941. The difficulties of crystallizing the sugar were overcome as a result of recent research which showed that crystallization is satisfactory after the starch and the aconitic acid crystals are removed by centrifuging. The stalks must be harvested promptly when they reach the proper stage and they deteriorate rapidly if not processed at once. Sorghum often is less uniform in yield and composition than are sugarcane and sugar beets. The yields of sorghum that is grown during a period of 4 or 5 months obviously are less than are obtained from sugarcane that has a growing period of 8 to 14 months. Further research, and development of varieties adapted to the extreme south which also yield a high percentage of sucrose, may ultimately create an economical source of sugar.

Diseases

The principal diseases attacking sorghum in this country[11] are smuts, leaf spots, and root and stalk rots.

KERNEL SMUTS

The kernel smuts may reduce seed production materially, but probably have less effect on forage yields. All sorgos, kafirs, and broomcorns are susceptible. Each infected ovule becomes a mass of dark-colored spores instead of a sorghum (Figure 113). Both covered kernel smut (*Sphacelotheca sorghi*) and loose kernel smut (*S. cruenta*) can be controlled by seed treatment with dust fungicides, such as ceresan and other organic mercury compounds, copper carbonate, Arasan and Spergon. Varieties of feterita, milo, and hegari are resistant to certain races of these smut organisms.

HEAD SMUT

The head smut disease, caused by *Sphacelotheca reiliana,* is much less common than the kernel smuts. The entire head is replaced by a gall or smut mass (Figure 113). The spores are carried in the soil and occasionally on the seed. Seed from fields where the disease is prevalent should be avoided. Certain varieties, including Early Sumac, Leoti, and Red Amber are inclined to have head smut.[27] Seed treatment offers no protection against infection carried in the soil. Removal and burning of diseased plants will eliminate reinfestation of the soil.

ROOT AND STALK ROTS

Root rot, which attacks the roots and crown of a plant, formerly caused extensive damage to darso and all varieties of milo, but at the present time resistant strains have replaced nearly all of the susceptible varieties.[40] This disease is caused by a widespread soil-borne fungus, *Periconia circinati*. Charcoal rot attacks the base of the stalk and also the larger roots, rotting away the pith and caus-

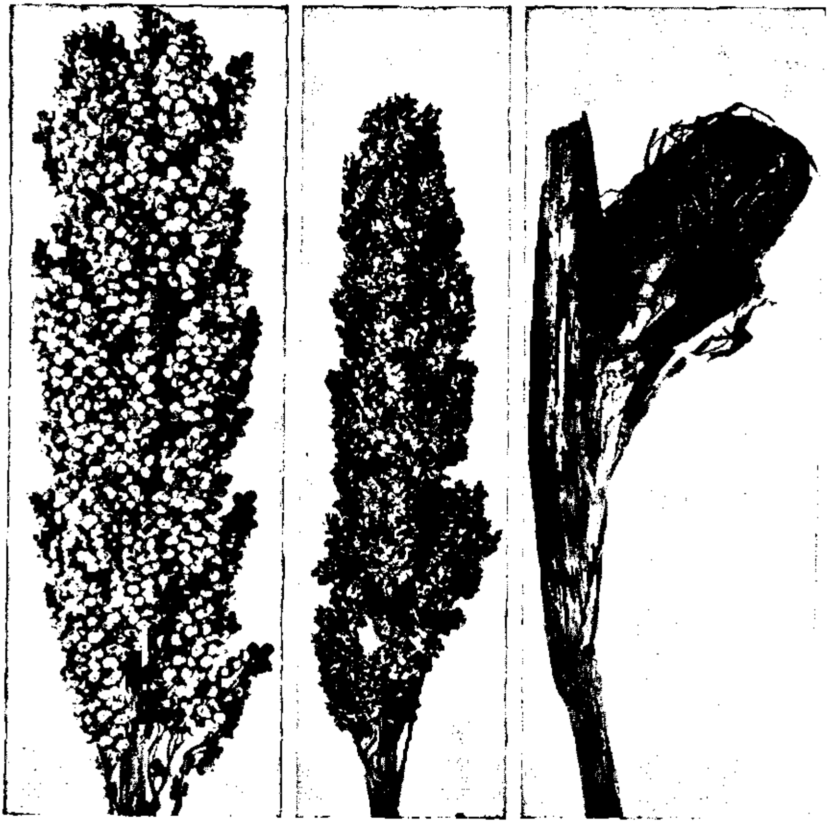

FIG. 113. Healthy kafir head (*left*), kernel smut (*center*), and head smut (*right*).

ing the stalk to fall over. The disease is caused by a soil-borne fungus, *Macrophomina phaseoli* (*Sclerotium bataticola*) which also attacks several other crop plants. Damage from this disease is limited where the soil is well supplied with moisture, and the sorghum planting is delayed so that the crop reaches maturity under mild favorable fall conditions. Most varieties of sorgo and kafir are partly resistant to charcoal rot.

LEAF SPOTS

Bacterial leaf spot diseases include stripe, caused by *Pseudomonas andropogoni;* spot, caused by *Pseudomonas syringae;* and streak, caused by *Xanthomonas holicola.* Fungus leaf spot diseases include sooty stripe, cause by *Titeospora andropogonis;* rough spot, caused by *Ascochyta sorghina;* anthracnose, caused by *Colletotrichum graminicolum;* leaf blight, caused by *Helminthosporium turcicum;* zonate leaf spot, caused by *Gleocercospora sorghi;* gray leaf spot, caused by *Cercospora sorghi;* and rust, caused by *Puccinia purpurea.* Cody, Tift Sudan grass, Sweet Sudan grass, Leoti sorgo, and shallu are resistant to bacterial leaf spots. Atlas sorgo and most varieties of kafir are resistant to several of the fungus leaf spot diseases.[11]

OTHER DISEASES

Other diseases attacking sorghum include *Rhizoctonia* stalk rot, caused by *Rhizoctonia solani;* and anthracnose stalk rot and red rot caused by species of *Colletotrichum.* Weakneck is not a true disease, but a decay at the base of the peduncle, occurring after the upper part of the stalk has ceased growth and begun to dry. This decay, which causes mature heads to fall over and be lost, is most damaging to combine types of grain sorghum that must stand in the field for some time after they are ripe. The Midland variety is relatively free from weakneck damage.

Insects

The most destructive insect pests on the sorghums are the chinch bug, sorghum midge, corn-leaf aphis, corn earworm, and sorghum webworm. Grasshoppers cause little injury to the foliage of sorghum even where corn is wholly destroyed (Figure 114). However, they seem to prefer the leaves of milo and hegari to those of most other sorghums. Grasshoppers eat developing sorghum grain, but they may be controlled with poisoned bran mash or with chlordane or toxaphene sprays.

CHINCH BUGS

The chinch bug, *Blissus leucopterus,* is a sucking insect that feeds heavily on the leaves and sheaths of sorghum. The chinch bug moves to sorghum from nearby small-grain fields after the harvest of the latter.[8] They usually migrate on foot from small grains to corn in Kansas and northward, but later in the season they acquire

FIG. 114. Grasshoppers stripped the corn at the left but scarcely attacked the kafir at the right.

FIG. 115. Chinch bugs destroyed the sorghum varieties in the two rows where the stakes stand but caused only slight damage to the three resistant varieties.

wings and fly to the sorghum field. There they mate and deposit eggs. These eggs hatch a second generation which continues to feed on the sorghum plants. A third generation develops in the south in the fall. The most serious injury is caused in seasons of low rainfall. Many chinch bugs die in cool wet weather. The migration of chinch bugs at harvest from small grain fields to the sorghums may be prevented by construction of a creosote-posthole barrier line between the two fields. South of central Kansas chinch bugs develop wings by the time the small grains are harvested. When they migrate by flight, creosote barriers are ineffective, but injury can be reduced by early planting, and by use of resistant varieties [22] (Figure 115). The adult chinch bugs hibernate at the base of bunches of grass or in trash. Spraying with insecticides such as chlordane, benzene hexachloride, and sabadilla will kill chinch bugs.

The milos are very susceptible, the feteritas susceptible, and the kafirs and sorgos rather resistant to chinch bug injury.[31] Most of the sorgos are slightly more resistant than the kafirs, but others are susceptible. Atlas sorgo is very resistant to chinch bugs.

SORGHUM MIDGE

The sorghum midge is abundant in the southern states. It formerly made grain sorghum production unprofitable in that region but in recent years, the damage has been less severe, probably because sorghum is more abundant and because more natural enemies are present. The midge is a small fly with a red body.[22] It lays its eggs inside the glumes at the blossom stage. The egg produces a small white larva that absorbs juices from the ovary and prevents seed development. The adult midge emerges to start a new generation every 14 to 20 days under favorable conditions. The larva causes the injury to the developing seed.

The midge breeds on Johnson grass in the spring, and infests sorghums as soon as they head. All sorghums are subject to attack. The midge overwinters in the larval stage on sorghum heads, in Johnson grass, and on trash. Planting sorghums very early in the season, so that they come into bloom before the midge is plentiful, is one means of combating this insect.

CORN-LEAF APHID

In some seasons, the corn-leaf aphid (*Aphis maidis*) is a serious pest of sorghum,[9] when large numbers occur in the leaf curl. This hinders the exsertion of the head from the boot. The secretion of honey-dew by the aphids forms a sticky mass about the heads, which encourages the growth of molds, which in turn prevent the production of high-quality seed. Aphids winter in the southern states and migrate north. No control method has been developed.

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14 SUGARCANE

Economic Importance

Practically the entire acreage of sugarcane grown for sugar production in the continental United States is found in Louisiana and Florida. Louisiana produced about five-sixths of the 465,000 tons of cane sugar obtained annually. In the 10-year period from 1937 to 1946 about 299,000 acres produced an average of 6,100,000 tons of cane. The average yield was 20 tons of cane per acre. About 8 per cent of the total cane is saved for planting. As a by-product of cane sugar, nearly 38 million gallons of molasses are recovered each year.

Sugarcane is grown rather extensively for sirup manufacture in Georgia, Alabama, Louisiana, Mississippi, and Texas. In the 10-year period from 1937 to 1946 an average of 130,000 acres was harvested for sirup, the average yield being about 164 gallons per acre, and annual production some 21 million gallons. Most of the sugarcane for sirup is produced on small acreages for home use, a small surplus being placed on the market. It is produced for sirup as far north as southern North Carolina westward through southern Arkansas, and occasionally in Oklahoma. Some sugarcane also is grown for silage or forage in the south.

The leading countries in sugarcane production are: India, Cuba, Java, Brazil, Philippine Islands, and United States (including the territories of Puerto Rico and Hawaii) (Figure 116). The world production of sugar from cane is nearly 23,000,000 tons. Sugar beets produce almost another 13,000,000 tons of "cane" sugar (sucrose). Sugar is an economical source of food energy. It supplies fully one-seventh of the energy in the American diet.

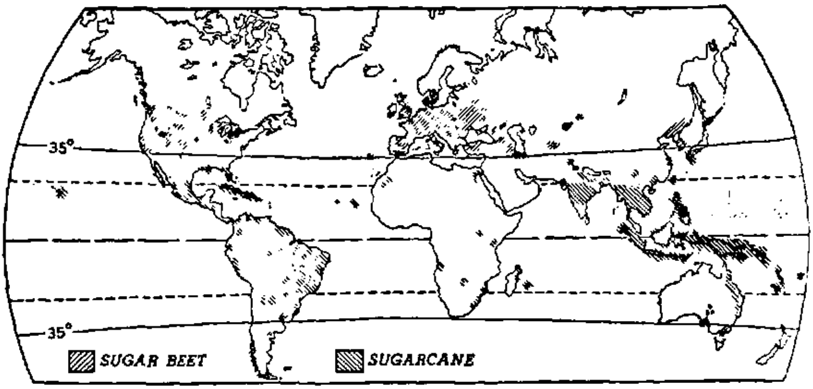

FIG. 116. Sugarcane and sugar beet producing regions of the world.

Origin and History

The cultivated sugarcanes are probably derived from wild species indigenous in Asia and the islands of Melanesia.[7] Sugarcane of economic usefulness has been transported by man probably for thousands of years. Sugarcane was cultivated in India as early as 1000 B.C., and in China crude sugar was being made from it by 760 B.C. The first refined white sugar was made in Persia about 600 A.D.[19] Most people still prefer refined sugar.

Sugarcane was brought to Santo Domingo by Columbus on his second voyage in 1493, but the crop was not established permanently until 1506. Introduction of sugarcane to Louisiana dates from 1751, while the first sugar was refined in that state in 1791.

Adaptation

Sugarcane is primarily a tropical plant that usually requires 8 to 24 months to reach maturity. The temperatures should be high enough to permit rapid growth for 8 months or more. There usually is a period of low growth activity and increased sugar storage in most cane-producing countries, that follows a period of rapid growth. The cane is considered to be ripe when the sugar content is at its maximum. Sugarcane growing has gradually migrated from the tropics to the subtropical regions in the United States and other countries.

The best soils for sugarcane are well supplied with minerals and organic matter. In Louisiana, heavy Yazoo and Sharkey soils are used for sugar production. Silt loam, silty clay loam, and fine sandy loam soils are preferred for sirup production. Drainage must be provided where the water table is less than 3 feet from the surface. In Florida the best sugarcane soil is the Okeechobee muck (or custard apple land), which consists of about 50 per cent organic matter. Less favorable lands are the Okeechobee peaty muck (or willow and elder land) containing 75 to 85 per cent of organic matter, and Everglades peat (or sawgrass land) containing 90 to 97 per cent organic matter.

In Louisiana 25 to 30 tons of cane per acre is considered a good yield, but in Hawaii, where the crop grows 18 to 24 months, average yields up to 70 tons per acre have been obtained. Extreme yields may exceed 100 tons per acre. On the better lands in Florida planted cane may yield 60 to 70 tons per acre, and ratoon or stubble cane as much as 40 to 45 tons per acre.

Botanical Description

Sugarcane is a tall perennial grass[4] with culms bunched in stools of 5 to 50 culms or evenly scattered. The stalks are 1 to 2 inches in diameter and may be 15 feet or more in height. The internodes are comparatively short, usually 2 to 3 inches, often being marked by corky cracks. A sugarcane plant has a leafy appearance because of the abundant tillers and the numerous nodes, each of which produces a leaf. The stalks are covered with a layer of wax that forms a band at the top of each internode. In addition to the growth ring there is a root band and a single bud or *eye* at each node (Figure 13). The leaf blade is usually erect, ascending, and gently curved, but it may be erect with drooping tip. The leaf blade is green, sometimes with a purplish cast. The leaf sheath folds around the stem and serves as a protection to the bud.

Sugarcane seldom produces seed in the United States except in Florida, and consequently it is harvested before the inflorescence appears. Ordinarily the panicles do not appear until at least 12 to 24 months after the cane is planted. The inflorescence is an open, much-branched plumelike panicle known as the arrow, 8 to

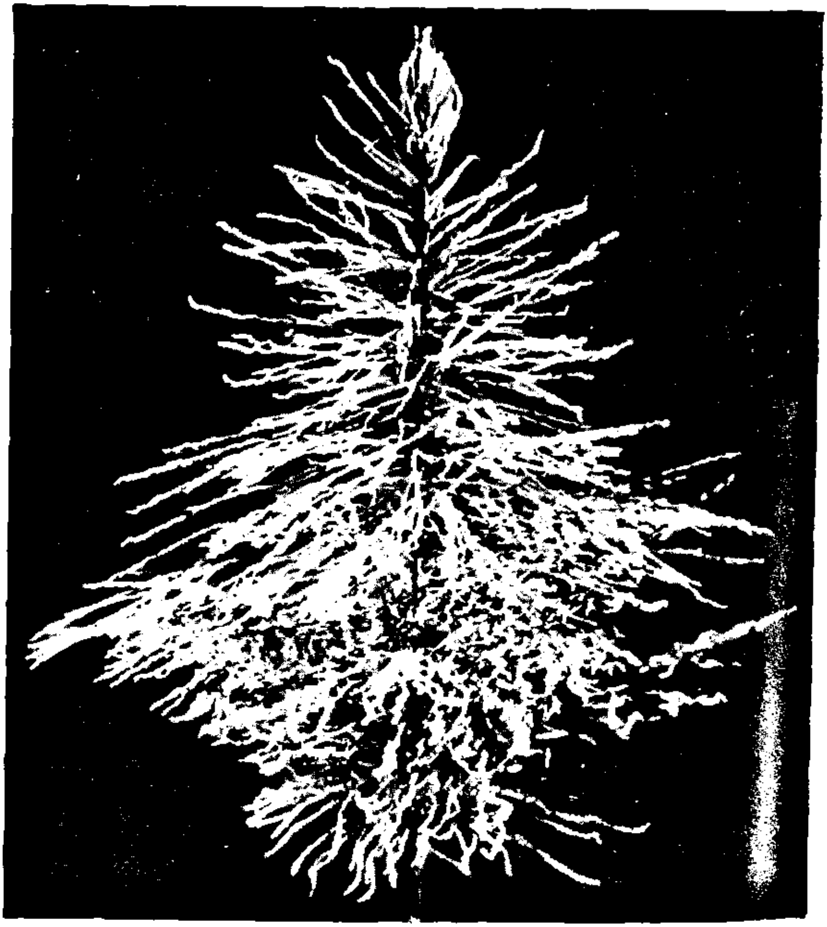

FIG. 117. Extra large sugarcane inflorescence or "arrow" about 3 feet long.

24 inches long (Figure 117). The spikelets, about 3 mm. long, are obscured in a tuft of silky hairs two to three times as long as the spikelet. Each flower is subtended by two bracts which form the outer and inner glumes (Figure 14). There is also a sterile lemma, but the fertile lemma and palea of the typical grass flower are wanting.[3] The fruit is small, about 1.5 mm. long, with a distinct constriction in the region opposite the embryo. The seed, which is enclosed in the glumes and the sterile lemma, is of low viability.

While the flowers of all sugarcane varieties are perfect, many plants are pollen sterile or at least self-sterile.[10] There are probably no completely sterile varieties, except under extreme conditions.

Sugarcane Species

The sugarcanes of America are derived from five species and their hybrids. In the good sugar quality *noble* canes, *Saccharum officinarum,* the axis of the inflorescence is without long hairs.[12] The stalk girth is large, the leaves wide, and the fiber content low. The Chinese canes, S. *sinense,* have long hairs on the axis of inflorescence. The northern Indian canes, S. *barberi,* differ from the Chinese canes in having narrower blades and more slender stalks. The wild canes of Asia, S. *spontaneum,* are used in making hybrids with other species. The stalks are very slender, while the leaves are narrow. The wild cane of New Guinea, S. *robustum,*[7] has stalks of medium thickness (about 2.5 cm. in diameter), very hard, and 25 to 30 feet in height. The nodes are swollen. The leaves are of medium width and rather long. The flowers are very similar to those of S. *officinarum.*

Varieties

Disease epidemics resulted in almost total destruction of the commonly cultivated sugarcane varieties in the United States by 1926. Disease-resistant varieties were soon introduced and others were developed in this country at Canal Point, Florida. These have largely replaced D–74 and Louisiana Purple, two noble canes susceptible to mosaic, root rot, and red rot.[6] The resistant varieties of *Saccharum officinarum* were developed by crossing the susceptible, high-sugar noble varieties with other species, especially S. *spontaneum* and S. *barberi* which are resistant to the most serious sugarcane diseases. These hybrids were then backcrossed to the noble varieties. High-yielding disease-resistant plants that were high in sugar percentage were selected from the back-cross progeny and increased by vegetative propagation. Practically all the improved American varieties were derived from all three of the above species.

The standard varieties in Louisiana are Co. 290, C. P. 29–120, C. P. 34–120, and C. P. 29–320.* Others grown to some extent are C. P. 807, C. P. 28–11, C. P. 29–103, C. P. 29–116, C. P. 34–79. Co. 281 formerly was a desirable variety in Louisiana because it lost very little sugar by deterioration in the windrow. It has now been replaced by C. P. 34–120. A sufficient acreage of a windrowing cane, for example, C. P. 34–120, should be planted to guard against early freezes,[11] and early-maturing varieties such as C. P. 28–19 and C. P. 29–320 should be planted for early mill operations. It is unsafe in Louisiana to plant too large a proportion of Co. 290, a midseason cane, because serious losses from early freezes are likely to occur. The most important sirup varieties are Co. 290 and C. P. 29–116.[8]

A variety of S. *sinense* called Japanese sugarcane has been grown in the south for forage since 1878,[17] and occasionally it is harvested for sirup. It is hardy and ratoons well, but has slender, hard, fibrous stalks rather low in sugar content. This variety is planted like other sugarcanes because it also does not produce seed. At the present time varieties with a higher sugar content such as Co. 281, Co. 290, and C. P. 29–116 are the chief forage types. The so-called Japanese Seeded Ribbon Cane, also grown in the south, is a sorghum and not a sugarcane. It was misnamed for promotional purposes.

Sugarcane-sorghum crosses have been made with the object of producing a sugar plant that would mature in a shorter period, be adapted farther north, or be grown commercially from seed. The first of such crosses was made in India.[6] P.O.J. 2725 sugarcane has been crossed with Honey sorgo (Japanese Seeded Ribbon Cane), as well as with Kansas Orange sorgo.[5] About 3 per cent of the hybrids showed sufficient promise to warrant further trial. Since sugarcane and sorghum differ in chromosome number most of the hybrid plants are sterile. The objectives of this cross are extremely important but the probability of successful achievement now seems rather remote.

* Varieties having the designation C. P. originated at the U. S. Sugar Plant Field Station, Canal Point, Florida. The Co. varieties are from the Coimbatore Breeding Station, Coimbatore, Madras, India. The P.O.J. canes are from the East Java Experiment Station (Proef-Station Oost-Java) at Pasoeroean, Java.

Culture

Sugarcane usually is not grown in a regular rotation with other crops. In Louisiana the land usually is spring-plowed and then planted to soybeans for green manure after two or three cane crops have been harvested. This is plowed under in early fall and the land is again planted to sugarcane. In the Florida Everglades region the intervening green manure crop is omitted because the muck soils there already contain excessive quantities of organic matter and nitrogen.

A common fertilizer for sugarcane in Louisiana is an application each spring of 200 to 300 pounds per acre of a 12–4–4 mixture. Often only nitrogen is required and this is supplied by the application of about 175 pounds per acre of ammonium sulfate or calcium cyanamid, which furnishes about 36 pounds of nitrogen. No additions of nitrogen are needed for Florida muck soils. The usual fertilizer practice there is an application of 100 to 150 pounds annually of sulfate of potash or muriate of potash, plus the three minor elements, manganese, copper, and zinc. These latter may be supplied by applications of 60, 25, and 25 pounds per acre, respectively, of manganese sulfate, copper sulfate, and zinc sulfate. The final product of sugarcane, refined sugar, contains no fertilizer elements.

Seedbed preparation for sugarcane is similar to that for corn in the same region. In Louisiana the soil is thrown into beds 1 to 2 feet wide and 5½ to 6 feet apart. A water furrow is left between the beds where the land is inclined to be wet. Level culture is practiced in Florida.

PLANTING

Sugarcane is produced commercially from stalk cuttings or seed canes. The cane is stripped and cut into 2 or 3 foot lengths. These cuttings are planted in furrows, one to three continuous lines of stalks being dropped in each row. The spacing between rows ranges from 4 to 7 feet. The amount of seed cane planted varies from 1 to 4 tons per acre, depending upon the stalk diameter as well as upon the number of lines planted in a single furrow (Figure 118). The stalks are covered 2 to 8 inches deep, or only deep

FIG. 118. Planting sugarcane.

enough to avoid frost injury. A light furrow turned from each side covers the seed canes.

The canes can be planted either in fall or spring.[8] In Louisiana, the greater part of the crop is planted for sugar production in October and November. Planting previous to sugar harvest is commonly practiced in order to avoid labor conflicts. In the northern portion of the sugarcane growing area, the crop is spring planted. There the canes are preserved over winter in mats or windrows, being covered with soil to protect them from the cold. Even when fall planted, the new crop makes very little growth until spring.

In the areas where sugar is produced, more than one crop of sugarcane may be harvested from a single planting. The first crop is known as plant cane, while subsequent crops are known as stubble or ratoon crops. In the spring, the general practice is to bar-off, i.e., to throw aside the soil covering from either the stubble or non-emerged fall-planted cane, using a plow, harrow, or other implement. This leaves the cane on a narrow bed that warms up quickly to start spring growth of the sugarcane. After growth is well started, the fertilizer is applied in the furrows next to the row and the furrows are levelled. The seasonal cultivation and the bedding move so much soil toward the cane row that it is necessary to bar-off each spring. Cultivation to control weeds is necessary until the plants shade the ground. Weeds within the row are destroyed by hand hoeing. Recently the weeds, chiefly Johnson grass and alligator weed (*Alternanthera philoxeroides*), have been controlled by flaming. Alligator weed also can be controlled with 1½ to 2 pounds of 2,4–D per acre, applied as a spray or dust mixture before the cane is 2 feet tall.

Stands of sugarcane are not permanent, but in Louisiana and other sugar-producing areas the harvesting of two ratoon crops is rather common despite the low yields as compared with plant cane. Usually an appreciable percentage of row space comprises gaps of different lengths that originate either in plant-cane or second-year stubble, but occasionally in first-year stubble. The varieties Co. 290, C. P. 807, C. P. 28–19, C. P. 28–11, and C. P. 29–320 will ordinarily produce satisfactory second-stubble crops because of better initial stands than those obtained with the previously cultivated P.O.J. varieties.[2]

HARVESTING

Sugarcane begins to mature with the advent of cool nights in the fall, usually in October. It continues to mature until its growth is checked by frost. Hand harvesting consists of stripping off the leaves, removing the tops, and cutting off the stalks at the bottom (Figure 119). Specially designed knives and stripping implements are used. About 20 to 30 per cent of the total crop is leaves and tops. Sometimes the harvested cane is laid across the beds in windrows; after the leaves are nearly dry the windrows are fired to burn off the leaves, thus eliminating hand stripping. About 40 per cent of the Louisiana sugarcane crop is harvested by machinery, but the Florida crop is cut by hand. One type of machine cuts, tops, and loads the cane (Figure 120). Other machines only cut and top it. The harvested stalks are hauled to the cane mill where the juice is extracted to make sugar or sirup. Practically all the cane except small lots is loaded mechanically whether it is cut by machine or by hand. The loaders or derricks usually are of the grapple type driven with a gasoline engine and mounted on a wagon or truck. The cane is loaded on trucks or on rubber-tired

FIG. 119. Sugarcane topped and stripped before cutting.

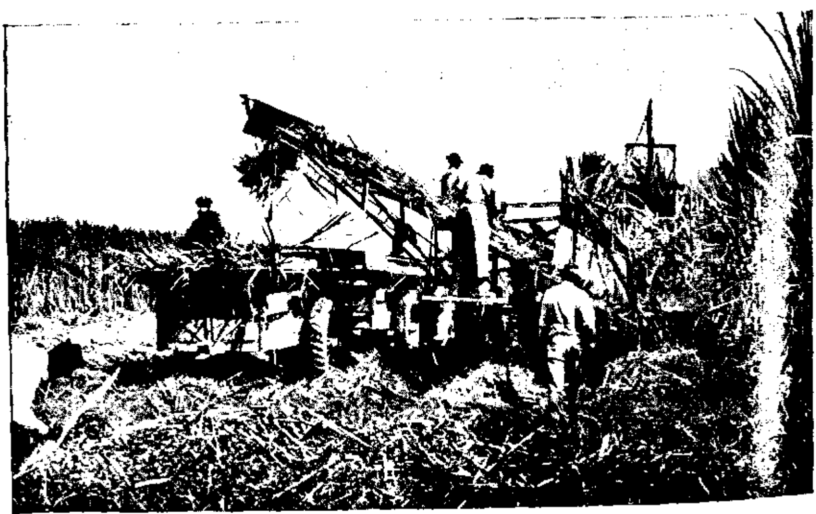

FIG. 120. A machine that cuts and loads sugarcane. (Courtesy of Bureau Plant Industry, Soils, and Agricultural Engineering.)

carts holding 2 or 3 tons. It is hauled to the mill on these vehicles or is reloaded for shipment. It is shipped in cars on narrow-gauge private railroads, in standard railroad cars, or on barges by water.

In Louisiana, cane should be windrowed when the grinding season is to be prolonged after December 20.[11] While this protects the cane against freezing damage, there is some loss of sucrose through physiological inversion. It is desirable to windrow only varieties that show the least sugar inversion. The cane varieties Co. 281 and Co. 290 will windrow 3 to 6 weeks without serious deterioration.[16] It is safer to windrow cane before it is injured by freezing temperatures, but damaged cane can be windrowed to protect it from further freezing injury so long as the cane stalks have sound eyes. Sugarcane, particularly the Co. 281 variety, can be stored in the mill yard for 6 to 10 days without serious deterioration so long as it is kept thoroughly wet.[15] Storage during fair weather insures more continuous mill operation during periods of wet weather that interfere with harvesting.

Sugar and Sirup Manufacture

In sugar manufacture, the sugarcane stalks are cut, sometimes shredded, and then passed between a series of heavy grooved iron rollers to press out the juice.[9] The crushed residue is known as bagasse. Milk of lime (hydrated lime in water) is added to the strained juice after which the limed juice is heated with steam. The impurities unite with the lime and appear on the surface as scum or at the bottom of the clear juice as sediment. The clear juice, along with the settlings, is conducted into a series of multiple-effect vacuum evaporators where it is concentrated to a semisirup containing about 50 per cent sucrose. This sirup is then pumped into other vacuum pans where it is crystallized by further evaporation. The mixture of sugar crystals and molasses, called massecuite, is then separated in a centrifuge chamber with perforated walls. The resultant raw sugar containing about 96 per cent sucrose is then shipped to refineries.

A large sugar mill may grind 2,000 to 4,000 tons of cane in 24 hours and process the crop from 5,000 to 10,000 acres in a season. Fresh sugarcane may contain 80 per cent water and 88 to 90 per cent juice, including dissolved and suspended solids. In efficient sugar mills the juice extracted is 75 per cent or even 80 per cent of the weight of the cane. Small sirup mills extract 50 to 65 per cent of juice. Average juice contains 15 to 20 per cent total solids, of which some 2 to 3 per cent is impurities (invert sugar, nitrogen compounds, salts, fats, wax, fiber, etc.), leaving 12 to 17 per cent sucrose. In Cuba and Hawaii a ton of average cane yields about 240 pounds of raw (96 per cent) sugar and 5 gallons of blackstrap molasses but in the United States only 160 to 175 pounds of sugar are obtained on the average. About 500 pounds of bagasse containing 50 per cent or more moisture also is obtained from a ton of cane. The juice of sugar plants (sugarcane, sorghum, or sugar beets) usually is tested with a Baume hydrometer, giving an arbitrary reading in degrees, or with a Brix hydrometer having a scale reading that approximates the percentage of total solids (degrees Brix) based upon the weight of sugar.[20] A similar measure, using only a few drops of juice, can be obtained with a refractometer that measures the refractive index of the liquid, and that also has a scale giving a reading of the percentage of total solids. The percentage of sucrose in the juice is measured with a saccharimeter, a special type of polariscope having a sugar percentage scale. The purity of the juice in per cent is then determined by the formula Sucrose/Brix × 100.

Most of the sugarcane used for sirup is milled on 3-roll mills, many of which are operated by animal power. These have a lower pressure than the 30 tons per square inch used on the rolls of commercial sugar mills, and the juice extraction is less.

The primary manufactured products are sugar, sirup, and edible molasses. By-products consist of blackstrap molasses, bagasse or stalk residue, filter-press cake, and bagasse ashes. Blackstrap molasses is largely used for the production of alcohol and for livestock feed. The cane fiber in bagasse is used for manufacture of wall board such as that sold under the trade-name Celotex. Most of the bagasse is burned for fuel in the operation of the sugar mills, the ashes being returned to the sugarcane fields as fertilizer. Filter-press cake has a fertilizer value equal to barnyard manure.

Diseases

MOSAIC

Mosaic is a virus disease introduced into this country probably about 1914. Mottling of the leaves is the principal symptom. One type of mosaic appears as longitudinal streaks. The principal damage is caused by stunting, particularly in the noble canes. The disease is transmitted by several species of aphids. The only practical control for mosaic is the use of resistant varieties.

RED ROT

Red rot caused by the organism *Colletotrichum falcatum* is one of the major sugarcane diseases, especially in areas where the crop is produced for sirup. The disease attacks the stalks, stubble rhizomes, and leaf midribs of the sugarcane plant.[1] The disease is recognized by longitudinal reddening of the normally white internal tissues of the internodes, a discoloration that may extend through many joints of the stalk. Lesions on the leaf midrib are dark reddish areas. Red rot causes poor stands of both plant and stubble crops, brings about destruction of seed cane in storage beds in sirup-producing states, and induces inversion of sucrose in mature canes. Among the control measures advocated are seed cane selection, summer planting of susceptible varieties, and burning of trash and diseased cutting discarded from the seedbed in sirup areas. Resistant varieties include C. P. 34–120, C. P. 34–79, C. P. 28–11, C. P. 28–19, C. P. 29–320, Co. 281, and Co. 290.

ROOT ROTS

The root rot diseases cause great damage to sugarcane, particularly in Louisiana. The principal cause appears to be *Pythium arrhenomanes*. Root rot is usually manifested by an unthrifty appearance, deficient tillering and closing in of the rows, yellowing of the leaves and severe wilting, and even death of young plants in occasional years.[18] Poor stands may result in failure of the crop on heavy clay soils due to destruction of the roots. A high water table combined with a fine-textured soil, and low winter and spring temperatures, are probably indirect causes of severe outbreaks. Cultural practices that promote rapid growth are the most beneficial controls. Root rot damage of susceptible varieties has been markedly reduced by plowing under all cane trash by moderate applications of filter-press cake or barnyard manure, and by good drainage. Among present commercial varieties in Louisiana, C. P. 34–120, Co. 290, C. P. 807, C. P. 28–11, and C. P. 29–116 are classed as resistant. Being susceptible to root rot, Co. 281 and C. P. 28–19 ordinarily succeed only in light well-drained soils.

Insects

The chief insects attacking sugarcane [14] include the sugarcane borer (*Diatraea saccharalis*) and the sugarcane beetle (*Euetheola rugiceps*). Other pests include the mealy bug (*Pseudococcus boninsis*), termites, chinch bug (*Blissus leucopterus*), wireworms, southern cornstalk borer (*Diatraea crambidoides*), the southwestern cornborer (*Diatraea grandiosella*), and the lesser cornstalk borer (*Elasmopalpus lignosellus*). The sugarcane borer may attack the growing point of the plant, causing *dead heart*, or kill the tops of older plants or cause them to break over. Borings in the stalk reduce the sugar yields and contribute to the decay of seed cane. The borers overwinter in sugarcane stalks and stubble and in coarse grasses. Control methods [13] include removal or burning of stalks and trash in the fields and adjacent grass borders, low cutting, flooding cane fields for 3 or 4 days after harvest, selection of borer-free canes for planting, soaking the seed canes before planting in cold water for 3 days, planting varieties resistant to the sugarcane borer, and dusting the growing cane with cryolite. Four applications of cryolite a week apart at about 10 pounds per acre, with the application beginning in the middle or latter part of April when the first borers are hatching from eggs laid on the cane leaves by the adult moths, has been found to be profitable. Control of second-generation borers by the same method, beginning when this brood begins to hatch, also is feasible. Airplanes may be used in either case, and are the most practical machines for second-generation dusting because the cane has grown so tall by that time.

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15 WHEAT

Economic Importance

Wheat is the world's most important grain crop. It occupies about 300 million acres a year in a total of 50 countries (Figure 121). The production of more than 300 billion pounds exceeds that of any other grain crop. The principal countries from the standpoint of acreage are: United States, China, Russia (U.S.S.R.), India, Canada, and Argentina. Argentina, United States, Canada, and Australia are the chief exporting countries.

Wheat ranks second as a cereal crop in the United States, being exceeded only by corn in acreage and in production in pounds. The average annual area harvested from 1937 to 1946 was nearly 58 million acres. The average yearly production was about 944 million bushels. Of this, about 688 million bushels, or 73 per cent, was winter wheat, and 256 million bushels, or 27 per cent, was spring wheat (Figures 122 and 123). According to commercial class, about 415 million bushels, or 44 per cent, was hard winter wheat; 208 million, or 22 per cent, was soft red winter; 189 million, or 20 per cent, was hard red spring; 37 million, or 4 per cent, was durum (spring); and 95 million bushels, or 10 per cent, was white (winter and spring) wheat. The 10-year (1937–46) average acre yield of wheat was 16.1 bushels, ranging from 13.3 bushels in 1938 to 19.8 bushels in 1942. The total production of wheat exceeded a billion bushels in 1915 and every year from 1944 to 1948.

The yields of wheat in the United States are about as high as, or higher than, those of other countries where the climatic conditions are no more favorable for wheat, including Russia, Rumania, Argentina, Australia, and Canada.

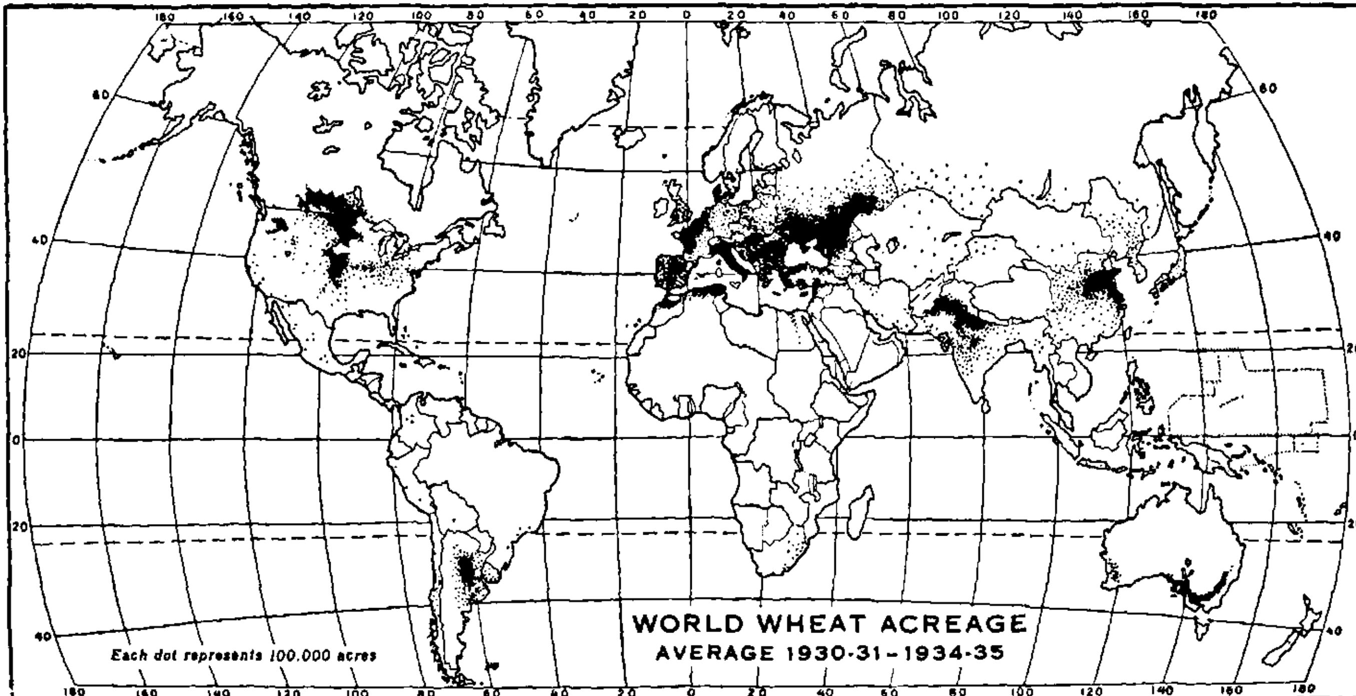

Fig. 121. World wheat acreage.

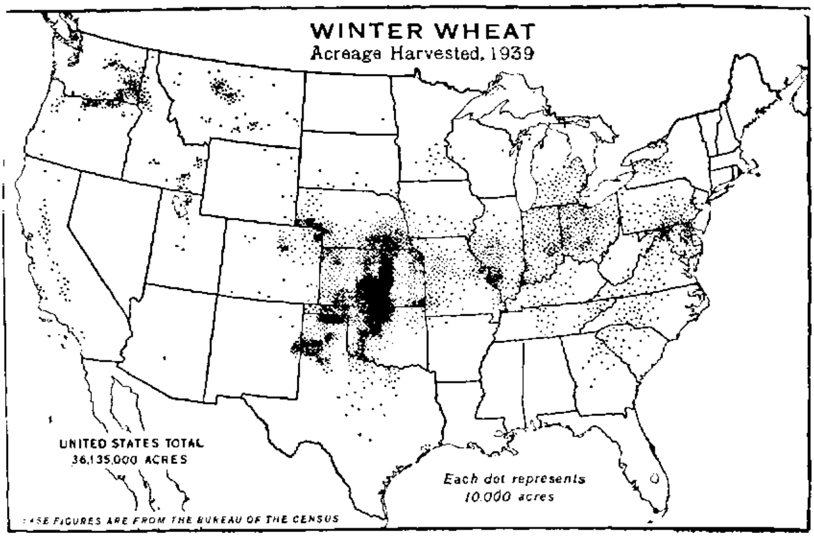

FIG. 122. Distribution of winter wheat in the United States.

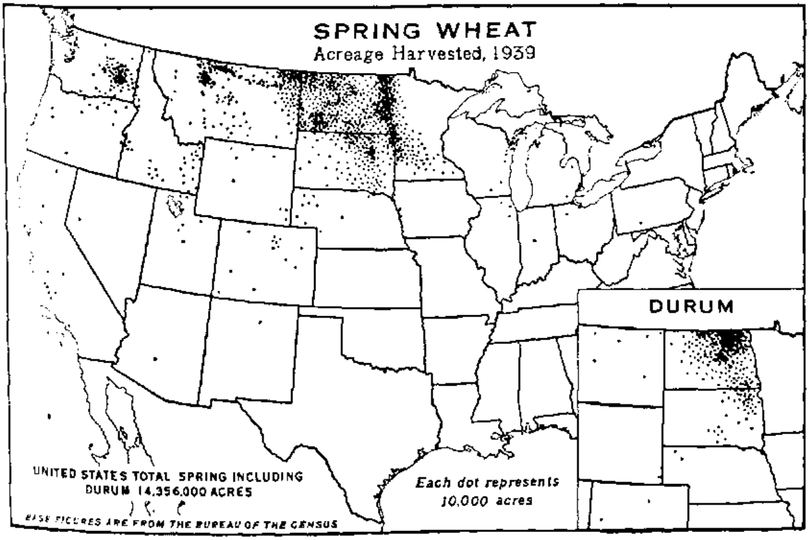

FIG. 123. Distribution of spring wheat in the United States.

Yields in the British Isles, Sweden, Denmark, The Netherlands, Belgium, Switzerland, and Germany range from 30 to 44 bushels per acre. These countries are favorable for wheat production because of relatively mild winters, a cool summer climate, and ample rainfall. Furthermore, these countries use large quantities of fertilizer and manure. The average yield of wheat under the somewhat comparable conditions of France and New Jersey is about 22 bushels per acre. The average yield exceeds 22 bushels per acre in Nevada, Washington, Idaho, New York, and Oregon.

The states that led in wheat production during the decade 1937–1946 were Kansas, North Dakota, Oklahoma, Nebraska, Montana, Texas, South Dakota, Washington, and Ohio, in the order named. Wheat is grown on a field scale on about 1,100,000 farms in 41 states. Only Louisiana, Florida, and five of the six New England states (Maine being the exception) are not counted among the wheat-producing states.

History of Wheat Culture

Wheat from the earliest times has played an important role in the development of civilization. It is preferred to any grain for human food. The origin of cultivated wheat, like that of most of our crops, is lost in antiquity. The present wheats probably originated from two or three wild species through hybridization, mutation, and selection.[53] Wheat is believed by many writers to have originated in southwestern Asia. A wild emmer with a fragile rachis found in Syria is a primitive type of wheat. A speltlike plant produced by crossing wild emmer (*T. dicoccoides*), with a grass, *Aegilops squarrosa,* suggests that spelt may have originated from such a cross,[45] and that common or bread wheat may have originated from a cross between spelt and the progenitor of Persian wheat (*T. persicum*). Persian wheat still persists in the wild in the Russian Caucasus. The Persian wheat might have descended from the wheat of the Neolithic Swiss lake dwellers, which in turn might have originated from a cross between einkorn and a grass, *Agropyron triticum.*

Emmer is a type of wheat cultivated in very early times. Specimens from Egyptian tombs closely resemble the varieties grown in other countries 5,000 years later. Wheat was cultivated throughout Europe in prehistoric times, and was one of the most valuable cereals of ancient Persia, Greece, and Egypt. Archaeologists have come upon carbonized grains of wheat in Turkey, in the tombs of Egypt, and in storage vessels found in many other countries. Wheat was already an important cultivated crop at the beginning of recorded history. Wheat culture in the United States began along the Atlantic coast early in the seventeenth century and moved westward as the country was settled. Wheat was sown on Elizabeth Island, Mass., in Buzzards bay, by Captain Gosnold in 1602. It was sown in the Jamestown Colony as early as 1611 and in the Plymouth Colony by 1621.[10] Many varieties were introduced from foreign countries during the Colonial period.

Adaptation

Wheat is poorly adapted to warm or moist climates unless there is a comparatively cool dry season which favors plant growth and retards parasitic diseases. The world wheat crop is grown in the temperate regions where the annual rainfall averages between 10 and 70 inches, being mostly in regions having a precipitation of 15 to 45 inches. High rainfall, especially when accompanied by high temperatures, is unfavorable for wheat, chiefly because these conditions favor development of wheat diseases. High rainfall also promotes lodging, interferes with harvesting, threshing, storing, seeding, and soil preparation, and leaches fertility elements, particularly nitrates, from the soil.[63] The greater part of the wheat grown in the United States is found where the rainfall averages less than 30 inches per year. The highest average yields in general are obtained where the annual precipitation is 25 to 30 inches. The best quality bread wheats are produced in areas where the winters are cold and the summers comparatively hot and the precipitation moderate.

In the eastern United States the rainfall in certain seasons is sometimes too high for maximum wheat yields,[66, 78] because it promotes certain parasitic diseases such as *Septoria*. On the other hand, insufficient rainfall is the principal climatic factor limiting wheat yields in all western states.

The highest recorded yield of wheat in the United States is 117.2 bushels per acre produced in 1895 on an 18-acre field in Island County, Washington.

Under semiarid Great Plains conditions, good yields are obtained in most years when the soil is wet to a depth of 3 feet at seeding time.[15, 22] Failures or low yields usually result when the soil is wet to a depth of a foot or less at the time of seeding. The good crop of 1948, however, was a striking exception to this rule.

Winter wheat in a hardened condition has survived temperatures as low as $-40°$ F. when protected by snow and probably as low as $-25°$ F. without snow protection. Spring wheat may survive temperatures as low as 15° F. in the early stages of growth. A light frost of 28° to 30° F. may cause sterility in wheat that has headed, or is about to head. A light frost before wheat is fully mature produces blisters on the seed coat and stops further grain development. In general, wheat requires a frost-free period of about 100 days or more for safe production. Quick-maturing varieties may be grown where the frost-free period is 90 days or less in Canada and Alaska where long days hasten flowering.

Short days or high temperatures stimulate tillering and leaf formation but delay flowering of wheat plants. Although wheat is a long-day plant, quick-maturing varieties can be grown to maturity in any photoperiod ranging from the 12-hour days of the Andes Highlands of equatorial Ecuador to the 20-hour days of the "Land of the Midnight Sun" at Rampart, Alaska, at 66° north latitude. Wheat plants grown under continuous artificial light are poorly developed and produce small heads and very little grain.

Much of the superior protein content and baking quality of hard wheats is due to the environment in which they are grown. When grown in the soft wheat regions the grains of the hard wheats are starchy or "yellow berry," and are only slightly if any higher in protein content and baking quality than are the soft wheats.[19] In general high-yielding wheat may be expected to be relatively low in protein content except where soil nitrates are abundant as when following alfalfa or summer fallow.

Most of the plant nutrients derived from the soil are taken up before the plant blooms, being later translocated to the kernel.[2]

The ratio of protein to starch in the wheat kernel is largely determined by moisture conditions at the blossom and postfloral period, by temperature, and by available nitrates in the soil. When the weather is cool, and the rainfall and atmospheric humidity are fairly high, and there is sufficient available soil moisture for the plant, the fruiting or postfloral period tends to be prolonged. Relatively, a large amount of starch tends to be deposited and a plump starchy kernel of low protein content results.[2, 5] When sufficient nitrogenous material has been absorbed before or at the blossom stage, and when moisture conditions are such as not to prolong the postfloral period, the grain tends to be plump and fairly high in gluten. Starch deposition tends to be interfered with relatively more than is gluten formation in hot dry weather. This results in small-berried kernels rich in gluten. Dark, hard, and vitreous kernels in the bread wheats are usually an indication of a comparatively high protein content. When the development of wheat on soil containing ample nitrates is stopped prematurely by drought, the grain is shrunken, high in protein, and low in starch. Grain shrunken as a result of the stem rust disease is low in both starch and protein because both nitrogenous and carbohydrate compounds are withdrawn from the wheat plant by the growing rust fungus.

In a North Dakota study the protein content of wheat was above 13 per cent when the average July temperature was greater than 70° F.[41] Lower protein was obtained in years when the July temperature was slightly above 65° F., and the June temperatures relatively low. Temperatures above 90° F. lower the baking quality of high-protein wheats.

The influence of the soil on the protein content of wheat is less marked than is that of climate.[5] In many cases, the supply of available soil nitrogen is insufficient, and part or all of the endosperm is yellow berry (soft and starchy). Wheats of high protein content are found on soils of high nitrogen content with a low moisture content at time of maturity.[5] The addition of irrigation water or prolonged heavy rainfall that leaches out soil nitrates may be expected to result in wheat of low protein content. Applications of nitrogenous fertilizers, particularly inorganic forms, usually result in wheat with a higher protein content. Nitrogen applications as

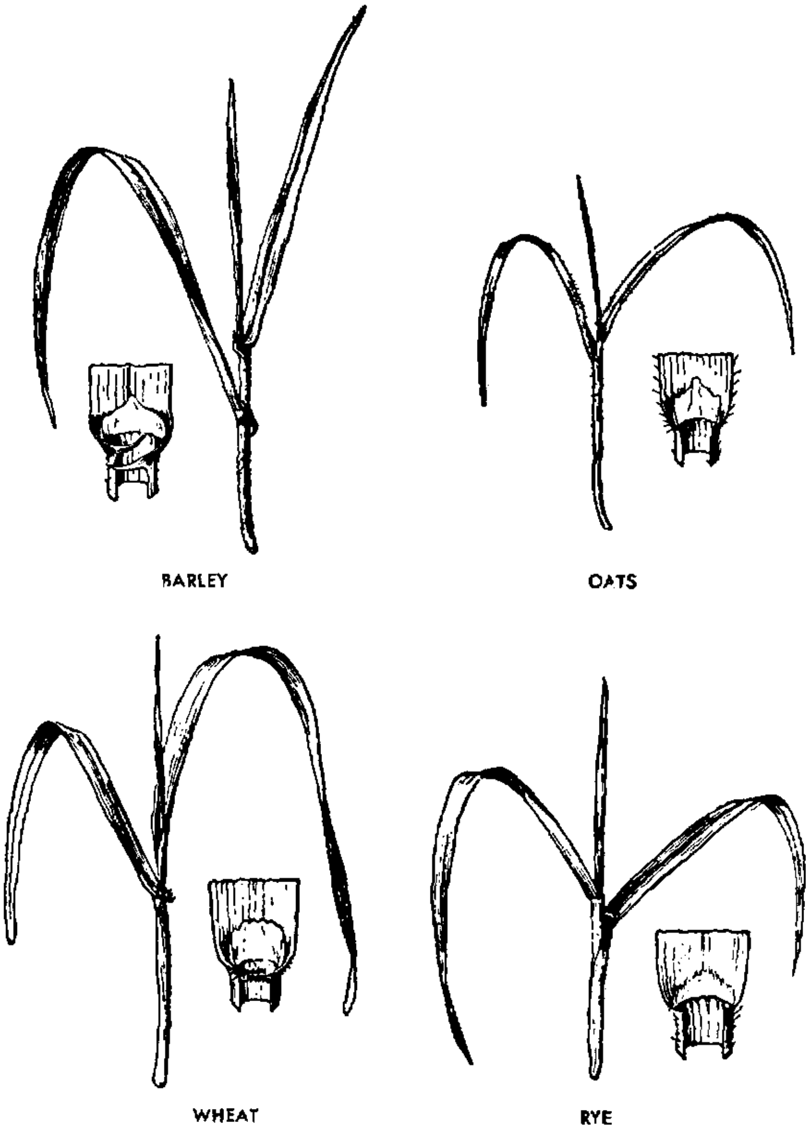

FIG. 154. Distinguishing characters of young cereal leaves and sheaths. Barley (see inserts) has long clasping smooth auricles; wheat has shorter, hairy auricles; rye has very short auricles, whereas the oat leaf has no auricles. The sheaths of rye and oats and the leaf margins of oats have hairs. Note also differences in the shape of the shield-like ligule (see inserts) at the base of each leaf blade.

late as the blossom period generally will increase the protein in the kernel.

Wheat is best adapted to fertile medium-to-heavy textured soils that are well drained. The silt and clay loams in general give the highest yields of wheat but wheat growing also is successful on either clay soils or fine sandy loams. In general, it is an unsatisfactory crop on very sandy or poorly drained soils. Wheat tends to lodge on rich bottom lands.

The Chernozem soils such as those of the Barnes, Bearden, Fargo, Holdredge, Hastings, Hays, and Palouse series, and the Chestnut and Red Chestnut soils which include the Williams, Morton, Rosebud, Keith, Weld, Walla Walla, St. Paul, Abilene, Pullman and Richfield series, occupy most of the regions of heaviest wheat production.

FIG. 125. Portion of spike of common wheat showing interior of one floret at center, enlarged about 3½ times.

Botanical Description

Wheat is classified in the grass tribe *Hordeae* and in the genus *Triticum*. This genus is characterized by 2- to 5-flowered spikelets placed flatwise at each rachis joint.

Wheat is an annual or winter annual grass (Figure 124) with a spikelet inflorescence which consists of a sessile spikelet placed at each notch of the zigzag rachis (Figure 125). A spikelet is composed of two broad glumes and one to several florets. A floret consists of a lemma, palea, and caryopsis (Figure 126). The awn arises dorsally on the tip of the lemma in awned sorts. The caryopsis or grain has a deep furrow (or crease) and a hairy tip or brush. The color of the grain

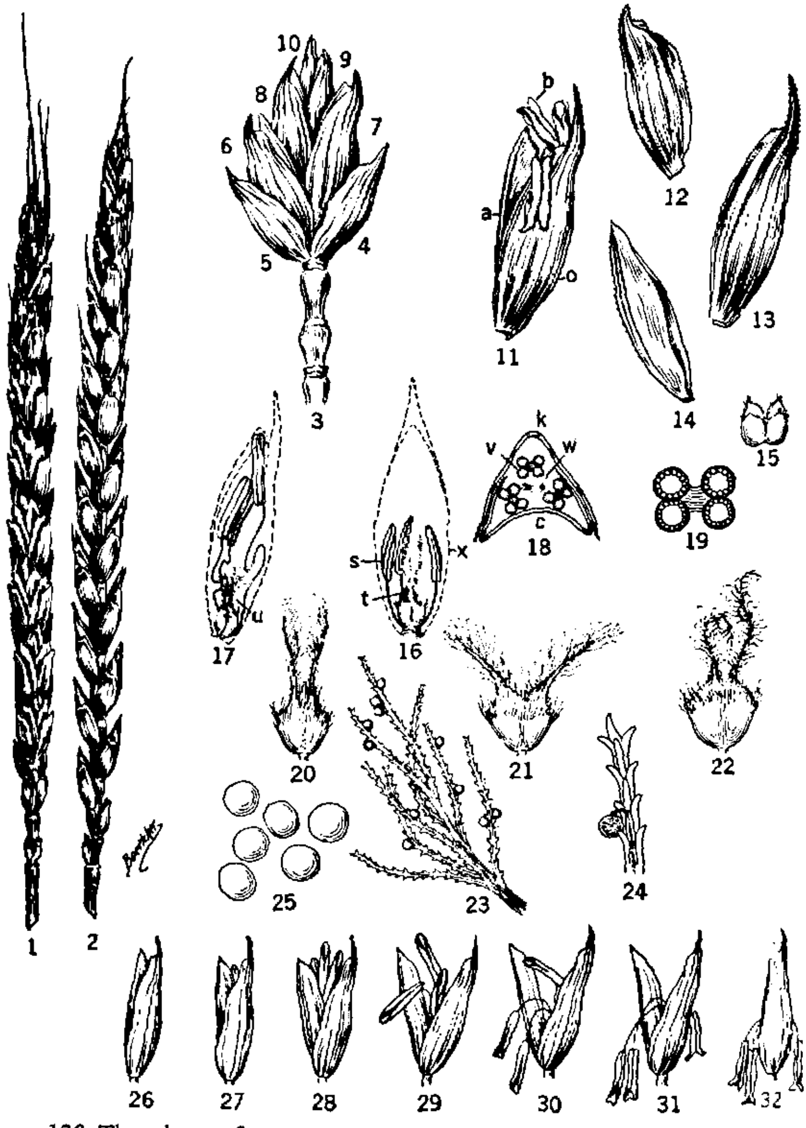

FIG. 126. The wheat inflorescence.

1. Spike, dorso-ventral view. **2.** Spike, lateral view. **3.** Spikelet, lateral view and subtending rachis. **4.** Upper glume. **5.** Lower glume. **6, 7, 8, 9 & 10.** Florets. No. 7 is largest and No. 6 second largest, while Nos. 8, 9 & 10 are progressively smaller. **11.** Floret, lateral view, opening in anthesis. **12.** Glume, lateral view. **13.** Lemma, lateral view. **14.** Palea, lateral view. **15.** Lodicules, which swell to open the glumes. **16.** Florets before anthesis, showing may be a creamy white, amber, red, or purple in different varieties. The purple sorts are not grown in the United States.

The plants normally produce two or three tillers under typical crowded field conditions but individual plants on fertile soil with ample space may produce as many as 30 to 100 tillers. The average spike (head) of common wheat contains 25 to 30 grains in 14 to 17 spikelets (Figure 127). Large spikes may contain 50 to 75 grains. The shape of individual kernels depends in part upon the degree of crowding within a spikelet. The spikelets at the base and tip of the spike usually contain small kernels. Within a spikelet the second grain from the base usually is the largest, and the first grain is next in size but, when present, the third, fourth, and fifth grains are progressively smaller. A pound of wheat may contain 8,000 to 24,000 kernels. A bushel of common wheat averages 700,000 to 1,000,000 grains. The legal weight of a bushel of wheat in business transactions is 60 pounds, but the average test weight is about 58 pounds. The maximum test weight is about 67 pounds and the minimum about 40 pounds per bushel.

Pollination

The time required for the wheat flower to open fully and the anthers to assume a pendant position has averaged 3 minutes and 36 seconds.[36] Approximately 86 per cent of the flowers may bloom in daylight. Flowers bloom at temperatures ranging from 56° to 78° F.

Although wheat is normally a self-pollinated plant, natural cross-pollination sometimes occurs in 1 to 4 per cent of the flowers.[20] Wheat that is partly self-sterile from chromosomal irregularities or adverse environment sometimes becomes crossed extensively. In

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positions of stamens (s) and pistil (t). **17.** Floret at anthesis, showing position of pistil (u) and the elongating filaments of the stamens. **18.** Cross section of floret: (c) palea, (k) lemma, (v) stamen, and (w) stigma. **19.** Cross section of anther. **20.** Pistil before anthesis. **21.** Pistil at anthesis. **22.** Pistil after fertilization. **23.** Portion of stigma (greatly enlarged) showing adhering pollen grains. **24.** Tip of stigma hair (greatly enlarged) penetrated by germinating pollen grain. **25.** Pollen grains, enormously enlarged. **26** to **32.** Florets during successive stages of blooming and anthesis. Time required for stages 26 to 31 is about 2 to 5 minutes, for stages 26 to 32 about 15 to 40 minutes.

FIG. 127. Spikes of 4 varieties of common wheat (half natural size) and 1 variety of club wheat (one-third natural size): (1) fully awnless, (2) & (3) awnless or tip-awned, (4) fully awned, and (5) Hybrid 128 club wheat with tip awns.

Virginia, a maximum of 34 per cent was observed in a strain of Fulcaster wheat in 1917.[37] In one season, approximately six times as much natural crossing occurred in the secondary heads as in the primary heads.

Blooming begins in the spikelets slightly below the middle of the spike and proceeds both upward and downward. Within a spikelet the upper flowers bloom last. Under ordinary conditions a wheat spike completes blooming within 2 or 3 days after the first anthers appear.

The Wheat Kernel

The wheat kernel or berry is a caryopsis, 3 to 10 mm long and 3 to 5 mm in diameter. The structure of the kernel is shown in Figure 128. The pericarp of the kernel consists of several layers that have developed from the ovary wall, and include the cuticle, epidermis, parenchyma, and cross layer. The latter three layers are sometimes referred to as the epicarp, mesocarp, and endocarp, respectively. The testa (or true seed coat) is often called the perisperm. The thickness of all of these layers may not exceed 3 per cent of the thickness of the grain. The testa of red-kernelled varieties contains a brownish pigment but that of white or amber varieties is practically unpigmented. The aleurone is the single layer of large cells, rectangular in outline, comprising the outer periphery of the endosperm. The rectangular cells of the aleurone are polyhedral when viewed from the top or outside of the grain. The aleurone cells contain no starch. The chief contents are aleurone grains composed of nitrogenous substances, probably proteins, but not gluten. In milling wheat the bran fraction consists of all of the pericarp layers, the testa, nucellus, and aleurone, and some adhering endosperm.

A plump well-developed kernel consists of about 2½ per cent germ (plumule, scutellum, radicle, and hypocotyl), 9 to 10 per cent pericarp, 85 to 86 per cent starchy endosperm, and 3 or 4 per cent aleurone. Shrunken wheat of one-half normal kernel weight (testing about 50 pounds per bushel) may contain not more than 65 per cent starchy endosperm. Under the aleurone layer the endosperm consists of cells filled with starch grains cemented together by a network of gluten. Gluten is a cohesive substance usually considered as being comprised of two proteins, glutenin and gliadin, but recently reported as being a single but complex protein. Gluten gives wheat flour its strength or ability to hold together and stretch and retain gas while the fermenting dough expands. Only wheat and rye flour have this ability. Rye contains a protein similar to gluten.

The development of the wheat kernel[5, 18, 47, 70] proceeds by cell division following the fertilization of the egg nucleus to produce the

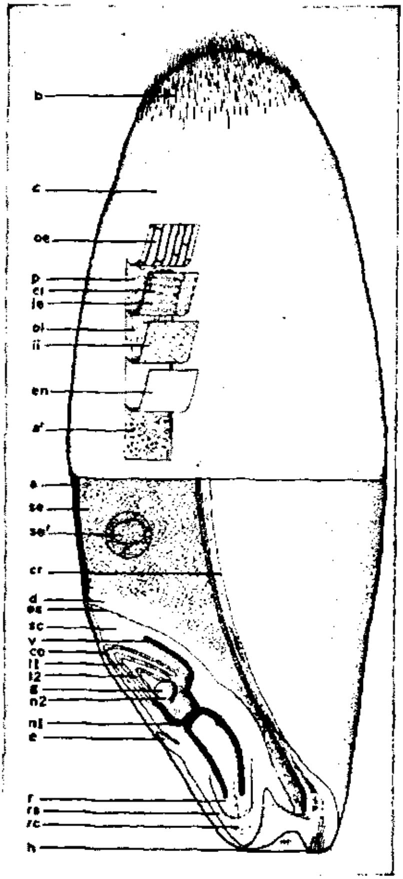

FIG. 128. A wheat kernel.

BRUSH (b)

PERICARP—consisting of cuticle (c), outer epidermis (oe), parenchyma (p), crosslayer (cl), and inner epidermis (ie).

TESTA—consisting of outer integument of seed (oi), and inner integument of seed (ii).

NUCELLAR LAYER—epidermis of nucellus (en).

ENDOSPERM—consisting of the aleurone (a and a'), starch and gluten parenchyma (se and se'), and crushed empty cells of endosperm (d).

GERM—consisting of the scutellum (sc), epithelium of scutellum (es), vascular bundle of scutellum (v), coleoptile (co), first foliage leaf (l_1), second foliage leaf (l_2), growing point (g), second node (n_2), first node (n_1), epiblast (e), primary root (r), root sheath or coleorhiza (rs), and root cap (rc).

HILUM—(h)

The bran layer is comprised of the pericarp, testa, nucellar layer and aleurone. (Drawn by M. N. Pope.)

FIG. 129. Wheat kernel development. (O) unfertilized ovary; kernels 2, 4, 6, 8, 10, and 12 days, respectively, after fertilization; (M) mature kernel. (Courtesy "Cereal Chemistry" and R. M. Sandstedt.)

embryo. The embryo reaches its approximate final size in advance of the full development of the endosperm (Figure 129). The integuments of the ovary become modified and form the layers of the pericarp. Repeated cell division following fertilization of the endosperm nucleus produces endosperm cells. These cells are gradually filled with starch grains and proteins, starting from the outer periphery, including the region of the crease, toward the interior of the endosperm (Figure 128). Sugars synthesized in the leaves and culms are transported to the endosperm to be deposited finally as starch. The grain increases in percentage of starch until it is fully mature. Amino acids synthesized in the leaves and transported to the endosperm change to proteins as the grain begins to dry. Nitrogen, phosphorus, potassium, and other mineral constituents absorbed by the plant before the grain is formed are transported to the kernel.

Winter Hardiness

Low temperatures cause losses to wheat nearly as great as those from all wheat diseases combined. An average of one-eighth of the winter wheat seeded is abandoned, much of it due to winter-killing.[58] Winter-killing may be due to one or more of these causes:

(1) heaving, (2) smothering, (3) physiological drought, and (4) direct effect of low temperature on plant tissues.[62]

Wheat varieties differ widely in winter hardiness.[56] Yogo, Marmin, and Minturki are the hardiest varieties grown.

FREEZING PROCESS IN PLANTS

Freezing injury occurs when water is withdrawn from the plant cells into the intercellular spaces. This results in concentration of the cell sap, with attendant increase in salt concentration and increase in hydrogen ion concentration. These conditions bring about an irreversible precipitation of the cell proteins as well as other changes in the organization of the cell. Death of the plant or plant part ensues when the protoplasm is disorganized beyond recovery. The plant loses water rapidly after thawing.

More winter wheat plants survive low temperatures in moist soils than in dry soils.[31] Plants in moist soils start to kill more quickly but the killing progresses more slowly. An erect growth habit often indicates a lack of hardiness but a recumbent habit does not always indicate hardiness.[32] Injury in wheat plants progresses from the older to the younger leaves, and the crown and meristematic tissues are the most hardy parts.[43] Late fall-sown wheat with shallow roots heaves more readily than that well rooted before the onset of winter.[26]

A cold-resistant plant must have the ability to harden, an inherited characteristic which comes into expression only after exposure to low temperatures [23] with ample sunlight. Hardening begins at temperatures below about 41° F., i.e., the threshold value above which growth commences. There is a concentration of sugars in the tissues of hardy wheat varieties which lowers the freezing point to some extent and decreases protein precipitation. A progressive increase in dry matter and sugar content of winter wheat plants follows low-temperature hardening.[56] The hardier the variety the lower the moisture content of the leaves, and in hardened-off leaves this moisture is held under a greater force.[43, 49] This condition is believed to be due to the hydrophilic colloid or bound water content. The more hardy wheat plants lose less water after thawing. After hardening, the plants become more susceptible to cold injury with advanced age and season.

Influence of Awns on Development of Wheat Kernels

In general, the awn of wheat has been considered a useful structure under certain climatic conditions.[4, 34, 48] Awned varieties often predominate in areas of limited rainfall but certain awnless varieties also yield well. The presence of awns on the florets of wheat has tended toward the production of heavier kernels.[61] A function of the awn affecting yield may be its role in removing from the transpiration system of the plant at filling time substances (possibly silicates) that otherwise might interfere with rapid movement of material into the grain.[34] De-awned heads transpire less than do awned heads.[21] Since it has not been demonstrated that abundant transpiration is beneficial, it seems likely that some other characteristic of the awns is responsible for the slight advantage for awned varieties. The most noticeable difference in the behavior of the two types of wheat is the tendency for the tips of awnless spikes to be blasted in hot dry weather. This suggests that the slight shading effect produced by the awns might be helpful to the developing grains, but proof for this idea also is lacking. Awns (beards) contain considerable chlorophyll, and doubtless contribute some carbohydrates to the plant from photosynthesis.

Species of Wheat

The species of wheat found in all parts of the world[45] are listed below. Those marked with asterisk have been cultivated in the United States.[11]

Einkorn Group (7 pairs of chromosomes) Diploid wheats
- Wild form, fragile rachis, kernel in hull
  - *Triticum aegilopoides*
- Cultivated form, fragile rachis, kernel in hull
  - *T. monococcum* Einkorn

Emmer Group (14 pairs of chromosomes) Tetraploid wheats
- Wild form, fragile rachis, kernel in hull
  - *T. dicoccoides*
  - *T. armeniacum*

Cultivated form, partly fragile rachis, kernel in hull

T. dicoccum Emmer *

T. timopheevi Timopheevi wheat

Cultivated form, tough rachis, free kernel

T. durum Durum wheat *

T. turgidum Poulard wheat *

T. polonicum Polish wheat *

T. persicum Persian wheat

T. pyramidale

T. orientale

Vulgare Group (21 pairs of chromosomes) Hexaploid wheats

Wild form, none; synthetic type only

Cultivated form, partly fragile rachis, kernel in hull

T. spelta Spelt *

T. vavilovi

T. macha

Cultivated form, tough rachis, free kernel

T. vulgare (*T. aestivum*) Common wheat *

T. compactum Club wheat *

T. sphaerococcum Shot wheat

T. speltaforme

T. rigidum

The spike of common wheat is usually dorsally compressed. The spikelets are 2- to 5-flowered, but usually contain only 2 or 3 kernels at maturity. The kernels, which thresh free from the chaff, are either red or white in color and soft or hard in texture. The so-called white kernel is in reality light yellow or amber in color. The common wheats may be winter or spring habit, awned or awnless, and white, brown, or black in glume color.

The plants of durum wheat are of spring habit and tall. The spikes are compact and laterally compressed (Figure 130). The glumes are persistent and sharply keeled and the lemmas awned in the commonly grown varieties. The long stiff awns and thick compact spikes and long glumes often cause laymen to confuse durum wheat with barley. The amber or red kernels are usually long and pointed, and the hardest of all known wheats. The kernels of poulard wheat are similar except in being shorter and thicker. Some poulard wheats have branched spikes (Figure 133).

Club wheat plants may be either winter or spring habit, and

FIG. 130. Spikes of spelt (1); durum wheat (2); timopheevi wheat (3); and winter emmer (4).

either tall or short. The spikes, which usually are awnless, may be elliptical, oblong, or clavate in shape. They are short, compact, and laterally compressed. The spikelets usually contain 5 and sometimes as many as 8 fertile florets. The kernels of club wheat, which may be either white or red, are small and laterally compressed.

The kernels of spelt, emmer, and einkorn, three species of minor importance in the United States, remain enclosed in the glumes after threshing (Figures 130 and 131). Emmer is distinguished from spelt by the shorter, denser spikes which are laterally compressed. When grown, the grain of these species is used for livestock feed. Both are grown for food in Europe. Einkorn differs from the other species in that many of the spikelets contain only one fertile floret. Einkorn or *one-grain* wheat is grown sparingly in Europe. Emmer, spelt, and einkorn have red kernels.

Because of their unusual appearance, Polish and poulard wheats have been *fraudulently exploited in this country* (Figures 132 and

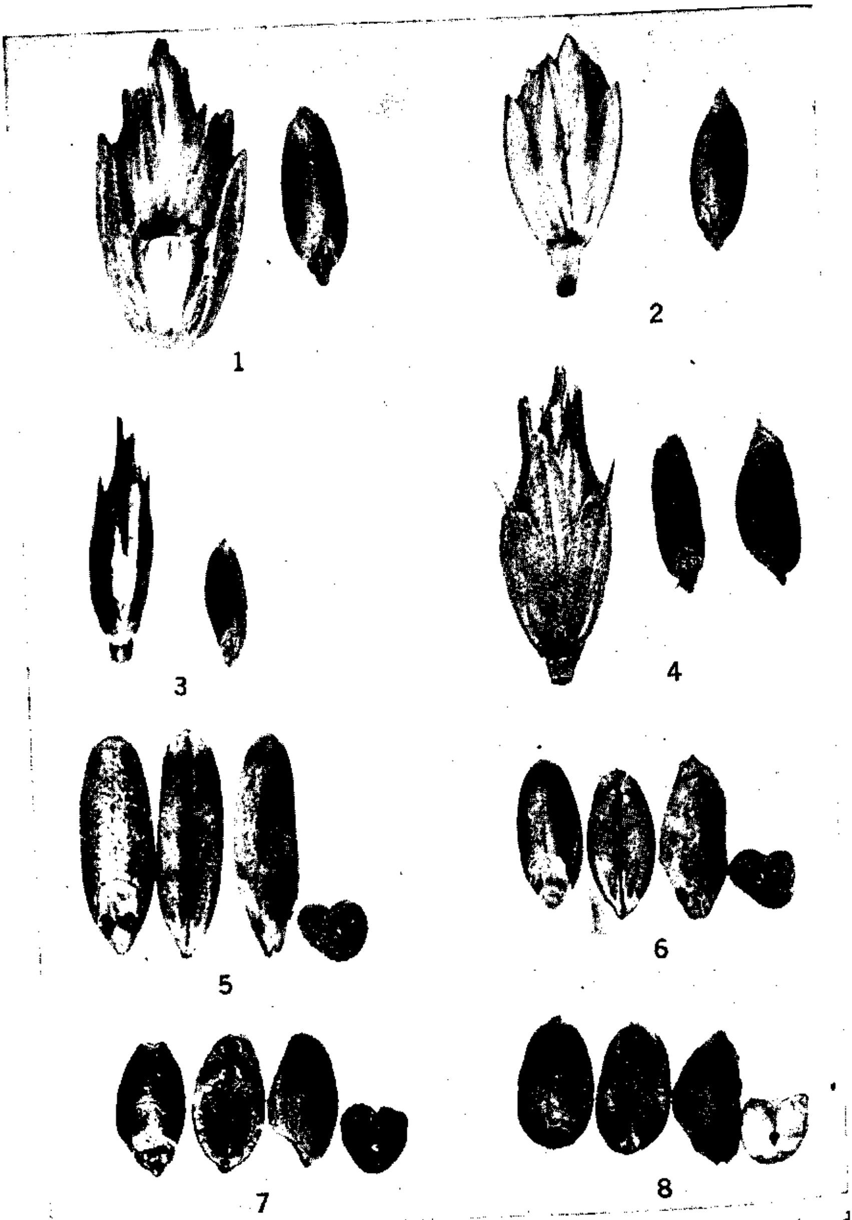

FIG. 131. Spikelet and kernel of spelt (1); spring emmer (2); einkorn (3); and timopheevi wheat (4); wheat kernels: Polish (5); durum (6); poulard (7); and club (8).

FIG. 132. Spikes and glumes of Polish wheat and einkorn.

133). Polish wheat, sometimes called corn wheat, has large, lax, awned heads that sometimes attain a length of 6 or 7 inches. The chaff is extremely long, thin, and papery. The kernels, which are sometimes one-half inch long and very hard, frequently have been confused with rye.

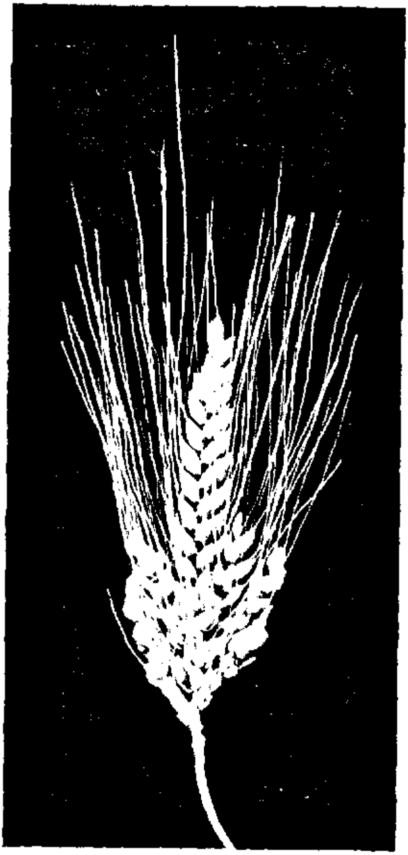

FIG. 133. Typical branched spike of the Alaska variety of poulard wheat.

Statistics on the production of emmer and spelt and Polish and poulard wheat are not available but probably not more than 200,000 acres are grown and used for feed.

Distinguishing Characters in Wheat Varieties

In Table 1 are listed 15 varieties of common wheat with some of the leading characteristics used in distinguishing varieties. Complete descriptions of all American varieties grown at the time the bulletin was published are presented by Clark and Bayles.[11] In recent years considerable attention has been given to identification of wheat varieties from examination of threshed grain. Many varieties are recognized readily by trained specialists.

Not less than 217 varieties of wheat were grown commercially in the United States in 1944. The 15 most widely grown varieties were in the order named: Tenmarq, Turkey, Blackhull, Thatcher, Rival, Chiefkan, Early Blackhull, Ceres, Thorne, Marquis, Cheyenne, Regent, Pilot, Fultz, and Kanred. These varieties, each grown on more than a million acres, occupied 68 per cent of the total wheat acreage.[12]

TABLE 1. CHIEF CHARACTERS DISTINGUISHING 15 VARIETIES OF WHEAT

VARIETY	GROWTH HABIT	AWN TYPE	GLUME SURFACE	GLUME COLOR	STEM COLOR	KERNEL COLOR	KERNEL TEXTURE
Clarkan	Winter	Awnless	Smooth	White	White	Red	Soft
Thorne	Winter	Awnless	Smooth	Brown	White	Red	Soft
Fulcaster	Winter	Awned	Smooth	White	Purple	Red	Soft
Tenmarq	Winter	Awned	Smooth	White	White	Red	Hard
Comanche	Winter	Awned	Smooth	White	White	Red	Hard
Chiefkan	Winter	Awnless	Smooth	White	White	Red	Hard
Iobred	Winter	Awned	Smooth	Brown	White	Red	Hard
Goldcoin	Winter	Awnless	Smooth	Brown	Purple	White	Soft
Honor	Winter	Awnless	Smooth	Brown	White	White	Soft
Baart	Spring	Awned	Smooth	White	White	White	Soft
Florence	Spring	Awnless	Smooth	White	White	White	Hard
Sonora	Spring	Awnless	Pubescent	Brown	White	White	Soft
Thatcher	Spring	Awnless	Smooth	White	White	Red	Hard
Rival	Spring	Awned	Smooth	White	White	Red	Hard
Reward	Spring	Awnless	Pubescent	White	White	Red	Hard

Wheat Classes

Under the official grain standards of the United States, wheat is now separated into six commercial classes: (1) Hard Red Spring, (2) Durum, (3) Red Durum, (4) Hard Red Winter, (5) Soft Red Winter, and (6) White. Emmer, spelt, einkorn, and Polish and poulard wheat are not considered wheat in the official grades. The distribution of some of these wheats as to principal production areas is shown in Figure 134.

HARD RED SPRING WHEAT

Hard red spring wheat is grown in the north central states, mostly where the winters are too severe for production of winter wheat. In 1944, a total of 15,765,582 acres of hard red spring wheat were grown, or 24 per cent of the total acreage of the country. This class of wheat led in Minnesota, North Dakota, South Dakota, and Montana. Hard red spring is the standard wheat for bread flour. Thatcher, Rival, Ceres, Marquis, Regent, Pilot, Renown, and Vesta are the most important varieties. Newer varieties include Newthatch, Mida, and Cadet.

Hard red spring wheats also are grown in Canada, Russia, and Poland.

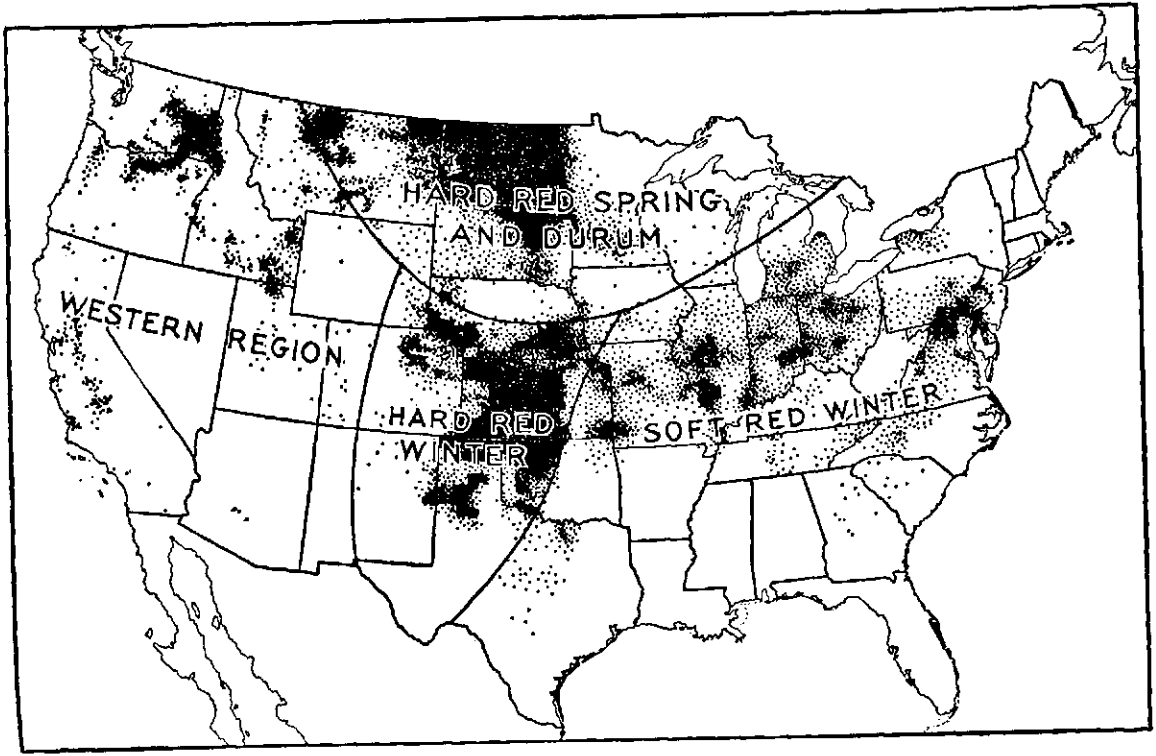

FIG. 134. The general producing regions of the different wheat classes.

DURUM WHEAT

Durum wheat is produced in the same general region where hard red spring is grown, but the chief section lies west of the Red River valley in North Dakota. Most of the durum wheat is grown in North Dakota, South Dakota, and Minnesota (Figure 123). About 2,179,258 acres, or 3.3 per cent, of the total wheat acreage was of this class (including red durum) in 1944. The principal varieties in 1944 were Mindum, Pentad, Kubanka, and Peliss. Stewart, Carleton, and Vernum are new rust-resistant varieties. Durum wheat is used in the making of semolina, from which macaroni, spaghetti, and similar products are manufactured.

Durum wheat is grown extensively in North Africa, southern Europe, and Russia.

HARD RED WINTER WHEAT

The hard red winter wheats are adapted to the southern half of the Great Plains region where the annual rainfall is less than 35 inches.[57] Approximately 30,709,456 acres, or 46.8 per cent of the total wheat acreage of the country was occupied by this class in 1944. Kansas, Nebraska, Oklahoma, Texas, and Colorado lead in the production of hard red winter wheat [12] (Figure 134). As bread wheat, the better varieties of this class are nearly or quite equal to hard red spring wheat.

The varieties that led in acreage are Tenmarq, Turkey, Blackhull, Chiefkan, Early Blackhull, Cheyenne, Kanred, Red Chief, Nebred, and Iobred. Turkey and Kharkof are identical. Blackhull has yielded well in southern Kansas, Oklahoma, and the Panhandle of Texas. Tenmarq has given good yields in the same area. Cheyenne and Nebred are popular in Nebraska. Important new varieties include Comanche, Pawnee, Triumph, Westar, Wichita, and Relief.

Among the beardless hard red winter wheats are Chiefkan and Red Chief in Kansas and nearby states, Ridit in Washington, Michikof in Indiana and Illinois, Newturk in Montana, and Mosida in Idaho.

Hard red winter wheats are grown extensively in southern Russia, the Danube Valley of Europe, and Argentina.

SOFT RED WINTER WHEAT

Soft red winter wheat is grown principally in the eastern states. The western border of this region coincides roughly with the line of a 30-inch average annual precipitation.[65] Ohio, Missouri, Indiana, Illinois, and Pennsylvania lead in the production of soft red winter wheat (Figure 134). There were 11,937,179 acres of wheat of this class grown in 1944, or 18.2 per cent of the entire wheat acreage of the country. More than one million acres each were sown to Thorne and Fultz. Six varieties, Clarkan, Fulcaster, Kawvale, Redhart, Leap, and Trumbull each had acreages between 500,000 and 1,000,000. New improved varieties include Viga, Austin, Seabreeze, Wabash, Fairfield, Sanford, and Leapland. The soft red winter wheats are softer in texture and lower in protein than the hard wheats. Wheats of this class are generally manufactured into *family*, cake, biscuit, cracker, and pastry flours. For bread flour it sometimes is blended with that of the hard red wheats.

Soft red winter wheats are grown in western Europe.

WHITE WHEAT

The white wheats are grown chiefly in the far western states, but to some extent in the northeastern states. In 1944 the estimated acreage of white wheat was 5,092,525 acres, or 7.7 per cent of the acreage of all wheat in the United States. Of this, 466,293 acres or 0.7 per cent were club wheats. The largest acreages are in Washington, Oregon, Michigan, California, Idaho, and New York. The leading varieties in 1944 were Baart, Federation, Dawson, Yorkwin, Rex, Goldcoin, and Hymar. Except for Hymar, these are all common white wheats. The two varieties, Hymar and Hybrid 128, occupied 66.8 per cent of the club wheat acreage. The white wheats are used principally for pastry flours, and shredded and puffed breakfast foods.

White wheats are grown in northern, eastern, and southern Europe, and in Australia, South Africa, western South America, and Asia.

Wheat Relatives

Wheat (genus *Triticum*) is related botanically to certain other grass genera that can be crossed with wheats. Several Kansas farmers were baffled several years ago when their fields, supposedly of volunteer wheat, produced only slender odd-appearing heads having only a slight resemblance to wheat. These were identified as goatgrass (*Aegilops cylindrica*), a weedy plant (Figure 135). Several species of *Aegilops* have been crossed with wheat.

Wheat has been crossed with several species of the genus *Agropyron* (wheatgrass). Crosses of wheat with western wheatgrass (*Agropyron smithii*), (attempted once by the senior author in 1924), and slender wheatgrass (*A. trachycaulum*), have not been successful. Successful crosses with several other species of *Agropyron*, including certain collections of quackgrass (*A. repens*) have been reported. Wheat was crossed with *Agropyron elongatum* in U.S.S.R., Canada, and the United States, in an endeavor to produce a perennial wheat. Thus far the long-lived perennial types obtained have been decidedly grasslike, whereas the more wheatlike selections have been annuals or short-lived perennials. The frequent glowing press reports of successful perennial wheats in U.S.S.R. still lack confirmation at this writing (May 1948). The desirability of a perennial wheat is not fully established since a crop that can grow any time in the season when conditions are favorable would leave little opportunity for accumulation of moisture or nitrates in the soil.

Wheat also has been crossed with rye, and selected progenies have had characters of both parents, but none is grown commercially. Wheat also has been crossed with the grass genus *Haynaldia*. Some of the reputed crosses of wheat and barley have not been authentic.

Many have heard the fictional story of how wheat "turns into cheat" when subjected to winter injury or when the developing spikes are mutilated in the boot stage. Such a transformation has been refuted by botanists and agricultural authorities for more than a century but the superstition still survives to some extent. Cheat appears in abundance where wheat is thinned out by winterkilling. Reports of the reputed change all come from sections where cheat (or chess), *Bromus secalinus*, is a common weed in grain fields and waste places (Figure 135). Cheat was grown extensively as a hay crop in western Oregon for many years. Recently cheat has been suggested as a possible crop for Maryland and Pennsylvania, with the ripe seed to be used as a feed grain. The botanical relationship between wheat and cheat appears to be too remote to permit intercrossing.

Fertilizers

In 1938 the Atlantic seaboard states used an average of 200 to 300 pounds per acre of commercial fertilizer for wheat. From Michigan southward through Indiana, Ohio, Kentucky, Tennessee, and Alabama an average equivalent to 100 to 200 pounds per acre on all of the wheat acreage was applied. Not more than one-third of the wheat acreage in Illinois, Missouri, and Arkansas is fertilized. West of the 100th meridian not more than one acre in 400 of wheat received commercial fertilizer. The use of fertilizers has expanded recently. Barnyard manure usually is applied to land for crops other than wheat. In the semiarid Great Plains, manure may not increase wheat yields except on fallowed land [50] well supplied with moisture.

The most commonly used fertilizer formulas for wheat include 2–12–6 and 3–8–3 or others of similar composition. In sections where potash is not needed, the fertilizer commonly is 100 to 400 pounds per acre of superphosphate and 100 to 150 pounds per acre of nitrate of soda or ammonium sulfate. Often the nitrogen fertilizer is applied wholly or in part as a top dressing in the spring. Wheat responds to fertilizers in most sections of the United States where the average precipitation exceeds 35 inches. In drier regions the use of nitrogen fertilizers may be helpful in overcoming the depressive effect on the subsequent wheat yield of returning a heavy growth of straw residues to the soil.

Nitrogen fertilization tends to produce wheats higher in protein content. Phosphorus fertilization, where crops respond to its application, increases the yield of wheat, but in such cases often results

FIG. 135. (*Left*) Plant (1); panicle (2); and spikelet (3); of cheat or chess; (*Right*) spike of goatgrass (*Aegilops cylindrica*), an unwelcome relative of wheat.

in a grain of low protein content because of insufficient nitrogen to care for the increased crop.

Rotations

In the eastern states where wheat often is seeded on corn stubble, the rotation is likely to contain at least one legume and one or more cultivated crops.

In the corn belt an efficient rotation[65] for much of the area is: wheat; clover and timothy (1 or 2 years); corn; oats. Soybeans may be substituted for oats in many localities. Where lespedeza is an important crop, it may be seeded in the spring on fall-sown wheat. After wheat harvest, the lespedeza may be permitted to produce a crop of hay or seed. A common rotation is: corn; wheat; lespedeza for pasture, hay, or seed; wheat.

In the cotton belt, wheat cannot be sown immediately after cotton because of the late maturity of the latter crop. A rotation satisfactory for this area is as follows: wheat, followed by cowpeas or soybeans for hay or seed; cotton well fertilized, with vetch or Austrian winter peas planted between the rows for green manure; corn, stalks cut and removed from the field.

For Kansas[64] a popular rotation for the northeastern part of the state is clover, corn, oats, and wheat. Red clover or sweetclover is seeded with the wheat to be grown for hay or seed the next year, making a 5-year rotation. The most satisfactory rotations in central Kansas are those that contain alfalfa. Because of subsoil moisture depletion by alfalfa, the crop that follows it must be able to endure drought. A satisfactory rotation is alfalfa (2 or 3 years), sorghum, corn, oats, wheat. In western Kansas, rotations have failed to show any marked gain in wheat yields over continuous cropping, except where wheat follows fallow. A suggested rotation is: grain sorghum, fallow, wheat (2 or 3 years).

Under dryland conditions, where the annual precipitation is less than 15 to 18 inches, alternate wheat and fallow has been a practical sequence. Continuous winter wheat has produced good yields in some areas where weeds and pests are not serious.

Spring wheat follows an intertilled crop such as corn, potatoes, or beets most advantageously in the northern spring wheat region.

Much of it is sown after wheat or other small grains because of the relatively small acreage of intertilled crops. On the dry lands of the Pacific northwest spring wheat usually is sown after fallow or occasionally after peas.

Culture

SEEDBED PREPARATION

The time and manner of seedbed preparation for winter wheat have proved important factors in yield.[64] These factors operate largely through their influence upon the elaboration and accumulation of soil nitrates, soil moisture, and the physical condition of the seedbed at seeding time. In seedbed experiments in eastern Kansas where wheat was grown continuously, soil worked early in July, regardless of method, usually gave comparatively high yields, whereas that worked late in September usually resulted in a low yield.[8] The advantage appeared to be due to the large supply of plant foods, especially nitrates, that were liberated. When the land was kept clean by tillage the time of tillage was the most important factor in the preparation of land for winter wheat.[67] An average difference between July and September plowing of approximately 11.0 bushels per acre was recorded. Early summer tillage increased the amount of soil moisture and nitrates in comparison with late summer tillage. Early tillage also resulted in control of weeds that otherwise would use the nitrates needed by the wheat seedlings. Increased yields resulting from early tillage for wheat grown continuously were obtained regardless of whether the land was plowed, listed, or disked and plowed. Early plowing gave better results than early listing, but early listing proved better than late plowing. Splitting lister ridges did not increase the yield as compared to single listing.

In experiments in southwestern Kansas, early plowing gave average yields 25 to 50 per cent higher than late plowing.[72] Land plowed late lost considerable moisture due to weed growth, and the seedbed was cloddy, loose, and in poor tilth. In eastern Nebraska plowing on July 15 at a depth of 7 inches, followed by disking on August 15 and again prior to seeding, gave an average yield of 33.9 bushels per acre.[30] Omission of the August 15 disking reduced the yield 6.7 bushels per acre. In another experiment plowing about July 15, followed by disking on August 15 and again prior to seeding, gave a yield of 28.4 bushels per acre. Disking in July, August, and September without plowing returned a yield of 21.6 bushels. Weed control was not the only factor concerned because tillage methods equally effective in weed control differed in their effect on the accumulation of nitrates. The type of tillage supplied by the lister or plow was more effective than that by disking.

The lister has been widely used in western Kansas for seedbed preparation. Some results from its use are given in Table 2.

TABLE 2. RELATION OF METHOD OF PREPARATION TO YIELDS OF WHEAT IN WESTERN KANSAS (AT HAYS), 1907–1927

METHOD OF PREPARATION	AVERAGE YIELD PER ACRE	FAILURES IN 21 YEARS
	(*bu.*)	(*no.*)
Late fall plowing	10.1	11
Early fall plowing	15.7	6
Early listing	19.1	4
Summer fallow	23.9	3

In the eastern states, the seedbed is often prepared with a disk or spring-tooth harrow when wheat follows corn, soybeans, or cotton. When land is to be plowed, as after a green manure crop, 3 or 4 weeks should intervene between plowing and seeding. Because of potential water erosion in the humid regions, rolling land should not be left bare of vegetation for long periods. Consequently plowing should not precede seeding by more than 4 weeks.

When spring wheat is sown after intertilled crops, the land usually is double-disked and harrowed before drilling. The plowing of such land offers little or no advantage. Yields after small grain are appreciably higher when the land is plowed than when it is merely disked, chiefly because of better weed and insect control. Spring plowing usually gives higher yields of spring wheat in the drier western section than does fall plowing. This is because more snow is caught in undisturbed stubble during the winter and more moisture is added to the soil. Fall plowing usually is practiced in the more favorable eastern sections to permit earlier seeding, which is of prime importance. Some fall plowing is advisable on farms having a large acreage in spring grain.

METHOD OF SEEDING

Nearly all the American wheat crop is sown with a drill. In Nebraska broadcast winter wheat averaged 17 per cent lower in yield than drilled wheat.[30] Drills with disk furrow-openers are used most generally in the humid regions. Hoe drills are popular in the semiarid sections of the Pacific northwest on fallowed land. This type of furrow opener turns up clods and does little pulverizing and thus is helpful in preventing soil blowing. The furrow drill is widely used in the semiarid western Great Plains where winters are severe. It is a partial insurance against winter killing and soil blowing and it places the seed deep enough to reach moist soil. In Montana average yields of winter wheat from furrow drilling have been higher than from surface drilling.[44] In Kansas the furrow drill has shown no advantage in average seasons. Under eastern Nebraska conditions, furrow drilling in 14-inch rows yielded 81 and 91 per cent as much as surface drilling in rows spaced 7 and 14 inches apart, respectively. The semifurrow drill with rows 10 inches apart has been more popular in recent years. The furrow drill has no appreciable merit for seeding spring wheat. The wider row spacing required for making the furrows may be detrimental to yield.[69]

Special narrow one-horse drills used for seeding between rows of standing corn may be connected together with overhead beams to make a gang or larger operating unit.

DEPTH OF SEEDING

Wheat usually is sown at a depth of 1½ to 3 inches. Seeding deeper than 1 to 2 inches is advantageous only in permitting germination to occur and roots to develop before the surface soil dries out. For example, at Lind, Washington, where spring rains are rather infrequent, the deepest sowing of spring wheat gave the highest yields.[69] With winter wheat the average yields from shallow (1 inch), medium (2½ inch), and deep (4 inch) seeding were 10.8, 9.9, and 8.9 bushels per acre, respectively. At Moro, Oregon, the yields of winter wheat from shallow, medium, and deep seeding were 25.7, 26.4, and 26.4 bushels per acre, respectively. These results were obtained on dry land where the seed often did not germinate until some time after seeding. It often has been observed that when fall rains are insufficient to wet the soil and germinate the shallow-sown wheat, the deeper-sown wheat also is not likely to thrive, except sometimes on fallowed land.

When wheat germinates the plumule grows upward from the sprouting seed enclosed in the coleoptile. It is pushed upward by the elongation of the subcrown internode which arises above the coleoptile node. Sometimes other internodes also elongate. The coleoptile opens and allows the first leaves to push out. Tillering begins after the growth of the coleoptile stops. Crown roots start to develop at nodes ¾ inch to 2 inches below the soil surface. Seeding wheat at a depth of one inch or less causes the crown to form just above the seed. Seeding deeper than 1½ inches, except where necessary to insure prompt germination, merely uses up part of the energy in the seed in producing an excessively long sprout, and delays and weakens the seedling accordingly. Deep seeding may cause the crown to form somewhat deeper than when seeding is shallow,[77] but the difference in crown depth is much less than the difference in seeding depth. High soil temperatures during seedling emergence cause the crowns to be formed at shallow depths. Hardy varieties of winter wheat have deeper crowns than do nonhardy varieties, and spring wheats have the shallowest crowns.[77]

TIME OF SEEDING

Factors determining the best time for seeding winter wheat were discussed in Chapter 7. Medium-season seeding of winter wheat for any locality is usually most favorable. Wheat sown late generally suffers more winter injury, tillers less, and may ripen later the next season. Wheat sown too early may use up soil moisture, joint in the fall, suffer from winter injury and foot rots, and become infested with the Hessian fly where that insect is prevalent. In the semiarid Great Plains the optimum date for seeding winter wheat is about September 1 in Montana, and progressively later to the southward to northwestern Texas, where the best time is about October 15. Earlier than optimum seeding is a common practice in the Great

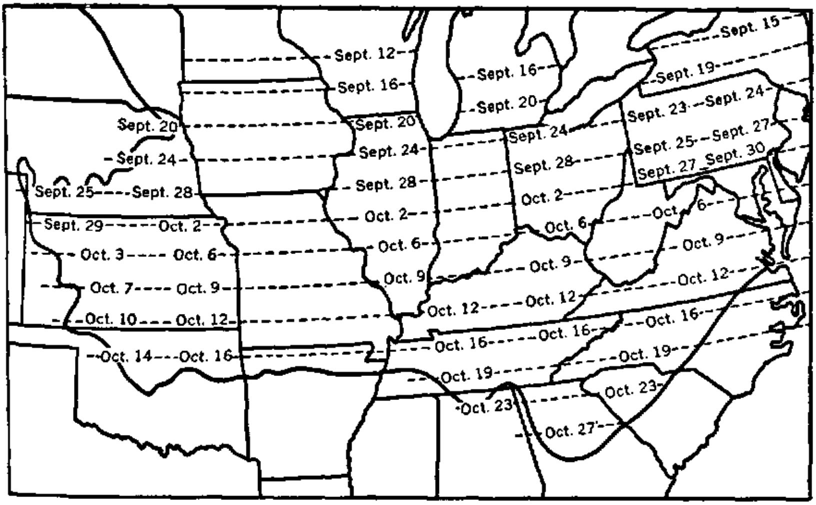

FIG. 136. Fly-free date for seeding winter wheat.

Plains either to take advantage of favorable soil moisture conditions when they occur or to provide wheat pasture. The chief disadvantage of too early seeding of winter wheat is the likelihood of injury from foot-rot diseases that develop under warm conditions.[60] Seeding about mid-September is recommended in the Pacific northwest. November and early December seeding is most favorable in California and southern Arizona. Under the mild climatic conditions in these states nearly all of the varieties have a spring growth habit but are grown as winter wheats. Spring wheats also are grown from fall or winter sowing in China, India, southern Europe and North Africa. In the central and eastern states the optimum seeding date is about the time, or a few days earlier, than the fly-free date [75] as shown in Figure 136. The safe date is the earliest date at which wheat can be seeded to escape damage from this insect. Wheat should generally be seeded a week to 10 days earlier than the safe date where the Hessian fly is not present (Figure 137). This gives the plants a better start in the fall.

Winter wheat fails to head when sown in the spring except when sown very early or under cool conditions. The critical seeding date for normal heading of varieties with a winter growth habit depends upon the variety. This date was February 15 for the winter variety

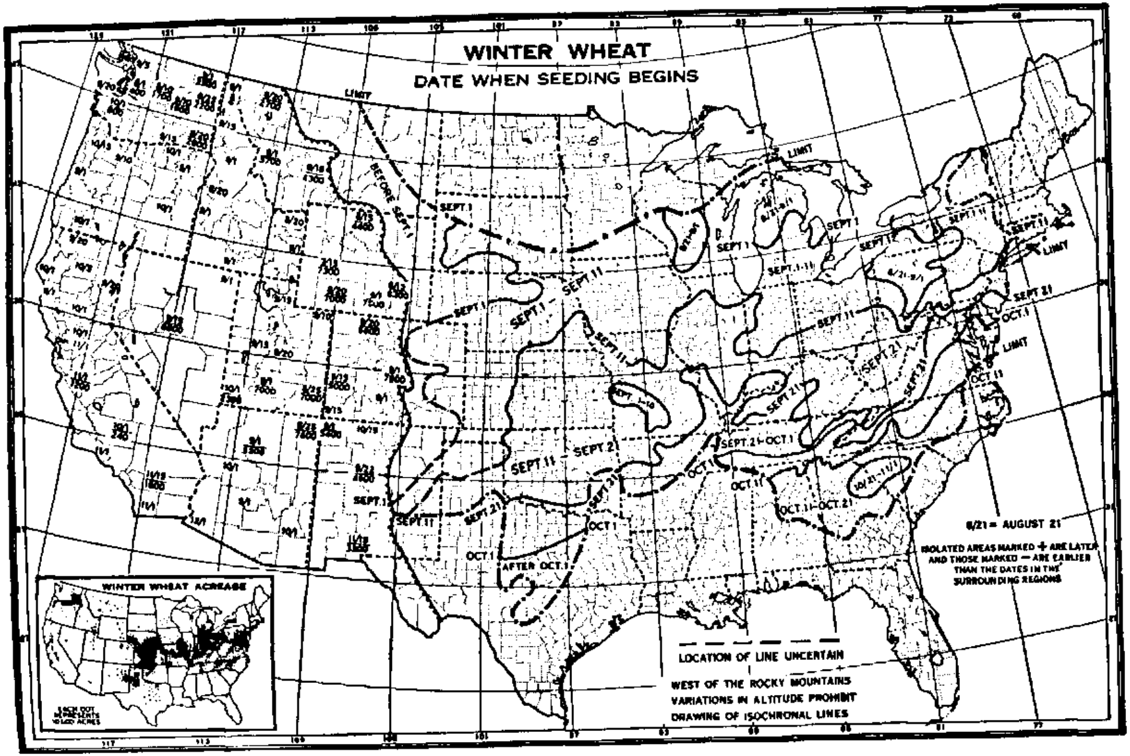

FIG. 137. Date when winter wheat seeding begins.

Hybrid 128 at Moro, Oreg., whereas the Turkey variety headed when sown fully a month later.[7] The critical date for Federation, a spring wheat with a partial winter habit, was about April 30, whereas Hard Federation and other true spring wheats headed when sown about a month thereafter.

Early seeding of spring wheat usually results in the highest yields. Early-sown spring wheat is most likely to escape injury from drought, heat, and diseases, which become more prevalent as the season advances.

The usual procedure is to sow spring wheat as early as the soil can be worked into a good seedbed. This time varies widely between seasons, usually arriving in March in Nebraska and Colorado, April in South Dakota and southern Minnesota, and in May along the Canadian border (Figure 138). Spring seeding usually is accomplished in March in Washington and Oregon, however, because of a milder climate than that east of the Rockies at the same latitude. When wheat is sown during an extremely early mild period that is followed by a cold snap, the wheat remains in the ground and emerges during subsequent warmer weather usually without evidence of having been injured. There is no advantage in extremely early seeding except to insure seeding in ample time.

RATE OF SEEDING

The optimum rate of seeding for wheat in the western half of United States is practically independent of soil type, moisture, locality, date of seeding, cultural treatment, and variety.[42] In general, 4 to 6 pecks per acre have produced the highest net grain yields of both winter and spring wheat. Yields from 2-peck seedings have been decidedly less than from heavier rates except from relatively early seeding on soil well supplied with moisture and nitrates. Many growers of hard winter wheat in the Great Plains sow only 20 to 30 pounds per acre, but the average rate there is about 40 pounds.[30]

There may be a rather wide range in seeding rate for winter wheat without material effect on the yield (Table 3, page 491).

Winter wheat in the eastern United States usually is seeded at the rate of 5 to 8 pecks per acre. At Arlington Farm in Virginia,

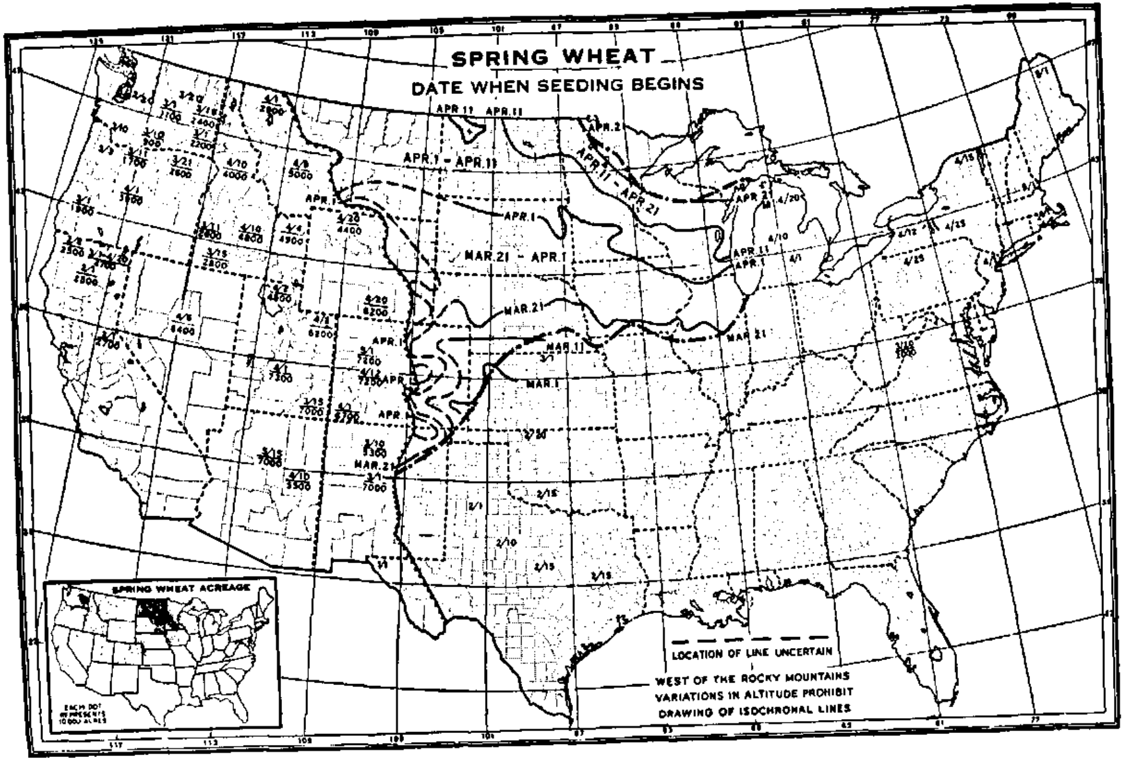

FIG. 138. Date when spring wheat seeding begins.

TABLE 3. EFFECT OF RATE OF SEEDING ON WINTER WHEAT IN NEBRASKA

RATE OF SEEDING	TILLERS PER PLANT IN *Fall*	*Spring*	YIELD PER ACRE (*8-year average*)
(*pecks*)			(*bu.*)
Three	3.8	3.8	24.7
Four	3.4	3.5	26.2
Five	3.2	2.6	26.4
Six	3.0	2.6	27.4
Eight	2.7	1.7	27.4

the highest grain yields were obtained from the 6-peck rate.[38] About 6 pecks or more will generally produce a larger yield than a lesser quantity of seed.[65] Heavier seeding than usual is advised where seeding is delayed beyond the normal date, because of less opportunity for the plants to tiller.

Extensive experiments in Ohio [79] have shown the highest net yield (yield minus seed sown) to be obtained from a seeding rate of 6 to 8 pecks per acre.

A former popular belief that wheat must be sown thinly under semiarid conditions to avoid crop failure has been refuted by numerous rate-of-seeding experiments in the western part of the United States.[42] The 12-year average yields, shown in Table 4, were obtained on corn land at Akron, Colo. The low average yields shown are largely the result of moisture deficiency. The heavier seeding rates gave higher average gross yields than did the one- and two-peck rates, and the net yields were slightly higher, although the difference probably is not significant. The higher seeding rates give some assurance against loss of stands under adverse conditions at very little cost.

TABLE 4. RATE AND DATE OF SEEDING TEST OF KANRED WINTER WHEAT AT AKRON, COLORADO (12-YEAR AVERAGE)

RATE SEEDED	ACRE YIELD IN BUSHELS WHEN SOWN: *Aug. 15*	*Sept. 1*	*Sept. 15*	*Oct. 1*	*Oct. 15*	*Average*
1	7.3	11.2	11.4	6.7	5.9	8.5
2	9.1	11.6	11.3	6.7	6.7	9.1
3	10.4	12.1	10.6	6.9	6.9	9.4
4	11.0	12.3	10.7	6.8	7.1	9.5
5	11.6	12.3	10.2	7.6	7.7	9.9
Average	9.9	11.9	10.8	7.0	6.9	9.3

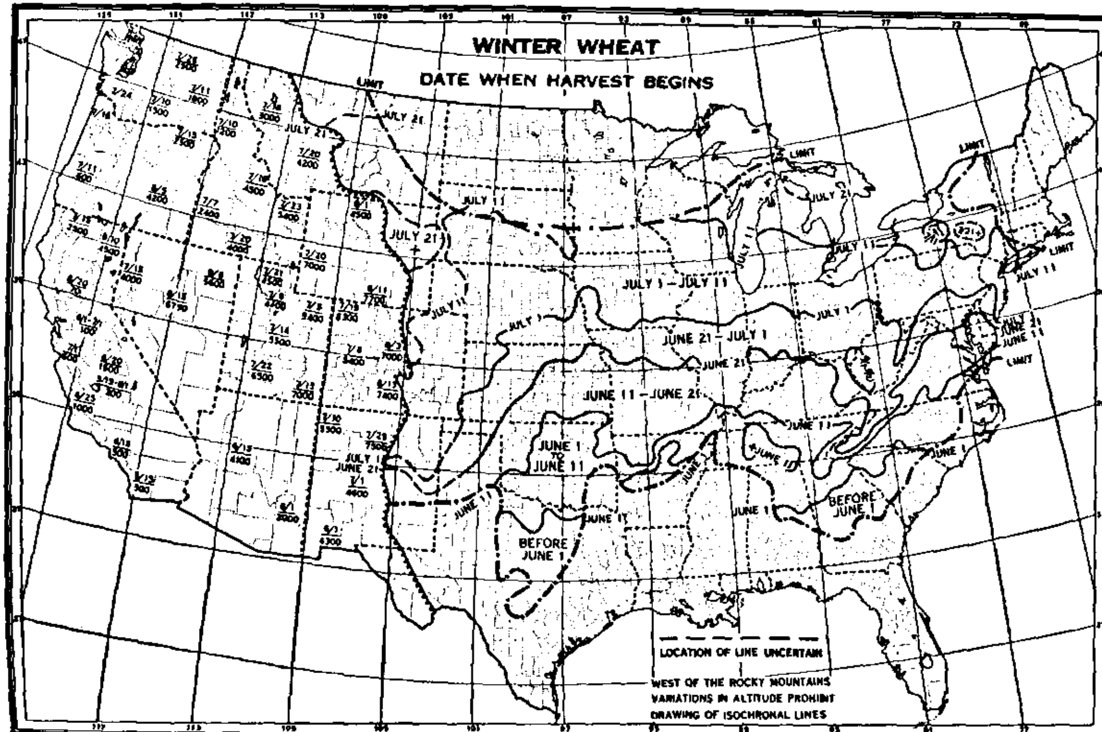

FIG. 139. Date when winter wheat harvest begins.

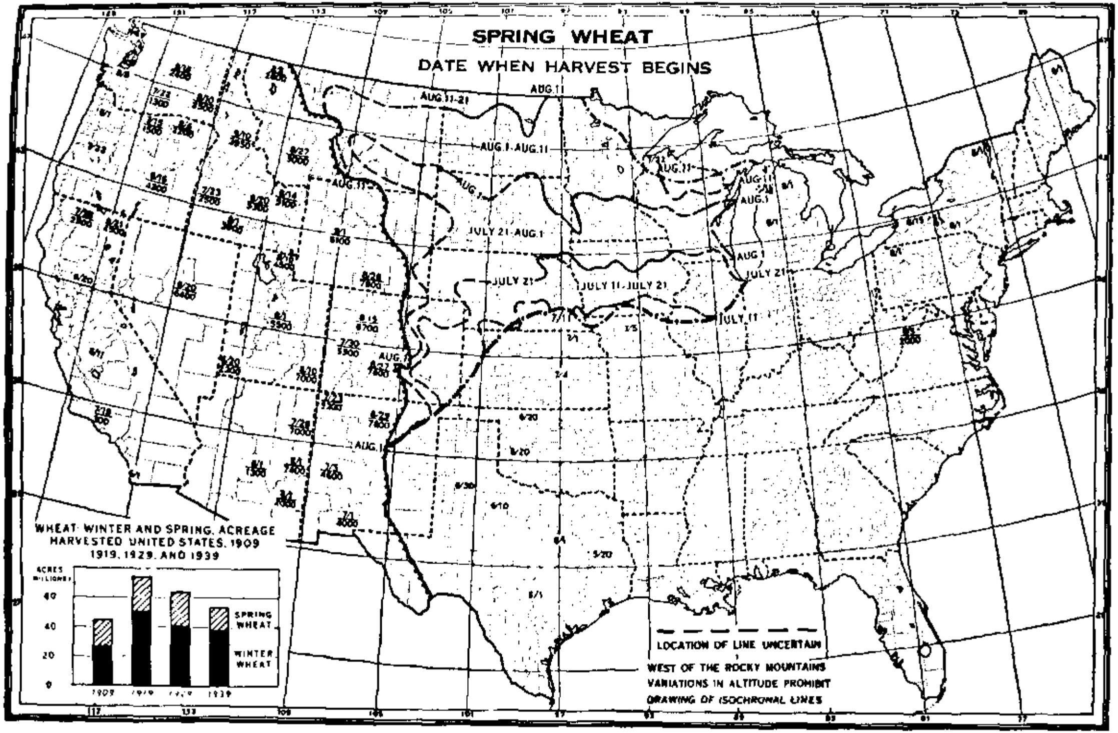

FIG. 140. Date when spring wheat harvest begins.

HARVESTING

About 78 per cent of the American wheat crop was harvested with a combine in 1945 (Chapter 8). The binder is still used to a considerable extent in the northern and eastern part of the United States, especially when it is desired to save all the straw. The header, with occasional exceptions, is used now only in emergencies when combine harvest is delayed by wet weather. The use of the self-rake reaper for harvesting wheat is now a rarity. The cradle is still used for cutting small patches of wheat on eastern and southern farms.

Wheat harvest is going on almost continuously during the year somewhere in the world (Figures 139 and 140). The list below shows some of the countries and states in which wheat usually is harvested during each month:

January: Argentina, Uruguay, Chile, and Australia.
February: Upper Egypt and southern India.
March: Egypt, Tripoli, Morocco, and India.
April: Persia, Asia Minor, and Mexico.
May: Algeria, Tunisia, central and southern Asia, Georgia, Texas, southern Arizona, southern California.
June: Greece, Italy, Spain, southern France, southern half of the United States.
July: France, central Europe, southern Russia, central United States.
August: Northern United States, southern Canada, Russia, England, Germany, Belgium, Holland, and Denmark.
September: Sweden, Norway, Siberia, Canada, northern parts of Minnesota, North Dakota, and Montana.
October: Scotland, Sweden, Norway, northern Russia, northern Canada.
November: Peru and South Africa.
December: Burma and Argentina.

Uses

Of the total domestic wheat crop, about 9 to 10 per cent is used for seed, 13 to 14 per cent is fed to livestock on the farm where it is produced, 1 to 3 per cent is ground at home mills or exchanged for flour, and the balance is sold. Annual exports to foreign countries and American territories of wheat, including that shipped as flour, have ranged from 7 million to 550 million bushels. Formerly in normal peacetimes, wheat exports usually exceeded 100 million bushels annually, or 10 to 15 per cent of the domestic crop. The remainder, or nearly 500 million bushels, is used for food and feed. The per capita consumption of wheat for food in the United States is now less than 4 bushels per year, compared with 5½ bushels about 1910. Wheat exported from the United States consists chiefly of hard red winter, and Pacific coast white wheat. There is no surplus of soft red winter or hard red spring wheat. Previous to about 1930 about one-half the durum wheat produced was exported. The recent replacement of much of the durum wheat by rust-resistant hard red spring varieties has left little of the former surplus for export.

The chief food use of wheat is in the form of flour for baked products. Other food uses include prepared breakfast foods, and the alimentary pastes made mostly from durum wheat semolina. Varieties of common or durum wheat with large white kernels such as Baart, Peliss, and Golden Ball are used for puffing. Shredded wheat products are made from soft white wheat varieties. Hard wheats are used chiefly for bread flours. Soft wheats, both red and white, are used mostly for cake, cracker, pastry, and family flours. Red durum wheat is used almost exclusively for feed, chiefly for poultry. Considerable quantities of common wheat are fed on farms in the Pacific coast and eastern states. In nutritive value, wheat is about equal to corn. Feed wheat requires grinding except for poultry. Recently, wheat has been used for making dextrose (glucose) and also for alcohol manufacture.

MILLING WHEAT

Preparation for Grinding. Wheat is first cleaned thoroughly at the mill to remove all weed seeds and foreign material. Then it is scoured to rub off hairs and dirt from the kernel. The scourer contains revolving beaters that throw the grains against the roughened walls of a drum. If the wheat is appreciably smutty or dirty, it also is washed. Smutty wheat sometimes is limed before it is scoured. Washed wheat often is dried before milling. The objects of tempering wheat just before grinding are to make grinding easier and to toughen the bran coat so it can be milled off in large flakes and thus be separated from the flour more completely. Wheat is tempered by adding sufficient water to raise the moisture content from the usual 12 to 13½ per cent up to about 15 per cent moisture. After adding the water to a moving mass of wheat, the grain is allowed to stand for 2 to 24 hours, but usually 4 to 6 hours, to permit the added moisture to penetrate the kernel to the proper depth for toughening the bran. Very dry wheat is first moistened and allowed to stand for 2 days or more for the moisture to penetrate the entire kernel. It is then tempered just before milling.

Heat generated during grinding and the aeration of the milled products during their sifting, purifying, and movement through the mill combine to reduce the moisture content in the milled products to about 13 to 13.5 per cent. There is an invisible loss in weight in milling due to evaporation when tempered wheat contains a higher moisture than 13.5 per cent before tempering. Wheat containing less than 13 per cent moisture before tempering usually shows a gain in milled weight.

The Milling Process. In a large mill the milled products are divided into numerous streams, each requiring different treatment or disposition.[16] The grain is first cracked or crushed gradually through a series of 4 to 6 pairs of chilled iron break rolls. The surface of the break rolls is roughened by sharp lengthwise corrugations. One member of each pair of break rolls runs about 2½ times as fast as the other, which produces a shearing action on the grain. The grist from each break is sifted and the coarsest particles are conducted to successive break rolls where the process is repeated.

Each successive pair of break rolls has finer corrugations and closer distances between the rolls in order to grind the grain into progressively smaller particles. The finest particles from the breaks are sifted off as flour.

The aim in milling on the break rolls is to get out as large a proportion of middlings as possible. These middlings are granular fractions of the endosperm from which the finer particles (flour), the bran, and shorts, have been separated. The middlings are rebolted and also aspirated in a middlings purifier to remove small light bran particles. The purified middlings pass through a series of reduction rolls. These rolls, which are smooth, are spaced so that each successive reduction produces finer particles. Flour is sifted out after each reduction. In milling straight flour all the flour streams are combined except for the one called red dog, which is dark in color, due to a high content of fine bran particles, and contains much of the aleurone. In usual milling practice, the finer and whiter fractions comprising 70 to 80 per cent of the total flour are combined into patent flour. The remaining darker grades, usually called clears or bakers flour, are marketed for special baking uses or are mixed with bran, graham, or rye flours. Low-grade flours (clears and red dog) sometimes are later washed to remove the starch, leaving a so-called gluten flour used mostly by diabetics, or by people with other digestive ailments.

Bleaching Flour. Most flour is bleached to make it whiter and more attractive. The bleaching is done with small quantities of such chemicals as chlorine, benzoyl peroxide, or nitrogen trichloride, or with nitrous oxide produced by an electric arc in air. Bleaching destroys the yellow pigments, chiefly xanthophyll, that are naturally present in the wheat flour. Extensive experiments failed to show any deleterious effect on the wholesomeness of the flour as a result of the bleaching process until about 1947. Excessive treatment of flour with nitrogen trichloride produces a substance that causes convulsions in dogs and monkeys. Its use in bleaching was discontinued in 1949.

By-products of Milling. The by-products of flour milling, often referred to as *offal*, are usually marketed as bran and shorts, and are valuable dairy feeds and poultry *mashes*. Some mills make three feed products, viz., bran, shorts (brown shorts), and white middlings. Scoured bran consists mostly of the large particles of pericarp and aleurone with only small quantities of starchy endosperm attached. Country bran contains more endosperm and is higher in starch and lower in fiber.

Shorts (or standard middlings) are the final middlings, consisting mostly of coarse particles of endosperm mixed with, or attached to, considerable quantities of fine bran particles. White middlings (not the intermediate milling product called middlings) comprise red dog and other low-grade flours mixed with the finer and whiter particles that otherwise would be included in the shorts. Shorts and middlings are often used as hog feed, with enough water added to make a slop. Mill feed from different mills may vary from equal parts to 3:2 proportions of bran and shorts. Bran is a bulky feed, a given volume weighing less than one-third as much as wheat.

The germ of wheat usually comes from the break rolls in a stream called sizings in which the germ is attached to a large particle of bran. The germ is flattened out and much of the bran detached in the reduction rolls. The germ usually is added to the shorts and thus used for feed. Sometimes the germ stream or the extracted oil from germs is saved for food purposes because of its high content of vitamins, particularly thiamin (vitamin B_1) and alpha-tocopherol (vitamin E). This latter vitamin is essential to fertility in rats, and to normal muscular functions in rodents and dogs, but its effect on the human system is not yet fully established.

Purified middlings of hard spring wheat are sometimes marketed as Cream of Wheat, and the corresponding product from hard winter wheat called farina also is used for a cooked breakfast cereal. Purified middlings from durum wheat, called semolina, are used in the manufacture of macaroni, spaghetti, and other edible paste products.

Flour Yields from Milling. The milling yield of about 72 per cent flour from wheat that consists of nearly 85 per cent endosperm is an indication of the difficulty of making a perfect separation of the kernel parts in the milling process. Particles of endosperm, particularly the aleurone, cling to the bran, and these are carried into the feed or by-products streams.

The average straight flour yield from wheat is about 70 to 74 per cent, or a barrel (196 pounds) of flour from about 4½ bushels of wheat. Higher extractions result in darker flour such as the 85 per cent dark "victory" flour used in European countries during the recent war. In the old days of custom grinding in small mills, 5 bushels of wheat made a barrel of straight flour (a flour yield of 65.3 per cent), and the miller often exchanged flour for wheat on that basis keeping the by-products as his toll.

A barrel of flour is sufficient for making about 300 to 315 pounds of freshly baked bread. During World War II the United States armed forces purchased flour in 100-pound bags in order to facilitate calculations of rations. By agreement, all flour was marketed on the same basis and it seems likely that the century-old barrel weight (196 pounds) may never return to the flour market.

FACTORS AFFECTING FLOUR YIELDS. The test weight per bushel is a very important factor determining the yield of flour. Lightweight (shrunken) wheat not only has a low percentage of endosperm, but the separation of bran and flour is difficult. Yields of total flour (including low grade) range from less than 62 per cent for 49-pound wheat to more than 79 per cent for wheat of a test weight of 64 pounds.

Wetting and drying in the field changes the texture of the wheat kernel, making it softer and more starchy in appearance, as well as lighter in test weight. This change is the result of additional air space between the starch grains. The low test weight resulting from weathering does not affect the flour yield in milling, and the softening of the endosperm does not impair the baking quality of the flour. In fact, its quality may even have been improved by the wetting, as the flour has the characteristics of having been aged. Weathered wheat thus is of better quality for milling and baking than its test weight and appearance indicate.

Graham flour is the entire wheat grain ground into flour, and it includes all the bran. *Whole wheat* flour and *entire wheat* flour are the same as graham flour under federal definitions formulated in 1941. Formerly whole wheat and entire wheat flour consisted of graham flour with part of the bran removed, an extraction of about 80 to 90 per cent of the wheat kernel. Often graham flour is ground in a burr mill or even between old-fashioned stone burrs. Apparently the people of the Stone Age ground their wheat into graham flour. However, the ancient Egyptians learned to bolt flour through papyrus sifters, and the tendency through the centuries has been to make the whitest flour possible.[6] The ancient Romans made a fairly white flour. George Washington sold bolted flour at his mill. In 1837 Dr. Sylvester Graham published a book extolling the virtues of flour made from the entire wheat kernel. Such flour has been called graham flour since that time. When the germ is retained in the flour as in graham and certain special flours, the fat in the germ tends to become rancid, which makes the flour unpalatable. Graham flour becomes infested with insects more quickly than does white flour. Graham flour usually sells at a higher price because of these storage risks and because of the small quantity marketed.

White flour now constitutes about 97 per cent of the wheat flour manufactured in the United States. The remainder is graham and other types of dark flour. White flour often is mixed with dark flours in making bread. Consequently, about 93 per cent of the bread baked is made from white flour only, 1 per cent is graham bread, and the remainder is mixed white and dark flours. These proportions represent the tastes and desires of the American public.

CHEMICAL COMPOSITION OF WHEAT AND FLOUR

The approximate chemical composition of the wheat kernel[29] in percentages is as follows: starch, 63 to 71; proteins, 10 to 15; water, 8 to 17; cellulose, 2 to 3; fat, 1.5 to 2.0; sugars, 2 to 3; and mineral matter, 1.5 to 2.0. The protein content of wheat varies for that grown in different regions. The approximate composition of white and graham flours, and of bran and wheat germ, are shown in Table 5. It is seen that white flour is lower in protein, fat, ash, and higher in starch than is the original wheat or the graham flour.

TABLE 5. AVERAGE COMPOSITION OF WHEAT FLOUR, BRAN, AND GERM CONTAINING ABOUT 13 PER CENT MOISTURE

	WHEAT OR GRAHAM FLOUR	WHITE FLOUR	BRAN	GERM
	%	%	%	%
Carbohydrates (nitrogen-free extract)	68	74	50	18
Starch	55	70	10	
Pentosans	6	3.5	25	6
Dextrines			4	
Sugars	2	1.5	1.5	15
Crude fiber	2.3	0.4	9	2
Fat	2	1	4	11
Crude protein	13	11	17	30
Ash (mineral matter)	2	0.45	7	5

A patent flour contains roughly 10 to 12 per cent of the total thiamin and niacin, 20 per cent of the riboflavin and iron, 25 per cent of the phosphorus, and 50 per cent of the calcium found in the wheat kernel.[3] Enrichment, as practiced for a majority of the flour used in the United States, restores about 60 per cent of the niacin, 80 per cent of the thiamin and iron, and about doubles the concentration of riboflavin in the wheat.

The germ fraction is high in thiamin, riboflavin, phosphorus, and iron. Bran is high in niacin, phosphorus, and iron. In milling, most of the thiamin is recovered in the red dog flour and the shorts, and the niacin is found mostly in the bran. The thiamin of the germ is chiefly in the scutellum rather than in the plumule and the embryonic stem and root tissues.

About 75 to 80 per cent of the thiamin in wheat is found in the bran and shorts (feed) after milling. When these two products are fed to dairy cows and hogs, respectively, not more than about one-sixth of the thiamin is returned to human food in the milk and edible pork produced.

During both of the two world wars, the people of certain European countries were forced by their governments to use high extraction wheat flour, i.e., 82 to 100 per cent of the grain. Such a diet has met with serious opposition among the populace. Also, a distinct rise in the incidence of digestive disorders, and of rickets in young children, has followed such mass consumption of high-extraction flours. Bran contains considerable percentages of indigestible but partly fermentable material that irritates the intestinal tract. Bran also contains phytic acid (inositol hexaphosphoric acid),[17] which inhibits the absorption of calcium from the intestinal contents. This appears to explain the development of rickets among children forced to eat large quantities of graham bread. Addition of calcium to the branny diet would reduce phosphorus absorption. If bread were the only food available, graham flour would doubtless be preferable to white flour from the nutritional standpoint. No one is forced to live by bread alone, however, except refractory convicts in temporary solitary confinement. Americans obtain not more than 25 per cent of their food energy in the form of wheat products. An occasional platter of pork and beans fully supplies the vitamin deficiencies in white bread resulting from the accepted milling processes.

Ash Content and Flour Quality. The ash content of flour is an important factor to flour merchandisers. Highly refined patent flour has a low ash content of 0.4 per cent or less. The more bran particles a flour contains the higher is the ash content. Therefore clear and straight flours have a higher ash content than does patent flour. Because of this relationship bakers and flour buyers often purchase flour on a guaranteed maximum allowable ash basis. High ash content is not necessarily an indication of high extraction, poor milling, or dirty wheat because wheat varieties differ in ash content. Hard wheat flours usually have a higher ash content than do soft wheat flours. Environment, chiefly weather conditions, also affects the ash content of wheat and the resultant flour. The chief constituents of wheat ash are phosphorus, potash, magnesium, sulfur, and calcium.

Protein Content and Flour Quality. The hard red spring and hard red winter wheats contain an average of about 11 to 15 per cent protein when grown in the Great Plains and northern prairie states.[14] Soft wheats contain 8 to 11 per cent protein when grown in humid areas. In years when the crop is generally low in protein large premiums of up to 15 cents a bushel may be paid for desirable lots of high protein hard wheat. Graduated premiums for fractional percentages of protein above 12.5 to 13 per cent usually are offered. In years when there is an abundance of high-protein wheat, protein premiums may be low or nonexistent. High protein wheat is blended with other wheats in order to bring up the average protein content of the resultant flour to established standards for the particular flour brand. Often wheat and flour are sold on the basis of a specified protein content.

It is customary for grain traders to attempt to establish the representative protein content for each locality supplying wheat for the particular market as soon after the marketing season begins as possible. Sometimes preliminary surveys are conducted by collecting and testing numerous early wheat samples, and then zones for protein content are mapped. This enables local buyers to pay premium prices at shipping points where wheat high in protein prevails. Individual growers with low protein wheat may profit from this practice.

The hard wheat flours as a rule are high in breadmaking quality, i.e., the ability to make a large, light, well-piled loaf of bread of good uniform texture and color. Strong wheats, i.e., those having ample gluten (protein) of good quality, are high in water absorption. They usually produce more baked 1-pound loaves of bread from a barrel of flour because of the greater ability to retain moisture as compared with the weaker flours from soft wheats. A light loaf of bread can be made from a weak flour but the pores of such bread are large and the loaf tends to dry out quickly. Hard wheats tend to produce flour of a granular texture regardless of their texture or protein content. The granular flour of hard wheats is not well suited for pastry food products, but soft wheats produce a fine, soft flour well suited to making cakes, crackers, cookies, and hot breads.

The gluten of the wheat kernel contains about 17.6 per cent nitrogen. The nitrogen per cent, determined by analysis, is multiplied by 5.7 to determine the protein content ($100 \div 17.6 = 5.7$). The protein of most feed crops contains about 16 per cent nitrogen, and the factor 6.25 is used.

MACARONI

In making macaroni and other alimentary paste products the semolina or farina is mixed with hot water and kneaded heavily under corrugated rolls until a stiff dough is formed. The dough is then placed in a cylindrical press where the heavy pressure of a plunger forces it out through a perforated plate or die at the end. The macaroni comes out in a series of continuous strands and is cut into desired lengths and hung up to dry. The pressure drives out air and compresses the dough thus leaving a dense product. Various shapes of cut or moulded macaroni and noodles, including flat noodles, are made in considerable quantities. The tubular types having a diameter of 0.11 to 0.27 inch are called macaroni. Smaller tubes, or solid strands, with a diameter larger than 0.06 inch and not more than 0.11 inch are called spaghetti. Very small solid strands, not more than 0.06 inch in diameter, are called vermicelli. The making of the holes in macaroni is relatively simple. Inside each round hole in the die plate is a small round rod attached only at the inside end of the hole. The dough surrounds this rod and forms a tube as it passes through the die plate. When the dies are shaped in the form of letters and the emerging dough strands are cut into very short sections the basic ingredient of the familiar alphabet soup is produced.

Durum semolina of high protein content is preferred for making macaroni because it produces a hard translucent product that is firm after cooking. Also semolina having a high content of yellow carotenoid pigments, i.e., a gasoline color value of 1.50 or more, is desired because it imparts a desirable rich yellow color to the macaroni.

Diseases

RUSTS

The three rusts attacking wheat are stem rust, or black stem rust, (*Puccinia graminis tritici*); leaf rust (*P. rubigo-vera tritici*) or (*P. triticina*); and stripe rust (*P. glumarum*). These are all fungous diseases, known for many centuries. The Romans attributed the crop damage to the rust god Robigus, who resorted to this means of wreaking his vengeance on a wicked people. Others, noting that rust followed damp weather, believed it to be similar to the rusting of their own iron tools. In fact, some laymen have believed that their wheat did not rust before the advent of barbed-wire fences around their fields.

Stem Rust. Stem rust has been, until recent years, the most destructive disease of wheat in the United States. It causes such severe shriveling of the grain of susceptible varieties that often the crop is not worth harvesting. It produces masses of pustules on the leaves and stems containing brick red spores. These spores spread the disease to other plants. Rusted plants transpire water at a greatly accelerated rate.

In the southern states and in Mexico, the red or urediospore stage of the stem rust organism lives throughout the year on seeded and volunteer wheat and on certain grasses. In the spring the spores multiply and spread to other plants or other spots on the same plant. A new generation of spores is produced every one to three weeks. The spores are caught by wind and air currents and may be carried upward 16,000 feet, and outward for hundreds of miles. By this means, wheat is infected as the season advances to the northward. A heavy epidemic of stem rust in Texas in April may be expected to produce a similar epidemic in North Dakota in July if the season favors rust development throughout the central wheat-growing region. A close relationship between rust epidemics in Kansas and North Dakota was recognized as early as 1910. Moist warm weather favors rust development. A lush growth of wheat produced on soils high in nitrogen and moisture is most subject to rust attack.

In the north the rust organism may pass through additional stages.[25] The red (uredio) spores on the plants are replaced by black (telio) spores as the wheat approaches maturity. These spores remain on the straw and stubble over winter, germinate in the spring, and produce basidiospores which infect the leaves of the common barberry bush (*Berberis vulgaris*) and wild species such as *B. canadensis* and *B. fendleri.* A type of spore (spermagonia or pycnospore) which develops on the barberry, constitutes the sexual reproductive cells of the fungus. The union of these cells produces tissues which give rise to cluster cups (aecia) in which aeciospores are borne. The aeciospores then are blown from the barberry bushes to wheat or grass plants which they infect. Urediospores are produced on the wheat and the life cycle is completed. The teliospores usually fail to survive the summer weather south of Nebraska, and consequently barberry bushes seldom are infected in the south. On the other hand, the urediospores of stem rust seldom live over winter north of Texas. Where barberry bushes are present in the northern states, they may be expected to spread the rust to nearby wheat fields, and the rust then spreads to other fields of wheat. The amount of inoculum coming from barberry bushes is insignificant compared with that from vast wheat fields and grass pastures. Wheat near barberry bushes becomes infected with rust fully 2 weeks earlier than that infected from spores from the south.

An effort to destroy the barberry bushes in the United States was begun in 13 states in 1918. Although 323 million bushes had been destroyed by 1945, eradication was far from complete. When the campaign was begun no one was aware of the large numbers of escaped bushes in pastures and wooded areas. In recent years barberry eradication has extended to several additional states.

Since the barberry bush also serves as a host for the stem rusts attacking grains other than wheat and also may be the medium through which new races of the rust fungus arise, its eradication has been helpful. The eradication of the wild species of barberry bushes in isolated valleys of Colorado, Virginia, and Pennsylvania has greatly reduced local damage from rust. However, in the plains and prairies of the middle west where rust clouds sweep up from the south, the eradication of barberry bushes can reduce total rust damage only to a minor degree.

Dusting wheat fields with sulfur will control stem rust if applications are begun before the rust starts and are repeated often enough to keep the leaves coated with dust. The necessity of several applications each year to insure against possible rust damage, precludes dusting as an economically feasible method at the present time. Since sulfur also controls leaf rust and mildew, airplane dusting may prove feasible.

Seed treatment has no effect on rust because the disease is not seed-borne. Early-sown wheat and early-maturing varieties partly evade rust injury.

The breeding and distribution of wheats resistant to stem rust has been one of the most spectacular achievements of American agriculture. The Hope and H–44 varieties developed by E. S. McFadden of the United States Department of Agriculture while working in South Dakota have furnished the most important basic material for breeding rust-resistant wheats throughout the world. These wheats, obtained from a cross between Marquis wheat and Yaroslav emmer, were first released in 1926. Thatcher wheat (Figure 141), developed cooperatively at the Minnesota Agricultural Experiment Station, obtained its resistance from durum wheat.[24] This variety has been widely grown but has not been used so successfully in breeding new varieties as were Hope and H–44. The eastern part of the northern spring wheat region of United States and Canada, where rust commonly occurs, is now growing rust-resistant varieties almost exclusively. Among the Hope and H–44 derivatives are Pilot, Rival, Newthatch, Mida, and Cadet that were developed in the United States, and Renown, Apex, and Regent in Canada.[9] Of these, Apex, Newthatch, and Cadet also have Thatcher in their parentage. Baart 38, Baart 46, and White Federation 38 are rust-resistant varieties grown in California that were developed from back-crosses involving the Hope variety. The winter wheats, Tenmarq, Pawnee, Comanche, Kawvale, Austin, and Seabreeze, grown in the south central states, are resistant to certain races of the stem rust organism.[59] None of them except Austin and Seabreeze have the high degree of resistance found in the spring varieties mentioned above.

About 200 distinct physiological races of the stem rust organism have been discovered, but only a few of these are of economic importance.

Leaf Rust. Leaf rust (*Puccinia rubigo-vera tritici*) occurs chiefly in the eastern half of the country, and has been less destructive than stem rust. Numerous races of the leaf rust organism are known. An early infection of leaf rust can reduce the yield of a susceptible wheat variety 42 to 94 per cent.[27] Reduction in yield is due primarily to a reduced number of kernels in the spike. The kernels also are reduced in weight but are not shriveled noticeably. Pustules containing the orange-red spores cover the leaves and part of the stems. The rust fungus lives over winter in wheat plants either in these pustules or as mycelium (vegetative strands) within the leaf tissue. Leaf rust can be controlled by several dustings with sulfur, but this is too expensive for field scale operations. Practical control is effected by the use of resistant varieties such as Pilot, Rival, Mida, and Cadet, hard red spring wheats; Westar and Comanche, hard red winter wheats; Austin, Kawvale, Seabreeze


A B

FIG. 141. Thatcher wheat (A) nearly free from rust. Marquis wheat (B) badly rusted.

and Wabash, soft red winter wheats; and Carleton and Stewart, durum wheats.

Stripe Rust (*Puccinia glumarum*). Stripe rust in the United States is confined to the western half of the country. Linear orange-yellow lesions develop on the leaves, and later on the floral bracts. Damage by stripe rust, although often unimportant, is similar to that caused by leaf rust, except that stripe rust shrivels the kernels. The urediospores overwinter where the winters are mild or where snow cover protects the foliage. The use of resistant varieties is the most practical control measure in regions where the disease is serious. Rex, Athena, Utac, Thatcher, Turkey, and Sol, are resistant.

SMUTS

Bunt or Stinking Smut. Bunt (caused by the fungi, *Tilletia caries* and *T. foetida*) is found throughout the country, but is most severe in the Pacific northwest where the spores overwinter in the soil. The disease usually is carried over from one crop to the next as black spores on the seed or as smut balls mixed with the seed. The smut spores germinate when bunt-infested seed is sown in moist cool soils. The most favorable soil temperature for bunt infection is 43° to 59° F.[39] The fungus infects the young seedlings, grows within them, and produces smut balls completely filled with black spores instead of kernels in the wheat head (Figure 142). The spores have the odor of stale fish.

Bunt can be controlled by seed treatment, the most effective being the dust fungicides, Arasan, copper carbonate, and New Improved Ceresan, applied in a mixing machine. Some varieties of common wheat are resistant to several physiological races as, for example, Ridit, Oro, Comanche, Minturki, Yogo, and Relief, winter wheats, and Pilot, Renown, Regent, and Rival, spring wheats.

Dwarf bunt is a type of *T. caries* that causes severe dwarfing of smutted plants, and it cannot be controlled by seed treatment because of heavy soil infestation where it occurs. Dwarf bunt attacks winter wheat only, chiefly in the northern intermountain states. The resistant varieties, Wasatch, Cache, and Relief, are grown where the disease is most prevalent.

Loose Smut. Loose smut (caused by the fungus *Ustilago tritici*) may occur wherever wheat is grown, but is most abundant under humid or irrigated conditions. The disease is noticeable as soon as the wheat plants head. The floral bracts are almost completely replaced by black smut masses. The spores are soon disseminated by wind, rain, and other agencies, leaving a naked rachis. Some of the spores infect flowers of sound heads while in blossom. Infection is heaviest under conditions of high humidity. When the

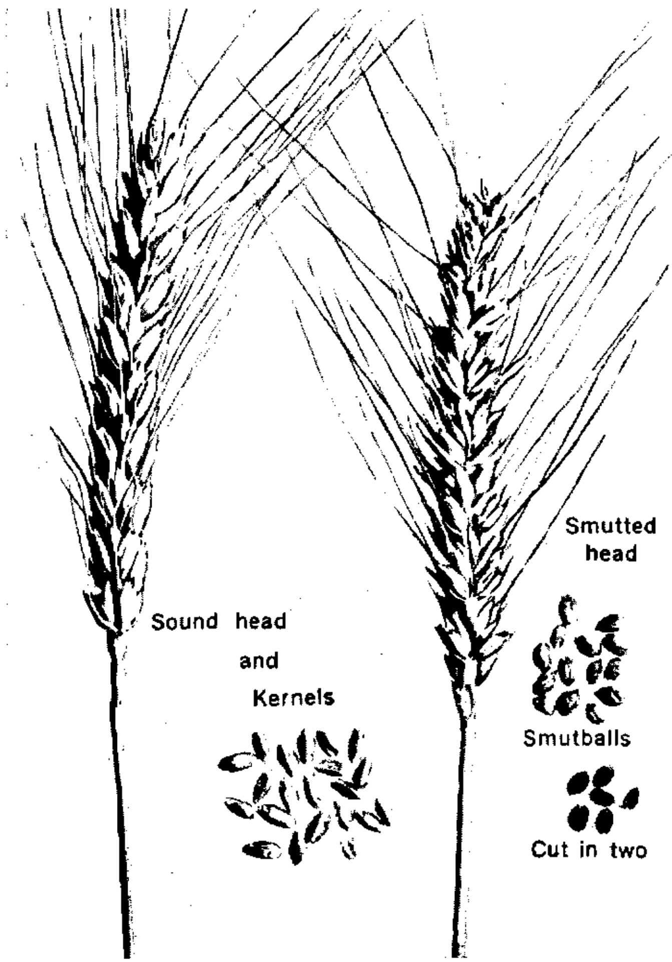

FIG. 142. Wheat bunt or stinking smut.

spores germinate, an internal infection is produced within the new kernel. Infected kernels are indistinguishable from normal kernels at maturity. When the infected seed is sown the fungus grows within the new plant as it develops. Surface disinfectants are ineffective because the loose smut organism is within the kernel. The modified hot water treatment will control the disease but it is injurious to the seed and rather expensive. It is a practical means of eliminating the disease from a foundation seed supply. The seed wheat is soaked for 6 hours in cold water, then placed in a warming tank at 120° F. for one minute, put in a hot water tank at 129° F. for 10 minutes, and finally dipped in cold water for one minute. The temperature in the hot water tank should not be allowed to rise above 131° F., or drop below 125° F. The treated seed is spread out to dry and is ready for planting as soon as it is dry enough to feed through a drill. Some varieties are resistant to loose smut, among them being Forward, Fulhio, Kawvale, Leap, Valprize, Pilot, Ridit, and Pawnee.

Flag Smut. Flag smut (caused by the fungus *Urocystis tritici*) has been reported from Illinois, Missouri, Kansas, and Washington. Losses in yield of 10 to 20 per cent may occur in susceptible varieties. Flag smut produces dark stripes on the leaves, sheaths, and culms. Infected plants are more or less dwarfed and often fail to form normal heads. The disease is carried to the next crop both on the seed and in the soil of infested fields. Flag smut can be controlled by the same seed treatments used for bunt if the seed is sown on noninfested soil. Several soft red winter varieties are highly resistant to the disease, among them being Trumbull, Fulhio, Kawvale, and Fulcaster. Resistant hard red winter wheat varieties include Cheyenne, Kanred, Turkey, and Tenmarq.

SCAB

Wheat scab, caused by *Gibberella saubinetii,* is a serious disease in the humid eastern states, particularly in the corn belt. The fungus attacks the heads shortly after they emerge. One or more spikelets may be killed, or the development of the kernel prevented. The disease can be identified by the appearance of a pinkish-white fungous growth on or around the dead tissue. The grain in diseased portions

FIG. 143. Clean and scabbed wheat kernels.

is shriveled, almost white, and scabby in appearance (Figure 143). The disease is carried from season to season both on the seed and on old crop refuse, such as cornstalks. It is most severe when wheat follows corn in the rotation. Infected seed should be treated with New Improved Ceresan before it is sown, to prevent seedling blight.

TAKE-ALL

Take-all (caused by *Ophiobolus graminis*) is a widely spread disease, but appears to be most serious in Kansas and New York. In some years, it has destroyed 10 to 50 per cent of the crop in infested fields in Kansas. Take-all may kill wheat plants in the rosette stage, or later after the heads begin to fill. In the latter case, the plants turn almost white. Nearly all plants in certain spots may be killed. Other plants are damaged by rotting of the roots. The bases of infected plants usually are black to a height of 1 or 2 inches above the soil. The take-all fungus lives over in the soil. The only feasible control measure is to keep infested land free from wheat, barley, and rye for at least 4 years.

MOSAIC

Wheat mosaic is a virus disease that produces a severe dwarfing or rosetting of the plants, or a mottling of the leaves, and often kills most of the plants in areas scattered over the fields. The virus persists in the soil for several years. The disease occurs in Illinois, Indiana, and a number of other states. It may be controlled by sowing resistant varieties such as Fairfield, Wabash, and Thorne.

The Harvest Queen variety is very susceptible to the disease, but resistant strains have been selected.[46]

NEMATODES

The nematode, or eelworm, disease caused by a small, almost microscopic round worm (*Anguinea tritici*) occurs in some of the eastern and southeastern states, particularly Virginia, Maryland, North Carolina, and South Carolina. The nematodes living in the soil enter the wheat plants through the roots and move up into the young developing heads before the latter emerge from the sheath. The infested ovary does not develop into a grain but instead forms a hard black gall filled with the nematodes. The galls resemble those formed by the bunt disease except that they are not easily crushed. The wheat nematode is controlled by rotation with crops other than rye for 1 or 2 years and by the planting of clean seed.

OTHER DISEASES

Ergot (*Claviceps purpurea*) sometimes attacks durum wheats rather severely but causes little damage to other wheats. It is controlled by use of clean seed combined with crop rotation.

Powdery mildew (*Erysiphe graminis tritici*), which occurs under moist conditions, can be controlled by use of resistant varieties such as Hardired, Pilot 13, Renown, Sonora, and Athena.

The foot rot diseases are caused by *Helminthosporium sativum*, *H. tritici*, *Pythium arrhenomanes*, other species of *Pythium*, species of *Fusarium* and other fungi.[68] The *Helminthosporium sativum* fungus also causes the *black point* disease of wheat, a discoloration and infection of the germ end, particularly of durum wheat. The western dryland foot-rot is associated with a mosaic disease.

Leaf spot (*Septoria*) attacks wheat over much of the eastern part of the United States when weather conditions favor the fungus. Black chaff and basal glume blotch occur in the middle west. There is no special control method for these diseases.

Insect Pests

Several insects are injurious to wheat, among them being the Hessian fly, wheat jointworm, wheat strawworms, chinch bugs, army worm,[76] and the false wireworm.[28]

THE HESSIAN FLY

The Hessian fly (*Phytophaga destructor*) is one of the most serious insect enemies of wheat, particularly east of the 100th meridian. The pest derives its name from the belief that it reached this country in the straw used for bedding by the Hessian mercenaries who landed on Long Island to aid the British general, Lord Howe, in the Revolutionary War. Damage occurs both in the fall and the spring. The injury is caused by the maggots (larvae) located between the leaf sheath and stem where they extract the juices of the young stems. Many of the small tillers are killed. The older stems are weakened and break over readily shortly before harvest. The fall brood may kill many plants outright in cases of serious infestation. The larvae (Figure 144) are transformed to a resting stage called a puparium or *flaxseed*. In the spring the flaxseed changes into a pupa and then into an adult fly. The female fly deposits eggs on the young wheat plants. Then another generation of larvae hatches out.

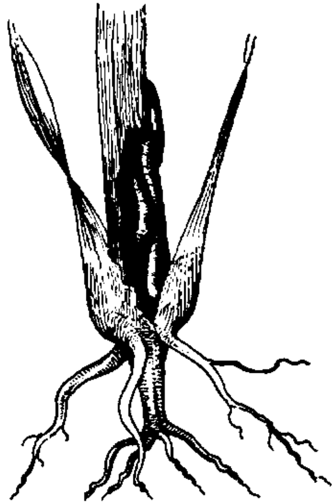

FIG. 144. Hessian fly larvae (maggots) on a wheat stem.

The most practical control measure is to sow winter wheat late enough so that the main brood of flies will have emerged and died before the young wheat plants appear above the ground. (Figure 136, p. 487.) Other methods are crop rotation, and the plowing under of infested stubble soon after harvest.[75] The sowing of resistant varieties also is helpful. Among the resistant varieties are Big Club 43, Poso 42, Dawson, Marvel, Mida, Pawnee, and Kawvale.

WHEAT JOINTWORM

As a wheat pest, the wheat jointworm (*Harmolita tritici*) ranks next to the Hessian fly in a majority of the wheat states east of the Mississippi River and in parts of Missouri, Utah, and Oregon. It is a small grub that lives in the stem and feeds on the juices. As a result, wartlike swellings on the stem usually occur above the joint or node. The egg from which the grub hatches is laid in the stem by the adult, which resembles a small black ant with wings. The damage to wheat, caused by the lodging of the infested straws, varies from slight injury to total destruction.

This jointworm can be controlled by plowing wheat stubble under deeply after harvest in order to bury it so that the jointworm adults cannot emerge. This may be impractical where grass, clover, or some other legume is seeded with the wheat, except where heavy infestations occur. Rye may be substituted for wheat in the more northerly states where the jointworm is severe.[54]

WHEAT STRAWWORM

Losses caused by the wheat strawworm (*Harmolita grandis*) may be severe throughout the wheat states east of the Mississippi River. It is also an important wheat pest in other wheat-growing states. The wheat strawworm is a serious menace in western Kansas.[64] Propagation of the worm is favored by infested stubble left on the ground following use of subsurface tillage implements and the one-way plow.

Two complete generations of the insect occur each year. The first generation, or spring form, kills outright each wheat tiller that it infests. As the larva completes its development, the tiller usually becomes bulblike at the point of infestation. The spring form is most injurious to winter wheat. The injury caused by the second generation, or summer form, is less severe except in spring wheat.

The wheat strawworm attacks only wheat. Since the spring form is wingless, it can be controlled where wheat is sown 75 yards or more from wheat stubble or straw of the previous season. Also where spring wheat is grown, all volunteer wheat should be destroyed when this pest is abundant, to prevent reinfestation.[55]

GRASSHOPPERS

Wheat is attacked by several species of grasshoppers belonging to the genus *Melanoplus*. The grasshopper deposits eggs enclosed in sacs about an inch or two below the surface of cropped, idle, or sod land. Good plowing with a moldboard plow at a depth of 5 inches or more prevents the young grasshoppers from emerging. The young grasshoppers hatch in the spring and soon begin feeding. The grasshoppers eat the leaves and often the stems and heads of the wheat plants.

The chief method of controlling grasshoppers, previous to the use of chlordane and toxaphene, was the spreading of poisoned bran mash by hand or machine at the rate of 10 to 15 pounds per acre. Spreading is best done on a bright morning when the temperature is between 70° F. and 85° F., the conditions under which the grasshoppers feed most readily.[52] The formula for the poisoned bait is as follows:

Mill-run bran, mixed feed, or shorts	25 pounds
Sawdust (three times bulk of mill-run bran)	3½ bushels
Sodium fluosilicate	4 to 6 pounds
Water	10 to 12 gallons

Toxaphene (chlorinated camphene) is applied at the rate of 7 to 10 pounds of a 20 per cent dust per acre. Chlordane is applied at the rate of 1 pound per acre in an emulsion spray or in a dust mixture.

GREEN BUG

The green bug or spring grain aphis (*Toxoptera graminum*) occurs in most of the wheat-growing states, and in some years causes severe losses, especially in Texas, Oklahoma, Kansas, and Missouri. It is a sucking insect, adults as well as young bugs feeding on the wheat plants throughout their lives. They reproduce very rapidly during the summer by vivipary (born alive) and later by eggs, with or without fertilization. The control measure is destruction of all volunteer wheat, oats, and barley in the summer and fall in each community.[73] Benzene hexachloride dusts will kill the green bug.

The Wichita, Denton, Early Blackhull, and Blackhull varieties are somewhat resistant to light or medium green bug attacks.[4] Oats and barley are damaged more severely than is wheat.

CHINCH BUG

The chinch bug (*Blissus leucopterus*), a sucking insect, often is present in damaging numbers from Illinois and Missouri westward to the central Great Plains.[51] It is more destructive to barley, corn, and sorghum than to wheat. No satisfactory methods of controlling infestation in small grains are yet known.

MORMON CRICKET

The Mormon cricket (*Anabrus simplex*) ranges from the Cascade and Sierra Nevada Mountains to the central Dakotas, devouring range grasses, grains, and other crops. This insect is wingless but it migrates on foot in dense hordes for considerable distances. Control is effected by broadcasting a poison bait such as that described for grasshopper control. An effective formula for Mormon cricket poison [15] is as follows:

Standard bran	100 pounds
Sodium fluosilicate	4 pounds
Water	12 to 15 gallons

Seagulls devoured the crickets invading the first crop in Utah.

WHEAT-STEM SAWFLY

The wheat-stem sawfly (*Cephus cinctus*) frequently causes severe damage in western Canada and in Montana and other states.[1] The adult female fly splits the wheat stem with a pair of sawlike ovipositor appendages and then deposits an egg inside the stem. The cannibalistic larvae feed downward inside the stem, and the survivor finally chews a groove or ring just above the soil surface, which causes the stems to fall over. The chief loss is from the broken stems that are difficult to save in harvesting. Control measures consist in rotation with other crops, and the turning under of the stubble with a breaking plow that turns the furrow completely. The adults have difficulty in emerging through 6 inches of soil. The use of a pickup reel on the combine would salvage most of the broken stems. Resistant varieties with solid stems are being developed. The resistant Rescue variety was released in Saskatchewan in 1946, and is grown in Montana and North Dakota. Similar pests, the black grain stem sawfly (*Cephus tabidus*), and the European wheat stem sawfly (*C. pygmaeus*), occur in the east central states.[71]

WIREWORMS

The Great Basin wireworm (*Ludius pruninus*, var. *noxius*) destroys considerable wheat in sections of Washington, Oregon, and Idaho having an annual precipitation of less than 15 inches. These wireworms, which live in the soil for 3 to 10 years, eat seeded grain and the underground parts of wheat plants, thus thinning the stands. The adults (*click beetles*) live only a few weeks. Partial control measures are thick seeding and clean fallowing. Keeping the land free from any growing weed or wheat plant during the fallow season will starve the young larvae.[35] About 20 to 25 pounds per acre of D.D.T. applied to the soil controls this pest.

False wireworms (*Eleodes* species) have damaged wheat severely in Kansas in recent years by devouring the seeded grain before it germinates. Control measures are crop rotation and seeding only when the soil is moist enough to insure rapid germination.[28]

OTHER INSECTS

The fall army worm (*Laphygma frugiperda*) attacks wheat and numerous other crops in the southern and central states. Control in wheat fields consists in the use of poison bran bait, furrow barriers, and delayed seeding of winter wheat as recommended for Hessian fly control.[40, 74]

The army worm (*Cirphis unipuncta*) has been destructive in many localities in the eastern half of the United States.[76] It is controlled with poisoned bran mash and the use of a furrow or ditch to check the migration of the worms.

Billbugs (*Calendra* species) attack wheat as well as other crops. The chief control measure is crop rotation.

The wheat stem maggot (*Meromyza americana*) feeds on the stem just above the top node. It cuts off the peduncle, causing the head to turn white. The percentage of plants injured is usually too small to justify control practices.

The pale western cutworm (*Agrostis orthogonia*) destroys considerable wheat in the dry land sections of Montana, North Dakota, Kansas, and other states. The light gray larvae hatch out in the spring and feed on the underground portions of wheat and grass plants. The moths deposit eggs in the soil in the fall. The best control method[28] is clean summer fallow to destroy all weeds, grass, and volunteer grain, and thus starve the larvae.

The insects attacking wheat in storage are described in Chapter 9.

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16 RYE

Economic Importance

Rye is a small grain of relatively minor importance in the United States. The average annual area sown to this crop from 1937 to 1946 was approximately 6 million acres. About 3 million acres were harvested for grain, and a similar area was pastured, cut for hay, turned under for green manure, or just abandoned. The average grain production was 37,400,000 bushels. The average acre yield was 12.1 bushels. The principal rye states are North Dakota, South Dakota, Nebraska, Minnesota, and Wisconsin (Figure 145).

In the north central and western states rye is grown primarily for grain but occasionally for hay or pasture. In other regions, particularly in the east and southeast, it frequently is grown for pasture or as a cover and green manure crop, often in mixtures with

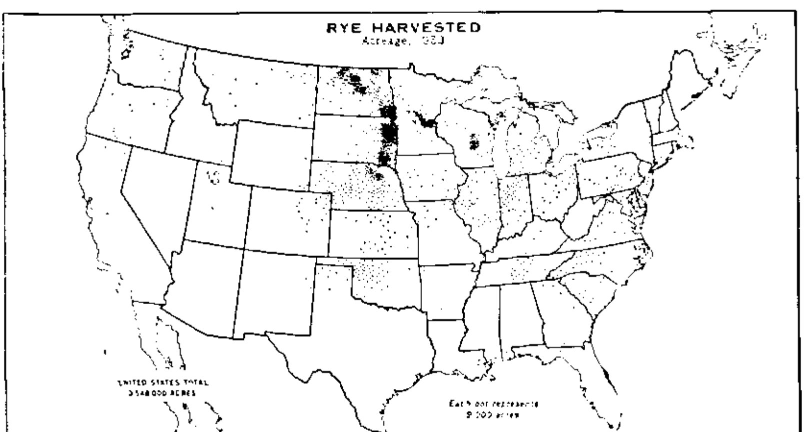

FIG. 145. Rye acreage harvested for grain.

vetch or clover. Rye also finds a place as a smother crop for weeds.

The leading countries in rye production are Russia (U.S.S.R.), Germany, Poland, Czechoslovakia, United States, France, and Hungary. The world production lies between 1½ and 2 billion bushels annually.

History

Rye evidently has been under cultivation for a much shorter time than has wheat, because it was unknown to the ancient Egyptians and Greeks. Rye is supposed to have come into cultivation in Turkestan. Rye is found as a weed widely distributed in wheat and barley fields in southwestern Asia where it has never been grown as a cultivated crop. Rye appears to be indigenous to that part of Asia. Rye was not intentionally sown with wheat and barley, but when its value became recognized, rye was sown as a separate crop. Cultivated rye (*Secale cereale*) may have descended from S. *anatolicum*,[1] a wild form of rye which is found in Syria, Armenia, Persia, Afghanistan, Turkestan, and the Kirghiz Steppe. Another opinion is that rye originated from S. *montanum*, a wild species found in southern Europe and the adjoining part of Asia, and that it was grown as a cultivated plant in the Bronze Age. The similarity between species makes it impossible to prove which one originated from the other.[15]

Adaptation

Rye can be grown in all states of the Union, but the chief acreage is in the northern and eastern states. Winter rye is the hardiest of all cereals.[3, 9]

The highest yields of rye usually are obtained on rich well-drained loam soils. Rye is more productive than other grains on infertile, sandy, or acid soils. It is an especially good crop for drained marsh lands and cutover areas of the southeastern states when brought under cultivation.[4] Rye usually yields less grain than winter wheat under conditions favorable for the latter crop because of its shorter growing period, heavier straw growth, and lower spikelet fertility. However, rye usually is sown on poorer soils and with poorer seedbed preparation than is wheat.

Rye volunteers freely because the grain shatters readily and the seeds and plants thrive under adverse cultural conditions. For this reason the growing of rye in winter wheat regions is likely to result in rye admixtures in the wheat, with a consequent depreciation in the market value of the wheat.

Botanical Description

Rye is an annual or winter annual grass classified in the tribe *Hordeae* to which wheat and barley also belong. The stems of rye are larger and longer than those of wheat. The leaves of the two plants are similar except that those of rye are coarser and more bluish in color. The roots of rye branch profusely, especially near the soil surface, but some roots may extend to a depth of 5 or 6 feet.[16] This extensive root system was suggested as one reason why rye grows better than wheat in certain dry climates and on poor soils.

The inflorescence of rye is a spike with a single spikelet at each rachis joint. The spikelet consists of three florets, two being fertile and one abortive. The spikelet is subtended by two narrow glumes. The lemma is broad, keeled, terminally awned, and bears barbs on the keel. The palea is thin and two-keeled. The caryopsis (Figure 146) is narrower than the wheat kernel. It usually is brownish-olive, greenish-brown, bluish-green, or yellow. The green or blue pigment, when present, is located in the aleurone, but the brownish pigment is in the pericarp. The grain color is determined by combinations of pigmentation in the two tissues.

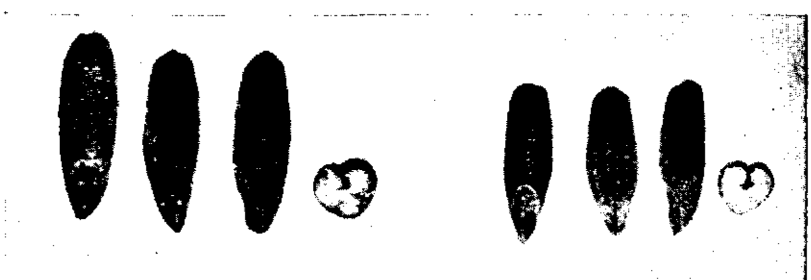

FIG. 146. Kernels (caryopses) of rye.

Pollination

Rye is a naturally cross-pollinated plant. The flower remains open for some time, which facilitates cross-pollination. About 50 per cent cross-pollination between adjacent rows of rye was observed in New Jersey.[13] Sterility is frequent in rye. Approximately one-third of the flowers in Wisconsin rye fields failed to set seed.[5] Considerably more self-sterility is encountered.[1] Selfed lines of rye usually show marked reduction in vigor, shriveling of the grain, and some reduction in plant height, as homozygosity is approached.[1] Some inbred lines are fairly productive.

Many plant breeders have crossed rye with wheat in a thus far futile attempt to transfer the extreme winterhardiness of rye over to wheat. In most of the crosses wheat was used as the female parent. The difficulty appears to be due to a lack of pairing between rye and wheat chromosomes. The wheatlike wheat-rye hybrid derivatives merely carry one or more entire rye chromosomes.[7] These extra rye chromosomes often are lost during meiosis (sexual cell division) in later generations, and the rye characters disappear, in which case the resultant progeny is typical wheat.

Varieties

Both winter and spring varieties of rye are grown, winter varieties being by far the more important. Few varieties of rye have distinct characteristics because they comprise a mixture of types maintained by cross-pollination. Winter varieties adapted to the northern states are wholly unsuited to conditions in the south where mild temperatures do not provide sufficient cold to force such true winter varieties into early heading. The so-called winter rye varieties grown in the south actually have a partial spring habit of growth. These varieties flower and mature before the advent of unfavorable hot summer weather.

Abruzzes (Abruzzi) rye, introduced from Italy, is well adapted to a large part of the cotton belt, where it is grown principally as a pasture or cover crop. It produces a vigorous growth even in cold weather. South Georgia rye, which is a few days earlier and somewhat taller than the Abruzzes variety, is grown in the southern part of the cotton belt. Balbo rye, also introduced from Italy, and similar to Abruzzes, is important in Tennessee.[10] Balbo also is now the leading variety in Kansas and Nebraska and the states to the east.

Rosen rye, which was introduced from Russia in 1912,[12] is adapted to the northeastern states, the corn belt, and both irrigated and dry lands in Colorado. It yielded about twice as much as common rye in Michigan.[11] Pure Rosen has large bluish-green kernels. It was kept pure for many years by growing foundation seed on South Manitou Island in Lake Michigan where no other rye was grown. Petkus, which is indistinguishable from Rosen, is adapted to the same conditions.

Dakold is very hardy and the most productive variety in North Dakota and northern Montana. It has small heads, small dark-colored kernels and slender stems. It matures early. Swedish rye (Minnesota No. 2) has been widely grown in Minnesota. In appearance, growth habit, and hardiness it is very similar to Dakold. Dean rye has been grown in Minnesota and Wisconsin, and is similar to Swedish. Advance, a selection from Dean, has been the most productive variety in eastern South Dakota and has yielded well in North Dakota and in central Oregon.

A selection from Schlanstedt rye, Wisconsin Pedigree No. 2, formerly was the most productive variety in Wisconsin. A "white" or yellow kerneled variety named Imperial, which was selected from Wisconsin Pedigree No. 2, is a vigorous, hardy, productive variety in Wisconsin.[6] It is the synthetic progeny of seven bulked superior, self-fertile selections.

The Mammoth White and Thousandfold varieties are grown in the northeastern states. Raritan has yielded 10 to 12 per cent more than other varieties in New Jersey. This variety is the progeny of 98 bulked strains selected and tested at the New Jersey Agricultural Experiment Station.[13]

A spring variety called Prolific is being grown in North Dakota, and the Emerald variety is grown in Minnesota.

The so-called Michels grass is a variety of rye identical with strains developed at the Washington Agricultural Experiment Station from a cross between ordinary rye and the wild perennial rye, *Secale montanum.* It has a partial perennial habit under favorable conditions but has no real advantage over ordinary rye.

Culture

Rye may replace wheat, oats, or barley in crop rotations that include a small grain. Cultural requirements are similar to those for wheat. Much of the rye grown in the western half of the country is drilled into small-grain stubble without previous soil preparation. This practice, which is economical of labor and also leaves the stubble to hold snow and protect the rye plants from winterkilling, is satisfactory on land that is reasonably free from weeds. Rye can be grown on disked corn land, fall-plowed land, or on summer fallow in the western states, but usually such land is reserved for wheat or other crops.

Winter rye can be seeded at almost any time during the late summer or early fall, but early seeding produces the most fall pasture. Winter rye ordinarily should be sown at about the same time that winter wheat is sown, but the time is less important with rye because it grows better at low temperatures and thus can be sown later. In the eastern states, rye for grain production should be sown from September 1 in the northern part of the country to November 30 in the southern part.[4] It may be seeded 2 to 4 weeks earlier when grown for pasture, a cover crop, or for green manure. Mid-November seeding has resulted in the highest yields in the central cotton belt. Winter rye is sown about August 15 to September 1 in the northern part of North Dakota and Minnesota, but at later dates farther south. The optimum date for seeding winter rye in central South Dakota is about September 15.[2]

Spring rye, like other spring small grains, should be sown as early as is feasible.

Rye is generally seeded in the western states at the rate of 4 to 6 pecks per acre. The usual rate in the northeastern states is 6 pecks, while in the cotton belt it varies from 3 to 4 pecks. On sandy loam soils in the central cotton belt, the 2-peck rate of seeding gave the highest grain yields of Abruzzi rye, but 3 pecks usually are recommended.[4]

Rye usually is harvested and threshed like other small grains, except where special use is made of the straw. In that case, rye is harvested before it is fully ripe, while there is still a slight green tinge about the plant. Special threshers are used to beat the grain from the heads, leaving the straw largely intact. Only the upper portion of the stems comes in contact with the thresher cylinder. About half of the rye crop is harvested with a combine.

Uses

About 5 million to 12 million bushels of rye are used annually in making whisky and alcohol. Some 9 million bushels are used for food, 8 million bushels for seed, and the balance is fed to livestock or is exported.

The protein content of rye averages somewhat less than in wheat. Rye flour does not develop true gluten but it has proteins which give it the capacity for making a leavened nutritious bread. The bread is somewhat heavier and darker than that from wheat flour. Rye flour usually is mixed with 25 to 50 per cent wheat flour for bread making. Winter rye is preferred generally for bread-making flour. Distillers prefer a plump light-colored grain.

Rye has a feeding value of about 85 to 90 per cent that of corn. It is not highly palatable and is sticky when masticated, so it usually is ground and fed in mixture with other grains. The proportion of rye in mixed feeds usually is less than a third.

Rye straw is used for packing nursery stock, crockery, and other materials. The long straw is used for stuffing horse collars.

Diseases

ERGOT

Ergot (*Claviceps purpurea*) causes serious losses in rye. The ergot bodies are poisonous to livestock as well as to human beings, and often cause abortion in pregnant animals. Rye that contains 0.50 per cent or more of ergot is considered dangerous when used for either food or feed. However, ergot does not cause abortion in mules which are naturally sterile. The ergot disease is caused by a fungus that infects the grains at the time of blossoming. About 7 to 14 days after infection, the honeydew stage becomes evident.

The honeydew contains spores that can infect other grains or grasses in blossom. Soon the fungus threads in the infected grains form ergot bodies (sclerotia) which resemble in shape the grain of the plant on which they develop (Figure 147). The purplish-black ergot bodies overwinter in the field, or with the seed in storage. They are able, under favorable conditions, to germinate in the spring. Abundant moisture for the germination of the ergot sclerotia, and warm dry weather for blossom infection, are favorable for development of the ergot disease in epidemic form.[17] The spores of the sclerotia are disseminated to a great extent by winds.

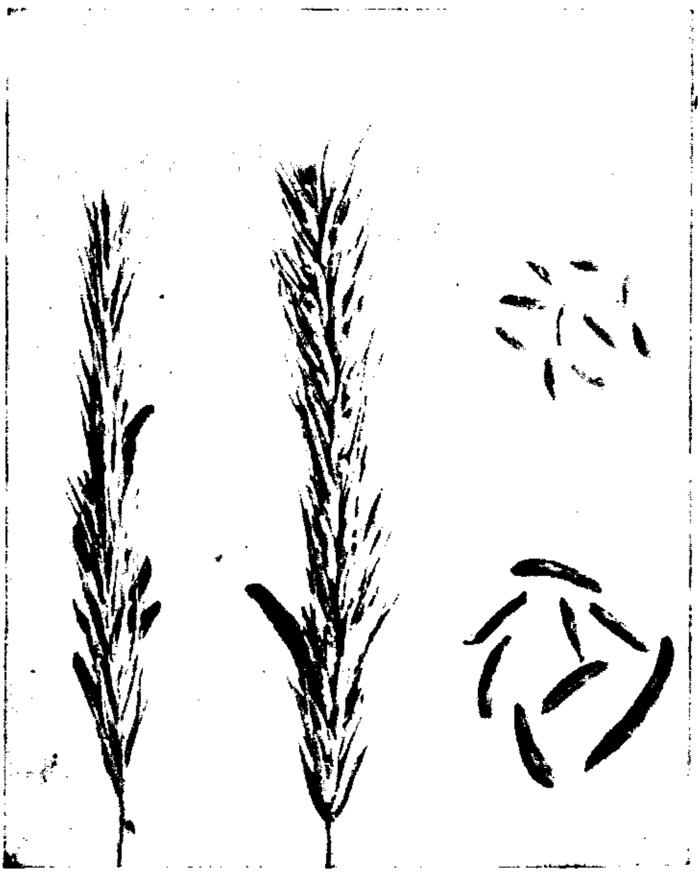

FIG. 147. Rye spikes infected with ergot (*left*). Ergot sclerotia (*right below*). Rye grains (*right above*).

Ergot can be controlled by sowing ergot-free seed on land where rye has not been grown for a year or two previously. Infested rye should be immersed in a 20 per cent solution of common salt to separate the ergot bodies. The grain is stirred and the ergot bodies float to the surface where they can be skimmed off. After the salt treatment, the grain should be washed and dried before seeding or feeding. Much of the ergot can be removed by aspiration cleaning equipment available in mills.

Ergot is used extensively in drug preparations and can be marketed for that purpose, although under peacetime conditions the supply is largely imported from the Mediterranean countries.

STEM SMUT

Stem smut (*Urocystis occulta*) attacks rye wherever it is grown, but particularly in Minnesota and nearby states. Serious losses are caused when infection is high.[14] The smut appears on the culms, leaf sheaths, and blades as long narrow stripes. These stripes first appear lead-gray but later turn black. Infected plants are more or less dwarfed and the heads fail to emerge from the sheath. The spores are carried both on the seed and in the soil. Seed treatment, as for stinking smut of wheat, will generally control the disease in the northern states. Crop rotation must be used where the spores are soil-borne.

OTHER DISEASES

Anthracnose (*Colletotrichum graminicolum*) is often found on rye in the humid to subhumid eastern states. Infection of the culm results in premature ripening and death of the tillers. Infected tissues are stained brown on the leaf-sheath that surrounds the diseased culm. Head infections may occur later to cause shriveled, light-brown kernels. The lower portion of the culm has a blackened appearance where attacked by the disease. Control measures involve proper crop sequences, and plowing under crop residues.

The early maturity of rye usually enables it to escape serious damage from stem rust caused by *Puccinia graminis secalis.* Leaf rust (*Puccinia dispersa*) likewise causes little injury. Severe infections, largely confined to the southern range of rye culture, cause a reduction in tillering and decreased yields. The disease over-winters in the leaves of winter rye as dormant mycelium.[8] Destruction of volunteer rye in stubble fields will aid in control of the disease.

Insects

Rye is attacked by grasshoppers, the chinch bug, Hessian fly, joint-worm, sawfly, and other common insects of small grains. The total losses are not large. However, early-sown winter rye furnishes a favorable environment for the depositing of grasshopper eggs and may thus promote grasshopper injury to other crops.

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17 BARLEY

Economic Importance

Barley ranks fourth in importance among the cereal crops of the country, being exceeded by corn, wheat, and oats. The average area harvested in the 10-year period 1937 to 1946 was about 12½ million acres, on which an average annual production of some 300 million bushels was obtained. The average yield per acre was about 24 bushels. The principal barley states were: Minnesota, North Dakota, California, South Dakota, Nebraska, and Wisconsin (Figure 148). The leading countries in barley production are Russia (U.S.S.R.), United States, Germany, Canada, India, Japan, Spain, and Portugal.

History of Barley Culture

Barley was cultivated by the Swiss lake dwellers in the Stone Age. Asia and Ethiopia have been suggested as probable centers of origin of barley. Cultivated barley may have originated from *Hordeum agriocrithon*, a wild 6-row barley with a brittle rachis found in eastern Tibet,[1] or possibly from *H. spontaneum*, a 2-row type.

Barley was grown in the early American settlements. The English brought over 2-row types, and the continental 6-row types were introduced by the Dutch. Spanish settlers introduced Coast barley into Arizona as early as 1701 and into California in 1771. Manchuria and Oderbrucker barleys, continental 6-row varieties, became established in the upper Mississippi Valley between 1860 and 1890. Several of the present-day 2-rowed varieties were introduced from Sweden and Germany about 1900.

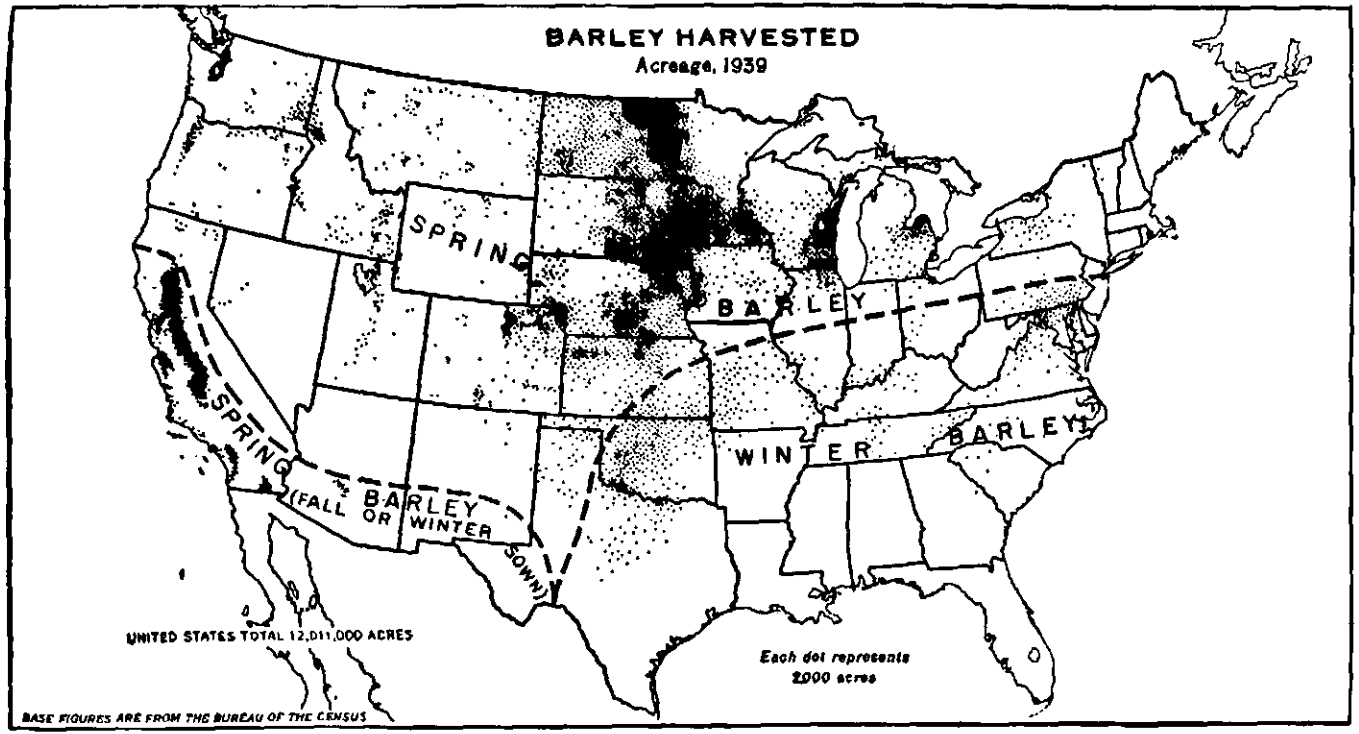

FIG. 148. Distribution of winter and spring barley in the United States.

Adaptation

Barley is grown throughout the more temperate regions of the world. It thrives in a cool climate. It will stand more heat under semiarid than under humid conditions.[17] In the warmer climates barley is sown in the fall or winter. The best barley soils appear to be well-drained loams. It produces a poor crop, especially as to grain quality, on heavy poorly drained soils in regions of frequent rains. Light sandy soils are poor for barley because growth often is erratic and the crop is also more likely to be ripened prematurely by drought. In spite of the better requirements for the most satisfactory growth of the crop, barley is the most dependable cereal under extreme conditions of alkali, frost, or drought.

The most common ecological groups of barley[15] include: (1) Manchuria, which embraces most of the 6-row barleys of the temperate plains of Eurasia, (2) the Coast group, which includes many 6-row barleys from North Africa, (3) Hannchen from Sweden, (4) Smyrna group from Asia Minor, (5) hull-less or naked forms from central Asia, and (6) winter barley from either the Balkan-Caucasus region or Korea. The effect of adaptation on variety survival in mixtures was determined by growing a mixture of 11 varieties at 10 stations for several years.[14] Population counts made each year showed a rapid elimination of the sorts less adapted to the environment and to competitive conditions at all places. The variety that eventually predominated the population was soon evident at most stations but a variety that led at one station might be eliminated at another. The varieties that survive best in mixtures are usually but not necessarily those giving the highest yields when grown alone.[28]

Botanical Characteristics

Barley belongs to the grass tribe Hordeae, in which the spikes have a zigzag rachis. It belongs to the genus *Hordeum*, section Cerealia. In this section are three cultivated species with a tough rachis, described later, and two uncultivated species with a brittle rachis, *H. agriocrithon* E. Åberg and *H. spontaneum* C. Koch.[2]

The vegetative portion of the barley plant is similar to that of the

FIG. 149. Kernels of naked barley.

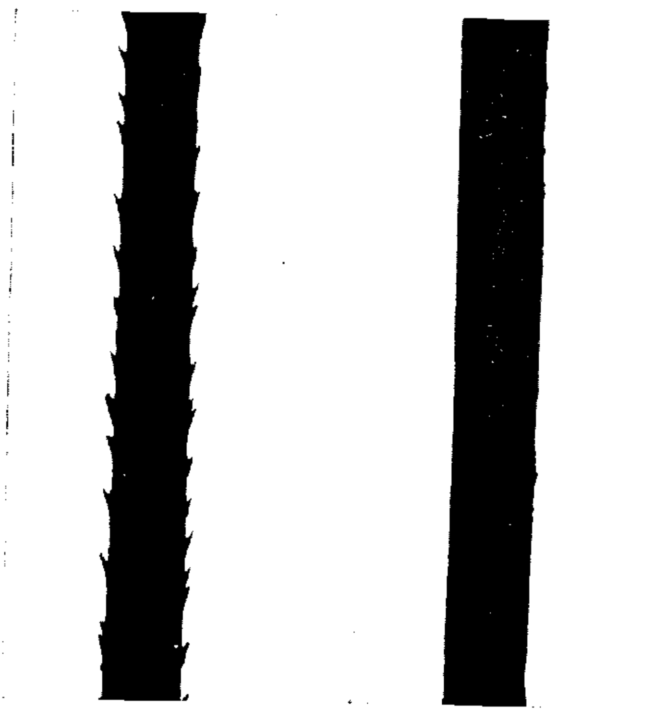

FIG. 150. Rough awn of Oderbrucker (*left*), and smooth awn of Wisconsin Barbless (*right*).

other cereal grasses except that the auricles on the leaf are conspicuous (Figure 124, Chapter 15). The lateral spread of the barley roots usually varies from 6 to 12 inches, while the depth of penetration varies from 3.0 to 6.5 feet.

The inflorescence is a spike with three spikelets borne at each rachis node. Each spikelet contains a single floret. A spike usually contains 10 to 30 nodes In 6-rowed forms, all three florets at a node are fertile, while in 2-rowed barley only the central floret is fertile. Each spikelet is subtended by a pair of glumes, which are normally narrow, lanceolate bracts with short bristlelike awns. The floret is composed of a lemma and a palea, and a caryopsis when fertile. Except in hull-less varieties (Figure 149), the lemma and palea adhere to the caryopsis when mature. The lemma may terminate in an awn or hood, or it may be merely rounded or pointed. The awns of barley may be either rough (barbed) or smooth (Figure 150), the latter usually being smooth at the base and slightly roughened at the tip. The hood is a trifurcate (three-forked) appendage that replaces the awn (Figure 151). Awnless varieties are comparatively rare. The rachilla is a small, long- or short-haired structure lying within the crease of the kernel.

FIG. 151. Spike of Meloy hooded barley.

The grains are about 8 to 12 mm long, 3 to 4 mm wide, and 2 to 3 mm thick. A pound of seed contains about 13,000 (8,000 to 16,000) grains. About 10 to 15 per cent (usually 12 to 13 per cent) of the kernel consists of hull, except in the naked varieties which are free from the hull after threshing. Typical bushel weights are: hulled 48 pounds and naked 60 pounds.

Five color conditions are recognized in the barley grain,[9, 13] viz., white, black, red, purple, and blue. The latter three colors are due to anthocyanin pigments. When these pigments occur in the barley hulls, they are red or purple, but when they occur in the aleurone layer, the grains are blue. The red color usually fades. Naked barleys with red in the pericarp and a blue aleurone appear to be purple.

Black comes from melanin-like pigments in the hulls or pericarp. The white and blue barleys are the only ones grown extensively.

Pollination

Barley is generally self-fertilized because pollination occurs while the head is in the boot in many varieties. In Minnesota, occasional natural cross-pollinations occurred in some varieties,[26] when white and black varieties were grown side by side. Similar results were obtained in Colorado, where the commercial varieties showed less than 0.15 per cent of natural crosses.[23] Variation was greater between varieties than between seasons.

During fertilization pollen may germinate within five minutes after it falls on the stigma. Within six hours after pollination, fertilization of both the egg cell and endosperm nucleus is completed and cell division has begun.[21]

Cultivated Barley Species

The cultivated barleys are classified into three species based on the fertility of the lateral spikelets: (1) *Hordeum vulgare* L. emend. Lam. (6-rowed barley), (2) *H. distichum* L. emend. Lam. (2-rowed barley), and (3) *H. irregulare* E. Åberg and Wiebe (irregular barley).[3]

The first species, with all florets fertile, includes the ordinary 6-rowed barleys with lateral kernels slightly smaller in size than the central one (Figure 152), and a subgroup, *H. intermedium*, in which the lateral kernels are markedly smaller in size than the central one.[9]

The *H. distichum* species with only the central florets fertile is divided into two groups: (1) the common 2-rowed with lateral florets consisting of lemma, palea, rachilla, and reduced sexual parts, and (2) a deficiens group with lateral florets reduced and consisting of lemma and rarely palea, and rachilla, but with no sexual parts.

In the *H. irregulare* species,[2] which is of Ethiopian origin and has sometimes been called Abyssinian intermediate, the central florets are fertile and the lateral florets are reduced to rachillae in some cases, and these are distributed irregularly on the spike. The

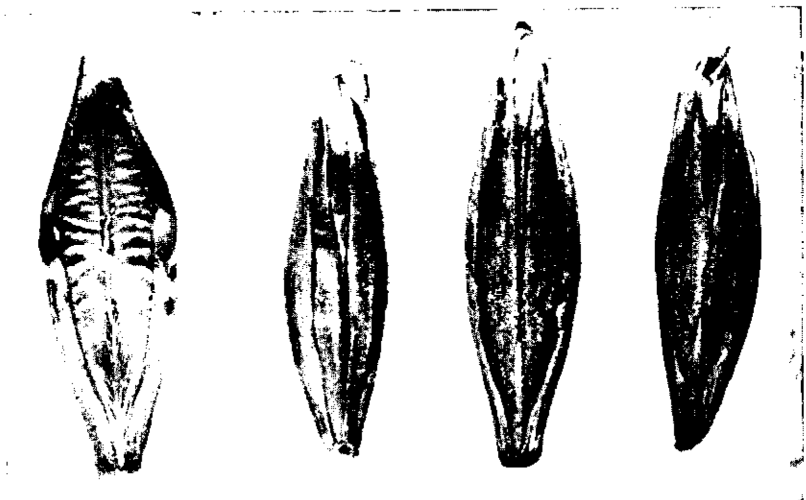

FIG. 152. (*Left*) Two-rowed Hannchen barley, showing long-haired rachilla and wrinkled palea. (*Right*) Central and lateral kernels of the more slender six-rowed barley. The lateral kernels are slightly curved. Rachilla with short hairs.

remainder of the lateral florets may be fertile, sterile, or sexless.

The barley varieties grown on farms are predominantly the ordinary 6-rowed forms of *Hordeum vulgare* and 2-rowed forms of *Hordeum distichum* (Figure 153). So-called 4-rowed barleys are 6-rowed forms in which 2 rows of lateral florets overlap to form single rows on each side of the spike. The 4-row effect usually occurs only in the upper two-thirds of the spike.

Regional Types and Varieties

More than 100 varieties of barley are grown commercially in the United States.[9] Probably 4,000 or more varieties are grown over the world. The country has been divided into three general barley regions: (1) the humid spring region, (2) the semiarid region, and (3) the humid winter region.[10] Recommended varieties[17] are indicated below.

THE HUMID SPRING REGION

The varieties grown in the humid spring region of the upper Mississippi Valley include Manchuria, Oderbrucker, Kindred, OAC

21, Trebi, Peatland, and several smooth-awned varieties including Wisconsin Barbless, Velvet, Plush, Mars, Tregal, and Bay. Odessa and Feebar are grown in eastern South Dakota. Manchuria was for many years the standard variety in the more humid parts of North Dakota.[27] Oderbrucker and Wisconsin Barbless have led in Wisconsin. Two-rowed varieties are not grown extensively. Spartan is produced in Michigan, South Dakota, Nebraska, and Wyoming.

FIG. 153. Three two-rowed barley varieties: Left to right—Hannchen, White Smyrna and Chevalier. Club Mariout (six-rowed) at extreme right.

It is the leading variety in South Dakota. Alpha is grown in New York and Pennsylvania.

THE SEMIARID REGION

Both 6-rowed and 2-rowed varieties are grown in the semiarid region. In the northern part, 2-rowed, hulled varieties are widely grown. Among these are Campana, Hannchen, Spartan, Hanna, Horn, and White Smyrna. Campana is grown mostly on Montana dry lands. Hannchen is grown in Oregon and California on both dry and irrigated land. Campana has semismooth awns. White Smyrna is a large-kerneled, drought-resistant early sort grown mostly in Wyoming, Idaho, and Colorado. The other varieties grown in the semiarid region are generally 6-rowed, hulled, rough-awned varieties of North African origin such as Trebi, Atlas, Coast, and Club Mariout, or smooth-awned varieties of hybrid origin (Velvon, Velvon II, Lico, Flynn 37, Rojo, Arivat, Flynn 1, Beecher, Glacier, Gem, Vaughn). Trebi and Velvon are the varieties most widely grown under irrigation on the Plains and in the Great Basin. Despite various weaknesses Trebi ranks as a high-yielding variety.[12] Club Mariout is grown on the Pacific coast as well as on the Great Plains as a dryland variety. Coast, with its tough rough awns, was the common barley of the western states for many years. Atlas is early, stiff-strawed, less blue than Coast, and has been widely grown in California in recent years.[8] Flynn 1, a semismooth variety, is grown in northwestern Kansas. Arivat and Vaughn are grown under irrigation in the southwest, whereas Glacier is grown largely on irrigated land in Montana. Flynn 37 and Rojo are California varieties. Beecher is most important in Colorado, and Lico in Colorado and Wyoming. Gem is grown chiefly in Idaho.

THE HUMID WINTER REGION

The Tennessee Winter type, including its selections such as Kentucky 1, Reno, Ward, and Tennessee Winter 52, is the most vigorous and widely adapted of the winter barleys, being grown in the southern states from Maryland and Pennsylvania to Oklahoma. It is a rough-awned, 6-rowed type, the kernels being similar to those of Manchuria in both size and character. Similar varieties, Kentucky No. 2, Purdue 21, and Michigan Winter, are grown to some extent. Wong, a winter 6-rowed variety from China with short spikes and awns, is grown in New York, Pennsylvania, New Jersey, Delaware, Maryland, and Virginia. Tennessee Beardless 5 and 6, Missouri Early Beardless, North Carolina Hooded 26, Iredell, Tucker, and Marett Hooded 4 are hooded winter sorts grown in the southern humid region. Iredell is grown in North Carolina, Marett Hooded in South Carolina, and Tucker in West Virginia. Reno is grown in southern and central Kansas, Missouri, and Texas, and Wintex and Texan are grown in Texas, Mississippi, and Arkansas. Texan is smooth-awned. Marnobarb, a smooth-awned variety, is recommended for Maryland, Virginia, and New Jersey. Smooth Awn 86 is grown in Virginia. Other smooth-awned winter varieties include Poland in New York, Briar in West Virginia, Randolph and Davidson in North Carolina, Fayette in Arkansas, Tenkow and Woodwin in Oklahoma, Tunis in South Texas, New Mexico Winter 1 in New Mexico, Santiam and Cascade in western Oregon, and Olympia in western Washington.

Barley Improvement

One of the most important developments in barley improvement has been the breeding of smooth-awned varieties.[13] This has eliminated the severe irritation resulting from handling rough-awned varieties previously grown. Lion, a black-glumed rather unproductive variety selected from a barley introduced from Russia in 1911, is the direct or indirect progenitor of the smooth-awned varieties in America. Awned varieties are valuable because the awns function in transpiration and photosynthesis and as a depository for mineral matter.[11] When the awns are removed, the ash content of the rachis increases, which may account for the tendency of such spikes to break easily. Smooth-awned barleys have no physiological limitations when compared with standard rough-awned varieties.[19] Three smooth-awned varieties, Velvet, Comfort, and Glabron, were released by the Minnesota Station in 1926. These varieties were equal to Manchuria in yield, strength of straw, and other agronomic characteristics, and resistant to the spot blotch disease.[18] Many other smooth-awned barleys have been bred in the United States since that time. Flynn 1, Vaughn, Beecher, Arivat, and Glacier are semi-smooth.

Breeding for disease resistance in barley likewise has been successful. The Mars and Kindred varieties are resistant to stem rust. Kindred is now the leading variety in North Dakota. Tunis is rather resistant to the races of the leaf rust organism occurring in south Texas. Tregal and Velvon are resistant to covered smut.

Development of winter hardy varieties by natural and artificial selection has extended the winter barley northward. New hardy varieties include Poland, Wong, Ward, Reno, Tenkow, and Woodwin.

A study of barley crosses in Idaho showed that high-yielding hybrids were obtained more frequently from intercrossing 6-rowed varieties than from 6-rowed × 2-rowed crosses. Hooded segregates were definitely inferior to awned ones, and naked segregates were slightly less productive than covered (hulled) strains. Smooth-awned forms averaged greater floret sterility and were slightly lower in yield than the rough-awned forms, but it seemed likely that some of the smooth strains might prove to be equal to the best rough ones.[16]

Cultural Methods

The cultural methods for barley are similar in most respects to those for wheat and oats.

ROTATIONS

In general, barley makes its best growth after a cultivated crop such as corn, sugar beets, or potatoes. In the humid region, the most practical rotation is one that includes corn, barley, and a leguminous hay or pasture crop, with barley as a companion crop in seeding the legume or grass.[10] Where hay is grown, the grass seed mixture may be timothy and red clover, which is usually left for two years. This rotation may be modified to include two years of corn or barley when more feed is necessary. On the irrigated lands of the west, barley is often used as a companion crop for alfalfa. The latter generally is retained for two years or more before being plowed up and is followed by one or two years of cultivated crops. In the semiarid Great Plains, a common practice is to grow barley on disked corn land. In the corn belt, barley often follows oats, wheat, or soybeans instead of corn in order to avoid losses from the scab disease, which is carried on corn. The winter barley-Korean lespedeza combination is popular in Missouri. The lespedeza is pastured after the barley is harvested, and the land is disked each fall in preparation for barley seeding. The lespedeza reseeds naturally. In the semiarid portions of eastern Washington and Oregon, barley may alternate with fallow or field peas. In the south, winter barley occupies the same place in the rotation as wheat. A satisfactory crop sequence is to sow barley after a summer legume, usually cowpeas, plowed under about September 1. In the piedmont region, corn (with crimson clover later seeded among the stalks), followed by cowpeas, and then by barley, makes a satisfactory 3-year rotation. This may be modified to include a second year of barley or a pasture crop.

SEEDING

Maximum yields from spring barley are obtained when the crop is seeded early in the spring. On the northern Great Plains, the most favorable period is from April 1 to 25. In Montana, North Dakota, and South Dakota the loss in yield from seeding after April 25 is more than one per cent per day. In southern Minnesota, Iowa, and Wisconsin where the season is slightly earlier, late seeding is more disastrous than in the northern plains. In New England, the cool summer permits a slightly later seeding. In California, maximum yields are obtained from late fall or early winter seeding, i.e., before December 20. The varieties grown there have a spring growth habit but they survive the winter under the mild temperature conditions. Cool temperatures and short photoperiods following late fall seeding prolong the vegetative period for about two or three months beyond that required for the same varieties when sown in the spring. The longer growing period favors greater yields. Good results have been obtained over most of the central and southern winter barley area with September seeding.

The best rates of seeding barley in Michigan were for Glabron and Wisconsin Barbless 4 to 10 pecks per acre; for Michigan 2-row, 6 to 10 pecks; and for Spartan, 8 to 12 pecks.[32] An increase beyond these ranges caused so great a reduction in plant size that the yield was reduced. A test of three barley varieties in Illinois showed that, when seeded at the same rate (in pounds), a small-seeded variety may outyield a large-seeded one owing to the larger number of plants per unit area.[5]

In practice, 8 pecks per acre are usually seeded in the humid regions.[10] On the northern Great Plains, 4 to 6 pecks is the usual rate, the lower rate being followed in the drier localities. In the very dry localities of the Great Basin, 3 pecks are sometimes seeded to advantage. In California, 7 pecks are commonly seeded, while in the winter barley regions the usual rate is 8 pecks. In Colorado, 95 pounds (about 8 pecks) are recommended for irrigated areas, and 4 pecks for the drylands.[22]

Barley seed should be sown at a depth at which both moisture and air are available, or about 1½ inches in the humid regions, 2 inches on the northern Great Plains, and 2½ to 3 inches in the Great Basin.[10] The crop is generally sown with a grain drill.

HARVESTING

About 65 per cent of the domestic crop was cut with a combine in 1945. In California, the Atlas, Coast, and Club Mariout varieties are suitable for combining because they do not shatter readily. Most of the barley in Kansas also is harvested with the combine.[29] Although this is the cheapest method, the additional time that the crop must stand in the field results in considerable loss from shattering, particularly in the case of the malting types. The windrow or swather-pickup combine method also is used, the barley being cut when the heads have turned a golden yellow, and while the straw is slightly green. After the grain has dried 3 or 4 days, the pickup-combine is used.

Barley is ready for harvest for grain with a binder when it is physiologically mature, i.e., after material ceases to be added to the kernel. Maturity is indicated when a thumbnail dent in the kernel remains visible for some time. At this stage the milky juices will have disappeared from the kernel. The ripening process after this time is principally moisture loss.

Uses

About 65 to 70 million bushels of barley are used annually for producing malt. About 95 per cent of the malt is used in making alcoholic beverages, chiefly beer and whisky. An average of 25 to 30 million bushels are required for seed. A similar quantity is used for food purposes. The remainder of 100 million to 200 million bushels is used chiefly for feed. Barley has a feeding value of about 95 per cent of that of corn. The hulls, comprising about 13 per cent of the kernel, detract from the nutritive value. Barley requires grinding or rolling for satisfactory feeding to animals other than sheep. Barley often is steamed to soften the grain before it passes to the rolls for crushing into flakes.

Barley is a better companion crop for legumes and grasses than are most varieties of oats or wheat because it shades the ground less and matures earlier. Barley has been cut for hay extensively in California. Winter barley is a good winter cover crop in the southeastern states.

MALTING AND BREWING

The maltsters in this country desire a plump, mellow, small-kerneled barley with tight hulls.[17] Such barley should be all of the same type, starchy, mellow, of high germinative capacity, sound, and free from either weather or disease damage. Certain proteins of high solubility are detrimental. Flinty or *glassy* kernels, a condition brought about by interrupted growth or other factors, are objectionable because they contain intermediate products undesirable for malting. The malting grades specify 75 per cent or more of mellow kernels which are not *semisteely.* Barley with a blue aleurone appears somewhat *steely,* but the color itself has no known effect upon malting quality. Broken kernels are objectionable because they will not malt. Skinned or peeled grains fail to germinate or convert properly during the malting process. Musty barley is unacceptable. Damaged barley, of which a maximum of 4 per cent is allowed in the malting grades, includes blighted, moldy, heat-damaged, and weathered kernels. The varieties acceptable to the maltsters in the humid spring region are Oderbrucker, Manchuria, Velvet, Wisconsin Barbless, Bay, Kindred, and Odessa. Hannchen, a 2-rowed variety grown in California, Washington, and Oregon, is quite acceptable to certain maltsters. Such 6-rowed varieties as Trebi and Plush are objectionable. Coast or Atlas (so-called Bay Brewing) barley grown in California is favored by importing maltsters in Great Britain.

Cultural practices may determine whether the barley crop will meet the requirements for the malting grades. Barley harvested before it is fully ripe in the field may have an objectionable green tinge. The crop should be shocked and stacked so as to reduce exposure to unfavorable weather to a minimum. Skinned or broken kernels usually result from threshing at too high a cylinder speed, from concave teeth set up too close to the cylinder, or from end play in the cylinder. The use of square teeth in the concaves instead of rounded ones is said to result in fewer broken kernels.

Malting Process. The object of malting barley is to develop or release the diastase and other enzyme systems, modify the starch of the grain, and develop the aroma and flavor of malt. In manufacturing malt, the cleaned barley is soaked (steeped) with occasional draining, for 2 to 3 days or until the grain contains 44 to 46 per cent moisture. It is then allowed to germinate for about 6 days or thereabouts at a temperature of 20° C. in a slowly-rotating drum (or in layers a foot or more thick within compartments with frequent but slow stirring), with water added to maintain the moisture content. When the sprouts (acrospires) are about three-fourths of the length to the full length of the kernel, germination is stopped by kiln drying the grain down to 4 to 5 per cent moisture. After the rootlets (malt sprouts), which in the meantime have been broken off in handling, are screened out, the product remaining is known as dried malt. A bushel of malt weighs 34 pounds. One bushel of barley produces about 38 pounds of dried malt. This quantity of malt with the addition of some 17 pounds of adjuncts (corn or rice products, sugar, sirup, etc.) and about 0.7 pound of hops and hop extracts is sufficient to make one barrel (31 gallons) of beer.

Brewing Process. The brewing industry usually is separate from that of malting. In brewing,[24] the malt is first ground and a portion of the ground malt mixed with unmalted cereals (corn grits, broken rice, etc.). These starchy adjuncts are used to furnish additional fermentable material and to reduce the protein content of the mash. This mixture is then cooked in water to gelatinize and liquefy the starch, after which it is added to and mixed with water and the remaining malt in a mash kettle or tub. The latter has previously been held for half an hour at approximately 48° C. to favor the breakdown of the proteins. The temperature is raised to 65° C. and held for a few minutes until the conversion of the starch is complete. Then the temperature is raised to 75° C., and the mash is mashed off, i.e., allowed to settle. The liquid (first wort plus spargings) is drawn off, boiled with hops, and the wort then drawn off and cooled. The wort is fermented with yeast for 7 to 10 days at temperatures ranging from 6° to 15° C. Proteins, yeast cells, hop resins, and other insoluble materials settle out during cooling and the subsequent cool storage for 3 to 8 weeks at temperatures usually ranging from 0° to 5° C. The finished beer is then carbonated and filtered, after which it is ready for the market.

Uses of Malt. In the brewing process malt is turned into beverages, particularly beer. The spent grain that is left is sold for feed, both as dried and wet brewer's grains. Malt sirup is used in baking, in candies, and in the textile industries. It is also added to medicines for its laxative effect and as an aid in the control of fevers. Many breakfast cereal manufacturers use malt sirup. Malt is also used for the production of malted milk, alcohol, vinegar, and yeast.

OTHER PRODUCTS OF BARLEY

Pearled barley is made by the removal of the outer portions of the kernel (hull, bran, aleurone, and germ) so as to leave a round pellet. These parts are removed by the abrasive surface of a whirling rough *pearling* stone. The larger, more spherical kernel types result in a better product with less loss to the processor.[10] Plump, large-grained, 2-rowed white-grained varieties with a shallow or closed crease, such as Spartan and Hannchen, are used for pearling.

Barley flour can be substituted up to 5 per cent with wheat flour without detriment to the quality of the bread. For hot breads, where baking powders are employed, 80 per cent barley flour may be used. Barley often is a constituent of the black bread of the Europeans. The principal obstacle to the use of barley flour in bread is that it contains no gluten and that it darkens the loaf. Large-grained, 2-rowed varieties with white aleurone layers are best suited to flour milling.

Diseases

COVERED SMUT

Covered smut (*Ustilago hordei*) attacks the heads and causes formation of hard, dark lumps of smut in place of the kernels (Figure 154). The diseased heads often are borne on shorter stems and appear later than the normal heads. Soon after the smutted heads appear, the membranes that enclose the smut heads begin to split which releases the spores carried to sound heads. Infection may occur before the barley is ripe or any time thereafter.[30] Spores that reach the barley kernels frequently germinate and send infection threads beneath the hulls. Covered smut is often found in threshed grain as black, irregular, hard masses.

Treatment with one of the organic mercury dusts is effective in control of covered smut.[20] New Improved Ceresan is applied at the rate of one-half ounce per bushel, either with a rotary seed treater or by the shovel method. After treatment the barley should be stored in sacks or in a covered pile for one to 10 days. Formaldehyde dust, applied at the rate of three ounces per bushel, is also effective. Covered smut is increased by deep seeding of barley.[31] Glabron and Peatland are moderately resistant to covered smut.

THE BROWN AND THE BLACK LOOSE SMUTS

The brown and the black loose smuts attack the heads, causing the formation of loose, powdery masses of smut in place of the normal spikelets. The dusty spores are blown over the field at the time the normal heads are in blossom. Some spores fall within the open blossoms, resulting eventually in the infection of the next crop. The spore masses of the brown loose smut (*Ustilago nuda*) are olive-brown, while those of the black loose smut (*U. nigra*) are dark brown, almost black. The brown loose smut infests the

FIG. 154. Loose smut (A), covered smut (B), healthy head (C).

interior of the seed, while the black loose smut infestation is superficial.

The modified hot water treatment is the only effective control of brown loose smut in infected seed. The seed is placed in burlap bags and soaked at about 70° F. for 6 hours, after which it is immersed in hot water at a temperature of 126° F. for 13 minutes.

This treatment is rather difficult to apply, since it is necessary to control the temperatures rigidly. It is feasible for treating foundation seed lots.

Resistant varieties include Trebi, Tregal, Titan, Velvon, Ezond, Iredell, Hooded 16, and Davidson. Even these varieties develop some smut when environmental conditions are especially favorable for infection.

Control measures for the shallow-borne black loose smut are the same as for covered smut.

BARLEY STRIPE

Barley stripe (*Helminthosporium gramineum*) is an important disease in the entire United States. It is not unusual for 5 to 15 per cent of the plants in a field to be affected. Each per cent of infection reduces the yield about 0.75 per cent. The disease causes long white or yellow stripes on the leaves. These stripes later enlarge and turn brown. Many of the stripes may run together so as to discolor the entire plant. The affected plants are stunted, the heads fail to emerge properly or at all, and the grain is discolored and shrunken. As the spores are seed-borne, the disease can be controlled by seed treatment with the organic mercury dusts. Spartan, Hannchen, Regal, Trebi, Velvon, Odessa, Wisconsin Barbless, and Glabron have been reported as being resistant.[7, 25]

SPOT BLOTCH

Spot blotch (*Helminthosporium sativum*) is widespread in the north central and southern portions of the barley area. As a seedling blight, it may cause considerable reduction in stand, while as a leaf spot it may bring about reductions in yield. It also causes *black point* or blight on the kernels, which reduces the market quality of barley. Any portion of the plant may be infected.[6] Dark brown spots coalesce to form blotches on the leaves, stems, and floral bracts. Root rots often follow, as do shrivelled, discolored kernels. Numerous secondary infections occur up to the time the plant ripens. The disease overwinters on seed and on plant remains in the field.

Both crop rotation and sanitation are important control measures because the organism develops on crop residues of cereal plants. The organic mercury dusts will control only seed infection. Several varieties, Peatland, Glabron, and Manchuria, are resistant to the disease.

SCAB OR FUSARIUM BLIGHT

Scab (*Gibberella saubinetti*) is particularly prevalent in the southern part of the spring barley region where the temperatures are favorable for this disease and where barley frequently follows corn in the rotation. It is a wet season disease. Scab causes reduction in grain yields as well as blight-damaged kernels. The scab fungus in blighted kernels causes nausea when eaten by hogs or men. The scab organism infects barley heads at the blossom stage. The diseased kernels ripen prematurely and turn pinkish to dark brown in color. The kernels are often shrunken. Infected seed produces seedling blight when it is sown. The scab organism overwinters principally on cornstalks and small-grain stubble.

A crop rotation in which barley does not follow either corn or small grains tends to reduce the amount of head blight somewhat, but it is not a complete control. Another partial control measure is to plow under all cereal crop residues completely. Seed treatment with an organic mercury disinfectant will reduce the amount of seedling blight. Among the varieties with some resistance are Spartan, Svansota, Golden Pheasant, and Chevron. Lax-headed varieties are least subject to scab.

RHYNCOSPORIUM SCALD

Rhyncosporium scald (*Rhyncosporium secalis*) sometimes damages barley seriously in California and in the south. It produces water-soaked and later *scalded* appearing lesions on the leaves, sheaths, and spikes, causing a shriveling of the grain. The use of a resistant variety, such as Atlas 46, is suggested as a control measure.

POWDERY MILDEW

Powdery mildew of barley caused by the fungus *Erysiphe graminis hordei* attacks many varieties of barley. It often damages barley except in the intermountain area and the Great Plains. The disease can be recognized by growths of mildew on the leaves and stems. Several varieties, including Atlas 46 and Chevron, are resistant to several races of the fungus.

STEM RUST

Stem rust caused by the fungus *Puccinia graminis* results in heavy losses in barley only occasionally. The Kindred, Chevron, Mars, and Peatland varieties are resistant. Moore, a new smooth-awned variety originating in Wisconsin, is resistant to stem rust and also to powdery mildew and spot blotch. It is being distributed in Wisconsin and several other north central states.

LEAF RUST

Leaf rust of barley caused by the fungus *Puccinia anomala* sometimes is damaging in the south. The Tunis variety grown in south Texas is somewhat resistant.

OTHER DISEASES

Among other barley diseases of some importance and their causal organisms are ergot (*Claviceps purpurea*). (See ergot of rye, page 529), net blotch (*Helminthosporium teres*), leaf spot (*Septoria passerinii*), anthracnose (*Colletotrichum graminicolum*), bacterial blight (*Phytomonas translucens*), and stripe rust (*Puccinia glumarum*). A root and stem disease caused by *Pythium graminicola* damaged barley seriously in the corn belt states in 1943 and 1944.

Insect Enemies

Among the chief insect enemies of barley are the chinch bug, green bug (spring grain aphis), and grasshoppers. No satisfactory method of controlling chinch bug infestation in barley or other small grains is yet known. Barley is very attractive to chinch bugs. Several barley varieties of Asiatic origin, e.g., Gatami, are resistant to green bugs. Commercial American varieties resistant to green bugs include Wong, Sunrise, and Smooth Awn 86.[4] Grasshoppers are controlled by poison baits or by chlordane and Toxaphene dusts or sprays.

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18 OATS

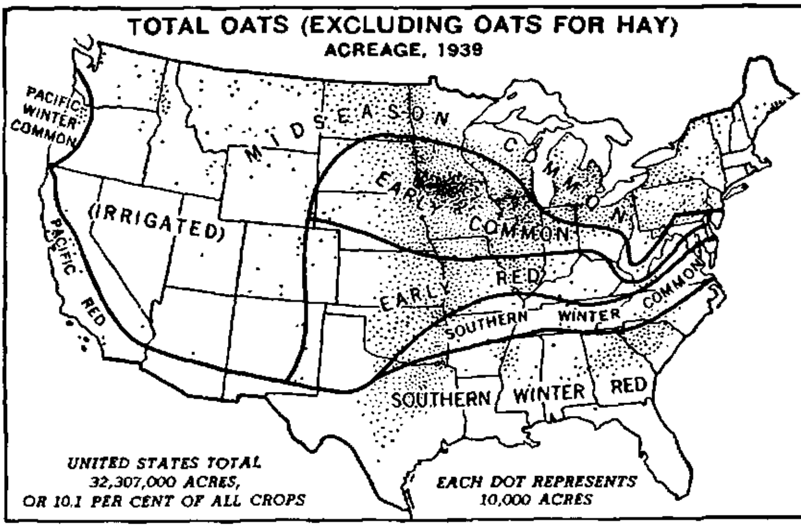
Economic Importance

Oats constitute the third most important cereal crop in the United States, being exceeded in production only by corn and wheat. The development of new disease-resistant varieties has greatly enhanced the importance and value of the oat crop since 1940. The average annual area from 1937 to 1946 was nearly 38 million acres. The average yield was about 32.4 bushels per acre. For the same period, the average annual production was 1,230,000,000 bushels. The 1945 and 1946 crops both exceeded 1½ billion bushels. The states leading in oat production are Iowa, Minnesota, Illinois, Wisconsin, and Nebraska (Figure 155). The world production is about 4½ billion bushels. The countries leading in oat production are Russia (U.S.S.R.), United States, Germany, Canada, France, and Poland.

Oats fit well into many crop rotations. Fall-sown oats are valuable in the south for pasture and for retarding soil erosion. Oats are used as a companion crop with red clover in the corn belt, and with lespedeza in Missouri and elsewhere. Compared with other grain crops, oats are the easiest and most pleasant to sow, harvest, thresh, handle, and feed. They can be fed to horses, sheep, and poultry without grinding. They can be sown early in the spring on corn ground before plowing for other crops is possible. They also furnish the best straw for feed or bedding. These facts account for the popularity of oats among farmers.

Origin of the Oat Plant

Cultivated oats (*Avena sativa*) formerly were believed to have been derived chiefly from two species, the common wild oat



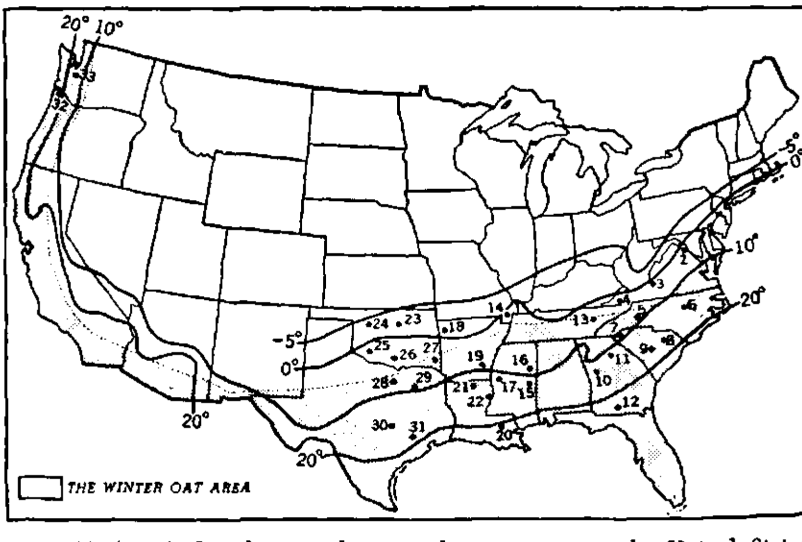


FIG. 155. (*Top*) Distribution of oats and oat regions in the United States. (*Bottom*) Winter oats are grown largely where the average minimum winter temperature is above 10° F. The figures distributed over the map indicate points at which oat varieties have been tested for cold resistance.

(*A. fatua*) and the wild red oat (*A. sterilis*),[26] but recent evidence[11] indicates that both *A. sativa* and *A. fatua* probably were derived from *A. sterilis*. Apparently cultivated oats were unknown to the ancient Chinese, Hebrews, and Hindus. Among the earliest indications of the existence of oats are those found in the remains of the Swiss lake dwellers. Classical writers in Roman times mention oats only as a weed which was sometimes used for medicinal purposes. Probably it was first distributed as a weed mixture in barley and domesticated later. Authentic historical information on the cultivated oat appears in the early Christian era. The common oat was reported by writers of this period to be grown by Europeans for grain, while the red oat was grown for fodder, particularly in Asia Minor. The common oat, first found growing in western Europe, spread to other parts of the world. It was believed to have been first cultivated by the ancient Slavonic peoples who inhabited this region during the Iron and Bronze Ages.

Adaptation

Common oats are best adapted to the cooler, more temperate regions where the annual precipitation is 30 inches or more or where the land is irrigated. Such areas are found in the northeastern fourth of the United States, in the Pacific northwest, and in valleys of the Rocky Mountain region, and in northern Europe and Canada. High yields of large, plump grains are possible in these areas. The oat crop often fails in the Great Plains because of drought and heat. Hot, dry weather just before heading causes the oats to blast, and during the heading and ripening period causes oats to ripen prematurely with poorly filled grain of light bushel weight. Such damage has been checked to some extent in the warmer regions by growing early varieties of common or red oats. However, red oats as a group are not any more resistant to heat than are certain common winter varieties.[10] The greatest heat resistance was shown by varieties adapted to the south that also were resistant to cold. Red oats are grown primarily in warm climates such as occur in North Africa and Argentina. Heat-tolerant varieties of red oats are grown in the southern states, as well as in the interior valleys of California. Some of these varieties are extremely early. Recent success in breeding oats resistant to crown rust indicates that much of the damage formerly attributed to heat actually was crown rust damage. Fall-sown oats are grown successfully only where the winters are comparatively mild, i.e., in the south and on the Pacific coast. The general oat areas[31] are shown in Figure 155.

Oats produce a satisfactory crop on a wide range of soil types, provided the soil is well drained and reasonably fertile. In general, loam soils, especially silt and clay loams, are best suited to oats. Heavy, poorly drained clays are likely to cause the crop to lodge or be injured by plant diseases, such as rusts and mildew. Excessive available nitrogen and moisture is the chief cause of lodging in oats.

Botanical Description

The oat plant is an annual grass classified in the genus *Avena*. Under average conditions, the plant[26] produces three to five hollow culms from one-eighth to one-fourth inch in diameter and from 2 to 5 feet in height. The Markton variety and many of its derivatives can be identified by hairs on the nodes. The roots are small, numerous, fibrous, and penetrate the soil to a depth of several feet. The leaves average about 10 inches long and ⅝ inch wide.

The inflorescence is either an equilateral (spreading) or a unilateral (one-sided) panicle (Figure 156). The panicle is a many-branched determinate inflorescence consisting of a main axis from which arise lateral axillary branches that are grouped on alternative sides of the main axis at its nodes.[5] The main axis and each of the lateral branches terminate in a single apical spikelet. Some varieties such as Brunker have only 4 or 5 whorls of branches, while others have 6.

The oat spikelet is borne on the thickened end of a slender drooping pedicel that terminates the panicle branch. Each spikelet usually contains two or more florets.[13] The lower two florets usually are perfect, while the third, when present, often is staminate or imperfect. The two glumes are somewhat unequal, lanceolate, acute, boat-shaped, spreading, glabrous, membranous, and usually persistent. Both usually exceed the lemma in length, except in naked (or

FIG. 156. Unilateral ("side" or "horse mane") panicle of the White Tarter variety (*left*). Spikelet, naked kernels (caryopses) and bilateral (spreading or "tree") panicle of the Liberty Hulless variety (*right*).

hull-less) oats (Figure 156.) The floret is composed of the lemma, palea, and the reproductive organs, namely, the ovary and three stamens (Figure 26). The lemma is the lower of the two bracts that enclose the kernel. It ranges in color from white, yellow, gray, and red to black. The base of the lemma may be extended into a callous, which often bears basal hairs. Most wild oat species are characterized by hairiness of the callous, lemma, and rachilla (Figure 159).

The awn of oats is an extension of the midrib of the lemma, usually arising slightly above the middle of the dorsal surface. The awn may vary from almost straight to twisted at the base and bent into a knee (geniculate). Some varieties are awnless. The palea is the inner bract of the floret, being thin and parchment-like. In hulled varieties the lemma and palea firmly enclose the caryopsis. The oat caryopsis is narrowly oblong or spindle-shaped, deeply furrowed, and usually covered with fine hairs, especially at the upper end (Figures 157 and 158).

FIG. 157. Caryopses of oats: side view (*left*), ventral view or crease side (*right*).

The natural separation of the lower kernel from the axis of the spikelet is termed disarticulation.[14, 27] In some wild oat species, as well as in their cultivated derivatives, disarticulation leaves a well-defined deep oval cavity commonly called sucker mouth. In most cultivated oat varieties, the separation is by a fracture or breaking that results in a roughened tissue with no observable cavity at the base of the lemma. Variations in the kernel base range from the absence of any scar, as in Victory, through variations of the obscure scar of Markton, to the prominent scar of varieties such as Red Rustproof. Most varieties of common white and yellow oats lack the scar.

The legal weight per bushel of oats is 32 pounds, but the actual test weight may range from 27 to 45 pounds. Clipped oats have a high test weight because the tip of the hull has been removed. Oats are clipped in a cylindrical drum having an indented or slotted case or wall against which the grains are thrown by a revolving beater.

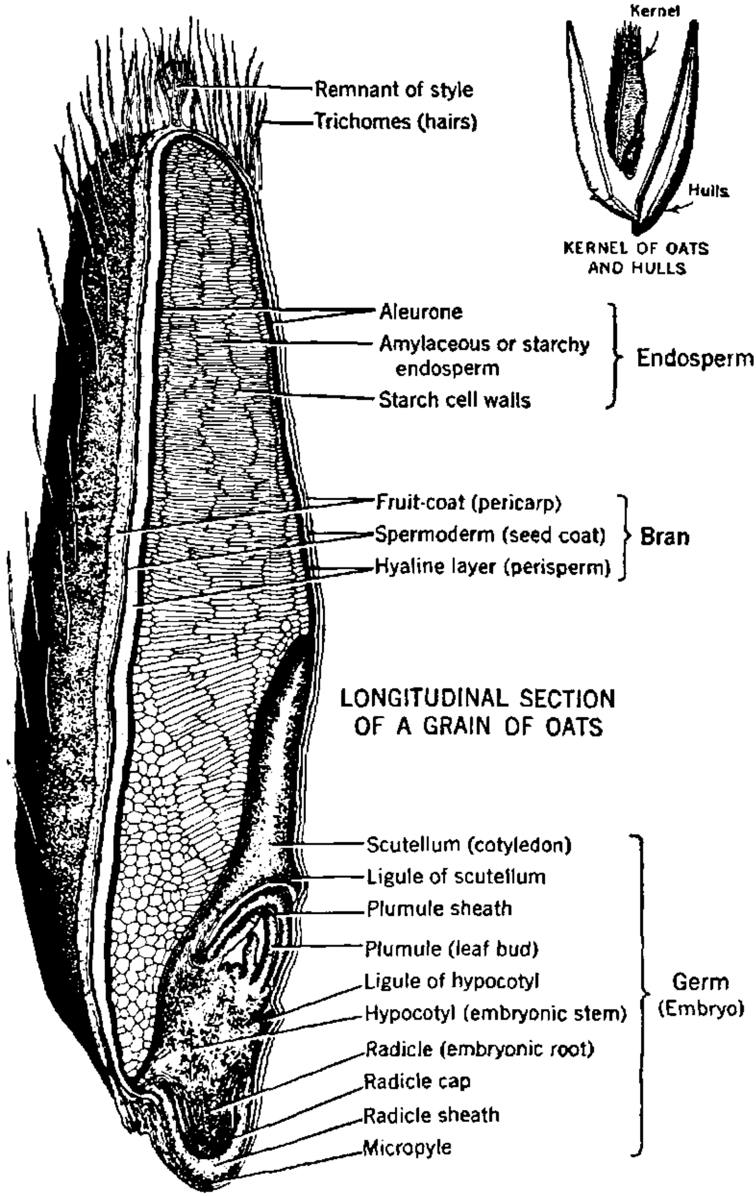


FIG. 158. The oat caryopsis. Other names used for its structures include the following: — starch cell walls = endosperm cells containing starch grains, spermoderm = testa, perisperm = nucellus, plumule sheath = coleoptile, ligule of hypocotyl = epiblast, hypocotyl = subcrown internode, radicle cap = rootcap, and radicle sheath = coleorhiza. (Courtesy of The Quaker Oats Company.)

Species or Races of Oats

Oats have been classified into eight more or less distinct groups by Etheridge [19] as follows:

A. Kernel loose within the surrounding hull; lemma and glumes alike in texture *Avena nuda* (*hull-less oats*)
AA. Kernel firmly clasped by the hull; lemma and glumes different in texture
  B. Upper grains persistent to their rachillas *Avena sterilis* (*red oats*)
  BB. Upper grains easily separating from their rachillas
    C. Lemma extended as teeth or awn points
      D. Lemma extended with four teeth or awn points *Avena abyssinica* (*Abyssinian oats*)
      DD. Lemma with two teeth or awn points
        E. Lemma elongate, lanceolate, with distinct awn points *Avena strigosa* (*sand oats*)
        EE. Lemma short, abrupt, blunt, rather toothed than awn-pointed *Avena brevis* (*short oats*)
    CC. Lemma without teeth or awn points
      D. Basilar connections of the grains articulate *Avena fatua* (*wild oats*)
      DD. Basilar connections of the grain solidified
        E. Panicles roughly equilateral, spreading *Avena sativa* (*common oats*)
        EE. Panicles unilateral, appressed *Avena sativa orientalis* (*side oats*)

Later it was concluded that the wild red oats should be classified as *A. sterilis* and the cultivated red oats as *A. byzantina*.[12] Oats have been classified into three groups on the basis of chromosome numbers.[26]

GROUP I: 7 HAPLOID CHROMOSOMES

A. brevis, short oat	*A. strigosa*, sand oat
A. wiestii, desert oat	*A. nudibrevis*, small-seeded naked oat

GROUP II: 14 HAPLOID CHROMOSOMES

A. barbata, slender oat	*A. abyssinica*, Abyssinian oat

GROUP III: 21 HAPLOID CHROMOSOMES

A. fatua, common wild oat
A. sativa, common white or northern oat
A. nuda, large-seeded naked or hull-less oat
A. sterilis, wild red or animated oat
A. byzantina, cultivated red oat

WILD OATS

The common wild oat (*A. fatua*) (Figure 159) is a noxious weed in many parts of the country, being particularly troublesome in the hard red spring wheat region of Minnesota, the Dakotas, and Montana. It is difficult to eradicate because the seeds shatter readily and because many of the seeds are plowed under where they lie dormant for one to many years and then germinate and grow when they are turned up near the surface. However, some collections of wild oats show little or no dormancy.[39] The common wild oat differs from cultivated oats in having taller, more vigorous plants and strongly twisted geniculate awns. The grain has a pronounced sucker mouth at the base, and usually a hairy lemma. In California, wild oats grow so abundantly on waste lands and uncropped fields that they are often harvested for hay.

The wild red oat, *A. sterilis*, occurs infrequently as a weed in this country. Another wild oat, *A. barbata*, is an important range grass in California. In other parts of the world, the sand oat, *A. strigosa*, is an important forage grass.

Fatuoids or false wild oats appear suddenly in cultivated oat varieties and somewhat resemble the common wild oat (*A. fatua*), although the fatuoids also are similar to the variety in which they occur, particularly as to lemma color and germination habits.[15, 35] Fulghum contains more fatuoids than does any other important American oat variety. The persistence of fatuoids is due to natural crossing and mutation.[16] Many fatuoids originate through natural hybridization between common cultivated oats and wild oats (*A. fatua*).[1]

Natural Cross-Pollination

Self-pollination is normal in oats but natural crossing occurs occasionally. Only one natural cross was found among 7,742 plants

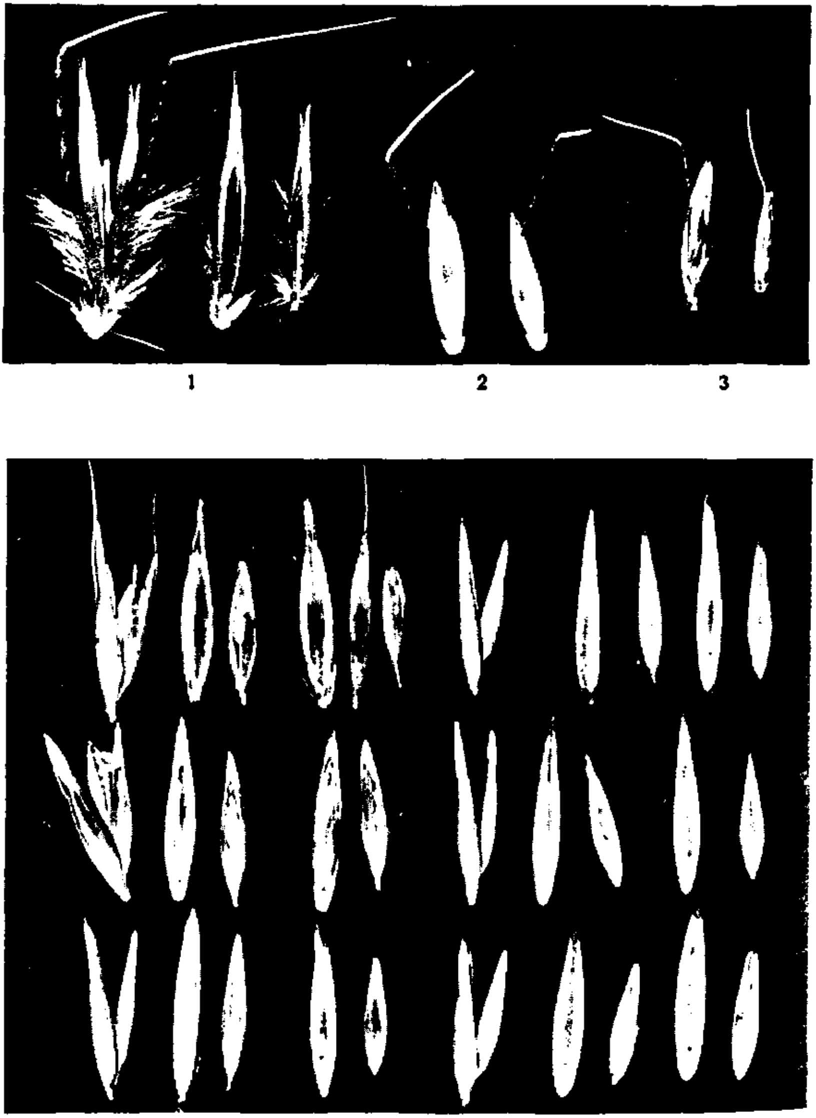


FIG 159. Spikelets and kernels of wild and cultivated oats:—(1) Wild red oat (*Avena sterilis macrocarpa*); (2) fatuoid from A. *sativa*; (3) wild oats (*A. fatua*); (4) Cultivated red oats (*A. byzantina*): (*upper*) Red Rustproof, (*middle*) Fulghum, (*bottom*) Columbia; (5) Cultivated common oats (*A. sativa*): (*upper*) Trojan, (*middle*) Richland, (*bottom*) Victory.

of common oat varieties in 3 years in West Virginia,[21] but the Fulghum variety, a red oat, averaged 0.41 per cent of natural crossing. The greatest number of natural hybrids in Fulghum occurred among plants produced from secondary seeds.[23] Perceptible natural crossing averaging 0.8 to 1.3 per cent has been observed in common oat varieties in western states.[17, 28] Open-pollinated fatuoids have shown a maximum of 47 per cent of cross-fertilization in a single season, the 5-year average being 11.6 per cent. Under similar conditions Fulghum contained less than 0.5 per cent of crosses in any season.[16] Natural crossing in cultivated oats may be sufficient under some conditions to affect varietal purity unless precautions are taken.

Dormancy in Oats

Freshly harvested seeds of oats often fail to germinate satisfactorily, while others germinate immediately. All degrees of prompt, slow, and delayed germination occur among common oat varieties, but all cultivated red oat varieties usually show slow or delayed germination.[14, 18] Dormancy is no longer evident in many varieties after storage for four weeks, Fulghum being an exception. Nortex seed failed to germinate satisfactorily when stored less than 66 days. This may explain the poor field stands frequently obtained from the use of freshly harvested seed of Red Rustproof strains. However, there appears to be no association between morphology of the oat kernel and dormancy. Characters associated with wild oats and fatuoids, such as the suckermouth base and the presence of basal hairs on the callus are unrelated to dormancy.[15, 39]

Oat Varieties

Among the seed or lemma colors white and yellow varieties are more commonly grown in the north, while red or gray oats are grown chiefly in the south. Black oats are grown rather rarely. Oats are sometimes grouped as early, midseason, and late. Victory, a midseason variety, matures 10 to 14 days later than the early variety Kherson.

Midseason varieties are well suited to the cooler regions along the northern border and in the irrigated intermountain region. To the south where hot weather may injure the plants before ripening, the early white and yellow varieties are grown. Further south in the central regions, still earlier spring-sown red varieties are grown, while in the extreme south fall- or winter-sown red or gray oats are grown, in each case in order that the crop will reach maturity before the advent of severe summer heat or drought. The country has been divided into seven oat regions [29, 31, 32] as follows:

(1) *North Central Oat Region.* This region comprises Minnesota, Iowa, Wisconsin, Michigan, the northern parts of Illinois, Indiana, and Ohio, and parts of Nebraska and the Dakotas, and the extreme northern portions of Kansas and Missouri. About 80 per cent of the national oat crop is produced in this region. Early-maturing common yellow and white varieties are of chief importance, but midseason varieties have been grown also, particularly in the northern portion, and red oats lead in the southern portion of the region. The early common varieties include Clinton, Benton, and Marion. Midseason varieties include Huron, Victory, and Rainbow. Varieties of the red oat group grown in this region include Columbia, Fulton, Brunker, Otoe, and Fulghum or Kanota.

Many of the newer varieties are resistant to various races of the organisms causing one or more of the five important oat diseases, viz., crown rust, stem rust, loose smut, covered smut, and Victoria blight. Nakota, a hull-less variety, is grown to a slight extent in South Dakota. Hull-less oats can be fed to hogs without hulling, but they often do not remain sound in storage. Few hull-less varieties yield as well as the hulled varieties.

(2) *Central or Spring-sown Red Oat Region.* This area comprises the southern parts of Ohio, Indiana, Illinois, southeastern Nebraska, Kentucky, Tennessee, Missouri, Arkansas, Oklahoma, northern Texas, and most of Kansas. The southern border of this area is transitional between the winter and spring oat regions. The principal varieties in the spring-sown red oat region are Fulghum, Red Rustproof, Fulton and Brunker. Kanota is the most important Fulghum strain, while Red Texas, Ferguson 922, and Nortex are Red Rustproof strains. Columbia, an early selection from Fulghum, is grown widely in Missouri [20] and parts of Illinois, Indiana,

and Ohio. The grains of Columbia are brownish-gray rather than red. Other varieties in this area are Otoe, Brunker, Fulton, Fultex, New Nortex, Rustler, Ranger, Clinton, Cherokee, and Nemaha.

(3) *Northeastern Oat Region.* The New England states, New York, Pennsylvania, New Jersey, Maryland, West Virginia, the eastern part of Ohio, western part of Virginia, and the northern part of Delaware are in this area. Vicland, Boone, Keystone, and Patterson are medium-early varieties. Midseason varieties include Victory, Cornellian, Wayne, Lenroc, and Maine 340. Lenroc is a new oat in New York. Early varieties such as Clinton and Mohawk are well adapted to the southern part of this region.

(4) *Southern or Fall-sown Oat Region.* This area includes the states of Delaware, Maryland, West Virginia, Kentucky, Arkansas, Oklahoma, and those southward. The winter oat belt could be moved northward by development of winter oats more resistant to cold than those now available.[9]

The less hardy red varieties are limited to the southern part of the winter oat belt. The Red Rustproof strains include Appler, Hastings, Ferguson 922, and Nortex. The most widely grown Fulghum strain is Kanota. Three strains of winter-type Fulghum (Fulwin, Forkedeer, and Tennex) have been distributed in Tennessee. Wintok, which was developed in Oklahoma, is the hardiest known common oat variety. Among the varieties in Texas are New Nortex, Ranger, Rustler, and Fultex. Coker's Victorgrain, Fulgrain, and Stanton are grown in Georgia, North Carolina, and South Carolina. Two new red oat varieties, Camellia grown in Louisiana and Florilee grown in Florida, are resistant to most of the major diseases occurring in the Gulf region. Several varieties developed from crosses between Lee and Victoria, including Letoria, Lelina, Desoto, and Stanton are grown[34] in the zone extending from Delaware to Arkansas.

(5) *Great Plains Oat Region.* The midseason and early midseason varieties grown in the northern Great Plains are mostly those grown in similar latitudes in the north central oat region. To the south early red oat varieties such as Kanota and Red Rustproof are being replaced by new improved varieties such as Fulton and

Clinton in Kansas, and New Nortex and Fultex in Texas. Brunker is adapted to dryland farms in Nebraska and northeastern Colorado.

(6) *Rocky Mountain Oat Region.* Midseason oats are mostly grown in this region, under irrigation. Among these varieties are Victory, Colorado 37, Idamine, and Markton. Markton is a widely grown highly productive, yellow-grained common oat variety highly resistant to the oat smuts. This variety practically replaced all other varieties in the nonirrigated areas of eastern Washington.[3] Among the new smut-resistant varieties in the Rocky Mountain region are Uton, Bannock, Carleton, Bridger, Mission, and Marida.

(7) *Pacific Coast Oat Region.* Winter Turf (Oregon Gray) is grown from fall seeding in the Willamette Valley and other sections. The plant grows rather tall and has narrow dark brown leaves. The kernels are gray, but clean and bright. Support, a strain of Winter Turf, has been grown in Oregon from fall seeding.[30] Varieties of the red oat group are grown in California, the principal ones being California Red, Fulghum, Kanota, Coastblack, and Ventura. Midseason varieties, such as Markton, Abundance, Banner, and Victory probably are the most extensively grown spring oats in Washington and Oregon. Victory is widely grown in the lowlands in Washington because of its stiff straw.

Rotations

A common rotation in the northeastern states is corn (1 year), oats seeded to clover or grass (1 year), and clover or grass (2 years).

In the northern portion of the spring-sown red oat region, a widely-followed rotation is corn 2 years, oats and wheat each for one year, and clover and timothy for 2 years. A 1-year rotation of oats and lespedeza has been suggested for Missouri.[20] Oats are sown in the spring on Korean lespedeza sod each year. The lespedeza volunteers each year from the seed produced and shattered to the ground.

In the far west, alternate fallow and small grain is a common rotation in the drier areas. Where a crop can be produced each year, and in the Great Plains, oats usually follow corn, sorghums, or potatoes. Under irrigation, oats are usually a companion crop for alfalfa or clover. A typical rotation is alfalfa three years, sugar beets or potatoes or corn for one or two years, and oats seeded to alfalfa. In the humid Pacific area, oats frequently occupy the season between row crops and clover.

In the fall-sown oat region, where cotton is grown, a good rotation is as follows:

First year, cotton followed by crimson clover, vetch, or Austrian peas as a winter cover crop.

Second year, corn after the winter legume plowed under. Cowpeas or soybeans may be sown in the corn at the last cultivation. The corn may be cut as fodder and the cowpeas or soybeans turned under in time to seed to fall oats.

Third year, fall-sown oats, followed by cowpeas or soybeans sown as a hay crop. The cowpea and soybean stubble is then plowed under, and the soil sown to rye as a winter cover. The rye is turned under the next spring for cotton.

Another rotation for fall-sown oats outside of the cotton area is:

First year, corn, with cowpeas or soybeans sown at the last cultivation, the legume and corn stubble being turned under for fall-sown oats.

Second year, fall-sown oats with clover or grass seeded in the oats.

Third year, meadow or pasture.

Fertilizers

Oats usually receive an application of about 200 pounds of commercial fertilizer per acre in the northeastern and middle Atlantic states and about 300 to 400 pounds per acre in the southeast. The fertilizer requirements for oats are similar to those for wheat. Oats respond to phosphorus in most sections east of the Mississippi River, and to nitrogen and potash also along the Atlantic seaboard. A spring top dressing of 100 pounds per acre of nitrate of soda or its equivalent is essential to high yields of winter oats in most of the southeast.

The response of oats to superphosphate and manure in Iowa is shown by an experiment[7] in which the manure was applied for the corn crop preceding the oats in a rotation. The acre yields of oats were: no fertilizer, 54.8 bushels; with manure, 64.5 bushels; with manure and superphosphate, 81.8 bushels.

Cultural Practices

SEEDBED PREPARATION

Oats generally follow corn or some other row crop in the spring-sown oat regions. In the northeastern states, where abundant weed growth and heavy soils are common, the corn stubble land is usually plowed, disked, and harrowed for seedbed preparation. In the corn belt, oats are sown either with a drill (Figure 48) or a broadcast seeder on corn land that is disked and harrowed but not plowed. The broadcast fields are harrowed or disked, or both, after seeding. Under dryland conditions, oats are often sown on stubble land prepared with a disk or duckfoot cultivator. Where the oat crop is irrigated, the land often is fall-plowed and left rough over winter, the land being harrowed in the spring. Plowing is generally necessary where oats follow small grains or a sod crop.

TIME OF SEEDING

Spring-sown oats should be seeded as early in the spring as a seedbed can be prepared and after the danger of prolonged cold weather is past. This is especially important in sections subject to

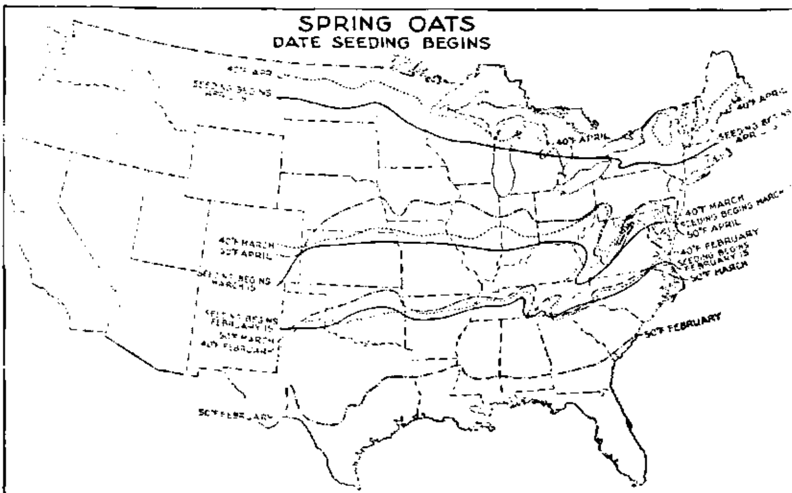


FIG. 160. Relation of temperature to seeding date of spring oats.

heat or drought. Dates of seeding spring oats are shown in Figure 160. The map indicates that oats should be sown before the average temperature reaches 50° F.[38]

Experiments with winter oats sown on different dates at Stillwater, Oklahoma, showed that seeding about October first gave the best yields (Table 1).

TABLE 1. YIELDS OF OATS FROM FALL SOWING ON DIFFERENT DATES AT STILLWATER, OKLA.

DATE SOWN	ACRE YIELD	DATE SOWN	ACRE YIELD
Aug. 15	32.0	Oct. 1	55.6
Sept. 1	45.6	Oct. 15	46.5
Sept. 15	52.6	Nov. 1	35.2

Experiments in Tennessee[22] gave similar results (Table 2).

TABLE 2. YIELDS OF OATS IN DATE-OF-SEEDING EXPERIMENTS IN TENNESSEE

FALL-SOWN OATS (1939–1944)		SPRING-SOWN OATS (1927–1931)	
DATE SOWN	ACRE YIELD (*bushels*)	DATE SOWN	ACRE YIELD (*bushels*)
Aug. 16	38.5	Feb. 15–29	31.4
Sept. 1	39.6	Mar. 1–15	27.3
Sept. 15	41.6	April 1–15	17.2
Oct. 1	41.4		
Oct. 15	41.3		
Nov. 1	31.1		
Nov. 15	29.3		
Dec. 1	20.0		

In the spring-sown red oat area, the crop is generally seeded by March 15. The time is usually later in the more northern regions, but seldom later than May 15, even in New England. Fall-sown oats may be seeded in the south at any time from October 1 to December 31, but October is often the best month. Most oats in California are seeded in November.

RATE OF SEEDING

The average rate of seeding oats in the United States is nearly 2½ bushels (10 pecks) per acre. Oats sown broadcast on corn stubble in the corn belt usually are sown at the rate of 12 to 16 pecks. In the northeastern states, the average rate of seeding is about 10 pecks.

Under irrigation in the west, 8 to 12 pecks is a common rate. Under conditions extremely favorable for oats in western Oregon and Washington, 14 to 16 pecks are sometimes sown. In the spring-sown red oat region, 8 to 12 pecks are usually seeded. In the colder part of the fall-sown oat area, 10 to 12 pecks are necessary because of the danger of winter killing. On the Great Plains, 4 to 8 pecks may be seeded, 5 or 6 pecks being the most common rate. The 9-year average yields under dryland conditions in Colorado (at Akron) for 4, 5, and 6 pecks of seed per acre, were 38.7, 39.6, and 40.1 bushels per acre, respectively.[8] Oats as a companion crop for legumes and grasses should be seeded one-fourth less than the rate where sown alone.

The summarized yields on a percentage basis of the results of 17 rate-of-seeding experiments with oats in Iowa[7] are shown in Table 3.

TABLE 3. YIELDS OF OATS FROM DIFFERENT RATES OF SEEDING IN IOWA

RATE SOWN (*bushels*)	ACRE YIELD (*per cent*)	RATE SOWN (*bushels*)	ACRE YIELD (*per cent*)
2	92	3½	100
2½	94	4	100
3	100	4½	98

In these experiments, drilled oats yielded 62.8 bushels per acre compared with 58.7 bushels broadcast on disked corn ground.

HARVESTING

Oats often are harvested with a binder in order to save the straw. The proper stage for binder harvest is when the grain is in the hard-dough and the straw still a little green. There is danger of loss by shattering and crinkling when oats are allowed to become too ripe. They may be threshed from the shock or stack or else stored in a barn before threshing. In the south, large quantities of oats are fed in the bundle without threshing. For combine harvest, the grain must be fully ripe. Ordinarily, all greenness has left the straw and the glumes have turned a dull white at this stage. The use of the small combine has increased greatly during the past few years, about 40 per cent of the crop being combined. The growing of stiff-strawed varieties such as Clinton facilitates combine harvesting. About one-third of the combined oats are windrowed first (Figure 161). This avoids losses from seed shattering and stalk crinkling. Sometimes oats are cut for hay with a mower. Premature harvesting of oats with a binder reduces both grain and straw yields.[2] There is no justification for premature harvest of oats during rust years, from the standpoint of yield.[40]

Uses

About 88 million bushels or 8 per cent of the oat crop is used for seed. About 29 million bushels or 2½ per cent is used for food largely in the form of rolled oats. Thus nearly 90 per cent of the crop is used for feed. It is regarded chiefly as a horse feed and for that purpose about 2 bushels are considered equivalent to a bushel of corn. Oats often are fed whole to horses and sheep. Ground or chopped oats are fed extensively to dairy cattle, breeding stock, and young stock. After the hulls are removed, oats are equivalent to corn for hog feed. Farm-size hullers are used largely. Oats are fed extensively to poultry, usually without hulling, but sometimes they are sprouted. The hulls supply some accessory food factor that checks a malnutrition in chickens inducing feather picking. Oat flour, in part a by-product of rolled oats manufacture, is used in breakfast foods and other foods. The flour possesses a property of retarding the development of rancidity in fat products. Paper containers coated with oat flour are used for packaging food products having a high fat content. Another oat product called "Avenex" is used as an antioxidant and stabilizer in ice cream and other dairy products.

Oats are one of the best crops for mowing while green to supply dried grass products and chlorophyll and carotene extracts for use in food, feed, and medicine. The young leaves are rich in protein and vitamins.

The manufacture of rolled oats consists first of cleaning and sizing the grain.[6] Then the grains are heated in steam jacketed pans where they dry down to about 6 per cent moisture and acquire a slight roasted flavor. After this drying the hulls are brittle enough to be removed readily by large hulling stones similar to the old-

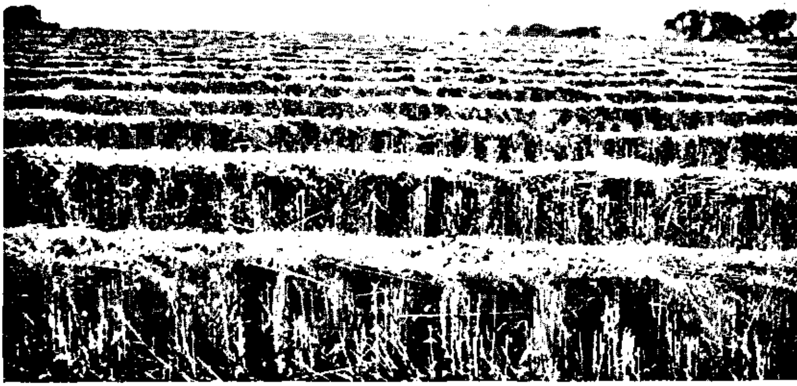


FIG. 161. (*Top*) Swaths of oats cut with the windrower. This field of stiff-strawed Clinton oats yielded 102 bushels per acre of grain testing 40 pounds per bushel. (*Bottom*) severe attack of Victoria blight of oats (center), and resistant varieties (left and right). Vicland and Tama are susceptible to this disease.

fashioned burr milling stones. The groats are then separated from the hulls and broken pieces. The whole groats are steamed to toughen them and are then passed between steel rolls to produce the familiar flakes of rolled oats. So-called "quick" oats are small thin flakes rolled from steel-cut pieces of oat groats. The small size and thinness speed up the cooking process. The hulls which constitute 27 to 30 per cent of the grain are used in the manufacture of furfural, a solvent widely used in chemical, fat and petroleum industries.

Diseases

SMUTS

Loose smut, *Ustilago avenae,* replaces the oat floret by a loose spore mass. In covered smut, *U. kolleri,* the dark brown spore mass is more or less enclosed within a grayish membrane, and frequently within the lemma and palea of the flower. The two smuts cannot be clearly differentiated in the field. Both can be controlled by seed treatment with volatile organic mercury dusts. The percentage of oat plants infected with covered smut may be highest from seed sown when the mean temperatures are relatively high.[5]

Losses from oat smuts can be largely eliminated in many sections by growing adapted resistant varieties. Brunker, a red oat, is somewhat resistant. Markton is nearly immune to most races of both smuts. New smut-resistant varieties are now being grown, including Clinton, Benton, Mindo, Bonda, Marion, Hancock, Bannock, Uton, Huron, Marida, Fulton, Fultex, Ranger, Rustler, Carleton, Letoria, Desoto, Lega, and Stanton.[12]

RUSTS

Stem rust of oats (*Puccinia graminis avenae*) produces symptoms similar to stem rust of wheat. The alternate host is the common barberry, but in the south the disease overwinters and develops independently of the alternate host and then spreads northward. Control measures consist chiefly of growing resistant varieties.

Most of the older standard varieties of oats were susceptible to stem rust,[24] but several varieties, including White Tartar and Richland, were resistant. The development of Rainbow and the introduction of Bond[33, 36] led to the recent breeding of valuable new stem rust-resistant and crown rust-resistant varieties such as Clinton, Benton, Mindo, Bonda, and Marion.

Crown rust (*Puccinia coronata*) is identified by the bright yellow pustules on the leaves. The alternate host is the buckthorn, but in the south the fungus spreads independently of the alternate host. For each unit increase in coefficient of crown rust infection (percentage of infection × numerical infection type) the yield is decreased from 0.2 to 0.3 bushel per acre.[25] As the eradication of the buckthorn is impractical, the principal control is resistant varieties.

The Rainbow variety is fairly resistant. However, Bond hybrid selections are highly resistant to nearly all races of crown rust except race 45,[36] and also resistant to most races of stem rust and to smuts. Vicland, Boone, Stanton, and several other resistant varieties were developed from crosses with Victoria.[37] Clinton, Benton, Mindo, Eaton, Mohawk, and Bonda were developed from crosses with the Bond variety. New early varieties from these crosses include Andrew, Cherokee, and Nemaha. Three new red oat varieties grown in Texas, viz., Fultex, Ranger, and Rustler, are resistant to crown rust.

VICTORIA BLIGHT

A new blight disease, Victoria blight (Figure 161), caused by *Helminthosporium victoriae* is causing heavy losses to oat varieties derived from crosses with the Victoria variety. Treating the seed with New Improved Ceresan seems to give only partial control. Clinton, Benton, Marion, Mindo, Mohawk, Cherokee, Nemaha, and Bonda and a number of other varieties are resistant.

Insects

Oats are less subject to insect attack than are barley and wheat. The Hessian fly does not attack oats. Chinch bugs, although damaging to oats, greatly prefer barley and wheat.

The bluegrass billbug (*Calendra parvulus*), certain leaf hoppers, the army worm, the grain bug (*Chlorocroa sayi*), grasshoppers, and

Mormon crickets attack oats readily. The spring grain aphis (or green bug, *Toxoptera graminum*) sometimes damages oats severely. Methods of controlling most of these insects are discussed in the chapter on wheat.

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19 RICE

Economic Importance

Rice is the principal food crop of about half the people of the world, particularly in the coastal regions and river basins of many countries of the Orient. About 95 per cent of the world crop is produced in the far east, less than 1 per cent being grown in the United States.

The leading rice-producing countries are China, India, Japan, Burma, French Indo-China, the Netherlands Indies, Thailand (Siam), Korea, Philippine Islands, Formosa, Brazil, and the United States. Italy, Spain, and Portugal produce rice as do Egypt, Madagascar, Sudan, and West Africa. India, China, and Japan import rice in peace times. Burma, French Indo-China, and Thailand are the chief exporting countries in normal times. Brazil and the United States export rice. The West Indies and Hawaii take most of the rice shipped from continental United States. The average annual acreage in the United States from 1937 to 1946 was 1,295,000 acres, on which an average of 60 million bushels was produced. The average yield for this period was 47 bushels per acre. During the war period the acreage expanded from about 1 million up to about 1½ million acres. The states of Louisiana, Texas, Arkansas, and California produce nearly all the rice grown in the United States (Figure 162). Louisiana has approximately two-fifths of the entire acreage in this country. A few hundred acres are grown in the southeastern states and formerly a little was grown on the Mississippi bottoms in Missouri.

Origin and History

Rice probably originated somewhere in the area extending from southern India to China. It is believed to have spread eastward to

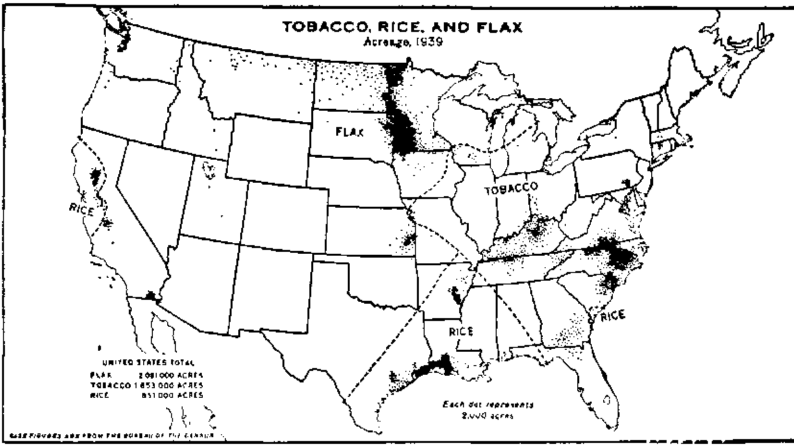

FIG. 162. Distribution of tobacco, rice and flax in the United States.

China probably 3,000 years before the Christian Era. Several native species, including *Oryza sativa spontanea, O. minuta,* and *O. latifolia,* are found in the Orient.

The first rice was planted in this country at Charleston, S. C., about 1685. The crop spread to North Carolina and Georgia. Most of the rice was produced largely by hand methods on the delta lands of the south Atlantic states from 1685 to 1888. Rice growing in this region was adversely affected by the Civil War, after which the acreage increased along the Mississippi River in Louisiana. In 1889, Louisiana became the leading state in rice production. In the Gulf coastal prairie section there it was first grown by machine methods. Rice culture spread from southwestern Louisiana to southeastern Texas about 1900, to eastern Arkansas in 1905, and to the Sacramento Valley in California in 1912.

Adaptation

Rice is unique among the cereals in being able to germinate and thrive in water. Other cereal crops are killed if submerged for 2 or 3 days in warm weather, because of lack of oxygen for the roots. The rice plant is able to transport oxygen to the submerged roots from the leaves where oxygen is released during photosynthesis. Thus it can live in an aquatic environment.

The principal factors limiting rice production in this country to rather definite regions are favorable temperatures, a constant supply of fresh water for irrigation, and suitable soils. Rice can be grown successfully only in regions having a mean temperature of about 70° F. or above during the entire growing season of 4 to 6 months.[18] A dependable supply of irrigation water is essential to maximum yields.

FIG. 163. Panicle of Colusa rice. A section of a rice culm showing the long ligule and a portion of a leaf and sheath is inserted at the lower left.

Rice is grown on soils of rather heavy texture underlain at from 1.5 to 5.0 feet from the surface by an impervious subsoil. The Crowley silt loam is a typical rice soil in Louisiana, while Stockton adobe-clay soil is well suited to the crop in California. The loss of water by seepage is small through such soils, and that is the chief reason for selecting heavy soils for rice culture. The land on which rice is grown in the south is normally submerged from 4 to 6 inches deep from the time the seedlings are 6 to 10 inches high until just before the crop has reached full maturity. This involves a period of submergence for 3 to 5 months. In California, the land is flooded before seeding and remains submerged for some 4 to 5 months.

Upland rice consists of certain varieties that can be grown without irrigation or submergence in regions of high rainfall where the soil is wet much of the time. Yields are much lower than when rice is grown under submergence. Upland rice is grown only on a small scale for home use by hand methods in the United States as well as other countries. It is limited to less than 3,000 acres on more than 1,000 farms in the south Atlantic states.

Botanical Description

Rice, *Oryza sativa*, belongs to the grass tribe *Oryzeae* characterized by one-flowered spikelets, laterally compressed, and two short glumes. The so-called wild rice, *Zizania aquatica* (or *Z. palustris*) bears little resemblance to rice. It belongs to the grass tribe *Zizanieae*.

Rice is an annual grass with erect culms 2 to 6 feet tall. The plant tillers freely, 4 or 5 culms per plant being common. Node branching may occur with early maturity and with ample space for plant development.[11]

The rice inflorescence is a loose terminal panicle of perfect flowers (Figure 163). At maturity the panicle in different varieties may be enclosed in the sheath, partly exserted, or well exserted. Each panicle branch bears a number of spikelets, each with a single floret (Figure 164). The flower has six stamens and two long plumose sessile styles, being surrounded by a lemma and a palea at the base of which are two small glumes. The lemma and palea may be straw-yellow, red, brown, or black. The lemmas of various varieties may be fully awned, partly awned, tip-awned, or awnless. The rice grain is enclosed by the lemma and palea, these structures

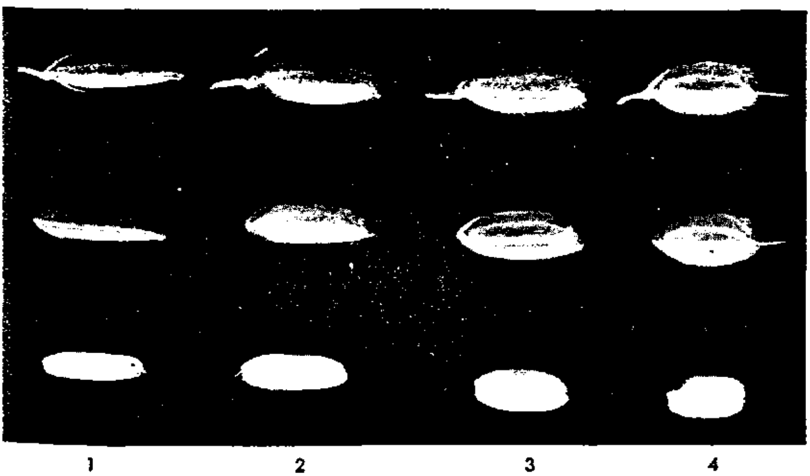

FIG. 164. Spikelets (*top*), seeds (*middle*), and kernels (*bottom*) of four types of rice. (1) Rexoro—slender grain, (2) Fortuna—long grain, (3) Blue Rose—medium grain, and (4) Caloro—short grain.

being called the hull. The hulled kernels vary from about 3.5 to 8.0 mm in length, 1.7 to 3.0 mm in breadth, and about 1.3 to 2.3 mm in thickness. They may be hard, semihard, or soft in texture. The color of the unmilled kernel may be white, brown, amber, red, or purple. Commercial American varieties are white, light brown, or amber. An average rice panicle contains 100 to 150 seeds.

Pollination

In blooming, rice flowers open rapidly and the anthers dehisce when the flower opens or, rarely, before opening. The flowers may remain open 20 minutes to 3 hours.[10, 23] Blooming starts early in the day when temperatures are high, but slows down materially when the sky becomes cloudy causing a drop in temperature.[1]

Rice is normally self-pollinated, but up to 3 or 4 per cent of natural crossing may occur, with less than 0.5 per cent on the average. Varieties differ materially in the extent of natural crossing.[4] Much more occurs in the south than under the higher temperature and lower humidity conditions prevailing in California.

Varieties

Thousands of varieties of rice are known in the Orient but comparatively few are grown in the United States.

GENERAL TYPES

The varieties grown include short, medium, and long grain types. The average length of the hulled kernel of the 3 types is: short grain 5.5 mm, medium grain 6.6 mm, and long grain 7 to 8 mm.[19] Early-maturing varieties in the southern states require about 120 to 129 days from seeding to maturity, the midseason varieties about 130 to 139 days, and the late varieties 140 days or more.

Rice varieties differ widely in their response to day length when sown on different dates[9] (Table 1). Responsive varieties such as Blue Rose mature at a similar season regardless of when sown. Indifferent varieties such as Rexoro mature very late when sown late as they require a long growing period regardless of seeding date.

TABLE 1. EFFECT OF SEEDING DATE ON THE GROWING PERIOD OF FOUR VARIETIES OF RICE AT CROWLEY, LA.

DATE SOWN	DAYS FROM EMERGENCE TO MATURITY			
	Early Prolific	*Fortuna*	*Blue Rose*	*Rexoro*
March 1	133	159	173	181
March 15	136	158	173	183
April 1	134	152	166	179
April 15	131	149	157	176
May 1	123	145	146	162
May 15	124	141	138	159
June 1	119	139	132	154
June 15	112	132	121	148

Blue Rose requires much longer to mature in the longer days of central California at latitude 39° N than it does in southern Louisiana at latitude 30° N. All rices are short-day plants.

The endosperm starch may be glutinous, or nonglutinous (common), but glutinous varieties are grown only rarely in the United States. Glutinous rices, which have the amylopectin type of starch, are used in preparing special delicacies.

VARIETY DESCRIPTIONS

Short-grain varieties are grown almost exclusively in California, while medium-grain and long-grain varieties are most widely grown in Louisiana, Texas, and Arkansas.[20] The short-grain rice varieties grown, which comprise 22 per cent of the domestic crop, are Japanese types. Caloro is a midseason, short-grain variety comprising about 85 per cent of the California rice acreage. Colusa, an early-maturing short-grain rice, also produces high yields in California. Conway is earlier than Caloro but later than Colusa. The most widely grown short-grain rices in the southern states are Acadia, Asahi, and Caloro.

Blue Rose, a medium-grain, late-maturing rice, is vigorous, stiff-strawed, and mills well. Early Prolific, another medium-grain but early variety grown in the south, is a relatively high yielder, but is inferior to Blue Rose in table quality. Zenith is the most satisfactory early-maturing, medium-grain variety under southern conditions, from the standpoint of both grain yield and milling quality.[24] Calrose and Calady 40 are medium-grain rices grown in California, and Magnolia is grown in Louisiana.

Long-grain varieties are more likely to be broken in milling than those of the other types.[20] Among these, Edith and Lady Wright have been largely replaced by the improved later-maturing Rexoro, Texas Patna, Nira, and Fortuna varieties. Rexoro is the leading variety of rice in the south. It is of high quality but late in maturing.[32] Texas Patna is similar to Rexoro but earlier.

Several varieties of different maturity may be grown advantageously on one farm to distribute harvest labor over a longer period.[24]

Rotations

Because of the conditions under which rice is grown, it is difficult to follow rice with other crops in a regular rotation.

The most common practice in Louisiana and Texas is to pasture rice land for 1 to 3 years before it is used for rice again.[19] Pasturing helps to retard red rice and other aquatic weeds. The accumulation of organic matter during the grazing period materially improves the land for the next rice crop. Rice is grown only occasionally in rotation with clean fallow, small grain, cotton, soybeans, corn, and green manure crops. Fallow is more common than growing crops. In the south, much of the rice land is simply allowed to lie idle, during which time it is used as pasture.

In California,[14] two or three consecutive rice crops are grown on new land that has never been in rice, until weeds become numerous. This is followed by idle land or spring or summer plowed fallow on which wheat or barley may be fall sown after the fallow season. Rice is again grown for 1 year. Fallowing allows one rice crop in alternate years. Some growers leave their rice land uncultivated and pasture it when not in rice.

Cultural Methods in the Orient

A large part of the oriental rice that enters commercial trade is grown by transplanting.[6, 30] The reasons for transplanting[3] include better utilization of land by growing two different crops in a year, the saving of irrigation water, and better weed control. In hand transplanting, the rows are spaced for convenient weeding, harvesting, and fertilizer application, all of which also are done by hand. The seed is sown in beds while the fields are still occupied by other crops. When the seedlings are about 30 to 50 days old they are transplanted in fields (paddies) that have been stirred into a thin soupy mud into which clumps of 3 or 4 seedlings can be pushed easily. Experiments in the United States show no advantage in yield from transplanting as compared with ordinary field seeding methods. Much of the rice in the Orient is harvested and threshed by hand, and water for irrigation is often lifted from streams to the fields by manpower. Considerable quantities of rice for home use are pounded out in a wooden mortar. Rice straw is used for weaving mats, bags, hats and baskets, for drinking straws and for making paper and cardboard.

Cultural Methods in the Southern States

Seedbed preparation for rice should include destruction of weeds and sufficient tillage to produce a mellow, firm surface layer for planting the seed. The land should be plowed 4 to 5 inches deep in the fall, winter, or spring.

SEEDING

Rice usually is sown with a grain drill, although some is sown with airplane and broadcast seeders. The crop usually is sown in the southern states between April 1 and May 15. Seed sown too early may rot because of low temperatures. Rice can be sown over a comparatively long period in the south without material reduction in yields. Under very favorable conditions, 80 pounds of seed per acre usually is sufficient to give good stands.[10] Under ordinary conditions, 90 to 100 pounds of seed sown with a drill or 125 to 150 pounds sown broadcast will prove adequate. Rice should be drilled 1 to 2 inches deep on good seedbeds, the shallower depth on heavy soils.

Seed containing red rice should be avoided. Although red rice belongs to the same species as cultivated rice and is grown in other countries, it is a serious pest in rice fields because the seeds shatter out early and contaminate the fields. The seed may live over in the ground for several years. Red rice admixtures spoil the appearance of milled white rice.

Weeds, including red rice (*Oryza sativa*), curly indigo (*Aeschynomene virginica*), Mexican weed (*Caperonia palustris*), tall indigo or coffee weed (*Sesbania macrocarpa*), redweed (*Melochia corchorifolia*), and barnyard grass are kept partly under control by hand pulling, mowing, pasturing, rotation, and flooding. The broad-leaved weeds can be controlled by one or two applications of 2,4-D, using 1 to 1½ pounds per acre of the chemical in a concentrated spray applied shortly before or some time after flooding the field. The application of 2,4-D to rice in the heading stage causes considerable sterility.

FERTILIZERS

A mixture of 100 pounds of ammonium sulfate and 100 pounds of superphosphate per acre in the drill with the seed at planting time is the most satisfactory fertilizer for rice in Texas.[31] The yields of rice were increased in Arkansas by addition of nitrogen fertilizers.[22] Nitrate nitrogen was more susceptible to loss by decomposition and leaching than were ammonium compounds. Maintenance of an adequate supply of organic matter in the soil is probably the best way to insure high yields.

IRRIGATION

After the young rice plants reach a height of 6 to 8 inches the land is submerged, or flooded, to a depth of 1 to 2 inches. As the plants grow taller, this depth is gradually increased until it reaches 4 to 6 inches. The water level is maintained at this depth for 60 to 90 days, or until the land is drained prior to harvesting. Levees with overflow outlets are built to maintain the water at the proper level. The water requirement of the rice crop varies from 24 to 48 acre inches, 6 to 20 inches of which is supplied by rainfall during the growing season in the southern states. The fields are drained[19] so that the land will dry before the crop is ready to harvest. Ordinarily, the land is drained after the rice is fully headed, i.e., when the panicles are turned down and ripening in the upper portions. This stage is reached 10 to 15 days before full maturity.

HARVESTING

In order to produce maximum yields of high milling quality rice should be harvested when the moisture content of the grain of standing rice has dropped to 23 to 28 per cent.[27] At that moisture, the kernels in the lower portion of the heads are in the hard-dough stage, while those in the upper portions of the head are ripe. Few chalky kernels (a result of immaturity) are found in rice harvested at this stage. Increased shattering and checking of the grains will occur in some varieties when harvested after this stage.

More than one-half the rice in the southern states is harvested with a binder. It is shocked for 10 to 14 days and threshed when the moisture content of the grain is reduced to about 14 per cent. When combined, it is advisable to harvest when the grain contains 23 to 28 per cent moisture and then dry it artificially before it is stored. The air temperature should be kept below 110° F. when completing the drying in one operation.[26] It usually is dried in several stages and is held to allow the grain to reach equilibrium between drying operations. After the grain is partly dried temperatures as high as 130° F. are not injurious.

Cultural Methods in California

Cultural methods in California were devised for the control of watergrass (*Echinochloa crusgalli*) on old rice land.[12] The seedbed for rice generally is prepared by early spring plowing 4 to 6 inches deep. It is then harrowed or the clods crushed with heavy wooden or iron drags, and levees are built along contour lines at proper intervals.

SEEDING

Ordinarily, rice is drilled on new land and sown broadcast on old land. When the field is to be submerged continuously in order to control watergrass on old land, the seed is broadcast either on the water, or on the soil surface and then submerged to a depth of 4 to 8 inches. Seed sown on the water is seldom covered by clods, while that sown on the soil surface and followed by submergence frequently is covered by slackened clods which prevents normal germination.

Rice is able to germinate with a lower supply of oxygen than is the case with other cereal seeds. Oxygen is released from the seed by fermentation.[28] This permits rice seedlings to emerge through cool water 6 inches or even more in depth. When the submerged rice seed is covered also with one inch or more of soil, the supply of oxygen is then insufficient for germination, so drilled rice fields are irrigated and then drained until after the crop is up.[15, 17] Rice usually is sown by broadcasting sprouted seed from an airplane (Figure 165) but the end-gate seeder also is used to sow rice on the water. The crop usually is sown between April 15 and June 1, but it should be sown as early as possible.

On new land, rice is generally drilled shallow at the rate of 120 to 130 pounds per acre and then irrigated and drained. The best results are obtained on old land to be continuously submerged when the seed is broadcast at the rate of 145 to 160 pounds per acre.

FERTILIZERS

Fertilizers were not used extensively on California rice fields until recently. Significant increases in grain yields have been obtained from (1) a combination of ammonium sulfate and superphosphate, (2) a complete fertilizer, and (3) green manure from bur clover.[16] Non-nitrogenous fertilizers have failed to increase yields materially. Ammonium sulfate at the rate of 150 pounds at seeding time is now extensively used by rice growers.[7] Ladino clover pasture aftermath is the popular green manure crop on rice land at the present time.

IRRIGATION

On the heavy soils used for rice culture in California, it is necessary to apply water to germinate the seed. For this reason, the irrigation season for drilled rice is divided into two periods. The first period consists of frequent irrigations, followed by drainage, to start the crop. The second period begins about 30 days after emergence when the land is submerged to a depth of 6 inches. This depth is maintained for 90 to 140 days, or until the crop is almost ready to harvest.

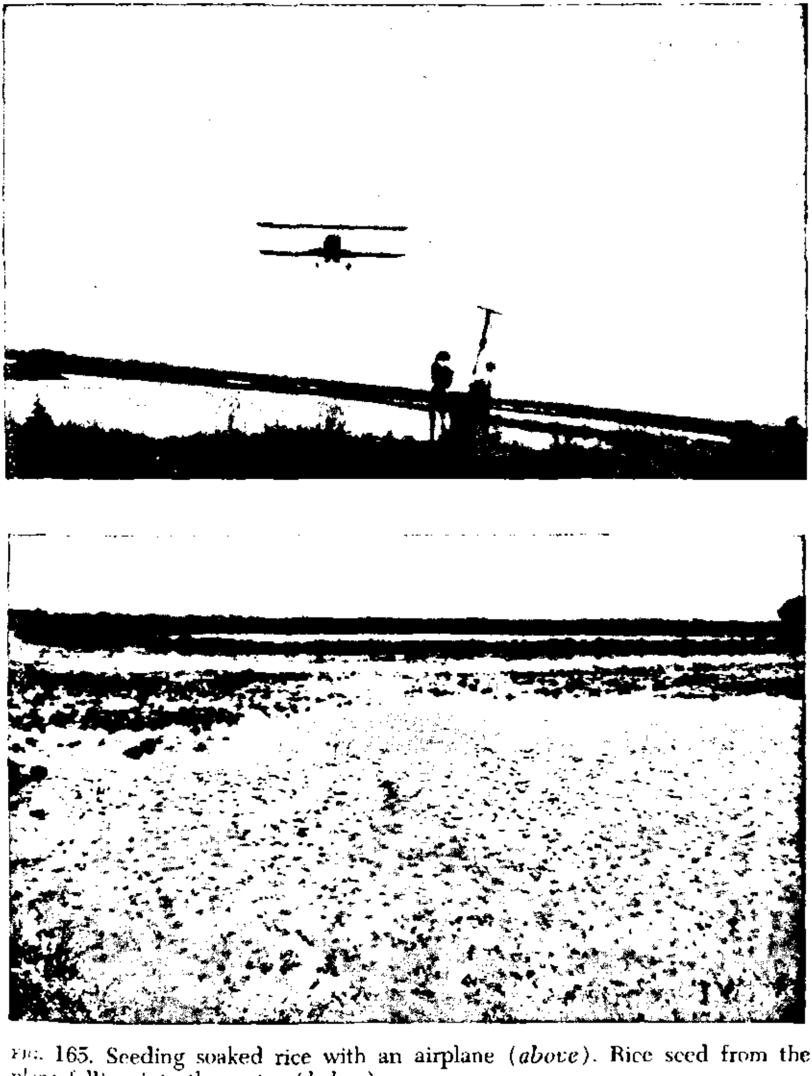

FIG. 165. Seeding soaked rice with an airplane (*above*). Rice seed from the plane falling into the water (*below*).

Water grass, or barnyard grass (*Echinochloa crusgalli*), is now controlled in California by continuous submergence. Common water grass plants will not emerge through 8 inches of water, and only a few plants emerge through a 6-inch submergence through which rice seedlings *stretch* to the surface.[13, 17]

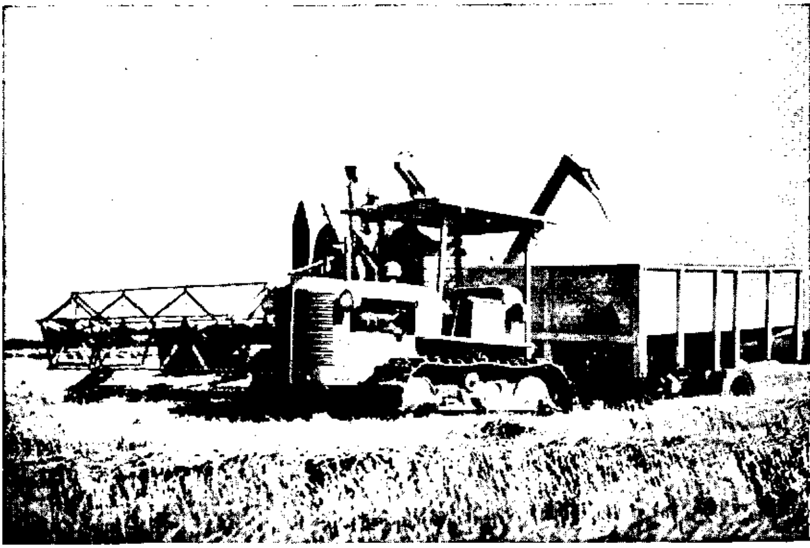

FIG. 166. Harvesting rice with a combine equipped with a pick-up reel. The fingers on this type of reel gather up badly-lodged stems of rice or other grains.

HARVESTING

About 97 per cent of the California crop is combined as compared with 42 per cent of the entire domestic crop (Figure 166). The crop is combined directly and then dried artificially.[25]

Milling

The rice kernel enclosed by the hulls as it leaves the thresher is known as rough rice or paddy. It weighs about 45 pounds per bushel. Rough rice is marketed in bulk or in bags. Yields commonly are reported in terms of 100-pound sacks in California, in bushels in Arkansas, and in barrels (162 pounds) in Louisiana and Texas. Rough rice is used for seed, but most of it is milled for food. Damaged or low-quality rough rice is used for feed. When milled, rough rice[19] yields about 64 per cent of whole and broken kernels, 13 per cent of bran, 3 to 4 per cent of polish, and 20 per cent of hulls. When somewhat undermilled the yields of head rice range from 65 to 70 per cent.

Rough rice is first fanned and screened to prepare it for milling. It is then conveyed to the hulling stones (or sheller) where the hulls are detached. The mixture of hulled rice, rough rice, and hulls is then aspirated to remove the detached hulls. The remaining portion of the mixture is then passed to paddy machines (separators) where rough rice is separated from the hulled kernels. The rough rice from the paddy machines is returned to the hulling stones for removal of the hulls, which are used for fuel or packing. The hulled kernels (brown rice) (Figure 167), are conveyed to the hullers where a part of the bran layer and the germ is removed by friction. The rice is then passed to a second set of hullers, and in some mills to a pearling cone also. From these machines it is passed to the bran reel for separation of the bran from the rice. The rice kernels are then conveyed to the brush for polishing. In this process, more of the bran as well as some of the starch cells are rubbed off and screened out. The light brown powder from the screens, known as rice polish, is used for feed. The polished rice is next conveyed to a revolving cylinder or trumble where it

A B C

FIG. 167. (A) Paddy or rough rice; (B) brown rice; (C) milled rice.

is steamed. Glucose and talc are also applied when the rice is to be coated. The milled rice is then separated into grades and bagged. A bag containing 100 pounds is called a *pocket.*

In certain Asiatic countries, especially India, Burma, and Ceylon, much of the rice is parboiled before milling. Several mills recently have parboiled rice in the United States. Parboiling consists of soaking and steaming the rough rice by various procedures until the endosperm starch is partly gelatinized, and then drying and milling the grain. The advantages of parboiled (or converted) rice are that it is broken less in milling, giving a higher yield of head rice, the kernels remain whole during long cooking; the rice keeps better (probably because of partial sterilization); and more of the water-soluble vitamins are preserved in the kernel. The B vitamins in the bran and hulls are absorbed by the endosperm from the water used in soaking the rice.[21]

Whole grains of milled rice are called head rice. Rice containing mostly half and three-quarter kernels is called second head. That composed mostly of half and third kernels is called screenings. Finely broken rice, called brewers rice, is used as a starchy adjunct in the brewing and distilling industries or for feed. Rice flour is a by-product sifted or ground from the coarser milled particles and used in foods and face powders.

In milling long-grained rice, yields of head and second head of 50 per cent of the weight of rough rice are common. In short-grained and medium-grained types, the yields of head rice are close to 60 per cent. Head rice consists of 11 to 12 per cent moisture, about 77 per cent starch, 2 per cent pentosans, 7 to 8 per cent protein, and fractional percentages of fat, minerals, and crude fiber. Like other refined cereal products it is incomplete from the dietary standpoint. This fact is of little consequence in the United States where the average yearly per capita consumption is only 6 pounds, but is important in parts of the Orient where rice comprises 40 to 80 per cent of the food calories, and annual consumption ranges from 125 to more than 400 pounds per capita. Those subsisting largely on well-milled rice sometimes develop beri beri, a nerve-damaging nutritional disease, because of a deficiency of thiamin (vitamin B_1) in the diet when the rice is not properly supplemented with such foods as meat, fish, soybeans, and vegetables. Brown rice is richer than well-milled (polished) rice in thiamin but it tends to become rancid in storage, and steady consumption of brown rice by heavy rice eaters often leads to digestive disturbances. Undermilled rice as eaten by many Asiatics contains thiamin.

Rice of high milling quality is free from checks, i.e., cleavage lines from stresses resulting from rapid drying; free from pecky grains resulting from insect and disease injury, and from starchy (opaque) spots caused by immaturity or poor environment, all of which increase the breakage and thus reduce the yield of head rice in milling. Rice of high cooking quality, including the Rexoro, Texas Patna, Nira, and Fortuna varieties leaves the kernels flaky, whole, and separated after boiling. The Blue Rose and Caloro varieties when cooked are whole but somewhat sticky. However, such rice is highly acceptable to numerous consumers, including those in Europe, the West Indies, Japan, and some other parts of the Orient. Rice grains of low cooking quality, such as those of the Early Prolific and Lady Wright varieties, break down during cooking.

For use in canned soups, only parboiled grains of high quality varieties, such as Rexoro and Texas Patna are acceptable, because other types are disintegrated by the steam-pressure sterilization incident to canning. So-called scented or fragrant rices that give off a distinct aroma during cooking are prized by some consumers. Only one variety of this type, Delrex, is grown in the United States and it is confined to a small acreage.

Diseases

The principal diseases of rice are seedling blight, brown leaf spot, narrow brown leaf spot, blast, and stem rot.[29]

SEEDLING BLIGHT

Seedling blight, caused by *Sclerotium rolfsii,* attacks the young seedlings in warm weather. Affected seedlings are slightly discolored. Later, small round light brown fungus bodies are found on the lower portions of the seedlings. Severely affected seedlings are killed. Early-sown rice seems to be more subject to injury by this fungus than that sown late. Immediate submergence will check the disease. Some commercial fungicidal dusts provide considerable protection to seedlings.

BROWN LEAF SPOT

Brown leaf spot, caused by *Helminthosporium oryzae,* is one of the most serious diseases in Louisiana, Texas, and Arkansas. This fungus attacks the seedlings, leaves, hulls, and kernels. It may cause seedling blight until the plants attain a height of 4 inches. Brownish discolorations first appear on the sheaths between the germinated seed and the soil surface, or on the roots. Small circular or elongate reddish-brown spots appear on the leaves, causing them to dry up on severely affected plants. Spots also appear on the hulls and on the kernels. Resistant varieties appear to be the only satisfactory control.

NARROW BROWN LEAF SPOT

This disease, caused by *Cercospora oryzae,* was the most widespread leaf spot in the southern states from 1934 to 1938. The spots on the leaves are long and narrow. The disease usually appears late in August and in September. The injury to plants is due principally to the reduction of the leaf area. The most satisfactory control is by the use of resistant varieties.[2]

BLAST

Rice blast or rotten neck, caused by *Piricularia oryzae,* is a long-known disease in many countries; it blights the panicles and rots the stems so that they break over. The fungus lives over on crabgrass and rice straw. The only known remedies are the use of strong-stemmed varieties that tolerate the injury, and avoidance of heavy nitrogen fertilization which encourages the disease. It is most severe on new rice land.

STEM ROT

Stem rot, caused by two different organisms, *Leptosphaeria salvinii* and *Helminthosporium sigmoideum,* is an important and widespread disease of rice, that causes the plants to lodge. Damage from the disease can be reduced by draining the fields and thereafter keeping the soil saturated but not submerged.

STRAIGHTHEAD

Straighthead is a physiological disorder. Heads of affected plants remain erect and fail to set seed. Plants affected with straighthead have dark green leaves that remain green after the normal plants have matured. Straighthead is most prevalent on new land or on old land uncropped to rice for several years, on which a heavy growth of weeds has been plowed under. The disease often can be controlled by draining the land before the rice is in the boot. After the soil has dried on the surface, the land should be submerged again.

WHITE TIP

White Tip, which is caused by a seed-borne nematode under certain soil conditions, produces white leaf tips. It is controlled by hot water seed treatment, early planting, and the use of resistant varieties such as Fortuna, Nira, and Bluebonnet.

OTHER DISEASES

Rice is attacked also by sheath spot, sheath rots, kernel spots, kernel smut, and leaf smut.

Insects

Insects cause little injury to rice in California.[8]

RICE STINKBUG

The rice stinkbug (*Solubea pugnax*) sucks the contents from rice kernels during the milk stage, leaving only an empty seed coat when all the milk is withdrawn and causing pecky rice when only partly consumed. Pecky rice is discolored and is likely to be broken in milling. The only control measure known where the insect occurs in the south is the winter burning of the coarse grasses in which the insect hibernates.

STALK BORERS

Two species of borers, the sugarcane borer (*Diatraea saccharalis*) and the rice stalk borer (*Chilo plejadellus*) damage rice in Louisiana and Texas. They tunnel inside the rice culms, eating the inner parts and often causing the panicles to turn white and produce no grain, a condition called "whitehead." In other culms, grain formation is not completely inhibited but some of the culms or panicles break off if the culm is badly girdled. The borers prefer large stems. The borers live over winter in the rice stubble. Heavy grazing of the stubble, mashing down the stubble by dragging, and flooding the stubble fields by closing up drainage outlets to hold water from winter rains kills the borers in their winter quarters.

SUGARCANE BEETLE

The sugarcane beetle (*Euetheola rugiceps*) injures rice in the southern states by gnawing off the plants at or just below the soil surface. They attack young rice plants before the land is submerged and old plants after the fields are drained before harvest. Control consists in avoiding sod land for rice production and treating the seed with kerosene or coal tar before planting, to repel insects from the young plants.

OTHER INSECTS

The rice water weevil (*Lissorhoptrus simplexi*) causes slight damage to rice. Before the fields are submerged, the rice plants sometimes are damaged by the fall army worm (*Laphygna frugiperda*), southern corn rootworm (*Diabrotica duodecimpunctata*), and the chinch bug (*Blissus leucopterus*). Flooding destroys the insects. Threshed rice is attacked by the rice weevil and other insects attacking stored grains.

Wild Rice

Wild rice, also called water oats, seldom is cultivated as a crop except in marshes where it is desired to attract waterfowl.[5] It is a native aquatic grass found from Lake Winnipeg southward to the Gulf and eastward to the Atlantic Ocean. It grows in lakes, and

FIG. 168. Wild rice (*Zizania aquatica*): Plants growing in water (1), panicle showing appressed branches of pistillate florets above and spreading branches of staminate florets below (2), natural-sized unhulled seeds (3), and hulled seeds (4).

also in tidal rivers and bays where the water does not contain enough salt to be tasted. A wide range of growth types adapted to local day lengths are found at different latitudes. Wild rice grows mostly in water 2 to 4 feet deep. On tidal lands the water may fluctuate through depths from nothing to 3 feet.

The seeds shatter quickly when ripe and fall to the muddy bottom where they remain until spring, when germination occurs. The plants can grow up through the water at depths up to 6 feet. The seed fails to germinate if it is allowed to dry, so it is kept covered with cool water when stored over winter for planting. The plants grow to a height of 3 to 11 feet and are topped by large open panicles bearing pistillate flowers in the upper half and staminate flowers below. This arrangement favors cross-pollination. The seed (Figure 168) is harvested mostly by northern Indian tribes who tap the tops with sticks and knock the seed into a boat or canoe. It is then partly dried on the ground, parched in an open vessel, and then hulled by pounding or tramping. Because of the labor required to gather and process the grain, it is sold as a high-priced delicacy.

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20 MILLETS

Economic Importance

The millets are minor crops in this country and no statistics regarding their production are available. Probably 100,000 acres or less are being grown in the United States. Some 5 million to 18 million acres annually of various millets are grown in each of the countries of China, India, Manchuria, Russia, and French Equatorial Africa.

Four distinct groups of millet are grown in the United States. Those grown for forage are foxtail millet, pearl millet, and Japanese barnyard millet. Proso is grown for grain.

Proso is grown chiefly in the northern half of the Great Plains and in the Great Lakes states. Foxtail millet is grown there and also in Texas, New Mexico, Tennessee and other southern states. Pearl millet is grown in the southeastern states. Japanese barnyard millet is grown only occasionally. The four millets mentioned above are classified in the grass tribe *Paniceae.*

Various other grasses are called millet. Ragi, or finger millet, or birdsfoot millet, *Eleusine coracana,* is grown extensively in India, Africa, and China. *Paspalum scrobiculatum* is grown in India as Koda millet and in New Zealand as Ditch millet. Sorghum is called millet in parts of the world. Broomcorn is called broom millet in Australia.

Foxtail Millet

HISTORY

Foxtail millet is one of the oldest of cultivated crops. It was grown in China as early as 2700 B.C. The crop probably had its origin in southern Asia, but its culture spread from there westward to Europe at an early date. Foxtail millet was rarely grown in the United States during colonial times, but it became a rather important crop in the central states after 1849. The total production amounted to 1,743,887 acres in this country in 1899, but the acreage has decreased materially since that time, its place for a late-sown annual grass having been taken by Sudan grass to a large extent.

ADAPTATION

Foxtail millet requires warm weather during the growing season for its best growth. It matures quickly when grown in the hot summer months of the most northern states. The crop is most productive where the rainfall is fairly abundant, but a large part of the acreage is found in the semiarid region.

Foxtail millet lacks the ability to recover after being injured by drought.[14] Because of its shallow root system it is one of the first crops to show the effects of drought. The millets succeed in localities subject to drought almost entirely through their ability to escape periods of acute drought because of their short growing season. Some early varieties will produce a hay crop in 65 to 70 days. When grown in the dry sections of New Mexico and western Texas, it is planted in wide cultivated rows to permit the crop to succeed. Other crops produce more forage than millet does under irrigation and at high altitudes in Colorado.[4] A fertile loam soil is best for millet, but good drainage is essential.

BOTANICAL DESCRIPTION

Foxtail millet (*Setaria italica*) is an annual grass with slender, erect, leafy stems. The plants vary in height from 1 to 5 feet under cultivation. The seeds are borne in a spikelike or compressed panicle. There is an involucre of 1 to 3 bristles at the base of each spikelet. The small, convex seeds are enclosed in the hulls (lemma and palea). The color of the hulls differs with the variety, some of the colors being creamy white, pale yellow, orange, reddish orange, green, dark purple, or mixtures of various colors. The two common annual weeds, yellow foxtail (*Setaria lutescens* or *S. glauca*), and green foxtail (*S. viridis*) resemble foxtail millet.

The foxtail millets are largely self-pollinated, with 0 to 10 per cent of natural crossing.[10, 13]

VARIETIES

Ten or more distinct varieties of foxtail millet are grown in this country. In Nebraska the Common and German varieties yielded about 3½ tons of hay per acre, respectively, or 75 per cent of the sorghum yield during the same period. The Siberian, Goldmine, and Golden (German) varieties outyielded the White Wonder, Dakota Kursk, and Hungarian varieties under dryland conditions in Colorado.[4] The highest seed yields were obtained from Dakota Kursk and White Wonder. Common and a strain of Kursk produced the highest seed yields in South Dakota trials.[1] The Golden millet is the most popular in Texas.

Plant characters of the principal foxtail millet varieties (Figure 169) are presented in Table 1.

ROTATIONS

Foxtail millet usually is grown as a catch crop since it matures in 75 to 90 days and can be sown when it is too late for seeding most other crops. Some crops do not yield well after millet under dryland conditions. Winter wheat yielded 12.4 bushels per acre after corn, and 9.0 bushels after foxtail millet in eastern Colorado.[4] Late spring-planted crops (corn or sorghum) follow millet in rotation better than fall or early spring-sown crops (wheat, oats, or barley). It is usually advisable to grow foxtail millet after small grain or corn.

CULTURE

Seedbed preparation for foxtail millet is similar to that for spring-sown small grains. A firm seedbed is essential because of the small size of millet seeds. Weeds should be controlled up to the time the crop is planted because the seedlings are small and compete poorly with weeds until they have attained some size.

FIG. 169. Spikes of foxtail millet varieties. Left to right—Kursk, Hungarian, Common, Siberian, Turkestan, and Golden Wonder.

Millet seed should be planted when the soil is warm, or 2 to 3 weeks after corn-planting time. For the late dates, a 60- to 70-day season before the normal date of fall frost should be allowed. In Colorado, the crop is generally planted between May 15 and July 1 whenever there is sufficient soil moisture to germinate the seed.

Millet usually is seeded with an ordinary grain drill, since close

TABLE 1. PLANT CHARACTERS OF VARIETIES OF FOXTAIL MILLET

VARIETY	AVERAGE PERIOD OF GROWTH (DAYS)	SIZE OF STEM	SIZE OF HEAD [a]	CHARACTER OF HEAD	LENGTH OF BRISTLES [b]	COLOR OF BRISTLES	OUTLINE OF SEED	COLOR OF SEED
Common	69	Slender	Medium	Not lobed	Long	Pale yellow	Oval to elliptical	Pale yellow
German	87	Stout	Large	Distinctly lobed	Long	Green to purple	Round	"
Golden Wonder	—	Stout	Large	"	Short	Pale yellow	"	"
Goldmine	69	Medium	Medium	Not lobed	Long	"	Oval to elliptical	"
Hungarian	69	Slender	Small	"	"	Purple	"	[c]
Siberian	72	Medium	Medium	"	—	"	"	Pale orange
Kursk	64	Slender	Small	"	Long	"	"	"
Turkestan	93	Stout	Large	Slightly lobed	"	"	"	"

[a] In this class the term *small* indicates heads 3 to 4.5 inches long, *medium* indicates heads 4.5 to 6.0 inches long; *large* indicates heads 6 to 9 inches long.

[b] Under this class the term *long* indicates bristles longer than the spikelets, making the heads appear bristly; *short* indicates bristles shorter or about equal in length to the spikelets, so that the heads appear smooth.

[c] Some pale yellow, some purple or black.

spacing helps the crop to suppress weeds.[4] The plants should be spaced not more than 2 inches apart in the row.[11] The seed should be placed in moist soil even though it is necessary to plant it 1 inch or slightly deeper.

Foxtail millet should be sown at the rate of 25 to 30 pounds per acre. On clean land in semiarid regions 10 to 15 pounds is sufficient. Five pounds is ample for cultivated rows. The best quality of hay is obtained when it is cut just as the first heads appear, since it is more palatable then than when fully mature. For seed, the crop is usually harvested with a binder and allowed to stand in the field until the seed can be rubbed from the head. The crop may be threshed with an ordinary grain separator equipped with screens for small seeds. The crop may be windrowed to be threshed later with a combine with a pickup attachment. Direct combining is less successful because part of the seeds shatter before the later seeds are ripe.

UTILIZATION

Millet hay is usually considered inferior to that of timothy. To some extent this is due to being less palatable, but the hay is injurious to horses when fed continuously as the sole roughage.[6] The hay acts as a diuretic, its effect on the kidneys being particularly noticeable in horses. It is also slightly laxative. When fed with other forage, up to one-third the forage ration may be foxtail millet without danger of injury to horses. The hay can be fed to cattle or sheep without danger.

Foxtail millet is seldom utilized as a grain crop in this country because the seed is slightly less palatable and has only about 83 per cent of the feeding value of proso.[4] The seed should be ground finely before being fed to livestock. It is used for food and feed in China, Manchuria, Japan, and India.

DISEASES

Foxtail millet is subject to several diseases including mildew, bacterial blight, and leaf spots. Kernel smut (*Ustilago crameri*) may be controlled by seed treatment.

Proso

HISTORY

Proso (*Panicum miliaceum*) has been grown since prehistoric times as a grain crop for human food. Records of its culture in China extend back for 20 centuries or more. It is grown in Russia, Manchuria, China, the Balkan countries, and western Europe. Proso was introduced into the United States from Europe during the eighteenth century, and it was grown sparingly along the Atlantic seaboard formerly under the name common millet. It began to assume some importance in the north central states after about 1875 when it was introduced into the Dakotas. It is now grown to some extent in the northern Great Plains in the Dakotas, Montana, Wyoming, Colorado, and Nebraska, and in Wisconsin and occasionally in other states. The most important section is northeastern Colorado. Proso also is called broomcorn millet, hog millet, and Hershey millet.

ADAPTATION

Proso is adapted only to regions where spring-sown small grains are fairly successful. It is a short-season plant that often requires only 60 to 65 days from seeding to maturity. Proso is readily injured by frost and is not adapted to regions where summer frosts occur. Moderately warm weather is necessary for plant growth.

While proso has the lowest water requirement of any grain crop, it is less resistant to drought than well-adapted varieties of other grains, largely because of its shallow root system.[12] Sometimes it is a complete failure where wheat or barley produces a fair crop. Proso is poorly adapted to irrigated conditions because it does not respond sufficiently to abundant soil moisture.

Proso grows well on all except coarse sandy soils.[3]

BOTANICAL DESCRIPTION

The proso inflorescence is a large open panicle. Proso has coarse, woody, hollow stems from 12 to 48 inches, but usually about 24 inches high. The stems are round or flattened and generally about as thick at the base as a lead pencil. The stems and leaves are covered with hairs. The stem and outer chaff are green, or sometimes yellowish or reddish green, when the seed is ripe. When threshed, most of the seed remains inclosed in the inner chaff or hull. The seed of proso is larger and not so tightly held in the hull as are those of the millets of the foxtail group. The hulls are of various shades and colors, including white, cream, yellow, red, brown, gray, and black. The bran, or seed coat, of all varieties is a creamy white (Figure 170).

FIG. 170. Seeds of three millets: (a) proso, (b) foxtail millet, and (c) Japanese millet, compared with (d) barnyard grass.

A large percentage of proso flowers are self-fertilized, but some cross-fertilization occurs.

A related species called browntop millet (*Panicum fasiculatum*) is sown occasionally on game preserves in the southeastern states for the wild birds, chiefly quail.

VARIETIES

The varieties of proso are divided into three main groups on the basis of the shape of the panicle (Figure 171). These are shown in Table 2.

The plump bright reddish seeds of the Early Fortune variety probably are the most attractive type for use in chick feed and birdseed mixtures. The Black Voronezh seeds are not desired for such uses because the dark seeds give the appearance of having been weather damaged or decayed when they are observed in a mixture with grain of brighter colors.

The most widely-grown proso varieties now grown in the United States probably are Yellow Manitoba, Turghai, and Early Fortune. Turghai usually gives the highest yields.[3] A variety called

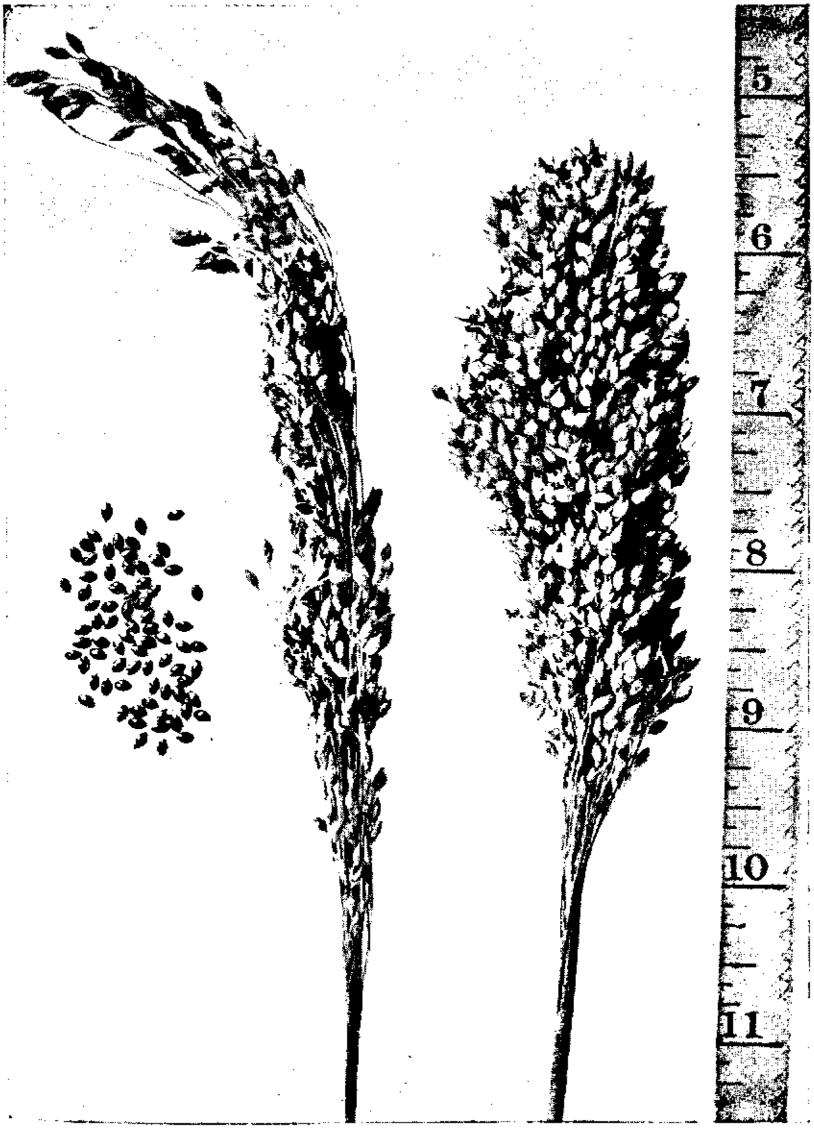

FIG. 171. Panicles of one-sided proso (*center*) and compact (*right*). Proso seeds at left.

TABLE 2. CHARACTERS OF LEADING VARIETIES OF PROSO

VARIETIES	CHARACTER OF PANICLE	COLOR OF OUTER CHAFF	COLOR OF SEED HULL	SEASON OF MATURITY	HEIGHT OF PLANTS
Hansen White Siberian	Spreading	Yellowish-green	Brownish-yellow	Early to midseason	Short to midtall
Red Russian (Tambov)	"	Reddish-green	Reddish-brown	"	"
Turghai	"	"	Yellowish-brown	"	Midtall to tall
White French	Loose, one-sided	Yellowish-green	Creamy-white	Midseason to late	"
Yellow Manitoba	"	"	Brownish-yellow	"	"
Black Voronezh	"	"	Brownish-black	Midseason to late	Midtall to tall
Early Fortune (Red Lump)	Compact, erect	"	Reddish-brown	Early to midseason	Short to midtall

Deerbrook, introduced from Czechoslovakia, is grown in Wisconsin. It has gray-green stripes on the hulls. Another variety, Crown, grown mostly in Canada, has greenish-gray hulls.

ROTATIONS

Proso may follow any other crop. It is a late-seeded, short-season summer catch crop. Its response to additional soil moisture is insufficient to justify its production on fallow land.[2]

CULTURE

Proso requires a firm seedbed that has been kept free from weeds up to seeding time. It will not germinate in a cold soil. Since the plants are readily killed by spring frosts, seeding should be delayed until the danger of frost is practically over. Most varieties require from 60 to 80 days from seeding to maturity. Generally the crop can be seeded safely from 2 to 4 weeks after corn is planted. In eastern Colorado good yields of proso were obtained when it was seeded between June 15 and July 1.[3] Earlier seedings were very weedy while later seedings often resulted in crop failure.

Proso is sown with an ordinary grain drill. The 35-pound rate of seeding has been most satisfactory since lighter seeding rates are noticeably weedier.[3]

Proso is ready to be harvested when the seeds in the upper half of the heads are ripe. At this stage the plant is still green.

Heading and windrowing are the best methods for harvesting the crop. Headed proso should be cured in small piles before threshing. Proso is not adapted to direct combine harvesting because (1) it shatters soon after it is ripe, (2) it lodges when left standing, and (3) the straw contains too much moisture at harvest time.

Where the binder is used, the crop must be handled carefully to prevent loss from shattering. The bundles may be placed in small, narrow shocks where they will cure satisfactorily.

DISEASES

Proso is relatively free from diseases. A bacterial stripe disease (*Phytomonas panici*) has been found on proso in Wisconsin and South Dakota.[5] Affected plants have brown water-soaked streaks on the leaves, sheaths, and culms. The long narrow lesions showed numerous thin white scales of the exudate. The disease is probably seed-borne. Head smut caused by the fungus, *Sphacelotheca destruens*, attacks proso.

UTILIZATION

Proso is a common article of food in the Orient. The hulled seed is used in soups and the ground meal is eaten as a cooked cereal. Digestion experiments with bread made from proso flour indicate that the carbohydrates are as well utilized as in other cereals, but that only about 40 per cent of the protein is digestible.[9]

Proso is eaten readily by all kinds of livestock. It has about the same feeding value as corn or barley, but should be ground before being fed. Proso, although cut green and cured occasionally, is a poor hay crop because of the coarse stems and hairy leaves. The chief commercial use of proso is as an ingredient of chick feeds and birdseed mixtures. Much of the grain grown is fed locally to cattle, sheep, and hogs.

Pearl Millet

Pearl millet (*Pennisetum glaucum*) or (*P. typhoideum*), also called cattail millet and penicillaria, is grown in the southern states.

It has become the leading temporary summer pasture crop on the southern coastal plain. In India it is grown extensively as a food grain, being usually called bajri or bajra. Pearl millet also is grown in countries of the Near East and also in Africa.

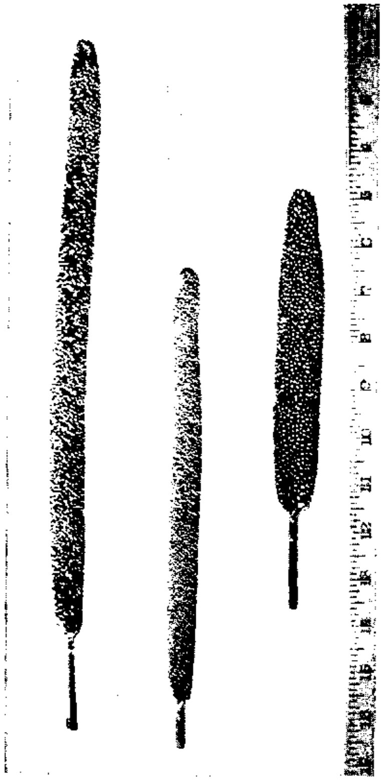

FIG. 172. Panicles of pearl millet.

HISTORY

The origin of pearl millet is unknown. It probably came from tropical Africa because of the extent to which it is cultivated there for food. Pearl millet was introduced in the United States at an early date but it was seldom grown until after 1875.

BOTANICAL DESCRIPTION

Pearl millet is a tall, erect, annual grass that grows from 6 to 15 feet in height. The stems are pithy, while the leaves are long-pointed. The plant tillers freely. The inflorescence is a dense spike-like panicle 6 to 14 inches long, and one inch or less in diameter (Figure 172). The mature panicle is brownish in color. The spikelets are borne in fascicles of two, being surrounded by a cluster of bristles. Each spikelet, subtended by two unequal glumes, has two florets. The lower floret is staminate, being represented in many cases only by a sterile lemma. The upper floret is fertile, the caryopsis being enclosed in the lemma and palea from which it threshes free at maturity. In some cases, spikelets contain two fertile florets. The plant is protogynous, i.e., the stigmas appear several days before the anthers are protruded. Consequently, pearl millet is largely cross-pollinated. It is partly self-sterile. No varieties have been described, but hybrids are being grown in Georgia.

CULTURE

Sandy loam soils are best suited to the crop.[1] It should be seeded after all danger of frost is past in warm soils. The date of planting varies from April in the Gulf states to May in the northern states. The seed is generally planted in drills 18 to 36 inches apart, with the plants 4 to 6 inches apart in the row. Close planting is practiced when the crop is intended for hay. From 3 to 4 pounds of seed per acre are planted on fertile soils, or 6 to 8 pounds on infertile soils or for thicker planting. The seed should be planted about one-half inch deep. For the best quality of hay, pearl millet is harvested when the heads begin to appear.

UTILIZATION

Pearl millet is utilized primarily for pasture and occasionally for silage in this country. The plant becomes woody as it approaches the flowering stage. The stover is of little value after the seed has matured. Yields as high as 16 tons of dry forage per acre have been recorded under warm favorable conditions. In Nebraska, pearl millet produced only 85 per cent as much forage as Black Amber sorgo.[8] In India, more than 2½ million tons of the seed are used annually for food.

Japanese Barnyard Millet

Japanese barnyard millet, or billion dollar grass (*Echinochloa frumentacea*) is grown occasionally in this country as a forage grass, mostly in Pennsylvania, New York, and Iowa. It is cultivated in oriental countries, chiefly Japan, for food. This millet probably originated from the common weed, barnyard grass (*E. crus-galli*), which it closely resembles.

Japanese barnyard millet is an annual that grows 2 to 4 feet tall. The inflorescence is a panicle made up of from 5 to 15 sessile erect branches. The spikelets are brownish to purple in color, being crowded on one side of the rachis. The spikelet is subtended by 2 glumes within which are 2 florets. The lower floret is staminate while the upper one is perfect. Within the glumes is the lemma of the staminate floret followed by the lemma, caryopsis, and palea of the fertile floret. The caryopsis remains enclosed in the lemma and palea. This millet differs from barnyard grass in its more erect habit, more turgid seeds, and in being awnless.

The cultural methods are similar to those for the foxtail millets. The plant is difficult to cure for hay because of its thick stems. Japanese barnyard millet is palatable before the plant heads, but much less so as it approaches maturity. High yields are obtained when moisture is ample.

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21 PERENNIAL FORAGE GRASSES

Economic Importance

Cultivated perennial grasses furnish an appreciable portion of the pasture and hay in the United States. About 60 cultivated grasses were listed by Piper [18] as being important in this country. Most of the grasses sown on farms are introduced species, but in recent years some of the native grasses, such as blue grama, side-oat grama, buffalo grass, big bluestem, little bluestem (Figure 173), western wheatgrass, slender wheatgrass, and reed canarygrass, have been seeded to a considerable extent for pasture, hay or soil erosion control. Nearly all grasses are highly variable.

Grass Types

Perennial grasses can be roughly divided into two classes, viz., bunch grasses and sod-forming grasses. The bunch grasses send up tillers from the crown of the plant and form dense tufts or clumps, while the sod-forming grasses spread laterally to form a more or less solid sod either by underground stems known as rootstalks (rhizomes) or, in a few species, by above-ground stems (stolons).[14] The nodes of rhizomes and stolons give rise to roots as well as stems. Tillers, stolons, and rhizomes all arise from buds in the crown of the grass plants below the surface of the soil. If the shoot from the growing bud is on a plant of a species that forms tillers (i.e., intravaginal), the growth is erect and a stem (culm) is formed. If in another species the shoot is slender and pliant and is ageotropic (not responsive to geotropic stimuli), a stolon is formed and both roots and culms arise from the nodes. If, as in still other species, the shoot bears scales with a hard, sharp, pointed tip it is a rhizome that grows along under the surface of the soil and likewise sends up both roots and culms. These distinctions are not absolute, however, because the shoots of certain tillering grasses, e.g., timothy, may grow somewhat like a rhizome and form roots[7] when buried deeply in soil. Also some grasses, e.g., Bermuda grass, often may bear rhizomes below the soil surface in loose soil and stolons above the surface in compact soil. Nearly any of the sod-forming grasses can be established by transplanting pieces of turf.

FIG. 173. Little bluestem plant (*left*), panicle (*center*), enlarged spikelet (*right*).

Adaptation

Some grass species such as reed canarygrass can be grown where water stands on the land part of the time, while others are drought resistant, but may not withstand prolonged flooding. Many grasses adapted to the south are limited in their northern range because of lack of winter hardiness. Many typical sod-forming northern grasses assume a bunch type of growth and lack aggressiveness when grown in Oklahoma.[16] This probably represents an adaptation to photoperiod and temperature.

Many species require cool weather for their establishment while others such as the grama grasses and Bermuda grass make their growth in warm weather. Nearly all perennial grasses have small seeds (Figure 174), and are difficult to establish from seeding unless the seedbed is firm enough to avoid covering the seed too deeply and to form a close contact between the seed and soil. In order to obtain the desired seedbed, plowed land should be harrowed several times or compacted with a corrugated roller before seeding (Figure 175). When the seed is sown in the spring in a

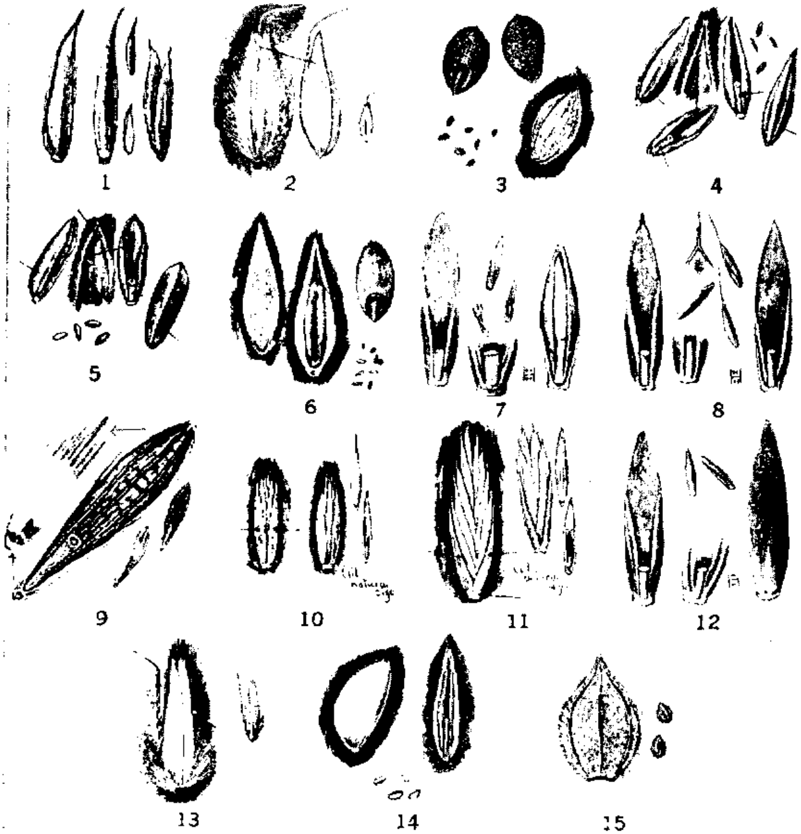

FIG. 174. Seeds of perennial grasses, natural size and enlarged: (1) Orchard grass, (2) meadow foxtail, (3) timothy, (4) Kentucky bluegrass, (5) Canada bluegrass, (6) redtop. (7) perennial ryegrass, (8) Italian ryegrass, (9) smooth bromegrass, (10) slender wheatgrass, (11) western wheatgrass, (12) meadow fescue, (13) tall meadow oatgrass, (14) Bermuda grass, (15) Dallis grass.

field of grain to be grown as a companion crop, the soil usually is sufficiently compact.

In dryland regions, the sowing of grass is attended with several hazards, chiefly drought and soil blowing. Plowed land that is harrowed or rolled is subject to blowing. Stubble land should be disked and harrowed to destroy weeds before grass is sown in the spring. Often a seedbed suitable for spring seeding is secured on fallow land that has settled during the winter or on corn or potato land that is disked and harrowed. In the northern Great Plains, considerable success has followed the drilling of certain cool weather grasses such as crested wheatgrass in weedy fields or unworked grain stubble in fall or early winter, preferably seeding in snow before the ground is frozen. The seed settles into the soil during thawing and comes up in the spring. In the southern Great Plains the most certain method of establishing grasses has been to first grow a crop of drilled Sudan grass or sorghum, mowing often enough to keep it from going to seed, and leaving the swaths on the ground over winter. The grass seed is drilled into this protective covering the next spring.[20]

Timothy

Timothy (*Phleum pratense*) is one of the most important cultivated grasses in America. It is grown more extensively for hay, alone or in mixtures, than all other grasses combined. Statistics on the acreage and production of timothy are combined with those of clover because the two crops are generally grown together. This mixture yields more than either crop grown alone, and it is higher in feeding value than timothy alone. Probably 20 million acres of

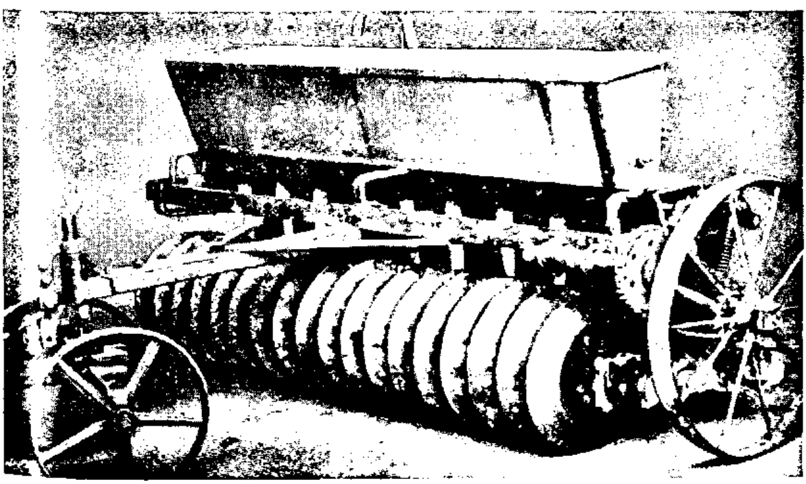

FIG. 175. A packer grass seeder used by the Soil Conservation Service. Sets of corrugated rolls in front of and also behind the seed sprouts compact the soil before and after the seed is dropped.

timothy alone or in mixture with clover are cut for hay and about 8 million acres are seeded each year. Timothy is harvested or grazed for two years or longer before it is plowed up for planting other crops in the rotation.

The timothy and clover, which usually are sown with a small grain companion crop, furnish some pasturage the first year. In the second year, the mixed hay is mostly clover, whereas the third-year crop is largely timothy. If left longer the crop is nearly all timothy. More than 400,000 acres of timothy are cut for seed each year with a production of about 1,500,000 bushels. The seed yield averages about 3½ bushels of 45 pounds each. The states leading in timothy production are New York, Wisconsin, Iowa, Pennsylvania, and Ohio.

Timothy is a native of Europe, and in England is called meadow cat's-tail. Timothy was first cultivated in the United States by John Herd, who found it growing wild in New Hampshire in 1711. First called Herd's grass, timothy acquired its present name from a Timothy Hanson, who grew it in Maryland in 1720.

ADAPTATION

Timothy is best adapted to the cool humid climate of the northeastern fourth of the United States, but it is grown also to some extent in the cool mountain valleys in the Rocky Mountain region, as well as in the coastal area of the Pacific northwest. It is not adapted to the drier regions, and does not thrive where the average July temperature exceeds 77 F. Timothy grows better on clay soils than on the lighter-textured sandy soils.

DESCRIPTION

Timothy is easily recognized by its erect culms and dense cylindric spikelike inflorescence (Figure 176). The spikelets are one-flowered. The plant is largely cross pollinated under natural conditions. Timothy, a bunch grass, differs from most grasses in that one of the lower internodes is swollen into a bulblike base, a haplocorm,[1] often called a corm. Organic food reserves, which accumulate in the haplocorm up to the stage of seed maturity, furnish nutrients for new shoots. Timothy survives for three years or more, but it gradually becomes contaminated with weeds and other grasses. Consequently it usually is plowed up after the second year.

The leaves of certain selected strains of timothy remain green longer than those of the ordinary timothy,[10] and yield as well or better.[11] Huron, an improved variety, is about 6 days later than common timothy,[8] and usually outyields it. Recent improved strains of timothy include Marietta and Lorain in Ohio and Itasca in Minnesota. Lorain is late in maturing.

FIG. 176. Timothy plants.

CULTURE

Timothy usually is sown with a grain drill having a grass-seeding attachment. It is sown either in the fall with winter grain or in early spring with spring oats or barley. Usually 10 pounds per acre of clover seed are sown in the spring in the same field. When the clover is broadcast in winter wheat or winter rye fields in the spring the timothy may be seeded with it. Seedlings that start in the fall are less likely to be injured by dry weather during late spring and early summer than are those from spring seeding.[9] The usual seeding rates for timothy are 3 to 5 pounds per acre in the fall, or 10 pounds in the spring.[12]

In most sections the yields are improved by application of commercial fertilizers, particularly those containing phosphorus and nitrogen. Complete fertilizer is essential in the northeast. The protein content of timothy is increased by very heavy application (300 pounds or more) of nitrogen fertilizers. The fertilizer is best applied in the spring.[12]

The largest yield of timothy hay, consistent with high quality, is obtained by cutting in the early bloom stage or even earlier.[11, 12] The digestibility of timothy declines steadily and the crude fiber content increases as the plant develops, beginning as early as when the plants are in full head (Chapter 8, p. 215); also the more mature plants are less palatable. Timothy cut prior to full bloom contains 70 per cent or more of the total protein of the hay in the leaf blades, leaf sheaths, and stems of the plant, while that left uncut until 10 per cent of the heads are straw-colored contains at least 50 per cent of the plant protein in the heads.[15] Much of this protein may be lost in the ripe seeds that shatter during handling and feeding. The total yield increases only slightly after the full bloom stage.[12] Cutting before blooming begins reduces the vigor and growth of subsequent cuttings because lower food reserve storage is present in the haplocorms.

Decreased yields that often occur in other crops that follow timothy are due largely to a temporary deficiency of available nitrogen in the soil until some of the crop residue has decomposed.

Timothy is harvested for seed with a combine after the seed is fully ripe and dry, or is cut with a binder somewhat earlier and then cured in the shock. In threshing, care is required to avoid hulling the seeds. Hulled seeds germinate satisfactorily at first but they lose their viability gradually after several months.[12]

UTILIZATION

Timothy is the standard hay for horses. As compared with legumes, timothy hay is relatively low in protein and minerals, especially calcium. In mixture with clover the hay is excellent for cattle and sheep.

Timothy also is one of the most palatable pasture grasses, usually being grazed in preference to redtop, orchard grass, or even Kentucky bluegrass. It is often included in mixtures of grasses and legumes sown in permanent pastures. As the pasture becomes older, the timothy is gradually replaced by other grasses. Timothy seed is a common ingredient of low-priced lawn-grass mixtures. It becomes established quickly, but its coarse, bunchy, erect growth makes it not well suited for lawns.

Kentucky Bluegrass

Kentucky bluegrass (*Poa pratensis*) is probably the most widely known grass in America, with the possible exception of timothy.

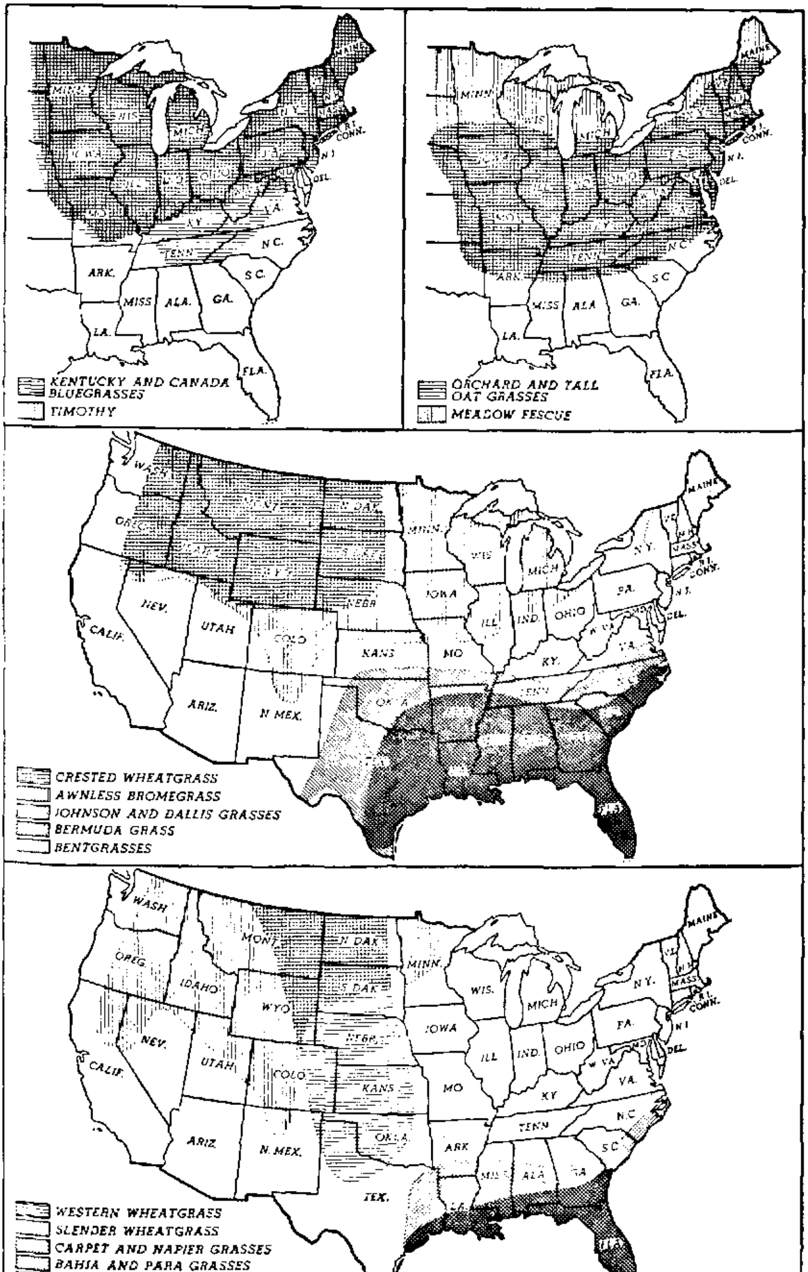

FIG. 177. Sections of the United States in which the different grasses are well-adapted and of primary importance.

It is a native of the Old World but has spread over the humid and subhumid sections in the northern half of the United States to such an extent that it is the dominant species in most of the pastures (Figure 177). The so-called bluegrass region includes central and eastern Kentucky, southern Ohio, and the mountainous sections of western Virginia, North Carolina, and eastern Tennessee. Bluegrass is so generally present where it is well adapted that cleared land and abandoned and uncultivated fields are likely to form a turf consisting largely of bluegrass without artificial seeding, if merely pastured or mowed discreetly for a few years, provided the land is fertile or fertilized.

ADAPTATION

Kentucky bluegrass is adapted throughout the northern half of the United States, except where the climate is too dry. It does best under cool, humid conditions on highly fertile limestone soils, but it also thrives on noncalcareous or slightly acid soils having a reaction as low as *p*H 6. It seems to prefer the heavier soils. An ample supply of phosphorus is essential.

FIG. 178. Plant and panicle of Kentucky bluegrass.

DESCRIPTION

Kentucky bluegrass is a dark green sod-forming grass, and a long-lived perennial. The stems are 1 to 2 feet in height when allowed to grow uncut, and usually are numerous in a tuft. The plants have narrow leaves 2 to 7 inches in length. The basal leaves are usually longer than the stem leaves. They are characterized by a boat-shaped tip. The inflorescence is a pyramid-shaped panicle about 2 to 8 inches long (Figure 178). The spikelets are composed of

3 to 5 florets. The lemmas are copiously webbed at the base. Kentucky bluegrass reproduces by rhizomes as well as by seed. New tufts with their roots arise from the nodes along the rhizomes, thus continually occupying the spaces left by the death of the older tufts that probably do not survive more than 2 years. Because of its dense turf, bluegrass often is used in sodded waterways to check erosion. Bluegrass is America's most popular lawn grass. Lawns are established either by seeding or by transplanting sod. It is sown in either very early fall or very early spring.

CULTURE

In pasture mixtures bluegrass is generally seeded with timothy and clover, using 5 to 15 pounds of bluegrass seed. About 20 to 40 pounds per acre are sown for pure stands. Usually 2 to 3 years are required to produce a good sod from seeding. Annual applications of nitrogenous fertilizers increased the average yield of dry matter 72.1 per cent in Wisconsin.[1]

Bluegrass seed is usually harvested from the ripening plants in the field by means of mechanical strippers equipped with revolving spiked beaters (Figure 179). Most of the seed comes from Minnesota, Iowa, Nebraska, Missouri, and Kentucky. The stripped seed is cured in ricks or windrows, being turned frequently to prevent heating. Temperatures above 140° F. during curing destroy the germination. Partial heating, together with the presence of immature seed and empty chaff, are responsible for the fact that much of the commercial bluegrass seed does not germinate more than 70 per cent. Sound plump seed germinates over 90 per cent.

UTILIZATION

Kentucky bluegrass is not a hay crop but is one of the best sod-forming permanent grasses for pasture. It starts growth early in the spring, and thus furnishes succulent forage for early grazing. It becomes nearly dormant during the heat of midsummer when daily maximum temperatures approach 90° F., and then resumes growth with the advent of cool weather in the fall, when it furnishes additional grazing. It supplies almost continuous summer grazing in the cooler sections of the northeastern states.

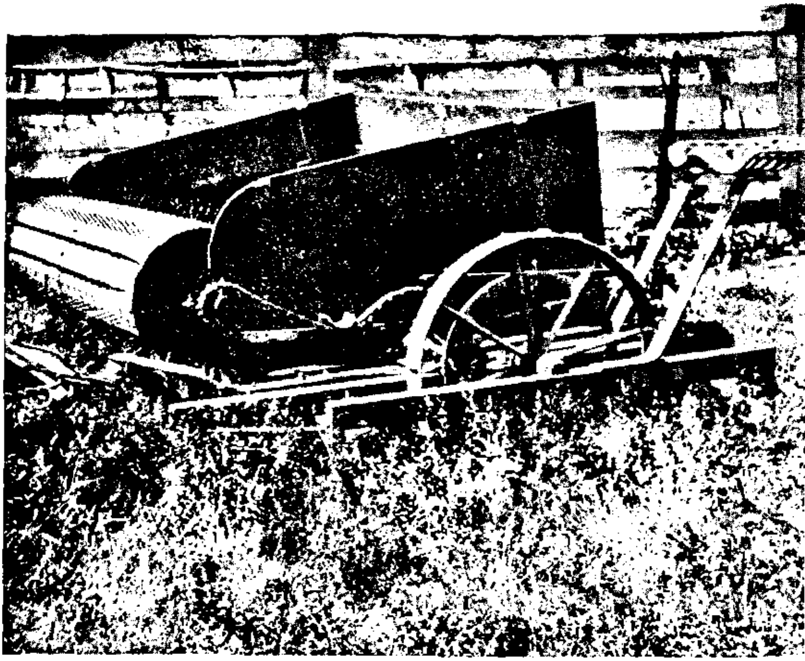

FIG. 179. Bluegrass seed stripper. Most present-day strippers are tractor-powered.

Other Bluegrasses

Canada bluegrass (*Poa compressa*) usually grows to a height of 6 to 8 inches. It is distinguished from Kentucky bluegrass by its compressed stems, which long remain green, by a single shoot at the end of each rhizome, and by narrower panicles. Canada bluegrass will thrive on all soils that will produce Kentucky bluegrass, as well as on some heavy clays and gravelly soils where the latter does not thrive. This species is found throughout the Kentucky bluegrass region, often on the less fertile soils, but it is generally recognized as being decidedly inferior to its popular competitor.

Bulbous bluegrass (*Poa bulbosa*) has become well established in certain areas of northern California and southern Oregon. It normally produces bulbs at the base of the stem and bulbils in the inflorescence. It is adapted to a wide range of soil types.[22] The chemical composition of the hay is similar to that of timothy.

Rough-stalked meadow grass or bird grass (*Poa trivialis*), also a native of Europe, has bright green leaves and thrives in the shade. It is sown in shady locations in lawns. Big bluegrass (*P. ampla*) and Texas bluegrass (*P. arachnifera*) are useful range grasses.

Bermuda Grass

Bermuda grass (*Cynodon dactylon*) is the most important pasture grass in the south and also is the most common lawn grass in sections too hot for Kentucky bluegrass. It probably is a native of Asia but is now distributed throughout the tropical and subtropical parts of the world.

ADAPTATION

Bermuda grass is found from Maryland to Kansas and south to the Gulf of Mexico. It is also found in the warmer areas of the Pacific coast. In general, it is adapted to the same area as is cotton. It is the best upland pasture grass in the cotton belt. The best use of Bermuda grass is in mixtures with white, hop, and Persian clover, or with lespedeza. Its growth in the northern states is limited by its lack of winter hardiness, although it is sufficiently hardy to endure the winter conditions in north central Oklahoma.[16] Bermuda grass makes its best growth on fertile lands that are well drained. It shows a marked preference for clay soils, but it grows more or less abundantly on sandy soils. Bermuda grass grows luxuriantly during hot midsummer weather, but does not start growth until late spring, and it stops growth and becomes bleached with the onset of cold weather in the fall.

DESCRIPTION

Bermuda grass is a long-lived perennial with numerous branched leafy stems that vary from 4 to 18 inches in height. Although the stems of Bermuda grass, like those of other grasses, have only one leaf at a node, it may appear to have 2 to 4, due to several contiguous short internodes (Figure 180). In ordinary Bermuda grass, there are numerous stout rhizomes which in very hard soil grow along above the surface as stolons for 1 to 3 feet. The flowers are borne in slender, spreading spikes arranged in umbels of 4 to 6. Bermuda grass produces very little seed in humid regions.

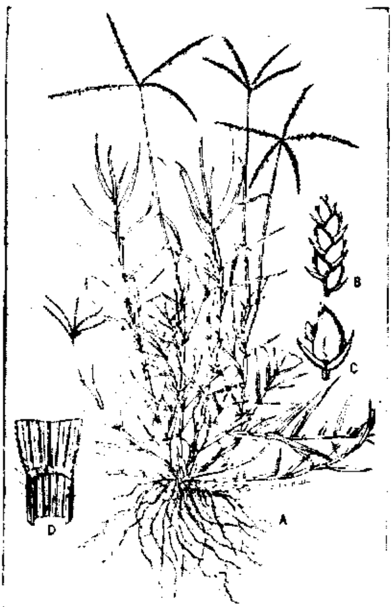

FIG. 180. Bermuda grass: plant (A), panicle branch (B), spikelet (C), and ligule (D). Rhizomes are shown at the crown region.

Several rather distinct varieties of Bermuda grass have been tried in the United States, but few have become established. Common Bermuda grass has white rootstocks as large as a goose quill, besides the leafy stems or stolons that creep on the soil surface. St. Lucie grass is identical in appearance[18] but lacks rootstocks and rarely survives the winter north of Florida. Coastal Bermuda is an improved hybrid strain that produces very little seed and must be propagated entirely by planting stolons.[4] It spreads rapidly, withstands light frosts, and produces well in southern Georgia. African Bermuda produces a fine turf for lawns.

CULTURE

Bermuda grass is planted from seed or by pieces of the rootstocks, usually the latter. The seed is usually sown in the spring at the rate of 5 pounds per acre. The seed should be covered not more than one-half inch deep, and seeding should not be attempted before the daily mean temperature is 65° F.[17]

In the south the most common practice is to break up the sod into small pieces and drop the pieces, 2 to 3 feet apart each way, into furrows on plowed land. These sod pieces may be planted any time from spring until midsummer whenever wet weather conditions are likely to prevail.

Bermuda grass stands tend to become sod bound. When this occurs, the yields are improved by disking, plowing, or harrowing. Bermuda grass often spreads onto cropped land, where frequent cultivation is necessary to keep it under control.

UTILIZATION

Bermuda grass is an excellent summer pasture plant, either alone or in mixtures, particularly when closely grazed. It becomes wiry and tough as it approaches maturity. Sometimes it is planted in mixtures with lespedeza. Bermuda grass sown along the highway borders of Florida furnishes much of the summer pasture for cattle which graze the roadsides of that state.

Smooth Bromegrass

Smooth bromegrass or awnless bromegrass (*Bromus inermis*), introduced in this country about 1884, soon became a valuable forage plant in the west. The total acreage was small for many years because native grasses, cereals, and legumes furnished most of the forage. Recently bromegrass has become a highly important pasture grass in the northern states from the western corn belt eastward to Pennsylvania.

ADAPTATION

Smooth bromegrass is adapted especially to regions of moderate rainfall and cool to moderate summer temperatures, particularly where the native vegetation consists of tall or medium-tall grasses. It is grown most widely in the north central and Great Lakes states. It is one of the best introduced grasses in the eastern parts of the Dakotas, Nebraska, and Kansas. Bromegrass is moderately drought-resistant but the more drought-resistant crested wheatgrass outyields and outlasts it in the drier areas of North Dakota.[24]

Bromegrass makes its best growth on moist, well-drained clay to silt loam soils, but it produces satisfactorily on sandy soils when there is sufficient moisture. It is particularly vigorous on fertile soils high in nitrogen. Bromegrass has only a small degree of alkali tolerance.

DESCRIPTION

Smooth bromegrass is an erect, sod-forming perennial that spreads by rhizomes. The stems vary in height from 2 to 4 feet. Numerous basal and stem leaves are produced that vary in length from 4 to 10 inches. Frequently, the rough (scabrous) leaves are marked by a transverse wrinkling a short distance below the tip. The inflorescence is a panicle 4 to 8 inches long, being spread when in flower. The flower head develops a characteristic rich, purplish-brown color when mature. There are several florets in a spikelet (Figure 181). The seeds are long, flat, and awnless (Figure 174).

FIG. 181. Bromegrass: Plant (1), panicle (2), and spikelet (3).

Solid stands of pure bromegrass are likely to develop a sodbound condition after 2 or 3 years, due primarily to the lack of nitrogen. The plant starts growth early in the spring, becomes more or less dormant in midsummer after seed production, and then resumes and continues growth late into the fall.

Improved strains of bromegrass distributed in recent years include the Lincoln, Achenbach, Martin, Manchar, and Southern Type.

Locally adapted lots of bromegrass usually are more successful than those brought from a distance. Strains of bromegrass have been developed that have a less extensive rhizome system than common brome. Parkl·nd, a noncreeping strain developed in Canada that is somewhat less vigorous than the ordinary strain, appears also to be less productive in this country. Parkland is somewhat finer stemmed and more leafy than common brome.

CULTURE

Late summer seeding after a small grain crop gives the best results in eastern Nebraska.[13] It is usually seeded between August 20 and September 15 at the rate of 15 to 20 pounds per acre. It is often included in a mixture with alfalfa, using 15 pounds of bromegrass and 3 pounds of alfalfa. The bromegrass and alfalfa are ready to cut at the same time. Where spring seeding is practiced, bromegrass should be seeded early. This grass is included in most recommended introduced grass mixtures in Nebraska and other north central states.

Maximum yields of bromegrass are usually obtained the second and third year after the stand is established. The yield decreases when the plants become sod bound. The sod-bound condition may be avoided or delayed by treatments that stimulate nitrogen production. Among these are (1) inclusion of mixtures of alfalfa, Ladino clover, or sweetclover; (2) shallow plowing or disking either in the spring or fall; (3) seeding a legume in the disturbed sod; and (4) application of manure or commercial nitrogenous fertilizers under favorable moisture conditions. Inclusion of a legume increases both the growth and the protein content of the grass.

The best quality of hay is obtained when bromegrass is cut in the bloom stage.

UTILIZATION

Bromegrass makes hay of excellent quality, the protein content being high and the crude fiber content relatively low.

It is one of the most palatable pasture plants, especially for spring and fall grazing.

Bromegrass has been used to retard soil erosion because of its heavy mass of roots. It is suitable for steep slopes, buffer strips in strip cropping, small sod dams, drainage outlets, terraces, and waterways through cultivated fields.

Redtop

Redtop (*Agrostis alba*) is a cultivated perennial grass introduced during the Colonial period.

ADAPTATION

Redtop will grow under a great variety of conditions, being one of the best wet land grasses among the cultivated species. It is especially adapted for growth on acid soils low in lime where most other grasses fail. It has only slight alkali tolerance.

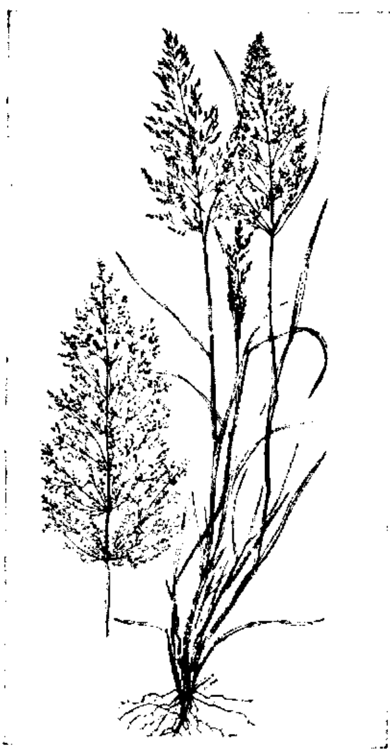

FIG. 182. Panicle and plant of redtop.

DESCRIPTION

Redtop spreads by rhizomes, making a coarse loose turf. The leaves are narrow and the stems slender. The panicle is loose, pyramidal, and reddish in color (Figure 182). The spikelets are small and contain one flower. Redtop matures at about the same time as timothy.

UTILIZATION

Redtop is second only to bluegrass as a pasture grass in the northeastern states. The uses of redtop are as follows:[18] (1) a wet-land hay crop, (2) as a part of pasture mixtures under humid conditions, (3) as a soil binder. and (4) as an ingredient of hay mixtures. It may be seeded either early in the spring or late in the summer at the rate of 4 to 5 pounds per acre when used with other grasses for hay. Redtop is a common ingredient of lawn grass mixtures. It does not make a fine, smooth turf, but it serves well as a companion grass while bluegrass is becoming established.

RELATED SPECIES

Rhode Island bent (*A. tenuis*) is commonly found on well-drained soils in New England and New York. It differs from redtop by its smaller size, smaller leaves, and its peculiar open panicle that does not become closed when mature. It thrives on acid soils, the turf being injured rather than improved by use of lime. This species is found in pastures where it is adapted. It is sometimes cut for hay, but the yields are low.

Creeping bent (*A. palustris*) is distinguished by its dense panicle and by its creeping stolons which may grow as much as 4 feet long in a single season. It is common in pastures in many places where the soil is moist. It is found in seaside meadows on both the Atlantic and Pacific coasts. Creeping bent and a similar species, seaside bent (*A. maritima*), are prized for golf greens because of their fine, smooth, dense turf.

Crested Wheatgrass

Crested wheatgrass (*Agropyron cristatum*) is a hardy, drought-resistant perennial bunch grass native to the cold dry plains of Russia. It was introduced in this country first in 1898, but did not become established from that introduction. After 1915 when experiments with new lots of seed from Russia at several points had demonstrated its promise in the northern Great Plains it was increased for distribution.[6]

ADAPTATION

Crested wheatgrass is especially well adapted to the northern Great Plains and the intermountain and Great Basin regions where winter temperatures are severe and the moisture supply limited. This grass makes its best growth in cool climates, forage production being reduced by the higher temperatures in the southern Great Plains. There is no known instance in which the plants were killed by either drought or cold under field conditions.[27] Crested wheatgrass is productive on practically all soil types, except that it is less tolerant of alkali than is western wheatgrass.

DESCRIPTION

Crested wheatgrass is an extremely long-lived perennial. The fine stems, which vary in height from 1.5 to 3.0 feet, occur in dense tufts. The leaves are flat, somewhat lax, narrow, and sparsely pubes-

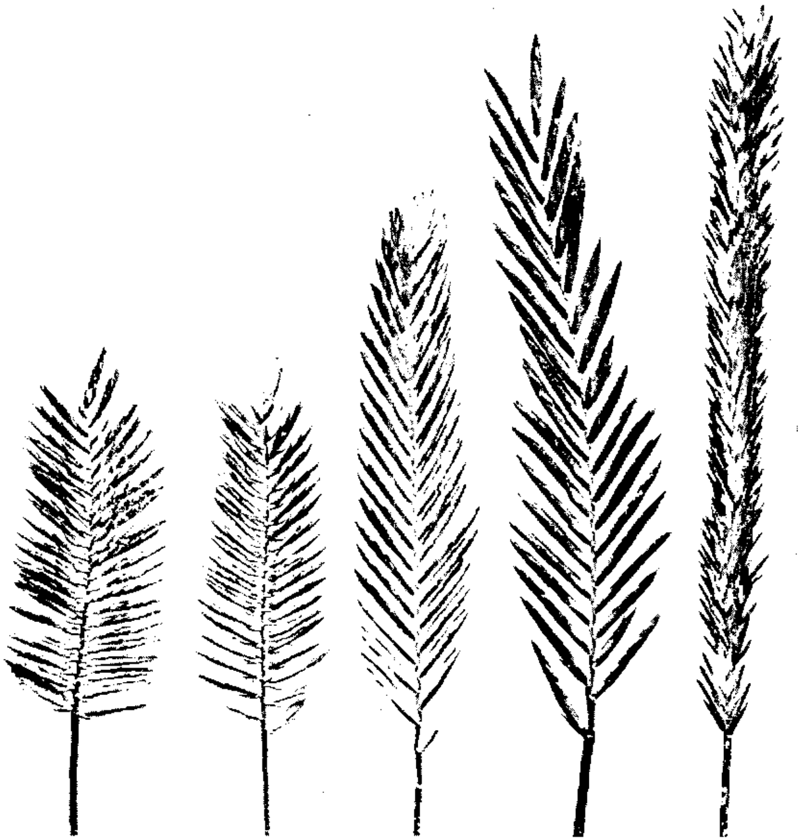

FIG. 183. Spikes of crested wheatgrass. The two at the left are Fairway and the original type from which Fairway originated as a mass selection. The three spikes at the right are awnless and awned strains of the Standard type.

cent on their upper surface. The dense spikes are 2 to 4 inches long, being considerably broader than those of most other species of wheatgrass. The spikelets are closely crowded on the tapered head and tend to stand out from the axis of the spike.

Standard, the ordinary commercial strain of crested wheatgrass, introduced as *Agropyron desertorum*, consists of a mixture of many different types or strains that vary in leafiness, stiffness of stems, and size of spike. The short-awned types are considered the most desirable (Figure 183).

A selected strain of crested wheatgrass, Fairway, introduced as *Agropyron cristatum*, is popular in Canada, but the taller Standard strain is more generally grown in this country because of its higher yields and better palatability. The two strains do not intercross. The Standard type has 14 pairs of chromosomes whereas the Fairway and the original *A. cristatum* type have 7 pairs.[9] Fairway plants are fine-stemmed, more leafy, and tiller more than those of the Standard. The leaves of the Fairway plants are covered with fine hairs. They are also bright green in color, while those of the Standard vary from dark green to grayish green. The seeds of Fairway are smaller, bear more awns, and are lighter than those of Standard.

CULTURE

Crested wheatgrass may be drilled directly in small grain stubble, where soil blowing is probable. It may be sown either in the fall or spring, in close drills for hay or pasture, or in cultivated rows for seed. Row plantings may be in single or double rows, the rows being 36 to 42 inches apart in either case. Recommended seeding rates are 5 to 8 pounds per acre for close drills, 1 to 2 pounds for single cultivated rows, and 2 to 3 pounds for double cultivated rows.[26] For hay, it should be cut at least by the time it starts to blossom.

UTILIZATION

Crested wheatgrass is highly palatable either for hay or pasture. The hay compares favorably with that of western wheatgrass in quality and palatability. The grass becomes harsh as it matures. Crested wheatgrass furnishes pasture earlier in the spring and later in the fall than other cultivated grasses. In the northern Great Plains it has 2 to 3 times the carrying capacity of the native range, especially in early spring.[24] It should be supplemented with other grasses because it tends to become more or less dormant during hot dry weather. Because of its persistence and its tough fibrous root system, this grass has been utilized effectively for wind or water erosion control in the northern intermountain region and also in the northern Great Plains.

Western Wheatgrass

Western wheatgrass (*Agropyron smithii*), often called bluejoint, is a native perennial introduced into cultivation. It is distributed generally throughout the United States, except in the more humid southeastern states, but is most prevalent in the northern and central Great Plains.

ADAPTATION

Western wheatgrass * is a cool season grass adapted to a wide range of soil types. It is extremely drought resistant as well as alkali tolerant. Nearly pure stands of this grass have been observed on heavy gumbo soils, in swales or flats where additional moisture from runoff had been received.

DESCRIPTION

Western wheatgrass has strong creeping rhizomes (Figure 184), and the stems usually are 1 to 2 feet in height. The leaves usually are 4 to 12 inches long and less than ¼ inch wide. The upper surfaces of the leaves are scabrous (rough) and prominently ridged lengthwise, while the under side of the leaf is relatively smooth. The leaves are rather stiff and erect and when dry roll up tightly to give the plant the appearance of having scanty foliage. The entire plant is usually glaucous, which gives it a bluish-green distinctive coloration. The wheatlike but more slender spikes are 2 to 6 inches long. Like nearly all other grasses, it consists of numerous diverse types.

The threshed seed is relatively free from awns or hairs so that it can be sown with a grain drill without previous treatment.

CULTURE

Western wheatgrass is best seeded in the fall or early spring at the rate of 10 to 12 pounds per acre. It is usually included in a mixture with crested wheatgrass. Seed yields of 100 to 250 pounds

* Hoover, M. M., "Native and Adapted Grasses for Conservation of Soil and Moisture in the Great Plains and Western States," Soil Conservation Service, Washington, D. C. (Processed).

FIG. 184. Western wheatgrass. Note rhizomes at lower left.

per acre are not uncommon. Good seed well cleaned should weigh 19 to 20 pounds per bushel. Germination of the seed is frequently delayed and stands of this grass are often slow in becoming established. Consequently, it is most valuable when seeded in a mixture.

UTILIZATION

Pioneer ranchers early recognized western wheatgrass as one of the most valuable native forage grasses in the low rainfall areas of the northern Great Plains.[5] It is high in palatability and nutritive value. It should be cut in the very early bloom stage for highest quality hay. It provides high-quality pasturage during the early part of the growing season. It has the ability to cure standing and still retain much of its palatability and nutritive value for winter pasture under semiarid conditions.

Because of its excellent sod-forming qualities, western wheatgrass is valuable for protecting terrace outlets, dam faces, and waterways through cultivated land.

Slender Wheatgrass

Slender wheatgrass (*Agropyron trachycaulum,* or *A. pauciflorum*) is another native American grass to become established as a cultivated crop. It is adapted to the northern Great Plains and intermountain regions. It is very short lived and produces well for only 2 or 3 years. The inflorescence is a slender, greenish spike on which the closely appressed spikelets are some distance apart. Recommended seeding rates range from 10 pounds to 35 pounds of seed per acre. For hay, it should be cut just before blooming. Slender wheatgrass should be used in pasture or hay mixtures, rather than sown alone. About 2 pounds per acre should be included in mixtures sown on dry land and about 4 pounds per acre when sown on irrigated land. Primar is an improved variety.

Reed Canarygrass

Reed canarygrass (*Phalaris arundinacea*) is native to the northern part of both hemispheres. It was cultivated first in Oregon about 1885, being among the later grasses to assume importance under cultivation.

ADAPTATION

Reed canarygrass is grown in the Pacific coast areas of Oregon, Washington, and northern California, as well as in the north central states. It makes its best growth in a moist cool climate, being sensitive to neither heat nor cold. It is not very successful where the average mean winter temperature is above 45° F., or the summer temperature above 80° F.[21] This grass is productive on fertile moist soils, being especially suited to swamp or overflow lands. It does well on peat soils, and on land that is too wet for other crops.[2] In Iowa, reed canarygrass produced higher hay yields than did timothy, brome, meadow fescue, tall meadow oat, redtop, or orchard grass.[28]

FIG. 185. Reed canarygrass. (1) plant, (2) panicle, (3) spikelet, (4) floret.

DESCRIPTION

Reed canarygrass is a long-lived perennial that spreads by rhizomes. The plants are 2 to 8 feet tall with leafy stems. They tend to grow in dense tussocks 2 to 3 feet in diameter. The leaves are broad, smooth, and light green in color. The inflorescence is a semi-dense spikelike panicle 2 to 8 inches long (Figure 185). The stems become coarse after the panicles begin to appear. The seeds are enclosed in blackish-brown or gray lemmas and paleas sparsely covered with long hairs. The seeds mature from the top of the panicle downward and shatter readily.

A distinct strain, the Superior variety, was selected in Oregon several years ago. It has a more upright growth, greater leafiness, stiffer stems, and better seeding habits, than ordinary reed canarygrass.[21] It is able to grow on uplands that often become dry in spring, summer, or fall. It thrives as well as the ordinary strain in the lowlands. Another strain called Ioseed was developed in Iowa.

CULTURE

Reed canarygrass is grown from fall or spring seeding on the Pacific coast, but early spring seeding is the most common practice in the north central states. It is usually seeded at the rate of 5 to 8 pounds per acre in close drills. It is seldom sown with other grasses, but it may be seeded with small grains on fertile moist soils. The crop is sometimes seeded in cultivated rows 18 to 20 inches apart on rather dry uplands in some areas. The first crop should be cut for hay as soon as the panicles begin to appear The later crops usually do not produce panicles.

UTILIZATION

Reed canarygrass furnishes abundant pasturage where soil moisture is adequate because it starts growth early in the spring, and continues until late in the fall. It is more palatable than other wetland grasses when grazed closely; otherwise it becomes coarse. Likewise, the hay is palatable if cut before the stems are too coarse.

RELATED SPECIES

Harding grass (*Phalaris tuberosa, var. stenoptera*) is a productive hay crop in California. Canary grass (*P. canariensis*), a native of the Mediterranean region, is established in many parts of the United States. Canary grass furnishes the canary seed used so generally for feeding canaries. Most of the seed for this purpose is grown in Europe and Argentina.

Perennial Ryegrass

Perennial ryegrass, or English ryegrass (*Lolium perenne*), is one of the first perennial grasses to be cultivated for forage.

ADAPTATION

Perennial ryegrass is less hardy than many other grasses.[23] It is grown principally in the Pacific coast states, in the southern humid states, and in other regions where the climate is not too severe. While it is considered a wet-land grass in some regions, production usually declines as drainage becomes poor. Hot dry weather affects plant growth adversely.

DESCRIPTION

Perennial ryegrass is a tufted, short-lived perennial that persists for 3 to 4 years. The plants grow 1 to 2 feet in height. There are numerous long, narrow leaves near the base of the plant, the seed stems being nearly naked. The inflorescence is a spike, the spikelets being set edgewise to the rachis (Figure 186). The lemmas of the florets are entirely or nearly awnless. The so-called domestic ryegrass or common ryegrass grown in the United States is a mechanical and hybrid mixture of perennial ryegrass with some Italian ryegrass.

FIG. 186. Plant and spike of perennial ryegrass.

CULTURE

Perennial ryegrass may be seeded either in the fall or early spring, but usually in the spring where the winters are severe. The crop is sown at the rate of 20 to 25 pounds per acre where used alone for forage or seed production. Common ryegrass is sometimes seeded with small grain at the rate of 8 to 10 pounds per acre for annual pastures. For the best quality of hay, it should be cut in the soft-dough stage.

UTILIZATION

Perennial ryegrass is used primarily in permanent pasture mixtures to furnish early grazing while long-lived grasses are becoming established. It is used occasionally for hay or winter cover. It is often used for seeding lawns, particularly in mixtures, and is easily established, but the turf is coarse and not permanent.

OTHER SPECIES

Italian ryegrass (*Lolium multiflorum*) is a hardy, short-lived grass, usually an annual or winter annual. Some plants live into the second season. It makes a rapid growth when seeded in the spring, late summer, or fall.

Awns are present on the seeds of Italian ryegrass and usually absent in perennial ryegrass (Figure 174). The culm of Italian ryegrass is cylindrical, whereas perennial ryegrass culms are slightly flattened. The leaves of Italian ryegrass are rolled in the bud, while those of perennial ryegrass are folded. The plants of Italian ryegrass are yellowish at the base, while those of perennial ryegrass are commonly reddish.

Italian ryegrass is a very palatable and productive pasture plant. It grows so rapidly that it can be grazed in a short time after seeding. The quick germination and large seeds (and seedlings) account for its prompt establishment.

Italian ryegrass is used as a companion crop for spring-seeded permanent pastures. Sown in combination with winter grains or crimson clover for temporary pasture, it makes a desirable bottom grass and increases the length of the grazing season. Formerly it was grown to a considerable extent for hay in western Oregon.

Orchard Grass

Orchard grass or cocksfoot (*Dactylis glomerata*), a native of Europe, is grown to some extent in nearly every state. It is most widely grown in the region east of the Mississippi and north of Alabama and Georgia, and is growing naturally in many localities.

This grass is distinguished by its large circular bunches, folded leaf blades, compressed sheaths, and particularly by the spikelets grouped in dense one-sided fascicles borne at the ends of the panicle branches (Figure 187). Orchard grass is able to grow in the shade.

It formerly was regarded unfavorably because of its bunch habit and the tendency of the hay to be coarse and woody. The value of orchard grass is now generally recognized when grown in mixtures with Ladino or alsike clover, with tall oatgrass, or with meadow fescue. Orchard grass should be cut for hay when it starts to bloom. As a pasture plant, it should be grown in mixtures with other grasses and clovers and grazed in rotation. Orchard grass is a palatable pasture grass when young but is not relished by livestock after it has become coarse.

FIG. 187. Orchard grass during anthesis.

Meadow Fescue

Meadow fescue (*Festuca elatior*) is a hay and pasture grass grown to a limited extent chiefly in the northeastern states. The crop is grown for seed in eastern Kansas and Nebraska and in parts of Missouri. It has declined in importance. A taller type called tall fescue is, including its named strains, now much more important, especially in the Pacific northwest.

Meadow fescue is adapted to practically the same conditions as is timothy. It is most productive on fertile, moist, or even wet soils. It is not well adapted to sandy soils. It seems to thrive as well as orchard grass in shady places.

Meadow fescue is a hardy perennial grass that attains a height of 1 to 3 feet. Tall fescue is 6 to 12 inches taller. It does not form a heavy sod nor is it inclined to have as much of a bunch habit as orchard grass. The leaves are bright green and very succulent. The inflorescence is a narrow panicle, there being several florets per spikelet.

This grass is usually seeded at the rate of 10 to 15 pounds per acre on a firm seedbed either in the fall or spring. Red clover is sometimes mixed with it to improve the subsequent crop of hay or pasture.

Meadow fescue is used primarily as a pasture grass. It can be grazed early in the spring and late in the fall. It has good quality as a hay crop when harvested just as it comes into bloom.

An improved variety of tall fescue, Alta, was grown on 500,000 acres in the United States in 1942. A similar selected strain, called K 31, is grown in Kentucky and other eastern states.

Tall Meadow Oat-Grass

Tall meadow oat-grass (*Arrhenatherum elatius*) is grown generally over the United States, but is not important in any locality.

Tall oat-grass is adapted to well-drained soils, especially those that are sandy. It makes very poor growth in shade.

Tall oat-grass is a hardy, short-lived perennial bunchgrass, growing to a height of 2 to 5 feet. The inflorescence is an open panicle similar to that of cultivated oats, but the seed is much smaller.

This grass is often sown in mixtures. A suggested mixture is red clover, alsike clover, orchard grass, and tall oat-grass.[18] A mixture with sweetclover or occasionally with alfalfa is now being recommended. A stand is difficult to obtain because the seed is of low viability. It is necessary to use 30 to 50 pounds of seed per acre when this grass is sown alone.

Tall oat-grass is used for pasture and hay. Although succulent, the grass has a peculiar taste to which grazing animals must become accustomed. It is considered palatable and highly nutritious. This grass will furnish an abundance of grazing from early spring to late in the fall. For hay, the crop should be cut at about the bloom stage.

Blue Grama Grass

ADAPTATION

Blue grama grass (*Bouteloua gracilis*) probably is the most important range grass in the Great Plains. It occurs generally throughout the dry portions of the Great Plains as a component of the short grass prairie. It predominates in drier sections and on sandier soils than those favoring buffalo grass. Blue grama grass recently has been introduced into cultivation. The presence of rhizomes makes it sod-forming in habit, although it does not form a dense turf and it spreads slowly. Southern strains tend to make a greater vegetative growth and a lower seed yield when moved northward, while northern strains grow too sparingly for southern conditions. Also, southern strains often are lacking in cold resistance.

FIG. 188. Plant, floret (1), spikelet (2), and glumes (3), of blue grama.

DESCRIPTION

Blue grama grass is a low, sod-forming perennial with fine, curling basal leaves of a grayish-green color. The leaves are 2 to 5 inches long and less than ⅛-inch wide, with the ligules sparsely (or occasionally distinctly) hairy (Figure 188).

The spikelet consists of an awned fertile floret and an awned, densely bearded, rudimentary floret. These appendages make the seed light and fluffy and interfere with drill seeding unless they are removed by processing.

The root system consists of dense masses of fine roots concentrated mainly in the upper 2½ feet of soil with a few roots extending to greater depths.

Blue grama frequently is confused with the staminate plants of buffalo grass.

CULTURE

Stands of blue grama are established by seeding. Being a warm season grass, it is sown in the spring, in April or May in the central Great Plains. A compact clean seedbed is essential. Considerable success has followed seeding in drilled Sudan grass stubble that had been allowed to produce some aftermath. Such land may be disked lightly and packed before seeding. Seeding may be done with a grain drill with the grain tubes hanging outside the spouts, or sown with a packer seeder, or it may be broadcast. Unprocessed seed is sown with a grain drill equipped with cotton planter boxes, or is broadcast. The land should be packed again after seeding.

Seed having a purity of 40 to 50 per cent should be sown at 15 to 20 pounds per acre, while processed seed having a purity of 60 to 70 per cent may be sown at a corresponding lighter rate. It is desirable to include 2 to 4 pounds per acre of buffalo grass burs and some side-oats grama with the blue grama seed. The seed should not be covered with more than ½ inch of soil. Successful stands have been obtained by spreading blue grama hay containing mature seed on a well-prepared seedbed and then running over it with a drill, subsurface packer, or a herd of livestock, to work the seed into the ground.

In the north, blue grama grass usually is harvested with a bluegrass stripper, while in the central and southern Great Plains small combines and grain headers have been used extensively.

In good seasons seed may be harvested from native stands. Such seed may have a purity of only 20 to 40 per cent because of the presence of sterile (blasted) florets. Sound plump caryopses often germinate 90 per cent or higher.

UTILIZATION

Blue grama grass is highly palatable and provides choice forage during the summer grazing period. The mature grass cures on the range and retains some of its nutritive value, thus providing excellent fall and winter grazing.

The protein content of blue grama grass decreases toward maturity. At the early bloom stage the protein content is about two-thirds that of alfalfa at the same stage.

A related species, side-oats grama (*Bouteloua curtipendula*), also has been introduced into cultivation. Other grama grasses are black (*B. eriopoda*), hairy (*B. hirsuta*), and Rothrock (*B. rothrockii*).

Buffalo Grass

Buffalo grass (*Buchloë dactyloides*) is a native long-lived perennial sod-forming grass. It is one of the most important range grasses in the Great Plains, probably being second only to blue grama. It has been cultivated only since about 1930. Buffalo grass is found in the Great Plains region from Texas to North Dakota, but is most abundant on the heavier soils of the central Great Plains. It is not well adapted to sandy soils.[24] It is highly resistant to drought and heat. Although resistant to cold, it is a warm-weather grass that starts growth late in the spring and ceases growth when cold fall weather arrives. Buffalo grass forms a dense tough sod under suitable growing conditions and withstands close grazing and tramping better than almost any other grass. Buffalo grass furnished abundant forage to buffaloes, antelopes, and Indian ponies in the Great Plains. White settlers used the turf to build their sod houses. With the opening of the region to cattle grazing, it increased in importance because it soon replaced some of the taller grasses such as the bluestems (*Andropogon* species) that, owing to their higher palatability, could not withstand heavy grazing.

DESCRIPTION

Buffalo grass produces fine grayish-green leaves usually 2 to 4 inches long. The plant is largely dioecious, the staminate plants sending up spikes 4 to 8 inches in height, and the pistillate plants producing seeds in burs borne down in the turf just above the surface of the soil. It produces rapidly growing long stolons that enable the plants to sod over bare spots quickly. Small clumps may cover an area of 4 square feet or more in a single season.

CULTURE

Buffalo grass was first propagated vegetatively by planting pieces of sod 4 to 6 inches in diameter at intervals of 2 to 3 feet. Fields planted in this manner usually become sodded over in 2 or 3 years.

The seed is difficult to harvest because it is borne among the leaves close to the ground. Recently, combines have been adapted to harvesting the seed so that it is now more plentiful. Buffalo grass seed is low in germination due both to unsound seed and a high percentage of dormancy.[25] The dormancy can be broken by hulling the seed or by special treatments. Seeding of buffalo grass is now more feasible than is sodding. About 4 or 5 pounds of treated seed per acre are sufficient because of the rapid spreading of the plants.

UTILIZATION

Buffalo grass is often too short to cut for hay, but the acre yields in the central and southern Great Plains are about as large as those of many of the taller grasses. It furnishes palatable nutritious pasturage. In seasons of drought, the stand or cover may become very thin but when moisture conditions again become favorable the few surviving plants soon spread to form a thick turf. Furthermore, dormant seeds in pastures that appear to be ruined germinate and re-establish an adequate ground cover. Buffalo grass lawns composed of pistillate plants are popular because they require little mowing or watering. The grass withstands drought better than any other grass producing a dense turf. Its color is less attractive than that of other turf grasses. It is more cold resistant than Bermuda grass and fully as hardy as Kentucky bluegrass.

Carpet Grass

Carpet grass (*Axonopus affinis*) is a native of the West Indies, but is now widespread in the tropics of both hemispheres.

It is grown in this country on the coastal plains soils from southern Virginia to Texas. It is especially adapted to sandy or sandy loam soils, particularly where the moisture is near the soil surface. This plant requires abundant heat and moisture. It grows throughout the year except when damaged by severe drought or heavy frosts. Carpet grass tends to become established naturally on pastured land in the south, much as Kentucky bluegrass does in the north.

Carpet grass is a perennial creeping grass that forms a dense turf. It is readily distinguished by the compressed 2-edged creeping stems that root at each joint, as well as by the blunt leaf tips (Figure 189). The flower stems grow to a height of about 1 foot.

Carpet grass is one of the most common perennial grasses for permanent pastures over much of the area where it is adapted. It is easily established, seeds abundantly and forms a dense turf. It can stand heavy continuous grazing. It may be pastured in the south from May to November. Lespedeza and white clover mixed with carpet grass improve the pasturage but are difficult to maintain because of the dense carpet grass turf. Carpet grass lawns are popular in the southeast.

FIG. 189. Carpet grass. (1) Plant, (2) panicle branch, (3) glume, (4) ligule, (5) floret.

Napier Grass

Napier grass (***Pennisetum purpureum***), a native of tropical Africa, is grown in the warmer regions of this country.

Napier grass is adapted to the southeastern states and southern California.

This grass is a robust, canelike, leafy perennial which grows 5 to 7 feet or more in height. It grows in clumps of 20 to 200 stalks. The inflorescence is a long, narrow, erect, golden spike about 7 inches long. The plant is rather woody when mature. It is easily propagated from the nodes of the canes which are pushed into the soil. It is also grown from seeds, the seedlings being transplanted later.

Napier grass is utilized primarily as a soiling crop in tropical countries. The mature plants are rather woody, but silage made from the mature crop is eaten readily. Napier grass is palatable and nutritious when grazed rotationally in Florida.[3] The pasture should be stocked so that most of the grass blades are consumed in 5 to 8 days, after which 20 or more days are allowed between grazings for the grass to recover.

Dallis Grass

Dallis grass (*Paspalum dilatatum*) occurs abundantly from North Carolina to Florida and west to Texas. Farther north it is too tender for survival.[19]

Dallis grass is a perennial with a deep root system. It grows in clumps or bunches 2 to 4 feet in height. The leaves are numerous near the ground, but the stems are practically leafless (Figure 190). The slender stems usually droop from the weight of the flower clusters.

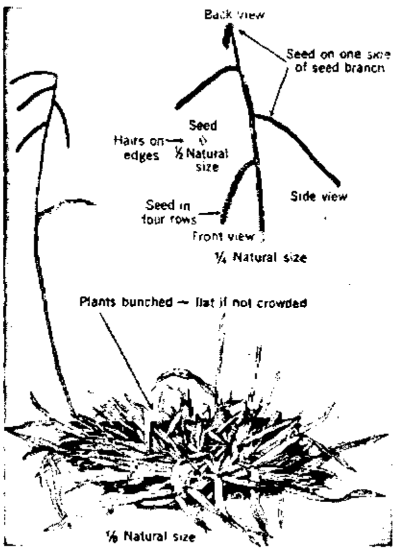

FIG. 190. Dallis grass.

The seed is very light so the seedbed must be carefully prepared for Dallis grass. Usually 5 to 10 pounds of hand-picked seeds per acre are sown. In the southern states, the crop is generally sown in October or November. The production of Dallis grass seed is difficult because of heavy ergot attack and a high percentage of sterile florets.

Dallis grass is primarily a pasture crop because of its tendency to lodge when left for hay. It is a good summer pasture grass for heavy, moist, fertile soils when grown with legumes such as white, hop, or Persian clover. It is not injured by persistent grazing, the leaves being quickly renewed. Permanent pastures of carpet grass and Bermuda grass are made more valuable when this grass is included.

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PART III LEGUMES

22 ALFALFA

Economic Importance

Alfalfa is one of the most important forage crops in the United States. The average annual acreage harvested from 1937 to 1946 was about 14,355,000 acres, on which a production of nearly 31 million tons, or 2.1 tons of hay per acre, was obtained. During this period an average of 844,000 acres a year were harvested for seed, producing about 1,250,000 bushels, or 1.5 bushels per acre. Among the principal alfalfa states are California, Wisconsin, Minnesota, Michigan, and Iowa (Figure 191). Alfalfa is widely distributed throughout the world. About 35 million acres are grown, chiefly in Argentina and the United States.

History of Alfalfa Culture

The name alfalfa, which comes from the Arabic language, means *best fodder*. In Europe it is usually called lucerne. Most authorities believe that alfalfa originated in southwestern Asia, although forms from which it could have arisen are found in China and Siberia.[46] Alfalfa was first cultivated in Iran, and was carried from there to Arabia, the Mediterranean countries, and finally to the New World. Evidence of the ancient introduction of alfalfa into Arabia is found in the strongly marked characteristics of Arabian varieties,[13] apparently representing centuries of acclimatization in an arid region.

The first recorded attempt to grow alfalfa in this country was in Georgia in 1736. Although alfalfa later was tried in the eastern states from time to time, it was not always successful. An introduction from Chile into California about 1850 was the start of a rapid expansion.

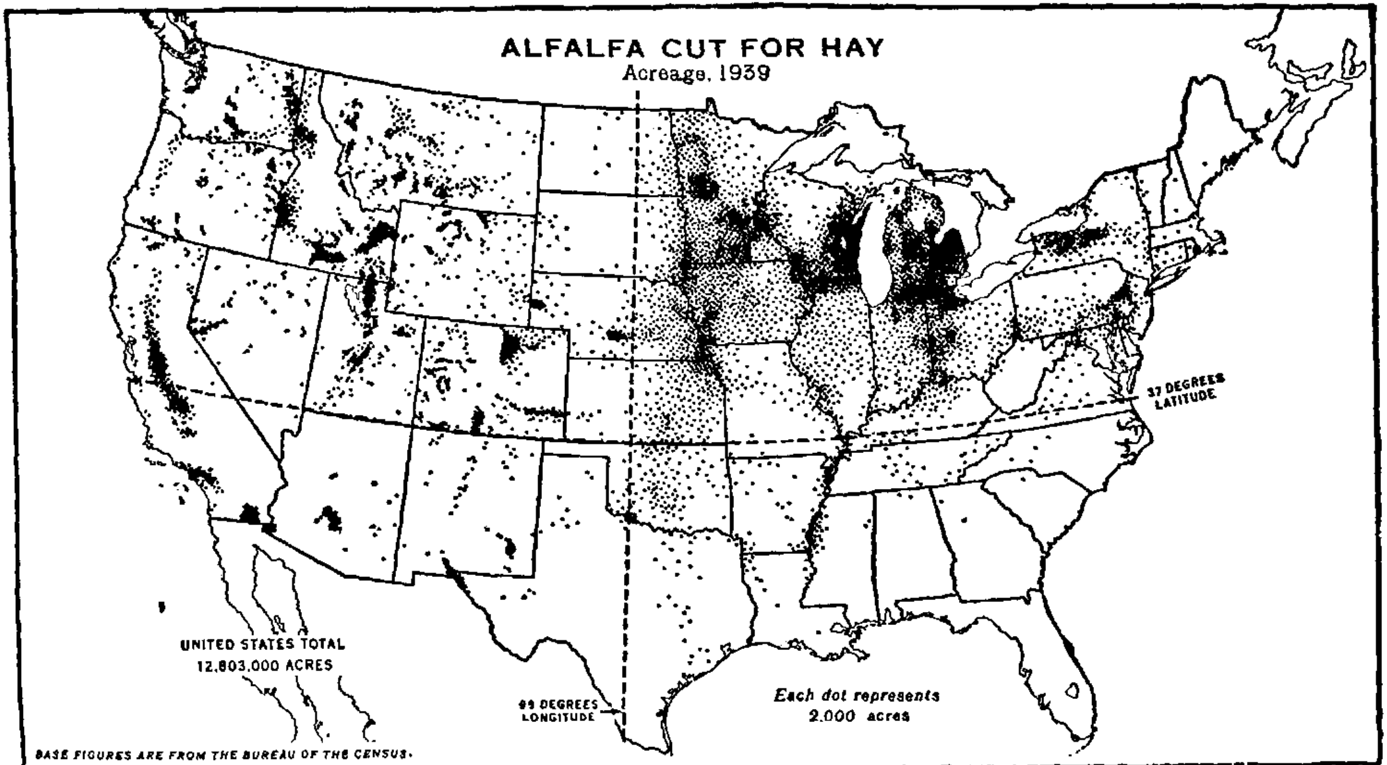

FIG. 191. Alfalfa hay acreage. The concentrated sections in the western half of the United States are mostly irrigated valleys.

Adaptation

Alfalfa has a remarkable adaptability to various climatic and soil conditions as shown by its wide distribution.

The alfalfa plant makes its best growth in relatively dry climates where water is available for irrigation. It will withstand long periods of drought but is unproductive under such conditions. Alfalfa is not so well adapted to humid climates but despite this fact it is grown successfully in central and eastern United States and also in the south.

Alfalfa tolerates extremes of heat and cold. Yellow-flowered alfalfa has survived temperatures as low as $-84°$ F.[1] Common alfalfa has been grown in the Death Valley of California where maximum summer temperatures are as high as 120° F., but the humidity is low. However, alfalfa is relatively dormant during the summer in very hot regions.

Alfalfa is best adapted to deep loam soils with porous subsoils. Good drainage is essential. The plant requires a large amount of calcium for satisfactory growth. It survives on almost all soils in the semiarid region except those high in alkaline salts, or that have a shallow water table.

Alfalfa has spread to the more humid eastern states in recent years with the increased knowledge of the requirements for lime, for inoculation with nitrogen-fixing bacteria, and for certain plant nutrients. Except on a few limestone soils, applications of lime are essential for satisfactory growth of alfalfa east of the Mississippi River.

Botanical Description

Alfalfa is an herbaceous perennial legume that may live 15 to 20 years or even more in dry climates unless insects or diseases destroy it. The most commonly cultivated species is *Medicago sativa.* Yellow-flowered alfalfa (*M. falcata*) is sometimes regarded as a subspecies (*M. sativa falcata*) of common alfalfa. Yellow-flowered alfalfa is distinguished by its yellow flowers, sickle-shaped seed pods, decumbent growth habit, low-set branching crowns, and a preponderance of branched roots. It is not satisfactory for American

FIG. 192. Branches and flowers of alfalfa. Leaves at lower right.

conditions because it is somewhat prostrate and usually yields only one cutting a season in the northern states. This species is of interest primarily for hybridization with common alfalfa in an effort to produce hardier varieties.

THE ALFALFA PLANT

The alfalfa plant varies in height from 2 to 3 feet. It has 5 to 20 or more erect stems that continue to arise from the fleshy crown branch as the older branches mature and are harvested. Several short branches may grow from each stem. The leaves, arranged alternately on the stem, are pinnately trifoliate. The oblong leaflets are sharply toothed on the upper one-third of the margin, the tip being terminated by the projected midrib (Figure 192). About 48 per cent of the weight of the plant may consist of leaves.[19]

The root system consists of an almost straight taproot, which, under favorable conditions, penetrates the soil to a depth of 25 to 30 feet or more. There are a few side branches that extend short distances from the main taproot. The main root normally persists during the entire life of the plant. All varieties of alfalfa develop branch roots in compact soil, while taproots predominate in porous soil.[4]

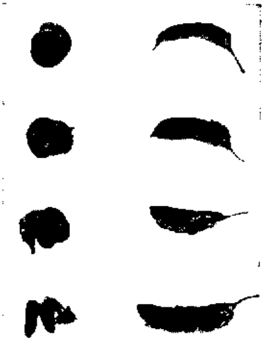

FIG. 193. Coiled pods of common alfalfa seed (*left*). Sickle-shaped pods of yellow-flowered alfalfa (*right*).

The flowers of common alfalfa, borne in axillary racemes, are purple except in the variegated types. The fruit is a spirally twisted pod that usually contains from 1 to 8 small kidney-shaped seeds (Figure 193). The seeds are normally olive-green in color (Figure 194).

Alfalfa can be propagated vegetatively from stem or crown cuttings.

POLLINATION

Some self-pollination occurs in alfalfa but within a species 80 to 95 per cent of the flowers usually are cross-pollinated. From 7 to as high as 80 per cent crossing between closely associated plants of

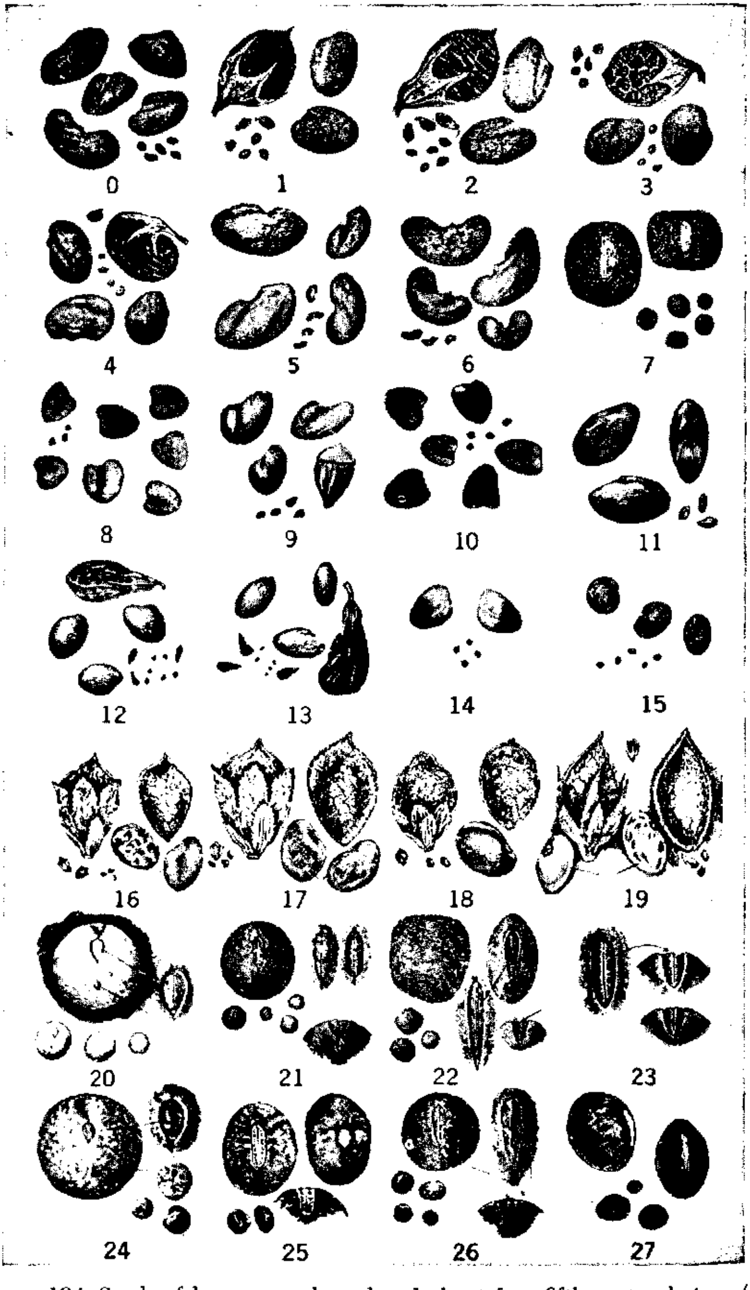

FIG. 194. Seeds of legumes, enlarged and about four-fifths natural size: (0) alfalfa, (1) white sweetclover, (2) yellow sweetclover, (3) sourclover, (4) black

purple-flowered and yellow-flowered alfalfa has been observed.[38, 42] A decrease in both forage and seed yields usually occurs when flowers are self-fertilized, the decrease being marked in most cases.

The external flower structures, the keel, wings, and standard enclose the reproductive tissues and serve to attract insects. Tripping is necessary for seed set except in a small percentage of the flowers. Tripping is the release of the sexual column from the keel to the flower[36, 37] (Figure 18). The sexual column includes the style, stigma, and part of the ovary enclosed and surrounded by 10 stamens and diadelphous filaments. Tripping, which takes place when the flower is in a turgid condition, is accompanied by an explosive action as though a spring under tension has been released. Some seed is produced by self-tripping and by tripping caused by wind, rain, and sun, but these are unimportant in comparison with pollination resulting from the visitation of insects.

Wild bees, chiefly leaf-cutter bees (*Megachile spp.*) and alkali or ground bees (*Paranomia spp.*) are the most effective pollinators but bumblebees (*Bombus spp.*) are fairly effective trippers.[40] Honeybees collecting pollen rather than nectar are very effective pollinators. Other flowers in bloom may attract bees away from alfalfa and thus reduce the seed set. Lack of tripping by beneficial insects probably is the chief cause of poor yields.* Environmental factors affect the insect population and thus contribute to seed setting chiefly in an indirect manner. Thickly planted and lodged plants give poor seed sets. Ample food reserves in alfalfa roots also contribute to good seed sets.

Rupture of the stigmatic surface by tripping is essential to the penetration of the pollen tubes.[3] After tripping occurs, the proper

* A series of papers on "Alfalfa seed setting" was published in Volume 38, No. 6, of the *Journal of the American Society of Agronomy*, pp. 461–535, June, 1946.

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medic, (5) California burclover, (6) spotted burclover, (7) roughpea, (8) white clover, (9) red clover, (10) alsike clover, (11) crimson clover, (12) small hop clover, (13) large hop clover, (14) hop clover, (15) birdsfoot trefoil, (16) common lespedeza, (17) Kobe lespedeza, (18) Korean lespedeza, (19) sericea lespedeza, (20) smooth green pea, (21) hairy vetch, (22) common vetch, (23) woolypod vetch, (24) mottled field pea, (25) Hungarian vetch, (26) narrowleaf vetch, (27) purple vetch.

moisture relationship for pollen germination and pollen-tube growth must be maintained to effect fertilization. Partial self-incompatibility and ovule abortion result in a low percentage of fertilization when alfalfa plants are self-pollinated.[7] The net fertility 144 hours after pollination may be about 6 times as high in crossed plants as in selfed plants. *Lygus* bugs cause bud damage and flower dropping, and often cause a poor seed set in alfalfa.[5, 34]

Varieties

Four somewhat distinct groups of commercial alfalfas grown in this country are recognized.[45, 46] These are Common, Turkistan, Variegated, and Nonhardy.

COMMON ALFALFA GROUP

The common group includes the ordinary purple-flowered, smooth alfalfa. The various strains are usually distinguished by the name of the state where adapted, as, for example, Montana Common, Kansas Common, and Arizona Common. Regional strains developed in Montana and other northern states have a tendency to recover more slowly after being cut than those produced farther south. Since they are more cold resistant, northern-grown strains are preferable where winterkilling occurs frequently. The strains produced in the southwest recover rapidly after being cut, but they are very susceptible to winter injury except when grown in the southern states. Adaptation, especially as to cold resistance, is extremely important in Common alfalfa (Figure 195). Seed should be procured from a source where the winters approximate in severity the conditions where it is to be planted. None of the strains in this group, except Buffalo, is resistant to bacterial wilt. Buffalo was selected from Kansas Common.[14]

TURKISTAN GROUP

The Turkistan group includes alfalfas that originated in Turkistan. They are characterized by slow recovery after being cut, early fall dormancy, susceptibility to leaf diseases, winterhardiness, resistance to bacterial wilt, and low seed yields. Turkistan alfalfa is practically indistinguishable from Common. The growth is somewhat shorter and more spreading, while the leaves are smaller

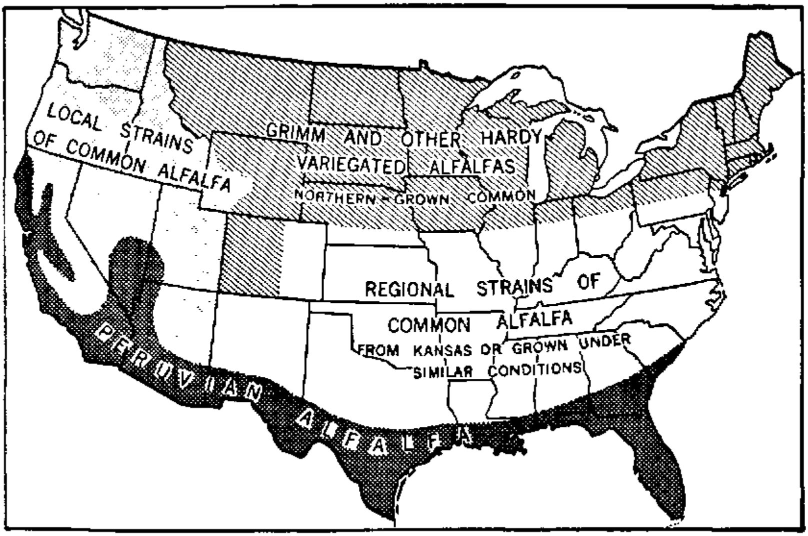

FIG. 195. Regions in which different types of alfalfa are adapted.

with slightly more hairiness. Rabbits and hogs graze it in preference to Common alfalfa. The principal varieties are Turkistan, Hardistan, and Orestan.

Turkistan is resistant to both cold and wilt. Where bacterial wilt is destructive Turkistan can be used to advantage in the states west of the Mississippi River and from Kansas northward. It has given poor performance in the east because of susceptibility to leaf diseases. Hardistan is a Nebraska strain that is relatively resistant to cold and bacterial wilt. Hardistan is the progeny of a mass lot of alfalfa grown by a farmer who continued to use his own seed and later sold seed to his neighbors.[21] Orestan is a selection grown in eastern Oregon. Both Hardistan and Orestan are poor seed producers and are being replaced by equally resistant but higher producers, such as Ranger. A new variety, Nemastan, is resistant to the stem nematode, *Ditylenchus dipsaci*.

VARIEGATED GROUP

Introduction, testing, and distribution of cold-resistant variegated varieties is largely responsible for the successful culture of alfalfa in several northern states.

The variegated alfalfas appear to have resulted from natural crossing between the purple-flowered and yellow-flowered species. The predominant flower color is purple, but some brown, green, greenish-yellow, yellow, and smoky to nearly white flowers occur. The seed pods vary in shape from sickle-shaped to coiled. Such variegation is characteristic of many selected plant progenies owing to repeated cross-pollination. The alfalfas of the variegated group are more cold resistant than common alfalfas. Their hardiness is due to the presence of yellow-flowered alfalfa in their ancestry as well as to natural selection under severe climatic conditions. With the exception of Ranger and Ladak, none of them has shown resistance to bacterial wilt.

Ranger is a synthetic variety developed in Nebraska by compositing of five strains. Selected inbred lines were outcrossed with selected lines from the Cossack, Turkistan, and Ladak varieties to produce the five strains. Ranger is resistant to bacterial wilt, is winterhardy, and has a variegated flower color with a limited number of yellow flowers. It is adapted to the northern states.[14, 42]

Grimm alfalfa is the most widely grown variegated alfalfa in this country. Because of its cold resistance, the culture of Grimm is confined to the northern half of the United States where the winters are severe. It is susceptible to bacterial wilt.

Ladak, originally from northern India, shows more variegation with a greater percentage of yellow flowers than any other alfalfa in the group. It is particularly adapted to the northern Great Plains where it is hardier and more drought resistant than other variegated alfalfa. It is also somewhat resistant to bacterial wilt. Ladak produces an exceptionally heavy first crop, being especially valuable where only one good cutting is normally obtained. It recovers slowly after being cut, with the result that the second and third cuttings are materially less than obtained from other varieties. For optimum production, Ladak should be allowed to grow somewhat longer for the first cutting and between subsequent cuttings than is usually the case with Grimm or Common.[39]

Several other variegated varieties are similar to Grimm in winterhardiness, general plant characters, and in yield. Among these varieties are Cossack, Baltic, Canadian Variegated, and Hardigan.

Meeker Baltic is a natural selection from Baltic originating in Colorado. All are susceptible to bacterial wilt, and adapted to the same general region as is Grimm. A new variety, Atlantic, is adapted to eastern United States.

NONHARDY GROUP

Nonhardy varieties adapted to the deep southwest include Hairy Peruvian, African, and Indian. Hairy Peruvian has pubescent leaves and stems. Despite its inability to withstand cold winters it grows very well in cool weather.

HYBRID ALFALFA

Hybrid alfalfa is being produced on a limited scale by choosing clonal lines that combine well and increasing them from stem cuttings. Lines to be crossed are grown in alternate rows from transplanted cuttings. Inbreeding these lines is unnecessary because they can be reproduced at will by maintaining them as perennials and by propagating them vegetatively. Emasculation (comparable to detasseling in corn) is omitted, but despite this probably 90 per cent of the seed produced is hybrid because the lines used are largely self-sterile.[41]

Hard or Impermeable Seed

Impermeable or so-called hard seeds occur commonly in alfalfa, the average in Colorado-grown seed being 22 per cent,[24] and in all areas ranging from none to 72 per cent. The percentage of hard seed increases with maturity. There appears to be no relation between climate as influenced by altitude and production of impermeable seed. Hardy varieties exhibit a higher percentage of impermeable seeds than do the less hardy ones. Mature fresh hard alfalfa seeds are alive and there is no important difference between permeable and hard seeds in the rate of loss of viability when stored the same length of time.[25]

It often has been assumed that the failure of hard seeds to germinate in the laboratory means failure to grow when planted in the field, but experiments show that samples with 20 to 62 per cent of hard seeds all produce about 60 per cent germination in the field.[44]

Samples with less than 20 per cent hard seeds averaged slightly higher in field germination. Alfalfa seed lots with many hard seeds have almost the same agricultural value as those with only a few.

Winter Hardiness

Resistance of alfalfa to low winter temperatures is important for maintenance of stands in the northern states. Alfalfa plants have no autonomous rest period, but become dormant because of environmental conditions unfavorable for growth.[33] Winter hardiness is largely a varietal characteristic. In Nebraska the percentage survival of Kansas Common was 43; Nebraska Common, 58; Utah Common, 50; and Arizona Common, 5.[40] Plants from seed obtained in Italy and Argentina showed survivals of 13 and 15 per cent, respectively.

Hardy alfalfas become dormant earlier in the fall and harden more rapidly than do nonhardy alfalfas.[28] The hardening process in alfalfa appears to be cumulative over a rather long period in the fall and early winter, and then hardening decreases toward spring. Hardy varieties retain their hardiness longer than do nonhardy ones. The plants harden best at 5° C., but much greater hardiness develops under alternating temperatures of 0° C. for 16 hours and 20° C. for 8 hours.[35] Hardening progresses with decreasing day length and alternating temperatures in the fall.

Premature or too frequent cutting of alfalfa depletes the organic root reserves, with a subsequent reduction in stand either by winter injury or disease.[2, 23, 48] These reserves are the carbohydrate and nitrogen compounds elaborated in the leaves, stored mostly in the roots, and later utilized by the plant for maintenance and for future growth. New foliage growth is made partly at the expense of these root reserves. The root reserves are increased during the blossoming period.[9] Cool weather in the fall is especially conducive to food storage. The protection afforded by some fall top growth aids in maintenance of stands.[2, 11] In Michigan the roots of alfalfa plants cut in September were lower in percentage of dry matter than when cut in October.[31] From the standpoint of survival, alfalfa plants should not be cut before the blossom stage, nor permitted to go into the winter without some top growth in the northern states.

Rotations

Alfalfa is an important crop in irrigated rotations, where it usually is sown with a small-grain companion crop. It is cut for hay or seed for two or three years, and often longer when good stands are maintained. The alfalfa field is then plowed in preparation for an intertilled crop such as corn or potatoes. The roots and aftermath furnish nitrogen for the crops following alfalfa. Usually after two years devoted to the above intertilled crops or field beans, the land is again sown to alfalfa and grain. In turning under alfalfa sod, the land is often plowed shallow in the fall to cut off the roots below the crown of the plant, a procedure called crowning. The land is again plowed deeper the following spring. Ordinary spring plowing without crowning fails to kill many of the alfalfa plants and these are difficult to destroy by cultivation.

When seeding alfalfa in the humid regions it is desirable to precede it in the rotation with some cultivated crop for 1 or 2 years to eliminate weeds.

Alfalfa leaves the soil high in available nitrogen which is used to advantage by the next crop where sufficient soil moisture is available. In eastern Nebraska the increased nitrates after alfalfa bring favorable results in seasons of relatively high rainfall, but may prove detrimental when the rainfall is deficient.[40] The injury results from overstimulation and excessive vegetative growth early in the season with the result that the crop need for moisture is increased beyond the supply and the plants fire or burn. Intervals between alfalfa in rotations should be lengthened where burning is a problem. Sorghum has been suggested as a good crop to follow alfalfa. After alfalfa the soil may be but little drier within the zone of root depths of annual crops than it is after small grains.

In nonirrigated areas where the annual precipitation is less than 30 inches, alfalfa exhausts the subsoil moisture. Yields on land sown to alfalfa for the first time have declined abruptly after 4 or 5 years due to subsoil moisture depletion. Subsequent growth is dependent upon current rainfall which is not sufficient for maximum production under subhumid conditions. In Nebraska and Kansas alfalfa roots have penetrated 30 to 40 feet in the soil, and used the available subsoil moisture to these great depths.[8, 20 22, 40] Some of the Nebraska data are given in Table 1.

When alfalfa is sown again on moisture-depleted land the yields are far from satisfactory. In Nebraska, only 30 to 53 per cent of the moisture removed by the alfalfa was restored during the 13 to 15 years of cropping to annual crops. In eastern Kansas two years of fallow were necessary to restore subsoil moisture on old alfalfa ground to the point where the roots of a newly seeded crop could penetrate through moist soil to a depth of 25 feet or more.[12] Soil moisture needs explain the success of alfalfa on bottom lands subject to overflow or subirrigation, in the semiarid regions.

Culture

A firm, moist, well-prepared seedbed is favorable for obtaining a stand of alfalfa.[46] The land may be fall plowed for spring seeding, or in the northeastern states, merely disked where alfalfa is to be summer seeded after small grains. On most soils east of the 95th meridian alfalfa responds to lime, and also to commercial fertilizers, particularly superphosphate, and often to light applications of boron. Inoculation with nitrogen-fixing bacteria is advisable in the eastern states where the crop is grown for the first time. Alfalfa responds to phosphorus applications on many irrigated calcareous soils that have been cropped for some time.

SEEDING

It is a common practice to seed alfalfa one-half inch deep on heavy soils and slightly deeper on light soils, in close drills. It is seldom grown in cultivated rows, and is not an economically successful hay crop where the climate is so dry that production in cultivated rows is essential for satisfactory growth.

In the northern half of the country, alfalfa generally is seeded in the early spring, with a companion crop where rainfall is abundant or irrigation water is available. Sometimes it is sown in August or early September. In the southeast the most favorable time ranges from August 15 in the latitude of Washington, D.C., to October or November along the Gulf coast. In the southern Great Plains, as well as in the southern parts of the corn belt, late sum-

TABLE 1. COMPARATIVE YIELDS OF ALFALFA VARIETIES BEFORE (1923–25) AND AFTER (1926–30) DEEP SUBSOIL MOISTURE DEPLETION IN NEBRASKA [a]

VARIETY	Yield of hay in tons per acre, 15% moisture, weed-free basis								Average yields		
	1923	*1924*	*1925*	*1926*	*1927*	*1928*	*1929*	*1930*	*First 3 yr.*	*Last 5 yr.*	*8-yr. Ave.*
Cossack	4.83	7.77	5.64	2.11	2.98	2.52	3.03	2.52	6.08	2.63	3.93
Baltic	4.76	7.49	5.51	2.10	3.02	2.80	2.84	2.57	5.92	2.67	3.89
Hardistan	5.04	6.98	5.09	1.81	2.44	2.46	2.77	2.59	5.70	2.41	3.65
Kaw	4.71	6.67	4.83	1.87	1.49	2.33	2.50	2.33	5.40	2.10	3.34
Turkistan	4.24	6.41	4.35	1.93	2.34	2.50	2.76	2.15	5.00	2.33	3.34
Average	4.72	7.06	5.08	1.96	2.45	2.52	2.78	2.43	5.62	2.43	3.63
Precipitation (in.)	28.95	21.91	25.09	26.24	21.41	27.83	23.51	20.74	25.32	23.95	24.46

[a] Favorable stands persisted throughout the period of these tests.

mer or early fall seeding is often practiced. October is the best month for seeding in the irrigated areas of the southwest, although good stands are obtained at other times up to April 15.

The general rate of seeding east of the Appalachian Mountains has been 15 to 20 pounds per acre because of frequent difficulties in establishing stands. Most corn belt experiment stations advise 8 to 12 pounds, which should be ample to produce satisfactory stands on well-prepared seedbeds, even in the east. About 10 to 15 pounds are commonly sown under irrigation in the west. Under dryland conditions, 6 to 8 pounds is the recommended rate for hay production.

CUTTING

Alfalfa produces one or two cuttings a season under semiarid conditions, 2 or 3 cuttings in the northern states, 3 to 5 in the central and southcentral zone, and 7 or 8 cuttings of hay on irrigated land in southern California and Arizona. In the latter region, the fields usually are pastured during July and August when growth is retarded by hot weather.

In tests in Wisconsin, alfalfa cut only twice in the season and then left over winter with a protective vegetative cover and abundant stored food reserves yielded 3.3 tons per acre of dry hay as an average for the 3 subsequent seasons.[10] After a third or fall cutting, the yields were 2.4 tons per acre, or a reduction of 26 per cent. The stands were badly thinned by the fall cutting. On soils of optimum fertility in Michigan the forage yield of the first crop in the spring was significantly less from alfalfa cut the previous September than from that not cut or cut in October after the food reserves had moved into the roots.[31]

At the Nebraska station, the average yields of common alfalfa were 3.00, 3.04, 3.35, 3.43, 3.19, and 2.82 tons per acre for cutting in the prebloom, initial bloom, one-tenth bloom, one-half bloom, full bloom, and seed stages of growth, respectively.[17]

"From the combined standpoints of acre yields of hay and feed constituents, quality of hay, and permanency of stand, harvesting alfalfa during the period from one-tenth to one-half bloom or at approximately the new growth stage should prove the most desirable practice. A modifica-

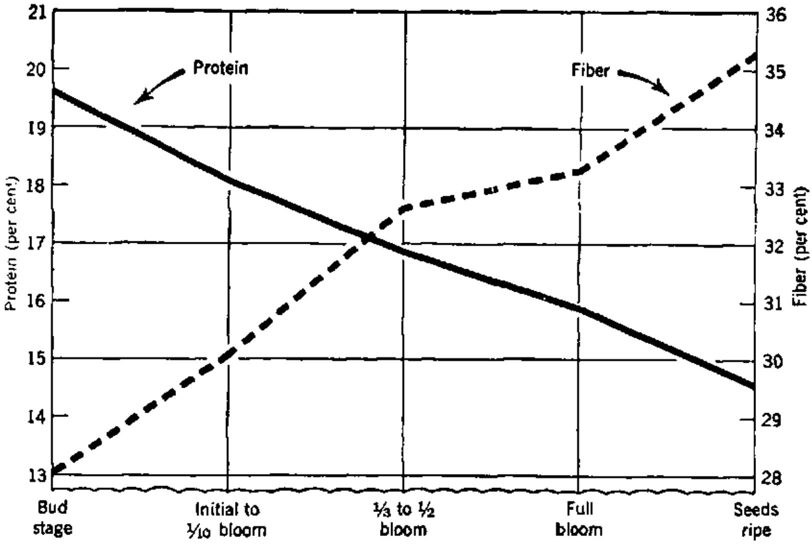

FIG. 196. Protein and fiber content of alfalfa at different stages of growth.

tion of this practice to satisfy local conditions may often prove desirable but frequent cutting in more immature stages should be avoided"[40] (Figure 196).

Quality in alfalfa hay depends upon color, leafiness, fineness of stems, and freedom from foreign material. Protein content is closely correlated with leafiness, while vitamin A content is closely associated with green color. These factors are definitely involved in the curing process. The leaves, which contain about 70 per cent of the total protein in the plant, are easily lost by shattering when the hay is handled improperly. Extensive experiments[17, 18, 19] indicate that partial swath curing to hasten the rate of drying, followed by windrowing before the leaves dry sufficiently to cause such shattering, and by prompt baling or storage, appears to be the best farm practice for Nebraska.

About 400,000 tons of alfalfa meal are produced annually for use as a protein feed. The hay either is ground (usually in a hammer mill) or is chopped into short (about ¼-inch) lengths. Well-cured, loose, or stacked hay often is used for grinding,[47] but much of it is made from fresh alfalfa that is chopped, dried artificially, and then ground. Portable driers and grinders, sometimes mounted on railway trucks, using gas fuel and electric power, are now widely used. Sometimes the dry leaves and stems are separated before grinding in order to obtain alfalfa leaf meal, a product that contains about 20 per cent protein.

Alfalfa as a Pasture Crop

Alfalfa is an excellent pasture for hogs when supplemented with grain. Despite the hazard from bloating, alfalfa has become increasingly important as a cattle pasture, particularly in the corn belt. There it is more productive than the usual permanent grass pastures, especially during hot dry periods. Summer pasturing of alfalfa is a common practice in the irrigated area of southern Arizona where the crop is cut for hay several times during the cooler spring and autumn periods. In Michigan [29] alfalfa pastured continuously has been as productive as when pastured after a first cutting taken for hay each year. Pasturing the first growth and harvesting the second growth for hay increased the number of annual weeds. Heavy grazing in September proved to be injurious to stands.

Alfalfa is less likely to cause bloat when sown in mixtures with adapted grasses. Bromegrass is used most often for this purpose north of the Kansas-Oklahoma line, usually 5 to 10 pounds of alfalfa and 10 to 15 pounds of bromegrass per acre being sown. A mixture of approximately 8 pounds of alfalfa and 5 to 7 pounds of bromegrass has been found satisfactory in Michigan.[30] About 4 pounds of alfalfa seed and 8 pounds of bromegrass have been recommended for Nebraska. Alfalfa is sometimes sown in mixtures with timothy or with orchard grass in the east. In the west it is seldom sown in mixtures for hay because alfalfa alone usually is more productive.

Seed Production

Alfalfa seed production is most successful where the climate is relatively dry, as in the semiarid and irrigated regions of the west. The most consistent seed production occurs where the crop makes a steady, continued growth. Abundant moisture results in rank vegetative growth unfavorable to seed production.[37] The insects important in seed production are very sensitive to weather conditions. They slow down their activity when the weather is cloudy, and stop entirely when it is cold and rainy.[40] As a rule, when seed production is incidental to hay production, growers leave the cutting for seed that matures during the hottest and driest part of the summer.

When alfalfa is grown specifically for seed, the highest average seed yields sometimes have been obtained where the crop has been planted in rows or spaced in hills under either irrigated or dryland conditions. In Utah alfalfa in 21-inch rows yielded 215 pounds of seed compared with 156 pounds per acre from the drilling method. Row spacings ranging from 21 to 49 inches gave similar results.[5] Growing the crop in hills for seed production gave an increase in acre yield of approximately 44 to 76 per cent, as compared with the row and drilling methods, respectively. Thin stands are helpful when the crop is solid drilled for seed production only, 2 to 3 pounds of seed per acre being sufficient. Cultivation of alfalfa grown for seed, whether in rows or solid drills, is of little value except for weed control.

Alfalfa is generally cut for seed when about two-thirds of the pods are brown or black. The crop may be harvested with a self-rake reaper or by a mower with a buncher or windrower attachment (Figure 197). Threshing direct from the windrow or stack may be done by an alfalfa huller or a grain separator with proper attachments. Alfalfa seed can be harvested with a combine after windrowing, or directly where the crop has matured uniformly.

Diseases

The most destructive alfalfa disease in the United States and the causal organisms are bacterial wilt (*Corynebacterium insidiosum*), leaf spot (*Pseudopeziza medicaginis*), yellow leaf blotch (*Pyrenopeziza medicaginis*), blackstem disease (*Ascochyta imperfecta*), crown wart (*Urophlyctis alfalfae*), mildew, rust, and Sclerotinia stem rot.

BACTERIAL WILT

Bacterial wilt is the most serious alfalfa disease in the United States at the present time, being found throughout the country.

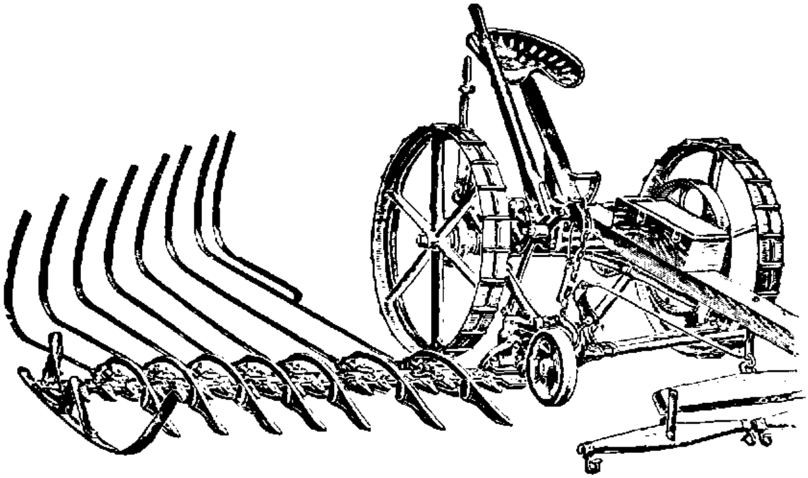

FIG. 197. Mower with lifter and windrower attachments.

In Nebraska it occurs wherever moisture conditions are favorable for a rapid, vigorous growth of the crop.[27]

The most conspicuous symptom, in addition to reduced stands, is a dwarfing of the infected plants. A bunch-growth effect is produced by an excessive number of shortened stems. The leaves are small, yellowish, and appear curled. Actual wilting occurs only in the advanced stages of the disease, especially during hot weather. A yellow to brown ring is observed under the bark when the roots are cut across.

The disease is spread from infected to healthy plants by mowers, drainage water, and irrigation water. Diseased plants are more susceptible to winter injury than are healthy plants of the same variety.[16] Infection enters the plant through wounds. Longevity of infected plants varies, but the greater number that show conspicuous symptoms of the disease die in the second year after infection.

The chief control measure is the use of resistant strains such as Buffalo, Ranger, Hardistan, Turkistan, Orestan, and possibly Ladak. All other commercial varieties appear to be susceptible.[26] The relative resistance of a few varieties [40] is given in Table 2. Breeding alfalfa for resistance to wilt is occupying considerable attention.

TABLE 2. WILT RESISTANCE OF SEVERAL ALFALFA VARIETIES IN NEBRASKA (1929–38)

VARIETY	SEED LOTS (*number*)	RESISTANCE TO BACTERIAL WILT [a] (%)
Turkistan (commercial)	14	63
Hardistan	12	48
Ladak	6	43
Kansas Common	2	10
Utah Common	1	9
Peruvian	1	6
Grimm	14	5

[a] Indicated by percentage of healthy plants after inoculation and subsequent growth.

Planting in soil upon which diseased alfalfa has been grown recently may cause the disease to appear one or two years earlier than otherwise.

LEAF DISEASES

Leaf spot is one of the most widespread of alfalfa fungus diseases, being most prevalent in the humid regions in cool wet weather. It causes small, circular, dark brown spots to appear on the leaves and may cause them to drop. To avoid loss of leaves, the crop should be cut when leaf spot infection becomes severe. The Turkistan alfalfas usually are more susceptible to the disease than the variegated or common varieties.

Leaf blotch, common in all large alfalfa-growing regions, also attacks the leaves. The disease is characterized by long yellow blotches sprinkled with minute brown dots. Where blotch is serious, the crop should be cut.

OTHER DISEASES

Crown wart occurs in greatest abundance in California, being characterized by the appearance of galls on the crown at the base of the stems.[46] Affected plants are seldom killed outright but produce low yields. Blackstem is most severe in the southeast and west. It is most serious after open winters and during long wet springs. The disease is characterized by large irregular brownish or blackish lesions that occur on the leaves and petioles as well as on the stems. Bacterial stem blight causes considerable damage in some sections.

A new variety, Williamsburg, is resistant to stem rot.

Insect Pests

The alfalfa weevil (*Hypera postica*), potato leafhopper (*Empoasca fabae*), Lygus bugs (*Lygus* species), grasshoppers, alfalfa caterpillar (*Colias philodice eurytheme*), three-cornered alfalfa hopper (*Stictocephala festina*), and the clover seed chalcid (*Bruchophagus gibbus*) are among the most destructive insect pests of alfalfa.

The alfalfa weevil is found in many western states. The insect feeds upon the leaves of the plant in both the larval and adult stages. The adult weevil overwinters in weeds, rubbish, and in alfalfa stubble. The most effective control is to cut the first crop early, i.e., in the bud stage. The larvae are killed either by starvation or exposure to heat immediately after the crop is removed. Another method of control is to spray the plants with calcium arsenate at the rate of 2 pounds per 100 gallons of water when the weevil begins to injure the crop.

The potato leafhopper may cause injury to alfalfa in the eastern states. It punctures the leaves and causes a yellowing of the plants. There is less loss from leafhopper injury in Kentucky when the first crop is cut near the full-bloom stage, or on June 10 to 15, and the second crop during the last week of July.[15] This involves a period of not less than 45 days between cuttings. The potato leafhopper eggs attached to the plants of the first crop fail to develop on the cured hay, and the young insects also are deprived of succulent food. An application of 25 pounds per acre of pyrethrum-sulfur dust controls the potato leafhopper rather effectively. The following dust mixture is recommended by Poos (*U. S. Dept. Agr. Circ.* 229).

Pyrethrins	0.0825	per cent
Petroleum hydrocarbons	0.6875	per cent
Sulfur (fine enough to pass through a 325-mesh sieve)	66.00	per cent
Inert dust	33.00	per cent

As little as a half-pound of DDT per acre applied in a dust mixture also controls the leafhopper but the hay crop may not be safe for feeding to dairy cows, because the DDT consumed by cows is secreted in the milk.

Most of the damage caused by the three-cornered alfalfa hopper occurs south of latitude 36° in the United States. Cleaning up hibernation quarters, viz., weeds, brush, grass bunches, and rubbish, keeps down the insect population.

The *Lygus* bug causes serious damage to alfalfa seed production.[5, 34] The bugs attack young alfalfa buds, floral parts, and immature seeds. Individual flowers are shed soon after injury by the *Lygus* bug. The injured seeds turn brown and in many cases shrivel and become papery. The application of DDT is the only satisfactory control for this insect. Sabadilla, or pyrethrum-sulfur dust, gives partial control.[32]

Grasshoppers cause extensive damage to alfalfa. They are controlled with chlordane, or with poisoned baits as described in Chapter 15.

The clover seed chalcid causes extensive damage to the alfalfa seed crop as well as to red clover and burclover. The wasplike adult chalcid deposits a single egg in each partly developed alfalfa seed. The resulting hatched larva devours the interior of the seed. Several generations may develop in one season. Late-developing larvae hibernate over winter inside dry seeds that are harvested or in those produced by plants along the ditches and borders of the field. Control measures include destruction of seed-bearing alfalfa and burclover plants along the irrigation ditch banks and field borders during the winter, and harvesting the crop for hay when heavy infestation threatens. Damage is reduced if the same cutting is saved for the seed crop throughout a locality so that the breeding period for the insect does not extend over the entire season. A heavy cleaning of the seed which removes the lighter infested seeds prevents the direct spread of the pest to new fields.

The beautiful yellow butterflies that flit about the alfalfa flowers in nearly all of the alfalfa fields in the western four-fifths of the United States are the adults of the destructive alfalfa caterpillar. They cause the most damage in the southwestern states. The larvae devour the leaves and buds of the alfalfa plants. This pest overwinters in the pupal stage on alfalfa stems, chiefly those of alfalfa standing along the ditch banks and field borders. The chief control measure is frequent irrigation to maintain a high humidity in the field, which promotes the development of a disease of the caterpillars. Other methods which help control the insect, such as early and close cutting of the alfalfa and tillage or renovating of the fields, are damaging also to the alfalfa stands.

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23 SWEETCLOVER

Economic Importance

Since about 1910, sweetclover (formerly called Bokhara clover), has advanced from the status of a roadside weed in many localities to an important American crop. The average annual area of sweetclover harvested for hay, from 1937 to 1946, was 665,000 acres, which produced 822,000 tons. In addition, a large acreage was pastured each year. During this decade, 320,000 acres were harvested annually for seed, the average annual production being 51 million pounds, or enough for sowing 2 to 3 million acres. The average acre yield was 1.2 tons of hay or 158 pounds of seed. It is now grown in almost every state in the Union, although it is most important in the north-central and Great Plains states. North Dakota, Minnesota, Montana, Iowa, and Wisconsin lead in sweetclover hay production. In 1933 it was estimated that 82 per cent of the sweetclover grown in the Great Plains region was pastured.[5] It is important also for green manure, and as a honey plant.

Sweetclover was used as a green manure crop and as a honey plant in the Mediterranean region 2,000 years ago. Asia Minor appears to be its native habitat. It was first observed in the United States as a wild plant in Virginia about 1739 but its real value was not recognized for many years. As late as 1910 sweetclover was legislated against as a weed in some states.

Adaptation

Sweetclover may be grown in any part of the country where the spring and summer rainfall is 17 inches or more. It also is grown under irrigation in drier sections of the northwestern states. The biennial species tolerate drought after once established, but a good supply of moisture and cool temperatures are essential for germination and early seedling growth.[1] While the plant may persist under dry conditions, little vegetative growth is made. It is more drought resistant than alfalfa or any of the true clovers in the Great Plains region, but it is not a dependable crop under dryland conditions in the central or the southern Great Plains unless moisture and temperature conditions are favorable for some time after seeding. Its consistent survival in Canada, Montana, Michigan, and other northern sections proves it to be very winter hardy.

Sweetclover will grow on a wide range of soils provided they are not acid. The soil reaction should be *p*H 6.5 or higher. It will grow on poorly-drained soil, heavy muck and peat soils high in organic matter, or on clay soils with almost none.[13] Most sweetclover failures in humid sections are due to lack of lime in the soil. Sweetclover grows on soils high in salts, even on alkali seepage lands [14] where cereal crops cannot be grown. The seed-shattering tendency and hard seeds help sweetclover to maintain itself as a weed in waste places and some cropped fields. Sweetclover in alfalfa fields harvested for seed contaminates the crop because sweetclover seeds cannot be screened out of alfalfa.

Botanical Description

The sweetclovers are legumes classified in the genus *Melilotus*. They are tall, erect, annual, or biennial herbs.

The plants grow from 2 to 6 feet in height. The stems are generally well-branched, coarse, and succulent. During the first year only one central stem per plant develops in the biennial sweetclovers, except in Alpha and certain new strains which have several. In the second year, numerous branches develop from crown buds formed the previous fall. New growth after cutting arises from buds in leaf axils rather than from crown buds. The leaves are pinnately trifoliolate and possess pointed stipules. The middle leaflet is stalked or petiolated. The leaflets are finely toothed along the margins. Young sweetclover plants can be distinguished from those of alfalfa by the coumarin taste and usually by the presence of serrations (teeth) along the entire margin of the leaflet rather than on the tip only, as in alfalfa.

Sweetclover has a fleshy taproot that penetrates the soil to a depth of 5 to 8 feet in the biennial forms.[29] A few to many side roots develop. The taproot of the annual types is relatively short and slender. Nodules occur on the roots when inoculated or when the nitrogen-fixing organism is present in the soil. In the biennial forms the taproot increases in weight slowly until the end of the growing season. The roots may double in weight after September 25, due to food storage.[32] During the second year the roots are depleted rapidly of their stored food for the production of top growth (Table 1).

TABLE 1. YIELD AND COMPOSITION OF TOPS AND ROOTS OF SWEETCLOVER AT SUCCESSIVE DATES IN THE SEEDING YEAR AND THE YEAR AFTER SEEDING

(Sweetclover sown in early oats which were harvested for grain; sweetclover not clipped or pastured after oat harvest)

DATE OF SAMPLING	AIR-DRY YIELD PER ACRE		NITROGEN IN		NITROGEN PER ACRE			PLANTS PER SQUARE YARD
	Tops *lb.*	*Roots* *lb.*	*Tops* *%*	*Roots* *%*	*Tops* *lb.*	*Roots* *lb.*	*Total* *lb.*	
DEVELOPMENT IN THE SEEDING YEAR								
July 1	515	....	3.25	...	...	..	...	...
July 15	588	75	2.85	2.30	16	2	18	...
August 1	659	182	2.54	2.53	17	4	21	...
August 15	963	310	2.69	2.90	28	9	37	...
Sept. 1	1431	577	2.88	3.02	41	18	59	...
Sept 15	1544	884	3.09	3.05	48	27	75	...
Oct. 1	1881	1273	2.87	3.12	54	40	94	...
Oct. 15	1714	1721	2.59	3.25	44	56	100	...
Nov 1	1616	2115	2.38	3.50	39	74	113	...
Nov. 8–10	1397	2324	2.32	3.45	32	77	109	...
DEVELOPMENT IN THE YEAR AFTER SEEDING								
April 1	420	2130	4.35	4.33	19	92	111	125
April 15	690	1750	4.21	4.15	29	73	102	125
May 1	1930	1360	3.90	3.57	75	49	114	117
May 15	3360	1280	3.27	2.90	110	37	147	102
June 1	4940	1200	2.70	2.38	133	29	162	92
June 15	6030	1110	2.35	2.14	142	24	166	82
July 1	7380	880	1.95	1.94	144	17	161	66
July 15	7990	790	1.77	1.72	141	14	155	50
August 1	7290	760	1.54	1.64	112	13	115	40

Sweetclover flowers of both the white and yellow types are borne in short-pedicelled racemes that arise in the axils of the leaves

(Figure 198). As many as 100 flowers may occur on a single large raceme. The inflorescence is indeterminate. Flowering occurs during the first year in the annual forms, but usually not until the second year in biennial types. Some plants of the biennial types may flower the first year under favorable growing conditions. Long days hasten flowering.

FIG. 198. Stem and flowers of white sweetclover.

The seeds of sweetclover mature in small, ovoid pods that are indehiscent or finally 2-valved. There usually is only one seed per pod, but as many as four may occur in some strains. The pods are dark brown when mature. Sweetclover sets seed readily, but it shatters easily when mature. The mature seeds of white sweetclover are golden yellow in color, but many of those of the yellow varieties are mottled. They are ovoid in shape and not laterally compressed at the ends like alfalfa seeds (Figure 194). A large percentage of the seeds may be hard or impermeable. Selected strains have a high percentage of permeable seeds.[3]

Sweetclover Species

Common biennial white sweetclover (*Melilotus alba*) is an aggregate of a variety of plant types, mostly tall-growing, high-branching and stemmy with low leaf percentages. The pods are slightly netted. The commonly grown types of biennial yellow sweetclover (*M. officinalis*) are somewhat less upright in growth habit than the white-flowered types, blossom earlier, have finer stems, and tend to be more persistent under pasture conditions. They usually are less productive and mature earlier than do the white-blossomed varieties.[21] Yellow varieties are somewhat less winter hardy than white ones in Canada.[18]

A yellow-blossom sweetclover (*M. suaveolens*) has growth habits similar to Common White. It usually is a biennial, but an annual form also is known. A nonbitter sweetclover (*M. dentata*) includes both annual and biennial types which are practically coumarin-free.[11] Sourclover (*M. indica*), an annual yellow *Melilotus*, is found in the south and southwest. The seeds are small, rough, and dark green (Figure 194). It is a green-manure crop on irrigated lands of the southwest, and along the Gulf coast.

Pollination

Under natural conditions, pollination of sweetclover is effected principally by honeybees, except for the species, varieties, and individual plants that are spontaneously self-fertilized.[19]

Common white sweetclover appears to be highly self-fertile. Plants may set seed when insects are wholly excluded.[18] Self-pollination takes place readily when the pistils and stamens are of the same length, but very little occurs when the pistil is longer than the stamens. Some natural crossing takes place under normal field conditions. About 10 per cent of cross-pollination occurred between green-seeded and yellow-seeded plants of *M. alba* when grown at a distance of 200 feet.[8]

Apparently the varieties of yellow sweetclover (*M. officinalis*) are not self-pollinated spontaneously, but probably they are not completely self-sterile.[21] They may be unable to set seed unless the flowers are visited by insects.[18]

White sweetclover has been crossed with Redfield Yellow (*M. suaveolens*) successfully, but the cross, *M. alba* × *M. officinalis*, did not produce any viable seeds.[25] Likewise, alfalfa pollinated with sweetclover produced no viable seed.

Varieties

Several varieties of biennial white-blossom sweetclover are recognized. Spanish Madrid (or Madrid White) and Willamette are late, high-branched, tall varieties with a low leaf percentage. These two varieties produce high yields in Washington, the latter one being resistant to stem-rot organisms.[11] The Grundy County and Arctic are dwarf varieties, notably earlier, shorter, and rather lower in yield than the ordinary types. Grundy County is grown principally in the Dakotas and Minnesota. Arctic is especially winterhardy, being grown extensively in Canada where it makes a better growth than in this country. The Alpha variety branches profusely at the crown, and is fine-stemmed and leafy. It is not well adapted to the United States except in the extreme northern Great Plains.

Evergreen is a tall late-blooming, coarse-stemmed variety of biennial white sweetclover selected at the Ohio agricultural experiment station between 1924 and 1934. Its advantage is the rank heavy growth and high yield. Other similar late white improved varieties include Sangamon (Ill. No. 8), Iowa Late and Wisconsin Late that were developed in the respective states indicated by the names.[21]

Hubam is an annual white sweetclover (*M. alba annua*) that is sometimes grown where it is to be plowed under within less than a year after seeding.[4] It grows 2 to 5 feet high, and has numerous strong stems with few leaves. The roots are small and without crown buds. It blooms from about July 15 to September 15. Hubam sweetclover is most popular in central and southern Texas where it can be sown in the fall and turned under in the spring in time for planting cotton. It also can be sown in the late winter or early spring for use as pasture in that region. It is a popular green manure crop in the Pacific northwest where it can be sown in the fall and then be turned under in early spring in preparation for potatoes or sugar beets. In general, the annual form is less desirable in the north central states than the biennial except for quick bee pasture or an orchard cover crop. The annual white variety produces larger yields of tops but lower yields of roots than do the biennials during the first season's growth.[2] The biennial sweetclover produces about 25 per cent more total dry matter, and the protein content of the roots is more than double that of the annual variety under Minnesota conditions. The protein content of the different types of biennial sweetclover is very similar.[17]

Yellow sweetclover sometimes is preferred for pasturing because it reseeds more readily under grazing conditions. However, it gives a shorter grazing season than does biennial white. Albotrea is much like the commercial yellow. Zouave is more erect in its growth during the first year than is the common yellow.[18] The seed is densely mottled with purple. Madrid is a rather tall-growing yellow variety recommended in Washington, Kansas, Nebraska, and Oklahoma. It matures seed in Oklahoma before summer drought occurs.[10] Redfield apparently is a variety of *M. suaveolens.* It blooms very late. It is low-yielding except in Canada and most northern parts of the United States.

Rotations

One of the most common crop sequences that includes sweetclover in the northern corn belt is: (1) corn; (2) small grain—usually oats or barley—seeded to sweetclover; and (3) sweetclover for pasture, hay, or seed.[6] Many grain farms use a shorter rotation of corn and small grain—barley, oats, or wheat—seeded to sweetclover. The sweetclover is plowed under in the spring for corn. This rotation has resulted in increases in corn yields of 30 to 70 per cent as compared with the same two year rotation without the sweetclover in experiments in Ohio. Small increases also were obtained in the small grain crop.

A rotation sometimes followed under irrigation is: (1) small grain seeded to sweetclover, (2) sweetclover for pasture or hay, (3) sugar beets, and (4) sugar beets. Sweetclover often is used as a green-manure crop in potato rotations.

Cultural Methods

The seedbed, inoculation, and lime requirements for sweetclover are similar to those for alfalfa. In experiments in Oklahoma,[10] light applications of finely pulverized limestone mixed with either rock phosphate or superphosphate and applied with a grain drill equipped with a fertilizer distributor resulted in excellent yields of sweetclover on land where a very poor growth occurred on unfertilized soil.

In Indiana [31] an application of 2 tons per acre of ground limestone was recommended for soils of *p*H 6.0 to 6.2; 3 tons per acre for medium-acid soils (*p*H 5.5 to 5.9); and 5 tons per acre for strongly-acid soils (*p*H 5.0 to 5.5). About 300 pounds per acre of superphosphate for thin pasture land was recommended and about 300 pounds per acre of 0–20–10 fertilizer was suggested for soils highly responsive to potash. In other states much smaller applications of limestone have been satisfactory on acid soils. Most of the sweetclover in the corn belt is seeded with small grain as a companion crop. Seeding sweetclover alone might be advantageous there were it not for the growth of annual weeds which develop freely in the unclipped crop. Spring grains are more satisfactory than winter grains as companion crops under Ohio conditions.[32] Field peas were a better companion crop for sweetclover in the nonirrigated areas of the Pacific northwest than any of the small grains.[14] Sweetclover should be seeded alone where moisture is a limiting factor, as in many parts of the Great Plains. In the Red River Valley of Minnesota, the maximum total weight of roots, tops, and stubble in October of the first year was obtained when all sweetclover varieties (except Grundy County) were sown alone in April.[7]

Owing to the high percentage of hard seed, scarified seed is used most widely, especially for spring seeding. The sowing of unhulled unscarified seed on winter wheat in January or February has been recommended,[33] but is not generally successful.

Sweetclover is almost always seeded in close drills, except under extremely dry conditions or for seed production. In Oklahoma, sweetclover seeded in 36- to 42-inch rows and cultivated to control weeds during the first season produced a yield of roots similar to that from seedings in rows 7 inches apart.[10] The wider rows also were advantageous in the western part of the state where the available moisture is relatively low. However, it is inadvisable to grow sweetclover where such methods are necessary. Deep seeding may be responsible for some sweetclover failures, as indicated by experiments in Saskatchewan [24] (Table 2).

Sweetclover is generally sown early in the spring at about the same time as and usually along with small grains. Sometimes it is seeded broadcast on winter wheat fields in February or March. In Ohio summer seeding produced lower yields of nitrogen and organic matter for plowing under early in May of the second year, than did spring seeding.[32] In Oklahoma and Kansas sweetclover frequently is seeded in the fall.

TABLE 2. EFFECT OF DEPTH SEEDING SWEETCLOVER UPON EMERGENCE OF SEEDLINGS

DEPTH OF SEEDING (*in.*)	DAYS FROM SEEDING TO EMERGENCE (*no.*)	EMERGENCE (%)
0.5	4	98
1.0	5	88
1.5	6	46
2.0	7	20
2.5	9	2
3.0	None emerged	0

The rate of seeding sweetclover usually ranges from 4 to 25 pounds, 10 to 12 pounds per acre of scarified seed being a popular rate. For Michigan conditions, 15 pounds of scarified seed, 18 to 20 pounds of unscarified seed, or 25 pounds of unhulled seed per acre were recommended.[20] For the Pacific northwest, 10 pounds per acre were recommended for nonirrigated, and 20 pounds for irrigated lands.[14, 15] Three to 6 pounds per acre were recommended for 36 to 42-inch rows in Oklahoma.[10] In an Ohio experiment the final stand of sweetclover in the second year was about 30 plants per square yard, regardless of the original stand.[32] Little change occurred in the stand during the first year unless the stand was abnormally thick or the season unusually dry.

Utilization

PASTURE

Sweetclover is a valuable pasture crop, especially in the Great Plains where it is reported to carry more livestock per acre than other plants common to the area. In the corn belt the average period of grazing for the second-year growth was reported as 111 days.[6] The best grazing is from about May 1 to July 20.

When conditions are favorable, sweetclover may be pastured lightly for 60 to 75 days during the fall of the seeding year. Some top growth should be left for winter protection in the northern states. The second-year plants are generally grazed early enough in the spring to avoid coarse woody growth. The danger of bloat is less than on alfalfa, red clover, or alsike clover. If not overgrazed, yellow sweetclover often reseeds itself. This seed production, together with the hard seeds that germinate after the first year, often maintains stands for several years.

HAY

Sweetclover is an important hay crop in many areas of the northern Great Plains. In 1933 it furnished about 30 per cent of the tame hay in North Dakota.[5] In the south, the first-year crop is cut for hay but in the northern plains the first-year crop seldom attains sufficient height. Where hay is the principal objective, sweetclover probably will never replace red or alsike clovers east of the Iowa-Nebraska boundary. It is unable to compete with alfalfa under irrigation in the west. Sweetclover has about the same feeding value as alfalfa when cut at the proper stage and cured into bright green hay. When cut too late, the coarse woody stems are largely rejected by livestock and the feeding value is low.

In West Virginia cutting biennial sweetclover the first year resulted in a reduced hay yield in the second-year crop, although the total yield was greater when cut both years[9] (Table 3).

TABLE 3. EFFECT ON YIELD OF CUTTING SWEETCLOVER THE FIRST YEAR OF GROWTH

DATE CUT IN 1931	AVERAGE HEIGHT *May 25* (*in.*)	AVERAGE HEIGHT *June 30* (*in.*)	AVERAGE YIELD DRY HAY *1931* (*gm.*)	AVERAGE YIELD DRY HAY *1932* (*gm.*)	AVERAGE YIELD DRY HAY *Total* (*gm.*)
Not cut	27.4	49.2	....	1912	1912
August 1	23.2	44.6	919	1571	2490
August 20	20.8	45.2	1121	1542	2663
Sept. 10	20.4	44.6	1190	1385	2575
Sept. 30	19.4	43.0	1095	1370	2465

Sweetclover should be cut for hay in the bud stage, or at least by the time the first blossoms open. Plants cut the second season at the prebud stage of growth make a more vigorous recovery than when cut later.[9] Delayed cutting until after the plants are in full bloom results in a coarse woody hay of relatively poor quality.

Sweetclover should be cut at a height of 6 to 10 inches where a second crop is desired. Since the new growth arises from buds in the axils of the branches and leaves on the lower stem, the plants are destroyed when cut below these buds. In Utah no second growth occurred on a 4-inch stubble, a 10 per cent crop on an 8-inch stubble, and a full crop on a 12-inch stubble.[27]

Sweetclover hay is more difficult to cure than that of alfalfa because the stems are thicker and dry more slowly and because the stems contain a higher percentage of moisture at the stage at which it should be cut. Delayed curing often results in loss of leaves. After the hay has wilted in the swath, the remainder of the curing should take place in the windrow or in cocks.

PRODUCTION FOR SOIL IMPROVEMENT

Sweetclover is widely used for green manure, especially in the humid regions. As is the case with other green manure crops, it has not resulted in any increase in average crop yields in dryland areas. The annual sweetclover may be grown where the crop is to be plowed under in the fall of the seeding year because of the difficulty in eradication of the biennial types at that time. The annual type can be grown for soil improvement in areas of Oklahoma where summer drought interferes with the normal development of the biennial varieties.[10] The annual type is used also in mild sections of Texas and the Pacific northwest irrigated sections where it survives the winter after fall seeding and can be plowed under in preparation for late-spring-planted crops.

The best time to plow under biennial sweetclover for soil improvement is in the spring of the year after seeding when the plants are 6 to 12 inches high. Under Ohio conditions, plowing between April 20 and May 10 secured 80 per cent of the maximum amount of nitrogen accumulated during the season.[32] This permits the planting of corn on the land. The plants are killed without difficulty at that time.

Seed Production

Seed yields vary from 2 to 10 bushels per acre and occasionally higher. The seed crop is harvested the second season. The seed crop should be cut when three-fourths of the pods have turned brown or black.[3] The seed pods shatter badly when mature, but this can be reduced to a minimum by cutting the plants when they are damp from rain or dew. Sweetclover seed is usually threshed with an ordinary grain separator equipped with a special huller attachment. The combine with the windrow and pickup has been used in some areas. Many of the seeds threshed even with the huller are hard, and do not germinate promptly unless they are scarified.

Coumarin in Sweetclover

The green sweetclover plant contains a large amount of coumarin, an aromatic substance which imparts a bitter taste, i.e., the so-called bitter principle. The coumarin renders the plant unpalatable to animals unaccustomed to its flavor. A study of eight different types of sweetclover revealed little difference in coumarin content among them.[17] The coumarin content varies in different parts of the sweetclover plant.[30] Newly formed leaves showed a higher content than old leaves. The buds have an extremely high content. The maximum coumarin content is found at the late bud or early flower stage of plant growth. The seeds also contain coumarin. A heavy growth of sweetclover or sourclover in a field of wheat may impart the coumarin odor to the threshed wheat to an extent that the bread made from it has the odor. This trouble rarely occurs in the United States except after sourclover in the southwest.

Coumarin may decompose into a toxic substance reported as hydroxycumarin or dicumarol that is believed to be responsible for the sweetclover disease of cattle, caused by the feeding of spoiled sweetclover hay or silage.[22] In this disease blood fails to clot normally when the animals are wounded. Affected animals may bleed to death from minor wounds. The toxic substance reduces the prothrombin content of the blood of animals that eat the spoiled hay. Prothrombin is essential to the clotting of the blood. A deficiency of prothrombin is responsible for the hemorrhages. Several cases of the disease occurred during the winter of 1922–23 in Minnesota, North Dakota, and Canada.[28] Apparently, bright hay free from mold is a safe feed. The hay of nonbitter sweetclover (*M. dentata*) does not become toxic on being similarly spoiled.[22] The use of second-year sweetclover for hay is hazardous because of the possibility of poisoning.

What was believed to be a low-coumarin strain was produced by continuous selection in Canada,[26] but later tests showed that the average coumarin content was nearly as high as in the unselected strain. Attempts to transfer the low coumarin character of *M. dentata* to other sweetclover species, at first unsuccessful, now appear rather promising. The low coumarin content is inherited as a simple recessive.[12]

Diseases

Diseases affecting sweetclover are more serious in the humid regions than west of the Iowa-Nebraska boundary.

The black-stem disease caused by *Mycosphaerella lethalis* (or *Ascochyta lethalis*), prevalent in Kentucky,[16] is characterized by blackened stems that become evident late in the spring on second-year stems. The leaves, as well as the young stems, may be killed when injury is severe. The disease appears to be most serious when wet weather occurs while the first 6 to 8 inches of growth is being made. Other diseases of sweetclover include root rot caused by *Phytophthora cactorum* and gooseneck stem blight caused by *Ascochyta caulicola.*

Insects

Sweetclover is relatively free from insect injury as compared with most other crops. In recent years the sweetclover weevil *Sitona cylindrocollis* has damaged the crop seriously in the northern states. This weevil can be controlled by dusting with DDT.

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24 THE TRUE CLOVERS

The farmer can ameliorate 100 acres with clover more certainly than he can 20 from his scanty dung heap. While his clover is *sheltering* the ground, *perspiring* its excrementitious effluvium on it, dropping its putrid leaves, and *mellowing* the soil with its tap roots, it gives full *food* to the stock of cattle, keeps them in heart, and increases the dung-hill.—J. B. Bradley, *Essays and Notes on Husbandry and Rural Affairs.* Philadelphia. 1801.

Economic Importance

The introduction of clover into customary crop rotations in the sixteenth century revolutionized agricultural practices throughout the world. Red clover is today one of the most widely adapted crops available for soil improvement and forage for the cooler humid parts of this country.

Statistics are available for clover only in combination with timothy hay. The average annual harvested acreage in this country from 1937 to 1946 was about 20 million acres. The production was 27 million tons, or nearly 1.4 tons per acre. The five states that led in hay production were New York, Wisconsin, Pennsylvania, Iowa, and Ohio (Figure 199). The various clovers are used for hay, pasture, soil improvement, and as cover crops.

An average of about 1,600,000 acres of red clover was harvested for seed yielding more than 1½ million bushels, or nearly 1 bushel per acre. Alsike clover harvested for seed averaged 126,000 acres yielding 302,000 bushels or 2.4 bushels per acre. During the 10-year period the annual production of white clover seed ranged from 275,000 to 2,300,000 pounds and of crimson clover seed from 1 million to 17 million pounds.

Four species of true clover are of primary importance in this

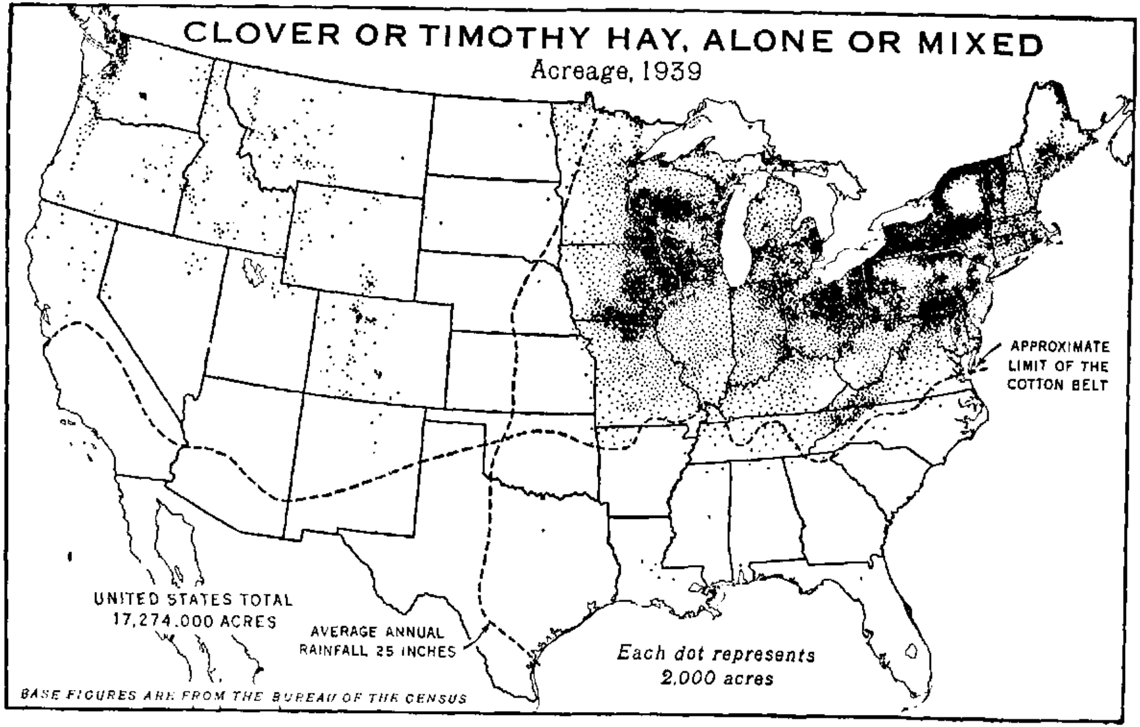

FIG. 199. Distribution of clover and timothy cut for hay.

country, viz., red, alsike, white, and crimson. Several others, viz., strawberry, hop, Persian, sub (subterranean), and cluster clover are of less importance except in certain regions. Sweetclover (Chap. 23), burclover (Chap. 30), Alyceclover (Chap. 30), and lespedeza (formerly called Japan clover) (Chap. 25) are not true clovers. Nine clover species, as well as several closely related plants, have been differentiated largely on the basis of their vegetative characteristics,[24] but some of the characters used are not wholly dependable for distinguishing the species.

Red Clover

HISTORY

Red clover (*Trifolium pratense*), including the type called Mammoth clover, is by far the most widely grown of the true clovers. It grows wild throughout most of Europe and ranges far into Siberia. The plant was generally cultivated in the Netherlands 370 years ago, from where it was carried to England in 1645. Red clover was grown by the American colonists as early as 1663. The crop has spread to nearly all regions in this country where there is sufficient rainfall. Under irrigation in the west, it is inferior to alfalfa for hay, except in some of the cooler intermountain valleys, particularly in Idaho, Utah, and Oregon. It is a heavy seed producer under irrigation.

ADAPTATION

In general, red clover is adapted to the humid sections in the northern half of the United States (Figure 200). It thrives in a cool, moist climate. In Ohio yields increased with increases in rainfall for April to June, inclusive.[38] Rainfall probably is the most important climatic factor determining clover adaptation in the northern states, although stands are often lost by winterkilling. Strains adapted to this area must be able to tolerate a long period of dormancy which at times may be accompanied by very low temperatures. High summer temperatures apparently cause little injury, provided moisture is abundant.[1]

Red clover makes its best growth on fertile well-drained soils con-

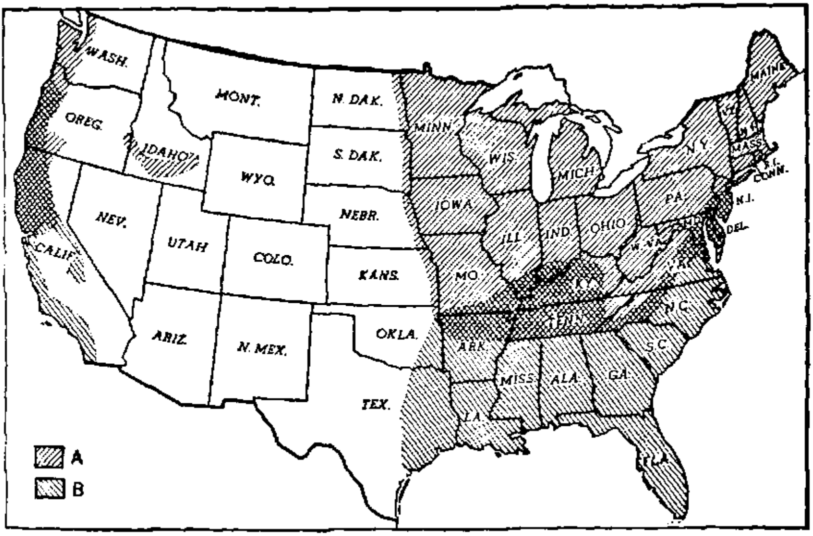

FIG. 200. General adaptation of clovers. A. Red, white and alsike clovers. B. White; and crimson and other winter-annual clovers, except that crimson clover is not grown along the Pacific Coast. In the Great Plains (not marked) the sweetclovers are grown. In the Intermountain Area strawberry clover is grown on wet saline soils.

taining an abundance of lime. Addition of phosphorus is necessary on most soils. It is not so well adapted to poorly drained or acid soils as is alsike clover. So-called clover failure, the partial or complete loss of stands either in the seeding year or second year, may be caused by an unfavorable soil condition. The addition of lime, phosphorus, and potash, alone or in combination, solves the soil difficulty.[26, 27]

REGIONAL STRAINS

Many clover failures in recent years have been due to the use of seed of unadapted strains, especially when the seed was imported from countries where the climatic conditions are less severe. Foreign clovers, with few exceptions, are unsatisfactory for use in the northeastern states.[29, 40, 41, 42] Strains from southern Europe are particularly unproductive. Foreign clovers that overwinter may produce a fair first crop, but a poor second cutting. They often die immediately after the first cutting. The stands generally go out because of winter injury, diseases (chiefly anthracnose and powdery mildew), or insects (chiefly leafhopper). Tests in Iowa, Ohio, and Kentucky of lots from Chile and eight European countries showed that they yielded only 60 to 71 per cent as much as did the local adapted strains. Those from France yielded 31 to 73 per cent as much. Foreign strains generally winterkill badly in Minnesota[5, 6] and Wisconsin.[9] The results shown in Table 1 are typical of the behavior of unadapted clovers from foreign and domestic sources when grown in the northern portion of the clover region.[6]

TABLE 1. HAY YIELDS OF RED CLOVER STRAINS IN MINNESOTA (TWO-YEAR AVERAGE)

SOURCE	LOSS IN STAND (%)	HAY YIELDS PER ACRE 15% MOISTURE BASIS *1st yr.* (*lb.*)	*2nd yr.* (*lb.*)	*Total* (*lb.*)
Domestic				
Northern grown	18.1	2862	1122	3983
Central, southern, and western	27.3	2409	1264	3673
Foreign				
Western and central Europe	21.3	2228	1016	3244
Southern Europe, England, Wales, and Chile	85.4	488	256	744

Locally adapted seed often is preferable to that from other states. In Kentucky, two local adapted strains of red clover outyielded foreign as well as domestic strains from other states.[11] Plants in the southern region must be resistant to southern anthracnose (*Colletotrichum trifolii*).

BOTANICAL DESCRIPTION

Wild red clover is extremely variable, most of the plants being short-lived perennials. Forms exist that are early, late, smooth, hairy, prostrate, erect, and semierect. One of these forms probably is the ancestor of the clover first used in agriculture.[30]

Red clover is a herbaceous plant composed of numerous leafy erect stems that arise from a thick crown. The stems generally attain a height of less than 30 inches. The leaf bears three oblong leaflets, usually with a pale spot in the center of each. The taproot, which has numerous laterals, may penetrate the soil to a depth of 3 to 6 feet. Red clover plants generally live two years, but a few survive longer. Thus, although a perennial from the botanical standpoint, agriculturally it is a biennial because of environmental hazards.

FIG. 201. (*Top*) Red clover heads. The two at the right have been attacked by the clover midge. (*Bottom*) Smooth (or appressed hair) European clover (*left*) and American domestic red clover with hairy stems (*right*).

The flowers are borne in compact clusters or heads at the tips of the branches (Figure 201). Each head contains 50 to 100 flowers. The flower consists of a green pubescent calyx with five pointed lobes, and an irregular magenta or purple corolla of five petals.[39] The flowers are pea-like, except that they are much more elongated and smaller, i.e., about one-half inch long. The claws of the petals are more or less united to the staminal tube. Nectar, secreted at the bases of the stamens, accumulates in the staminal tube around the base of the ovary. The pods are small, short, and break open transversally. Generally they contain a single kidney-shaped seed about one-twelfth inch long (Figure 194). The seeds vary in color from yellow to purple, the color variation being due largely to a complex heredity. Hard seeds are most frequent among those that are purplish.[34]

POLLINATION

In the pollination of red clover the florets develop and open from the base toward the top of the head.[30] The pistil usually is curved with the stigma extended beyond the anthers, but florets have been found with greatly shortened styles. The ovary has two ovules, one of which develops normally while the other aborts. Although the anthers shed their pollen in the bud stage, both stamens and pistil remain in the keel after the floret opens. The pistil is exposed only after the floret has been tripped.

Nearly all red clover plants are self-sterile. Because of the slow growth of the pollen tube in the style, the ovules disintegrate before the generative nucleus from the same plant reaches the egg. Self-fertile progenies have been obtained that continue to set selfed seeds. Other plants produce seeds when selfed, but the progenies may not necessarily be self-fertile. This phenomenon has been termed pseudo-self-fertility. A self-fertile line isolated in Minnesota was much less vigorous than commercial strains.[32] Cross-pollination is necessary for commercial seed production.

Cross-pollination of red clover is effected mainly by bumblebees and honeybees. They visit the floret for pollen or nectar or both. Honeybees obtain pollen principally. The honeybee is the major factor in pollination in Colorado.[37] On plants caged with honeybees 61.5 seeds per head were obtained as compared with 67.3 from the open field. Bees trip the florets and carry pollen from plant to plant. The nectar of red clover strains with short corolla tubes is more accessible to the honeybee, but less honeybee activity and less seed production has occurred in the Zofka (short-corolla tube) strain than in the American or Canadian strains.[4, 43]

TYPES AND VARIETIES

There are two distinct forms of red clover: (1) the early or double-cut that gives two hay crops in a season and (2) the late or single-cut that produces only one hay crop per season. The double-cut is known generally in this country as medium red clover, while the single-cut is commonly referred to as Mammoth red clover. Several types of each form are known. The single-cut clovers are taller, bloom 10 to 14 days later, and yield a heavier crop in the first cutting.[28] Except in unimportant particulars, the two forms do not differ in leaf shape, habit, root growth, or flower head.

Rough pubescent strains typify the red clovers of North America, with the hairs attached at right angles to the stems and leaf petioles. On the European forms the hairs are generally appressed or absent, and the plants are commonly classified as smooth. The two forms can be distinguished in the seedling stage.[18] The American form may have developed its characteristic hairiness as a result of the better defense of the hairy plants against leafhoppers, which prefer the smooth forms.[30]

Regional strains of red clover, which differ in productivity, winterhardiness, and disease resistance, have developed as a result of the action of local environment on a highly variable plant. The Tennessee Anthracnose-Resistant strain is a notable example. Winterhardy strains are available in most of the northern states. The Graham Mammoth strain is hardier than the medium or double-cut types under adverse conditions in Wisconsin.[2]

Improved varieties of red clover now being grown include Cumberland and Midland. Several others grown to a limited extent include Wagner, Tennessee Resistant, Kentucky 215, Van Fossen, Rahn, Letcher, Virginia Adapted, Kansas Red, Jacob Otten, and Emerson. Cumberland red clover originated as a composite of equal proportions of three strains, Kentucky No. 215, Tennessee Anthracnose-Resistant, and Virginia (Sanford). It is resistant to southern anthracnose and crown rot. Midland is a blend or composite of several strains, viz., Rahn and Letcher from Illinois, Kirch and Van Fossen from Ohio, Otten from Indiana, and Emerson from Iowa. Midland is winterhardy and has some resistance to anthracnose.[20]

CULTURAL METHODS

Red clover is well adapted to 3-year rotations. A common practice is to seed red clover with small grains the first year, harvest a hay crop the second year, and plow the clover under in preparation for corn the third year. The aftermath following the hay crop may be pastured before it is plowed under.

The seedbed for red clover should be fine, firm, and moist. Red clover is seeded most frequently either on stands of winter wheat or rye or with small grain in the spring. It is usually broadcast at the rate of 10 to 15 pounds, or often less, per acre, or is drilled with either a special clover drill or a grain drill with a grass-seeder attachment. The maximum safe depth of planting is about one-half inch on heavy soils or one inch on light soils. The crop is generally seeded early in the spring, although late summer seedings have been successful as far north as central Indiana.[27]

Red clover often is cut for hay when just past full bloom, although this is too late for the best quality of hay. At this stage the maximum of dry matter is present. Mammoth red clover is usually cut for hay in the early bloom stage on account of its tendency to become woody at later stages. Many of the leaves are lost when clover is allowed to become too dry either in the swath or windrow. The curing practices are similar to those for alfalfa.

UTILIZATION AS PASTURE

Red clover is an excellent pasture plant but close early grazing is injurious to the stand. Some pasture is ordinarily available in the fall of the seeding year, but some fall top growth should be allowed to remain to prevent winterkilling. There is some danger of bloat when the plants are pastured when young or wet.

SEED PRODUCTION

The production of red clover seed, especially in the corn belt, is generally incidental to hay production. An average set of 25 to 30 seeds per head indicates a fair seed crop, while 60 seeds indicates a good seed set. The factors that influence seed setting are not well understood. The general conditions that favor seed production are:[27] (1) a vigorous recovery after cutting; (2) clear warm weather when the second crop is in bloom; (3) an abundance of bees for pollination; (4) absence of injurious insects, such as the clover flower midge and the chalcis fly; and (5) good harvesting weather. Wide extremes in soil moisture do not prevent setting of red clover seed.[12]

High seed yields have been obtained in some of the intermountain states. In order to control injurious insects that affect seed, the first crop should be cut early for hay, or the first growth grazed.[13] Clover for seed should be irrigated sufficiently to produce a vigorous growth, but water should be withheld after the seeds are about half mature. Introduction of honeybees in the field when the plants are in full bloom will increase seed formation.

Red clover is ready to cut for seed when the heads have turned brown and the flower stalks are a deep yellow. The crop may stand until the heads are all black if cutting is done when the atmosphere is damp.[23] The mower with a windrower attachment is widely used for harvesting. The crop is now generally cured in the windrow. It is best threshed after the stems are dry, either with a clover huller or with a grain separator with proper equipment such as fine screens and corrugated cylinder teeth. A clover huller resembles a threshing machine (separator) except that it has two cylinders, one for threshing the pods from the stems and another to hull the seeds, and is constructed to avoid the leakage of small seeds which often occurs with a separator. Also the clover huller may have a recleaning attachment. At the present time much of the seed crop is threshed with a combine and pickup from windrows, but occasionally under ideal conditions by direct harvesting of the mature crop.

DISEASES

Southern anthracnose (*Colletotrichum trifolii*) is one of the most important factors in loss of stands south of the Ohio River, especially in Tennessee. This disease is characterized by a series of elliptical shrunken areas on the stems and leaf petioles which spread until the death of the plant. The disease is particularly virulent in damp hot weather. The Cumberland and Tennessee Resistant varieties are resistant. Northern anthracnose (*Kabatiella caulivora*) is often severe on the first crop of the second year in the northern clover belt, but seldom is it so virulent as the southern form. The Midland variety is somewhat resistant.

Powdery mildew (*Erysiphe polygoni*) occurs on red clover and causes some reduction in quality and yield throughout the clover belt. It appears as a powdery dust on the leaves of infected plants. A number of other diseases attack the leaves, but they seldom cause serious losses except in the quality of the hay.

The development of resistant varieties offers the most practical control for most clover diseases.

INSECT PESTS

Several insects cause damage to red clover, among them being the clover root-borer (*Hylastinus obscurus*), the clover-seed chalcis fly (*Bruchophagus gibbus*), the clover-flower midge (*Dasyneura leguminicola*), and the root curculio (*Sitonia hispidula*).

Fields frequently are heavily infested with the clover root-borer.

The larvae tunnel in the roots, especially in the summer of the second year. One control measure is to plow under the clover after the first hay crop has been removed, preferably between June 15 and August. A 3-year rotation has also been suggested.

The clover-seed chalcis fly is one of the worst seed pests in this country. It is a black wasplike insect about the size of a red-clover seed. The larva develops within the seed. To reduce the damage from this pest, all debris from threshing should be destroyed and the first spring growth should be grazed lightly.

The seed production of red clover is greatly reduced at times by the clover-flower midge (Figure 201). The maggots of this insect attack the florets, with the result that many fail to develop seed. Brown withered petals among the normally pink blossoms are a conspicuous symptom of attack by this pest. Midge may be controlled by cutting the first crop early enough to catch the maggots before they are fully developed. This is usually at the time they begin to change color from creamy white to salmon pink, i.e., early in June in most affected areas.

The root curculio gnaws and sometimes girdles the roots, causing wilting or death of the plants.

Other insects that may cause considerable damage are the clover aphids and the potato leafhopper. The former infest the clover heads, *honey dew* being secreted at the base of the florets. They bring about serious reduction in seed yield in the western states as well as causing the seed to be sticky when threshed. Late harvest of the hay crop and so-called burning of the stubble are effective control practices in southern Idaho. Burning is merely withholding irrigation water for one to two weeks to expose the stubble to the sun.[23] The potato leafhopper (*Emposaca fabae*) frequently attacks seedling or second-year plants in the humid regions, often stunting them. The European smooth clovers are particularly susceptible to leafhopper attacks.

Alsike Clover

Alsike clover (*Trifolium hybridum*), a native of northern Europe, has been cultivated in Sweden since the tenth century. It was introduced into the United States about 1839.

The geographical distribution of alsike clover is roughly the red clover-timothy area. It grows well in the intermountain states, especially under irrigation. Alsike clover requires a cool climate with an abundance of moisture. It rarely winterkills, being able to withstand more severe winters than does red clover. Alsike clover makes its best growth on heavy silt or clay soils that are moist. It is less sensitive to soil acidity and better adapted to low poorly drained soils than is red clover. Alsike clover sometimes thrives where clover failure is common with red clover.

Alsike clover is a perennial that persists for 4 to 6 years in a favorable environment, but usually lasts only two years in the middle west. The stems may reach a length of 2 to 3 feet. The stems and leaves are smooth. The flower heads are partly pink and partly white. Each pod may contain 2 to 4 seeds. The main axis continues to grow and single flower-bearing branches, each with one or more flower heads, arise successively from each leaf axil. The leafy branches grow in a similar manner. In red clover the main axis terminates in a flower to limit the growth. Branches arise from the leaf axils, these in turn being terminated by flowers.[25] The seeds of alsike clover are various shades of green mixed with yellow, and are about one-third as large as those of red clover (Figure 194).

Alsike clover plants are generally self-sterile. There are no recognized varieties.

The cultural methods are similar to those for red clover. The crop is seeded at the rate of 4 to 6 pounds per acre when grown alone. It is more often seeded with timothy or red clover or both. The crop is used for the same purposes as red clover.

Alsike usually yields less hay than does red clover, and produces only one crop in a season. The plant is especially suited for pasture mixtures, particularly in permanent pastures on wet sour land.

White Clover

White clover (*Trifolium repens*) is widely distributed in every continent, but is not believed to be indigenous to North America. It was brought to this country by the early settlers. It is a valuable addition to both humid region and irrigated pastures in America and is still a leading pasture legume.

ADAPTATION

The most favorable habitat for white clover is a moist, cool region under which growth is continuous. It will withstand greater temperature extremes than will either red or alsike clover. In the southeast[37] it is grown as a winter annual because most plants die there in early summer after they have produced seed.

White clover is adapted to moist soils, especially to clays or loams abundantly supplied with phosphorus and potash. Growth on strongly acid soils is not thrifty. Applications of phosphorus and potash are beneficial to growth on most soil types in humid regions.

BOTANICAL DESCRIPTION

White clover is a low, smooth, long-lived perennial plant with solid stems that root at the nodes. The roots are shallow. The flower heads arise from the leaf axils on long flower stalks. The flowers are small, and white to pink in color. They generally turn down when mature. The small seed pods usually contain four yellow seeds. White clover is extremely variable in leaf size, color, and markings; in size of runners; and in persistence.[3, 30]

White clover is practically self-sterile. The florets require cross-pollination for seed formation, usually done by bees.

TYPES OR VARIETIES

The white clovers of agricultural value have been grouped into three types, viz., (1) large, including Ladino, (2) intermediate (formerly called White Dutch) and Louisiana, and (3) small, which includes the types commonly found in closely grazed pastures. Representing the small type is the so-called English wild white clover. The small or low-growing type is more likely to show the presence of a cyanophoric glucoside but the quantity of hydrocyanic acid present is so small that it is harmless.[33] The development of varieties or strains has resulted from the action of environment on a variable species.

Ladino clover, which appears to have been introduced from the vicinity of Lodi in northern Italy, is about two to four times as large as common white in all plant parts except the seeds. The growth habits are similar to those of common white. Ladino does well and is widely grown under irrigation in the west. It is now also widely grown in the northeast and is spreading in the middle west. It has proved suitable for hay and silage as well as for pasture.

Common white clover is composed of many types that differ only in minor characters. Except in northern locations, strains produced in Louisiana are slightly more persistent and productive than those from other sources.[11] White clover strains from Louisiana winterkilled almost completely in Wisconsin.[2]

Native white clovers (i.e., the small low-growing types found in closely-grazed pastures) in the northeastern states may have a common descent with the English wild form,[30] which originated from old established stands in England. The Kent variety, representative of this type, has small leaves, stems, and flower heads, and is not so well adapted in this country as the commercial white clover types.

CULTURAL METHODS

White clover is usually seeded with grasses, either on new seedings or on an established turf. In new seedings, the white clover is mixed with grass seed and the entire mixture seeded at one time, usually early in the spring, although in some places it is sown in early fall. The grass should be clipped short when it is seeded in turf. The rate of seeding is 2 to 3 pounds of clover seed per acre. When early fall-seeded for winter pasturage in Florida and south Georgia, scarified seed germinates better, especially at high temperatures.[8] The yield of top growth was significantly higher in New Jersey experiments where a complete fertilizer of lime, phosphorus, and potash was used.[3]

Cultural methods for Ladino clover are very similar to those for common white.[19] It may be sown in mixtures with orchard grass, timothy, bromegrass, meadow fescue, or reed canarygrass. Kentucky bluegrass soon crowds out Ladino clover. For Connecticut, a recommended Ladino seed mixture for pasture is: orchard grass, 6 pounds; Ladino clover, 2 pounds.[1] For hay, the mixture is timothy, 6 pounds; red clover, 6 pounds, and Ladino clover, 1 pound. These mixtures may be seeded with small grain in the spring, or without a companion crop between July 15 and August 20. The best stands are maintained when not mowed until the plants are 6 to 8 inches high, and not closer than 4 inches above the ground. Close cutting in October is particularly harmful. The crop should be cut for hay when one-tenth of the flower heads have turned brown.[10] Continuous close grazing of Ladino clover is inadvisable. It is not suitable for lawns because of its tall growth and inability to withstand close clipping. Ladino clover responds to applications of manure and to phosphate and potash fertilizers in sections where those elements are deficient.

UTILIZATION

The white clovers, except Ladino, are almost always grown in grass mixtures for pasture or lawns. Ladino will produce a hay crop under favorable conditions. Ladino clover pastures carried 30 to 40 per cent more stock than an equal acreage of alfalfa, red clover, alsike clover, or ordinary white clover under Idaho conditions.[35]

Strawberry Clover

Strawberry clover (*Trifolium fragiferum*) has recently assumed considerable importance in this country. It is a native of the eastern Mediterranean region, but its culture has extended to every continent. The crop is grown extensively in Australia on low-lying overflow lands.

Strawberry clover is adapted to a wide range of conditions. The primary requirement of strawberry clover is an abundance of water.[22] It thrives in wide temperature ranges from $-40°$ F. to high summer temperatures. It is unable to compete with white clover in the eastern states. Strawberry clover is of particular value on wet saline soils. Good growth has been observed where the salt content of the soil was more than 1 per cent, and established stands have survived salt concentrations of more than 3 per cent for long periods.[17] It tolerates these high salt concentrations when ample water is present. It has been known to survive on soils flooded for one to two months. It is a profitable pasture crop in the intermountain and Pacific coast states in places where the subsoil water table is so high that other crop plants are largely or wholly eliminated.

Strawberry clover is a perennial, low-growing plant that spreads vegetatively by creeping stems that root at the nodes. The leaves, stems, and habit of growth are similar to white clover. It is readily identified by the characteristic strawberrylike flower heads. The flower heads are generally round, being pink to white in color (Figure 202). As the seed matures, the calyx around each seed becomes inflated. The mature head is gray to light brown in color. When ripe, the capsules break from the head. The seed color is reddish brown or yellow flecked with dark markings. The seeds are much larger than those of white clover but slightly smaller than red clover seeds. The flowers are self-fertile.

Strawberry clover is ordinarily spring seeded at the rate of 2 to 5 pounds per acre. Unhulled seed is generally advised for late winter planting, and scarified seed for spring planting in places where the soil is too wet to cultivate. Growth is aided by mowing to reduce the competition of rushes and similar plants, particularly on unprepared seedbeds.

Strawberry clover is utilized almost entirely for pasture, but it also has been used for green manure on saline soils. It offers promise in the reclamation of saline, alkaline soils now considered waste lands in the western states. Strawberry clover herbage is as palatable

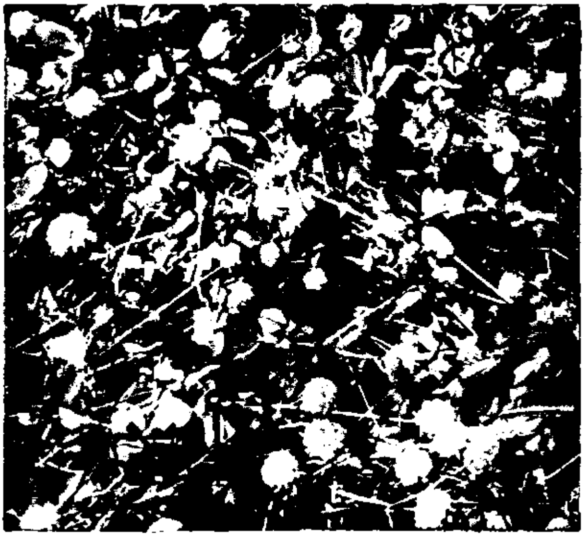

FIG. 202. Strawberry clover.

to livestock as is white clover. It survives close grazing, but it is more productive when grazed moderately.

Crimson Clover

Crimson clover (*Trifolium incarnatum*) is the most important winter annual among the true clovers. It is a native of Europe, being introduced into this country as early as 1819. It became agriculturally important about 1880. This clover is widely grown in the central belt of the eastern states.

Crimson clover is adapted to cool humid weather, where winter temperatures are moderate. It is sown in late summer or early fall in time to become established before winter. Crimson clover will grow on both sandy and clay soils. While the plant is tolerant of ordinary soil acidity, it is difficult to obtain a stand on very poor soils. This clover is being used effectively as a summer annual in Maine.

FIG. 203. Flower heads of crimson clover.

In general, the leaves and stems of crimson clover resemble those of red clover, but the leaflet tips of crimson clover are more rounded and there is a greater covering of hair on both leaves and stems. When sown in the fall, the young plants form a rosette that enlarges under favorable conditions. The inflorescence is an elongated spike-like head (Figure 203). The flowers are bright crimson in color, while the seeds (Figure 194) are yellow.

Crimson clover is self-fertile, and is less variable than either red or white clovers. Insects increase the amount of pollination since the florets are not self-tripping.

Two new hard-seeded varieties, Auburn and Dixie, are extremely useful because of their ability to maintain themselves in pastures and cultivated fields from self-seeding. The hard seeds do not germinate before autumn when conditions for plant growth are favorable. This provides winter cover and spring pasture where plants are allowed to go to seed. Dixie is a composite of three superior hard-seeded strains called Allen, Hardy, and Thornton.

Crimson clover is generally seeded in August or September between the rows of cultivated crops, either broadcast and covered with a cultivator, or with a drill. Crimson clover is sometimes seeded after a small grain crop, or with rye, vetch, Italian ryegrass, and fall-sown grain crops. The seeding rate is 15 to 20 pounds of hulled seed or 45 to 60 pounds of unhulled seed per acre.[16, 21]

Crimson clover is used for hay, pasture, winter cover and green manure. The crop furnishes an abundance of early spring grazing, as well as some fall and winter pasture under favorable growth conditions. It seldom causes bloat. This clover makes excellent hay when cut at the early bloom stage, although the yield is slightly less than at the full bloom stage. As crimson clover reaches maturity, the hairs on the plant become hard and tough. When such hay is fed, hair balls (phytobezoars) may be formed in the stomachs of horses, and these occasionally cause death.

As a green manure, crimson clover is generally plowed under 2 or 3 weeks before time to plant the next crop. As an orchard cover crop, it is generally allowed to mature, after which it is disked into the soil.

Winter Annual Clovers

Many winter annual species of *Trifolium* are found throughout the southern, south central, and Pacific states. Aside from crimson clover, the principal winter annual species are: large hop (*Trifolium procumbens*), small hop (*T. dubium*) called suckling clover in England (Figure 204), Persian (*T. resupinatum*), cluster (*T. glomeratum*), sub (or subterranean) (*T. subterraneum*), hop (*T. agrarium*) (Figure 205), and lappa (*T. lappaceum*). Hop, large hop, and small hop clover have yellow flowers.

Winter annuals seeded in the spring in the cotton belt or corn belt make only a small growth before the increasing length of day induces them to flower. Many of these winter annuals are perpetu-

FIG. 204. Pl. nt of small hop clover (*Trifolium dubium*).

ated from year to year by self-seeding in the early summer, from which they volunteer during the fall months. They become important agriculturally only when sufficient germinable seed is present to establish good stands. The seedcoats of many of these species are hard.[37] The seeds of the large hop, cluster, sub, and Persian clovers germinate when scarified. Even after scarification, germination of the seed of all species is inhibited in varying degrees by temperatures as high as 30° to 35° C.

FIG. 205. Branch of hop clover (*T. agrarium*).

Large hop and small hop clovers are both valuable pasture plants.[15] The association of hop clover with grass appears beneficial to the establishment of the clover, but tall northern grasses may shade it out. The clover is favored when the southern grasses become dormant in the fall. Most nearly complete stands are obtained with September and October seedings. Hop clover (*T. agrarium*) is becoming established naturally in the north central states. It is a native of Europe, probably introduced as a mixture in other clovers.

Sub (subterranean) clover is being used in pasture mixtures in the northwestern states. Tallarook and Mount Barker are new varieties.

Persian clover is a constituent of pasture mixtures in the southeastern states and sometimes is also cut for hay.

Berseem or Egyptian clover (*T. alexandrinum*) is grown to a slight extent as a winter annual in portions of southern Arizona and southern California where freezing weather seldom occurs. It succumbs quickly to temperatures a few degrees below freezing.

Lappa clover is reported to be well adapted to the black belt of Alabama where it has become naturalized.[36] It is able to reseed itself when used either for pasture or hay. Lappa clover appears to be inferior to some of the other annual types. This species has inconspicuous, lavender-rose, self-fertile flowers.

Zigzag clover (*T. medium*), a perennial species grown in England, has strong creeping rootstocks.

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25 LESPEDEZA

Economic Importance

Lespedeza is a major crop in the eastern half of the United States, exceeding all other tame hay crops of the nation except alfalfa, clover, and timothy. The area in lespedeza cut for hay increased from about 349,000 acres in 1929 to more than 7 million acres in 1946. The 10-year average area (1937–1946) was more than 5 million acres. The average yield was above 1 ton per acre. Seed was harvested on about 1 million acres in 1946, yielding about 220 pounds per acre. It is used widely for pasture and erosion control. Lespedeza had spread to 20 million acres of cropped and pasture land by 1940 [1] and now occupies nearly twice that area. Lespedeza provides a legume to help maintain soil productivity in the southeastern states where lime-deficient soils are too acid for economical production of either alfalfa or red clover, and the temperatures too high for perennial growth of red clover. It is especially valuable for growing on badly eroded soils in that region. Few crops make as much growth as sericea lespedeza on soils of low fertility.

The three cultivated species of lespedeza grown in this country are of Asiatic origin. The earliest record of common lespedeza, or Japan clover as it was called, indicates its presence in the southeastern states in 1846. The introduction of Korean lespedeza from Korea in 1919 has been the chief factor in the widespread use of lespedeza. The agricultural use of sericea lespedeza dates from an introduction from Japan in 1924, although the crop was first tried in North Carolina in 1896.[19, 20]

Adaptation

High rainfall well distributed throughout the growing season, relatively high humidity, and rather high temperatures favor the growth of lespedeza. The annual lespedezas are more drought-resistant than alfalfa or clovers [19] in the early growth stages, and the perennial sericea will endure extreme drought after it is well established. However, growth is so limited under dry conditions that none of the lespedezas is adapted to the semiarid Great Plains (Figure 225).

The lespedezas are warm-season plants that begin growth slowly in the spring. Except for Korean, which stops growth with seed maturity, the lespedezas continue to grow until frost.

All the annual lespedezas are sensitive to cold, and seedlings that start growth during warm periods in late winter may be killed by late spring frosts. The perennial sericea lespedeza has survived winter temperatures as low as − 17° F., but it may be killed down to the crowns by heavy spring freezes when in a growing condition. Lespedeza is most cold resistant in the cotyledon stage and becomes more tender as the plants develop.[25] In alfalfa and red clover, cold resistance increases with age, a reversal in this respect. A temperature of 23° F. for 16 hours has killed all lespedezas.[25]

Lespedeza may fail to set seed under extreme long-day conditions, and the photoperiod also affects the adaptation of varieties. Some varieties such as Early Korean and Harbin will mature seed from the Gulf of Mexico to the northern limits of the country whereas others mature seed only in the north or in the south. Fruiting is prevented in Korean when the day length is more than 14 hours.

The lespedezas will grow on most soils, especially on soils too acid for red clover without lime applications. However, plant growth is improved by use of lime or fertilizers, or both, on soils deficient in the mineral elements. Lespedeza makes little growth on the sandy soils of the coastal plain unless supplied with phosphorus.[23] In Florida, it was necessary to add calcium, phosphorus, and potassium to the sandy soils of the flat-pine lands to produce a satisfactory growth of lespedeza.[4] The distribution of the crop in Ohio is not limited by soil acidity even though lime applications increase growth.[3]

Sericea lespedeza can be grown on all Missouri soils without fertilizers or lime,[10] but it will respond to additions of lime or fertilizers on very poor soils. It fails on poorly drained soils.[19] It appears to make its best growth on the poor, eroded clays, silts, or silt loams of the Piedmont region and on similar soils elsewhere.

Botanical Description

The annual species of lespedeza in United States are common (*Lespedeza striata*) and Korean (*L. stipulacea*), while sericea (*L. cuneata*) is perennial. The prominent veins or furrowed surface of the leaflets serve to distinguish lespedezas from other legume crop plants. All varieties have a higher leaf percentage than does alfalfa.

ANNUAL LESPEDEZAS

The annual lespedezas are erect or spreading, small, branched plants.[9] They may attain a height of 24 to 30 inches, but the growth usually ranges from 4 to 12 inches. The leaves are small and trifoliate. The roots are medium deep and numerous. The plants produce two kinds of small flowers, that is, petaliferous flowers with purple or bluish petals, and the more numerous but inconspicuous apetalous flowers. Both kinds are believed to be self-pollinated.[20] The plants bloom from midsummer to early fall. The seeds are about the size of, or slightly larger than those of red clover, being borne in pods that retain the seeds when threshed (Figure 194). The hulls are brown.

FIG. 206. A branch of Korean lespedeza.

Common lespedeza is a slender plant, prostrate except in dense stands.[13] It usually grows to a height of 4 to 6 inches, but occasionally reaches 12 to 15 inches. The flowers are very small, purple, and inconspicuous. The seeds are borne in the axils of the leaves along the entire length of the stem. The seeds are dark purple mottled with white. The hairs on the stem are appressed downward.

Korean lespedeza (Figure 206) is coarser, and earlier than common,[12] and has broader leaflets, larger stipules, and longer petioles. The seed is borne in the leaf axils at the tips of all branches and not along the stem as in common. The seeds are a solid dark purple. At maturity the leaves of Korean turn forward so that the tips of the branches resemble small cones. The leaves of common do not turn forward. The hairs on the stems of Korean are appressed upward.

FIG. 207. Branch of sericea lespedeza.

SERICEA LESPEDEZA

Sericea is a perennial producing coarse, stiff, tough erect stems. A single stem on each plant 12 to 18 inches in height is produced the first season. Additional stems 2 to 5 feet in height arise from crown buds in subsequent years. The woody, widely branched roots penetrate the soil to a depth of 3 feet or more.[19] Both petaliferous and apetalous flowers occur in sericea, most of the seed being produced from apetalous flowers.[14] Pods from petaliferous flowers are larger and more acute. The sericea flowers are yellow or purple. The species varies in width of leaflets, height, coarseness and number of stems, and earliness [13] (Figure 207).

Hard Seeds in Lespedeza

The annual lespedezas often contain little or no hard seed, so that scarification is unnecessary. In tests made soon after harvest, considerable hard seed was found in Korean lespedeza,[15] but a rapid decrease in hard seed content occurred from November through January. Most of the hard seeds are small.[16]

Sericea lespedeza has a high percentage of hard seeds. Germination of unscarified seed ranges from 10 and 20 per cent,[19] so that scarification is necessary for prompt germination.

Varieties

Kobe and Tennessee 76 are selections from common lespedeza that differ in size of plant, both being larger than common. Tennessee 76 has an erect habit of growth, is highly productive, and matures later than common.[7] Kobe leaflets are broader and longer, and the seeds larger than those of common.[12] Kobe is less erect in thick stands than is Tennessee 76, but matures somewhat earlier. The seeds of all varieties of common lespedeza shatter badly. They are best adapted to the general region from northern Tennessee to the Gulf of Mexico because they require high temperatures.

Varieties of Korean lespedeza mature earlier than those of common lespedeza. Korean makes its best development in a zone that embraces Virginia and North Carolina on the east and eastern Kansas and eastern Oklahoma on the west. There are four selected varieties of Korean, viz., Harbin, Late Korean, Early Korean, and Climax. Harbin matures earlier than standard Korean, but resembles it in shape of leaflets and seeds and in seeding habits. Harbin will mature seed in the northern part of the country, but its dwarf habit makes it of little practical value. Early Korean resembles the standard type but matures about 2 weeks earlier. It is a reliable seed producer in northern Illinois but is unsuited to the southern range of the species. Aside from being later in maturity, Late Korean is similar to unselected Korean. Climax, a recently-developed variety, is about two weeks later in maturing than Korean and has produced larger yields of hay.

No named varieties of sericea lespedeza are being grown commercially at the present time. Sericea is well adapted to the middle latitudes of the eastern states.

Chemical Composition

At the usual hay cutting stage, the annual lespedezas contain significantly more dry matter and thus cure more rapidly than the other common legumes.[22] The lespedezas contain 36 to 49 per cent dry matter; alfalfa (first three cuttings), 27 to 29 per cent; and Laredo soybeans, 28 to 30 per cent.

The annual lespedezas are nearly equal to other legume hays in feeding value. In general, the digestible protein is slightly lower than in alfalfa while the digestible carbohydrate equivalent is higher. The protein content ranges from 9 to 17 per cent.[20] In sericea it varies with the stage of cutting. Sericea becomes very woody when the plants are 3 feet high, this being reflected in a high crude fiber content. The chemical composition of lespedeza in Illinois[18] is given in Table 1.

TABLE 1. CHEMICAL COMPOSITION OF LESPEDEZA AND OTHER LEGUME HAYS

CROP	MOISTURE (%)	ETHER EXTRACT (%)	PROTEIN (%)	CRUDE FIBER (%)	ASH (%)
Alfalfa	8.6	2.3	14.9	28.3	8.6
Red clover	12.9	3.1	12.8	25.5	7.1
Soybean	8.6	2.8	16.0	24.9	8.6
Common lespedeza	11.8	2.8	12.1	25.9	5.8
Korean "	7.2	3.3	16.2	26.0	7.4
Sericea "	5.9	1.8	12.3	30.1	6.0

All species of lespedeza contain some tannin, an astringent substance, most of it being found in the leaves.[24] The annual lespedezas have about 3 to 5 per cent of tannin while sericea contains much more. Tannin may occur in sufficient quantity in sericea to lower its palatability as pasturage. In sericea tannin is relatively low in the new growth but it may increase progressively from 7.5 up to 18 per cent between May and August. The whole plant may increase from 5 to 8 per cent in tannin content during this period. The tannin content decreases later in the season.[24]

The variations in tannin content appear to offer a plausible explanation of the apparently contradictory experience with the palatability of sericea as a forage plant.[5]

Rotations

In general, lespedeza rotations include a row crop followed by small grain with an annual lespedeza. The lespedezas will volunteer each year as long as desired, finally being plowed under in preparation for a row crop.

In the south, winter grain may be seeded on disked cotton, tobacco, or corn land, with annual lespedeza seeded in the grain.[20]

Farther north, Korean lespedeza may replace red clover in the standard rotations on soils not well suited to red clover. The volunteer stand of lespedeza will take the place of the second-year clover. A one-year small grain-lespedeza rotation is recommended for Missouri.[8] The harvested grain crop is followed by an abundance of lespedeza pasturage. The lespedeza will produce seed and volunteer each year, the land being disked or cultivated and the small grain seeded each fall.

Cultural Methods for Annual Lespedezas

Like all other crops, lespedeza will respond favorably to good cultural practices. A firm seedbed is essential whether the crop is seeded alone or with small grains. When seeding on meadows or pastures, a common practice is to first loosen the soil with a spring-tooth harrow or disk. Inoculation is seldom necessary in the south, except possibly on badly eroded soils. Korean developed fewer nodules than did other annual varieties in Alabama.[6] Inoculation resulted in an increase in the number of nodules on Korean. North of the Ohio river, it is generally advisable to inoculate lespedeza seed when growing it for the first time.[3]

SEEDING

The annual lespedezas are seeded either broadcast or one-half inch deep or less with a grain drill. In general, lespedeza is seeded in the spring about 2 weeks before the last freeze is expected in the locality. In Tennessee and farther south it is usually sown between February 15 and March 15. In the north, seedings are made from March 15 to April 15. Early seedings are subject to late freezes.

Korean, common, or Tennessee 76 should be seeded at the rate of 25 to 30 pounds per acre, and Kobe at 30 to 40 pounds.[12] For Missouri conditions, Korean should be sown at the rate of 20 to 25 pounds per acre on good land, or 15 to 20 pounds on poor land.[8] On pastures, or in pasture mixtures, 5 to 8 pounds of seed are generally sufficient.

Stands of lespedeza have been obtained on severely eroded land in the hilly areas of the southeast by the use of mulches, either applied or grown in place.[11]

UTILIZATION FOR PASTURE

The annual lespedezas grow actively during the hot summer months when grasses make little growth. They sometimes can be maintained in grass-legume mixtures for permanent pastures with grasses that do not form a dense sod. In many places, however, the pasture must be cultivated and lespedeza resown every year or two. In a perennial grass pasture close grazing of the grasses in the spring is often practiced to favor the lespedeza. Common lespedeza appears to survive longer in grass mixtures than do the improved varieties. The lespedezas persist in pastures because they set their seed near the ground. When grown with small grain lespedeza is ready for grazing soon after the grain is removed. The principal grazing months are July, August, and September.[20, 12]

HARVESTING FOR HAY

Annual lespedezas are used as hay crops, particularly where soil conditions are unfavorable for perennial legumes. Hay of excellent quality can be made from lespedeza, especially when cut in the bloom stage. This usually occurs about August 1 from Missouri to Virginia. By this time a growth of 8 to 10 inches is attained. Korean may be cut earlier than the other annual varieties because it makes a more rapid early growth. A stubble of 3 to 5 inches is generally left to permit new growth. Since lespedeza cures rapidly it usually is raked into windrows 2 to 4 hours after cutting A buncher or windrower attachment may be used on the mower to put the crop in windrows as it is being cut.[8]

HARVESTING FOR SEED

Seed of the common, Kobe, and Tennessee 76 varieties is generally harvested immediately after the first fall frost since they lose their seeds very rapidly thereafter. The usual harvest method is with a mower having a shallow pan covered with a perforated top attached to the cutter bar to catch the best seed as the ripe hay is raked across the pan by hand. The hay may be threshed if more seed is desired.

Korean varieties do not shatter so readily as those of the common type. They may be harvested at any time after maturity, but preferably after the plants are brown. Korean lespedeza is generally cut with a mower without a seed pan, windrowed, and threshed either with a pickup combine or with an ordinary thresher. Cutting should be done when the plants are damp, except when cutting with a combine.

Cultural Methods for Sericea Lespedeza

Sericea is seeded from March to July after all danger of frost is past. The crop is usually sown alone, although occasionally it is seeded on winter grain in the north. It is sown at the rate of 20 to 30 pounds of scarified seed or 50 pounds of unhulled seed per acre. In Virginia, best results were obtained with scarified seed sown from March 15 to April 15 on specially prepared soil.[9] The soil should be mulched when sericea is seeded on eroded knolls or in gullies. Seedings on established meadows and pastures have failed.[17]

HARVESTING

Sericea is primarily a hay plant. In Missouri, sericea will produce two hay crops per season, or one crop of hay and one seed crop, or one hay crop followed by summer pasture.[10]

Sericea is cut for hay when the plants are 10 to 15 inches high. At this stage the hay is comparatively high in protein and low in tannin. The plants develop little woodiness up to a height of 12 inches, but woody tissue increases rapidly in the later stages. As sericea cures quickly, it should be windrowed within one hour after cutting, or be cut and windrowed in one operation. Two or three cuttings may be harvested under favorable conditions. In Tennessee, yields of 4.14, 3.39, and 3.29 tons of hay per acre were obtained when sericea was cut 2, 3, and 4 times per season, respectively.[17] Four cuttings may seriously reduce the stand. Only one cutting is advisable on very poor soils. When cutting, a stubble of 3 to 5 inches should be left because the new growth comes from the stems as in sweetclover.

The first or second growth may be harvested for seed, usually after most of the pods have turned brown. The seed crop is harvested with a mower with a windrow attachment, with a binder, or with a combine. Seed yields average about 400 pounds per acre.

Sericea is ready to be grazed when it reaches a height of 4 to 6 inches, being palatable at this stage. The pasture should be grazed heavily to keep down coarse growth, which is unpalatable.

Role in Soil Conservation

Lespedeza is effective in the control of soil erosion because of its dense growth, its ability to establish a cover on poor soil, and the high retension of winter rains by old lespedeza sod. During a 12-month period the runoff from Korean lespedeza land was 11.7 per cent, with a soil loss of 1.6 tons per acre.[8] Under comparable conditions continuous corn showed a loss of 60.8 tons of soil per acre and a 30.3 per cent runoff. While the stubble of annual lespedeza tends to prevent erosion during the winter, a winter cover crop after lespedeza will improve the effectiveness.

Sericea is well suited for seeding buffer strips, critical slopes above the flow lines of terraces, small gullies, and depressions for water outlets. The annual lespedezas are used in some of these places, especially in combination with grass.

Diseases

Korean lespedeza is often attacked by the southern blight fungus (*Sclerotium rolfsii*) in the southern part of the region in which it is grown, but attacks are seldom severe enough to be of economic importance.

A bacterial wilt (caused by *Phytomonas lespedezae*) attacks the annual lespedezas.[2] The Early Korean is the only variety that has been particularly susceptible. The disease is recognized by dark water-soaked spots on the leaflets that soon become grayish brown, desiccated, and curled. Entire plants wilt and die within a few weeks. A bacterial exudate on the stems distinguishes it from the southern blight disease. The only prevention appears to be the use of disease-free seed.

Insects

Lespedeza is thus far relatively free from insect injury. Leafhoppers and some leaf-chewing insects, including webworms, occasionally attack the plants.

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26 SOYBEANS

Economic Importance

Soybeans * were grown on an average of nearly 12 million acres in the United States from 1937 to 1946. Of this, about 7,200,000 acres were harvested for seed, 3,300,000 acres were cut for hay, and the remainder was grazed or plowed under for soil improvement (Figure 208). The average acre yields of soybean seed and hay were about 18.7 bushels and 1.3 tons, respectively. The production of soybean seed ranged from about 46 million bushels in 1937 to nearly 200 million bushels in 1945 with an average of 134 million bushels. The urgent need for fats and proteins brought a large expansion after our entry into the war.† The five corn belt states, Illinois, Indiana, Ohio, Iowa, and Missouri, which lead in soybean production, account for 85 to 93 per cent of the seed crop (Figure 208). In the south and in the Atlantic states soybeans are grown primarily for forage and soil improvement. The leading countries in soybean production are China, Manchuria, United States, Korea, and Japan.

History of Soybean Culture

The soybean is one of the oldest of cultivated crops. Its early history is lost in antiquity. The first record of the plant in China dates back to 2838 B.C.[25] It was one of the five sacred grains upon which Chinese civilization depended. The cultivated soybean probably was derived from a wild type, *Glycine ussuriensis,* that grows in eastern Asia.[25]

* For summaries of soybean culture and uses see *The Soybean Digest,* Vol. 6, No. 11, Sept. 1946.

† Strand, E. G., *Soybean Production in War and Peace,* U. S. Dept. Agr. Bur. Agr. Economics, pp. 1–41 (1943) (Processed).

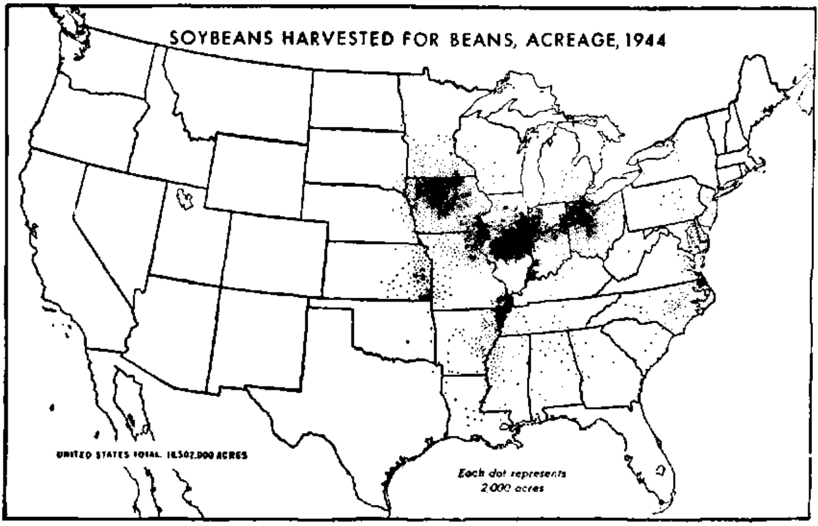

FIG. 208. Distribution of soybeans harvested for beans.

The soybean was known in Europe in the seventeenth century, and in the United States in 1804. Little attention was given to the soybean as a crop until 1889 when several experiment stations became interested in it. A large number of varieties were imported by the U. S. Department of Agriculture in 1898. Since that time there has been a rapid expansion in soybean production, particularly since about 1920.[30] Most of the soybeans were grown in the south prior to 1924, when they began to assume importance in the corn belt.

Adaptation

The climatic requirements for the soybean are about the same as those for corn. Soybeans will withstand short periods of drought after the plants are well established. In general, combinations of high temperature and low precipitation are unfavorable. Soybean seed produced under high temperature conditions tends to be low in oil and oil quality.[5] A wet season does not seriously retard plant growth, but soybeans are sensitive to overirrigation.[31] The period of germination is the most critical stage in plant growth, excess moisture or a prolonged drought at this time being particularly injurious.[26] Soybeans are less susceptible to frost injury than is corn. Light frosts have little effect on the plants either when young or nearly mature.

The soybean, a short-day plant, is sensitive to photoperiods.[11] Northern varieties mature quickly with little vegetative growth when grown in the south. With normal days there is a considerable spread in flowering between early and late varieties. In artificial 8-hour days all varieties flower quickly and at the same time. Within a variety, variations in time of flowering from year to year with the same day length appear to be closely associated with temperature conditions.

A mean midsummer temperature of 75° to 77° F. appears to be optimum for all varieties. Lower temperatures tend to delay flowering. About 4300 heat units in 5 months are required to mature soybeans.

Soybeans grow on nearly all types of soil, but they are especially productive on fertile loams. They are better adapted to low fertility soils than is corn, provided the proper nitrogen-fixing bacteria are present. Soybeans will grow on soils that are too acid for alfalfa and red clover.

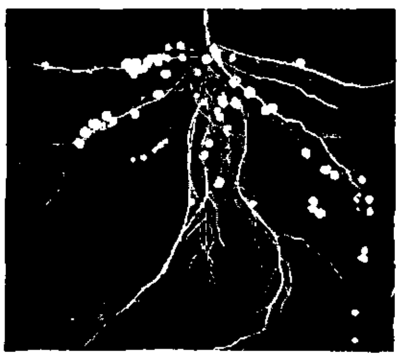

FIG. 209. The soybean plant produces large nodules on the roots when the proper nitrogen-fixing bacteria are present.

Botanical Description

The accepted botanical name for the soybean is *Glycine max*, formerly *Soja max*.[29] The soybean plant, an annual summer legume, is usually erect, bushy, and rather leafy (Figure 209). It attains a height of several feet under favorable conditions. Most varieties have a well-defined main stem that branches from the lower nodes when the plants have sufficient space. All soybeans are strictly determinate as to growth habit; that is, the plants reach a definite size, mature, and die. The leaves are trifoliate, the leaflets generally being ovate-lanceolate in shape. A few types have narrowly linear leaves. As the time of maturity approaches, the leaves nearly always begin to turn yellow. They usually drop off before the pods mature (Figure 210). The leaves and stems of nearly all varieties are covered with fine tawny or gray pubescence.[42]

FIG. 210. Mature soybean plants after the leaves have dropped.

The small purple or white flowers are borne in axillary racemes on peduncles arising at the nodes. The flowers appear first toward the base of the main stem, then progressively later toward the tip. The pods are small, being either straight or slightly curved, and are covered with long hairs. They range in color from very light straw through numerous shades of gray and brown to nearly black. The pods contain 1 to 4 seeds, but occasionally 5 seeds are found. The seeds vary in shape from round to elliptical. Most varieties have unicolored seeds that are straw yellow, greenish yellow, green, brown, or black. Bicolored seeds occur in some varieties, the common pattern being green or yellow with a saddle of black or brown.

The seedcoats of many yellow and green-seeded varieties sometimes become splashed or blotched with irregular brown or black markings superimposed on the basic color. This mottling, which is sporadic and never occurs in some areas, is due both to heredity and environment.[28] Rich soils, liberal spacing between plants, and shading are conducive to mottling. Selected strains have a high degree of resistance to mottling,[8, 42] and most of the widely used varieties are not subject to mottling.

The soybean is normally self-fertilized because pollination occurs about as soon as the flower opens or a little before. Although natural crossing is much less than one per cent,[10, 41] it may account for many varietal mixtures. Natural cross pollination appears to be the work of insects such as thrips and bees.

Varieties

More than 100 varieties of soybeans are grown in this country. They range in period of maturity from 75 to 175 or more days. The yellow-seeded types are generally grown for seed production, especially when they are to be processed for oil, oil meal, and flour, in order to avoid discoloration of these products. Forage types are generally those with black or brown seeds. They are generally smaller-seeded, finer-stemmed, and more leafy than the yellow-seeded varieties. The varieties most suitable for either dry edible or green-shelled beans are those with straw-yellow or olive-yellow seeds (Figure 211).

Soybean varieties differ widely in seed color, flower color, and color of pubescence.[9] A brief description prepared by W. J. Morse of some of the most widely grown varieties is given in Table 1, page 740.

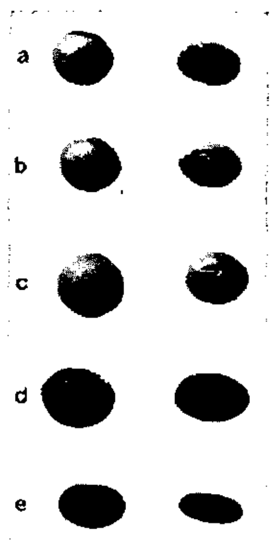

FIG. 211. Seeds of 5 soybean varieties: (a) Manchu, (b) Mammoth Yellow, and (c) Tokyo (all yellow seeded), and (d) Biloxi and (e) Virginia (both brown seeded).

Among the field varieties Manchu, Illini, Dunfield, Morse selection 230, and Macoupin are adapted to Illinois.[4] The most important varieties in Iowa are Lincoln, Richland, Earliana, Mukden, Manchu, Dunfield, and Illini. In Nebraska,[16] Illini, Dunfield, and Manchu are recommended. The Richland and Lincoln are grown in Ohio. The Hongkong, Dunfield, Lincoln, and A. K. varieties are adapted to Kansas. Late forage types grown in the southern states include Otootan, Avoyelles, Gatan, and Laredo. Ralsoy, Ogden, Laredo, Biloxi, Mammoth Brown, Mammoth Yellow, Arksoy, and Otootan are adapted to various conditions in Arkansas.[21]

Varieties developed for forage by selection from introductions include Virginia, Laredo, Otootan, Wisconsin Black, Manchu, Wilson-Five, Kingwa, Peking, Avoyelles, Gatan, and Ebony. Several yellow-

TABLE 1. DESCRIPTIONS OF IMPORTANT SOYBEAN VARIETIES

VARIETY	SEED COLOR	TYPE	DAYS TO MATURITY	HILUM COLOR	FLOWER COLOR	PUBESCENCE
Lincoln	Straw yellow	Grain	Early	Black	White	Tawny
Richland	Straw yellow	Grain	Early	Brown	Purple	Gray
Illini	Straw yellow	Grain	Early	Brown	White	Gray
Manchu	Straw yellow	Grain	Early	Black	Purple	Tawny
Dunfield	Straw yellow	Grain	Early	Brown	White	Gray
Earlyana	Straw yellow	Grain	Early	Black	Purple	Tawny
Mukden	Straw yellow	Grain	Early	Brown	White	Gray
Chief	Straw yellow	Grain	Medium	Brown	Purple	Gray
Virginia	Brown	Forage	Medium	Brown	Purple	Tawny
Ogden	Olive yellow	Grain	Medium late	Brown	Purple	Gray
Ralsoy	Straw yellow	Grain	Medium late	Brown	White	Gray
Mammoth Yellow	Straw yellow	Grain	Late	Brown	White	Gray
Tokyo	Olive yellow	Grain	Late	Pale	Purple	Gray
Woods Yellow	Straw yellow	Grain	Late	Brown	White	Gray
Avoyelles	Black	Forage	Very late	Black	Purple	Tawny

seeded varieties that have been selected for high oil content are Lincoln, Illini, Richland, Earlyana, Arksoy, Dunfield, Mukden, Mandell, Scioto, Mansoy, Manchu, Mamredo, Roanoke, Ogden, Mandarin, Wabash, Gibson, Patoka and Chief.

Vegetable varieties of soybeans cook up more readily than the field varieties. These varieties, which are used both as shelled green beans or as dry beans, include Bansei, Aoda, Rokusun, Hokkaido, Nanda, Seminole, and Kanro.[20, 33]

Chemical Composition

The chemical composition of soybeans as compiled by Morse[24] and by the Soybean Nutritional Research Council, Chicago, Ill., are given in Table 2.

The percentage of nitrogen in the leaves of soybean hay is nearly twice as high as that of the stems.[2] The percentage of nitrogen in the total tops decreases during the period of rapid growth and increases as the seed matures. More than half of the nitrogen in the total tops is stored in the seed at maturity.

The oil content of the seeds ranges from 14 to 24 per cent or more,[1] while the protein may range from 30 to 50 per cent. In general, soybeans with a low fat content are high in protein and vice

TABLE 2. ANALYSES OF SOYBEAN FORAGE, SEEDS, AND MEAL

ITEM	MOISTURE (%)	ASH (%)	CRUDE PROTEIN (%)	CARBOHYDRATES		OIL OR FAT (%)
				CRUDE FIBER (%)	N-FREE EXTRACT (%)	
Green forage	75.1	2.6	4.0	6.7	10.6	1.0
Hay	8.4	8.9	15.8	24.3	38.8	3.8
Seeds	6.4	4.8	39.1	5.2	25.8	18.7
Oil meal (hydraulic or expelled process)	8.3	5.7	44.3	5.6	30.3	5.7
Oil meal (solvent process)	8.4	6.0	46.4	5.9	31.7	1.6

versa. Soybean protein contains all the essential amino acids for animal feeds and human foods. Soybeans contain two to three times as much ash as wheat, and are a valuable source of calcium and phosphorus. Like other edible legume seeds, they are high in thiamin (vitamin B_1).

Rotations

The soybean is often grown in short rotations with corn, cotton, and small grains. As a full-season crop, it may occupy any place in a rotation where corn is used.[26] Soybeans may replace cowpeas in rotations. North of the Ohio River, a rotation of soybeans, wheat, and clover is common. Soybeans may be substituted for oats in the corn-oats-wheat-clover rotation or for the second crop of corn in a corn-corn-wheat-clover rotation. They may also be used as a catch crop where new seedings of grass and clover have failed.

On hilly land soybeans cannot take the place of sod legumes such as the clovers because they do not give sufficient protection against soil erosion, particularly when they are planted in cultivated rows. Erosion from soybean land is nearly as high as from land in corn.[8]

Cultural Methods

In general, the preparation of the land for soybeans should be the same as for corn. Applications of barnyard manure or of superphosphate and potash will increase yields on soils deficient in plant food elements. Nitrogen fertilizers are seldom necessary where the soil is inoculated with the soybean nodule bacteria. Lime applications on very acid soils stimulate nodulation and promote increased yields as well as a higher nitrogen content of both vines and seed. Even when inoculated, the growing of soybeans for seed cannot be expected to add to the total nitrogen of the soil unless the straw is returned.[32]

SEEDING

Soybeans may be planted from early spring until midsummer, the time being influenced by the latitude as well as the purpose for which the crop is grown. For grain or forage, soybeans generally produce the highest yields when planted at about the same time as is corn, or shortly afterwards. May plantings produced higher yields than June plantings in Illinois.[4] In West Virginia soybeans planted May 20 or later produced hay more nearly free from weeds than when planted about May 5,[27] whereas planting as late as June 25 made the crop so late that curing became more difficult. In Ohio,[2] Manchu and Peking soybeans produced the highest seed yields when planted April 15 to 20, and the forage yields of both varieties decreased with each successive planting made after June 1 because of the shorter season and lack of moisture. For pasturage, green manure, soiling, or even for hay, soybeans may be planted as late as August 1 in the southern states and July 1 in the northern states.[26]

Soybeans are planted either in rows far enough apart to allow for intertillage or in close drills (Figure 34). In general, the crop is planted in rows for seed production. Results [4] given in Table 3 indicate that in Illinois soybeans in rows 24 inches apart give higher seed yields than in close drills 8 inches apart.

TABLE 3. EFFECT OF RATE AND METHOD OF PLANTING ON YIELD OF ILLINI SOYBEANS IN ILLINOIS

METHOD OF SEEDING	RATE PER ACRE (*lb.*)	PLANTS IN 10 SQ. FT. (*no.*)	PODS PER PLANT (*no.*)	IMMATURE PODS (%)	YIELD PER ACRE (*bu.*)
24-inch rows (bean drill)	33.9	13	28	12	18.0
	59.3	21	20	8	20.5
	111.1	27	16	12	21.3
8-inch rows (grain drill)	121.4	56	8	48	18.4
	282.4	122	4	75	14.3

The crop is usually grown in close drills for hay, soiling, or green manure. A finer quality of hay is obtained by this method. The soybean has the ability to make wide adjustments to space, but the optimum spacing varies with the variety. For the Cayuga variety in New York, the optimum number of plants for maximum yields was 6 per square foot.[37] In the south most of the soybeans are planted in rows for hay as well as for seed. The row-cultivation method is especially superior to the close drilling in dry seasons.[22] Soybean rows range in width from 20 to 48 inches. The best results are generally obtained on fertile soils when the rows are from 24 to 36 inches apart, while on medium-fertile and poor soils the most satisfactory spacing is from 36 to 42 inches between the rows. In the southern states large late varieties are usually planted in rows from 36 to 48 inches apart.[26]

Under irrigation in Colorado,[30] higher seed yields were obtained from 20-inch rows than from 30-inch rows.

The grain drill is often used for planting in rows or close drills. The space between rows may be adjusted by closing some of the drills. The corn planter, cotton planter, and sugar beet drill are used for planting soybeans in rows.

The desired quantity of seed sown per acre for cultivated rows, varies from 10 pounds per acre for small-seeded varieties to 75 pounds for large-seeded varieties. The rate should provide enough seed to space the beans about one inch apart in the row. The rate of seeding in close drills should be from two or three times that in rows. In Illinois seedings of 50 to 70 pounds per acre produced higher yields than other rates in 24-inch rows.[4] For close drills the range was from 90 to 130 pounds per acre. In Nebraska, 30 to 40 pounds for 36-inch rows, or 90 pounds for close drills was recommended.[16] Variations in yield due to seasonal conditions are much more marked than those due to varying rates of seeding.[22]

A reduction in stand may result from seeding deeper than 2 inches in a fine sandy loam or 1 inch in a clay soil,[34] although satisfactory stands have been secured at a depth of 4 inches in loam and 2 inches in clay (Table 4, page 744).

HARVESTING FOR SEED

The soybean seed crop is ready to harvest when the pods are fully matured and the seed is in the hard-dough stage. The leaves

TABLE 4. MAXIMUM EMERGENCE OF ITO SAN SOYBEANS UNDER DIFFERENT SOIL AND TEMPERATURE CONDITIONS

DEPTH OF SEEDING (*inches*)	PERCENTAGE TOTAL EMERGENCE			
	Sandy loam soil		*Clay soil*	
	68.1°F.	*59.0°F.*	*68.1°F.*	*59.0°F.*
1	95	79	86	85
2	91	80	81	35
3	67	82	82	42
4	77	70	49	19
5	11	4	34	17

of most varieties turn yellow and drop as the plants approach maturity. The seed crop may be harvested with a combine, grain binder, mower with side-delivery attachment, self-rake reaper, or special bean harvester, but the combine is used almost universally. High seed setting adapts the Wabash variety to efficient combining.

When harvested with a binder, the crop is handled in practically the same manner as small grain crops. The bundles should be tied loosely and placed in small shocks for curing. With a few adjustments, the ordinary grain separator may be used to thresh soybeans.

The standing soybean plants are permitted to cure thoroughly in the field before being harvested with the combine or special bean harvesters. In the corn belt the combine is regarded as the most efficient method of harvesting soybeans because it saves a greater percentage of the seed. A light metal rim at the outer ends of the reel slats avoids the tearing of vines in combine harvesting.

HARVESTING FOR HAY

Soybeans may be cut for hay any time from pod formation until the leaves begin to fall. The best quality of hay is obtained when the seeds are about half developed. Although hay cut earlier will have a higher percentage of protein[23] (Table 5), it will yield less and be more difficult to cure. The weight of leaves increases until the beans are well formed, remains constant for about 3 weeks, and then decreases rapidly.[38] The hay contains about 60 per cent leaves when the beans are well formed, and about 50 per cent when the beans appear half grown. In addition to the loss of leaves, the stems become woody when cutting is delayed.

TABLE 5. COMPOSITION OF SOYBEAN HAY

STAGE OF GROWTH	MOISTURE (%)	PROTEIN (%)	FAT (%)	NITROGEN-FREE EXTRACT (%)	CRUDE FIBER (%)	ASH (%)
Full bloom	5.3	17.1	1.5	34.6	23.3	18.2
Pods forming	5.3	19.3	1.9	35.6	26.5	11.4
Beans half developed	5.0	16.6	3.0	36.3	26.3	12.8
Beans fully developed	5.3	16.8	8.8	34.9	25.1	9.1

The soybean hay crop is generally cut with a mower, although the binder is sometimes used. Soybeans are more difficult to cure than alfalfa or clover because the thicker stems dry out more slowly. When cut with a mower, a common practice is to allow the crop to remain in the swath for a day or two until thoroughly wilted. After wilting, the crop is raked into windrows where curing is allowed to continue for one to two days. Sometimes windrowed hay is bunched to complete curing. Some growers cure soybeans completely in the swath and rake them when slightly damp,[23] because drying is retarded in windrows in rainy weather.

Soybeans generally yield from 1 to 3 tons of hay per acre, the average yield of medium-maturing varieties on fertile soils in Illinois varying from 2 to 3 tons per acre.[12]

SOYBEAN MIXTURES

Soybeans may be grown in combination with other crops, especially corn. An average of more than 2 million acres are grown with other crops, mostly in the south. Often the soybeans are planted in alternate rows with corn. Soybean-corn mixtures are generally used for pasturage or silage. The most desirable rate of planting is an average of 2 corn plants and from 2 to 4 soybean plants per hill, or 1 corn plant every 12 inches and 1 soybean plant every 6 to 8 inches in drilled rows.[26]

The yield of corn as grain in mixed planting is reduced, but this is partly compensated for by the yield of soybeans and the higher protein content of the mixed crop. In West Virginia experiments, the yield of shelled corn was reduced 6 to 8 bushels per acre when grown with soybeans as compared with corn alone.[27] With unusually favorable conditions, corn with soybeans produced 91.8 per cent of the grain yield of corn alone at the Iowa Station.[13] Under less favorable conditions the corn yield was 82 per cent of normal. As an average for all conditions the yield of soybean seed was 52 per cent of the reduction in yield of corn grain. The yields of drilled beans more nearly approached the amount by which the corn yield was reduced than when both corn and beans were hill-planted. When cut for forage, the yield of both crops planted in hills was 101 per cent of that of corn alone, with the corn planted in hills and the beans drilled it was 110 per cent, while with both crops drilled it was 108 per cent. In New York, a gain of 7 to 15 per cent in dry matter was obtained when soybeans and corn were grown together as compared with corn alone.[36]

Soybeans grown in corn under more or less reduced light are inclined to lodge. Shaded soybean plants contain less dry matter and total carbohydrates than do those grown in the open.[35]

Soybeans and cowpeas are sometimes grown in mixture for hay, pasture, or green manure. The yield of the mixture is generally greater than either crop grown alone. Varieties of the two crops should be selected that mature at about the same time. Occasionally, soybeans are grown in combination with Sudan grass, small grains, millets, or sorghum.

Soybean Oil Extraction

Some 10 per cent or more of soybean seed is used for planting, and 3 to 7 per cent is fed to livestock on farms where it is produced. About 80 to 95 per cent of the soybeans in commerce are crushed to obtain the oil, the oil meal being a by-product. The remainder are used in feeds and foods or are exported. A bushel of soybeans (60 pounds) in the expeller process yields about 9 pounds of oil and 48 pounds of meal. The 3 pounds of loss is largely evaporated water. The oil content of the seed is 18 to 19 per cent.

Three general processes have been used to extract soybean oil, viz., the expeller, the hydraulic press, and the solvent-extraction processes.[3, 24] About 140 plants are operating in the United States.

The expeller or screw-press method, widely used in this country, is a continuous pressure process in which expellers are used (Fig-

FIG. 212. Extracting soybean oil in an expeller.

ure 212). The beans are crushed, dried to a moisture content of about 3 per cent, and passed through a steam-jacketed trough that heats the beans to about 150° F., before they reach the pressing cage of the expeller. This treatment renders the product more mobile without injury to either the oil or the meal. The expeller operates on the same principle as a household meat grinder. Pressure is applied to remove the oil which is pumped through a rotary strainer on its way to storage. The cake emerges in thin sheets that are broken up at the discharge end.

In the hydraulic press method, now nearly obsolete, the beans are prepared as for the expeller method, except that they are heated to a higher temperature before being pressed. Since the process is not continuous, much hand labor is required to load and unload the presses. This process is limited to mills crushing other seeds such as flaxseed and cottonseed.

In the solvent extraction process, which has increased in popularity recently, the oil is extracted from the ground beans by a chemical solvent such as benzol, naphtha, or ether. The solvent is recovered from the oil by distillation and is used again. Oil obtained by this process has superior bleaching properties, and the meal, since it contains less oil, is less subject to rancidity. Oil extraction by the solvent method is nearly complete, only 0.5 to 1.5 per cent being left in the meal. Meal or cake from the expeller or hydraulic press contains from 5 to 6 per cent of oil and has a toasted, somewhat nutlike flavor as a result of heating.

Quality of Soybean Oil

One of the most important qualities in soybean oil is the drying property as measured by the iodine number. A high iodine number indicates good drying quality for paint purposes, but oil with a low iodine number is regarded as more desirable for food purposes. The iodine number of soybean oil ranges from 118 to 141 in different varieties, while that of linseed oil is about 180.[25] However, soybean oil can be fractionated to produce oils of both high and low iodine number. In the hydrogenation process to produce solid fats for shortening or margarine, an oil with a low iodine number is desirable.

Soybean Utilization

As a forage crop, the soybean is preserved as hay or silage, or cut and fed green as soilage. The hay compares favorably with red clover, the chief objection being the coarse woody stems. Soybeans are a valuable supplement to corn for silage because of the high protein content. They may be used for late summer pasturage when perennial pasture is short. The dried beans are utilized to some extent as high protein feed for livestock. The soybean meal is also used as feed.

In the oriental countries soybeans are used in the production of soybean milk and curd, various soy sauces, fermented products, bean sprouts, and numerous other foods. Soybeans are also used in confections, soups, potted meats, food drinks, breakfast foods (puffed beans, flakes, and prepared meal), as salted roasted beans, soybean butter, and a substitute for coffee.[40] Most of the products except the fermented ones are now readily available in the United States. Soybeans are used widely as green shelled beans and dry beans.[7]

Soybean oil is now used primarily for shortening, margarine, and salad oil. The lecithin from the oil is used in baked goods, candies, chocolate, cocoa, and margarine.

Soybean flour is a valuable source of vegetable protein. It may be used in mixture with wheat flour in various baked products such as bread, cake, cookies, and crackers. Soybean flour has been used in ice cream, ice cream cones, candies, puddings, and salad dressing. Because of its low starch content, it has found a place as a diabetic food. Soybean flour will make good bread when mixed with wheat flour in any proportion up to 20 per cent.[1]

The meal is used in celluloid substitutes, core binders, glue, plastics, and water paints. The oil is utilized in the making of candles, celluloid, core oil, disinfectants, electric insulation, enamels, glycerin, insecticides, linoleum, oilcloth, paints, printing ink, rubber substitutes, varnish, soap, etc. The casein from vegetable milk produced from the dried bean is used in paints, glue, paper size, textile dressing, and for waterproofing.[1, 24, 25]

Diseases

While losses of soybeans from disease in this country are relatively less than for many other crops, a few diseases are of considerable consequence. The important diseases are sclerotial or southern blight, and the root knot or nematode disease.[14]

SCLEROTIAL BLIGHT (SOUTHERN BLIGHT)

Sclerotial blight caused by the fungus *Sclerotium rolfsii* is a rotting of the base of the stem. It occurs chiefly in sandy soil areas in the south. Losses sometimes are as high as 25 to 30 per cent. The disease attacks many other crop plants. No remedy is known.

CHARCOAL ROT

The charcoal rot disease caused by the fungus *Macrophomina phaseoli* (*Sclerotium bataticola*) also rots the base of the stems. After the plant is dead the stem and roots bear numerous black sclerotia (spore bodies). The fungus lives in the soil. No remedy for the disease is known.

ROOT KNOT

The root knot disease is caused by a nematode or microscopic thread worm (*Heterodera marioni*). The nematodes produce large galls on the roots. It has caused damage in many parts of the south. The best remedy is crop rotation and the use of resistant varieties such as Laredo.

BACTERIAL BLIGHT

Bacterial blight, caused by *Pseudomonas glycinea* and reported from various regions, occurs on the leaves as small angular spots. These spots at first are yellow to light brown, but later they become dark brown to almost black. Diseased tissues of the leaves may finally become dry and drop out. The spots sometimes spread to the stems and pods. Under favorable conditions, bacterial blight spreads rapidly in the field. The bacteria are seed borne, but they may overwinter on dead leaves.[26] Soybean varieties vary greatly in relative susceptibility to the disease, Midwest being highly susceptible.

POD AND STEM BLIGHT

Pod and stem blight, caused by the fungus *Diaporthe sojae*, has caused serious losses in the seed producing areas of the corn belt states. The stems and pods are heavily dotted with black spore-filled sacs (pycnidia). The fungus may girdle the stem, kill the plant, and prevent seed development. Sometimes the fungus penetrates the seed and destroys subsequent germination. The fungus is carried over winter on diseased stems and infected seed. Recommended control measures for the disease are crop rotation and the planting of disease-free seed.

BACTERIAL PUSTULE

The bacterial pustule disease, caused by *Xanthomonas phaseoli* var. *sojense*, occurs in most of the soybean fields of North Carolina and has been reported in several other states. The disease is confined largely to the foliage.[39] In the early stages the spots are light green in color. Later the disease is characterized by angular reddish brown spots on the leaves that may become large irregular brown areas. Portions of the larger spots frequently drop out. The organism overwinters in diseased leaf material as well as on the seed of diseased plants. Some control of the disease has resulted from disposal of dead diseased leaf material by plowing after harvest, and from crop rotation. The Columbia, Mandarin, and Old Dominion varieties are highly resistant to the disease.[19] Seed treatment has not been a satisfactory control measure.

FROG-EYE LEAF SPOT DISEASE

Frog-eye, a leaf spot disease caused by the fungus *Cercospora diazu*, attacks the leaves, pods, and stems of the soybean plant. It may go through the pod and enter the seed. The lesions are reddish in color when young, but change to brown, and then to smoky gray with age. The fungus overwinters on the diseased plant refuse left in the field after harvest. Frog-eye leaf spot is introduced into new fields by diseased seed.[18] Seed disinfectants have failed to give satisfactory control of the disease. Early varieties, although susceptible, escape serious injury.[17]

MOSAIC

Mosaic, a virus disease, is one of the most common soybean diseases in Illinois. Affected plants become stunted, while the leaflets are misshaped, with dark green puffy areas along the veins. Mosaic may reduce the yield of seed per plant from 30 to 75 per cent.[15] The disease has been found in seed 2 years old. Mosaic is very prevalent in the Midwest, Haberlandt, and Black Eyebrow varieties, but Soysota and Virginia tend to escape infection.

OTHER DISEASES

Other diseases of soybeans include root rots caused by the soil-inhabiting fungi, *Pythium debaryanum*, *Rhizoctonia solani*, and *Phymatotrichum omnivorium*, and stem rot caused by *Sclerotinia sclerotiorum*, and fusarium blight caused by *Fusarium oxysporum* f. *tracheiphilum*. The latter disease occurs on sandy soils in the south, and several varieties, including Laredo, are resistant.[14]

Brown spot is caused by *Septoria glycines,* anthracnose, by *Glomerella glycens,* downy mildew by *Peronospora manshurica,* and brown stem rot by *Cephalosporium* species.

Insect Pests

Soybeans have thus far suffered comparatively little damage from insect pests. The most serious insects [26] are grasshoppers, blister beetles, leafhoppers, the green clover worm, and the velvetbean caterpillar. Other insects attacking soybeans include army worms, cutworms, Mexican bean beetle, Japanese beetle, bean leaf beetle, flea beetle, and clover root curculio. Grasshoppers, cutworms, and army worms are controlled with poison bran bait. Dusting with cryolite or with a dust containing 5 per cent of DDT controls the velvetbean caterpillar, blister beetles, Mexican bean beetle, flea beetle, and the Japanese beetle. Leafhoppers also can be controlled with DDT dusts. Hay crops dusted with DDT should not be fed to dairy cows.

Rabbits

Rabbits, especially jack rabbits, have a great fondness for the soybean plant. Where rabbits are numerous they will completely destroy small fields of soybeans unless they are excluded by a tight fence.

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27 COWPEAS

Economic Importance

The cowpea was for years the leading legume crop in the south, but it is now being gradually replaced by others such as soybeans, lespedeza, and velvetbeans largely because of the high acre cost for planting seed.

Cowpeas were grown on an average of nearly 4,300,000 acres annually from 1937 to 1946. Of this acreage, nearly 1,300,000 acres, or 34 per cent of the total, were harvested for hay, 1,150,000 acres, or 27 per cent, were harvested for seed, and the remaining 1,850,000 acres were pastured, turned under for green manure, or both. During the 10 years before World War II, planting of cowpeas was stimulated somewhat by soil conservation programs. More recently, however, the acreage of cowpeas for all purposes has declined. The average acre yields of cowpeas are only about 1,660 pounds of hay and 5.3 bushels of seed. The average production has been about 1,280,000 tons of hay and 5,800,000 bushels of seed. In addition, an average of nearly 1,200,000 bushels of the California blackeye variety were grown in California for food and for seed (Chapter 28).

The leading states in cowpea production are South Carolina, Texas, Georgia, Alabama, Mississippi, Arkansas, and North Carolina.

History

The cowpea apparently is native to central Africa where wild forms are found at the present time. Hybrids of the wild plant and the cultivated cowpea are readily obtained.[6] The cowpea has been cultivated for human food since ancient times, particularly in Africa, southern Asia, and in the Mediterranean region of Europe. The cowpea is probably the *Phaseolus* mentioned by the Roman writers.[4]

It was introduced into the West Indies by early Spanish settlers. The crop was grown in North Carolina in 1714, and has spread throughout the southern states since that time.

Adaptation

Cowpeas are a warm-weather crop grown primarily in the southern states under humid conditions. They are grown to some extent as far north as southern Illinois, Indiana, Ohio, and New Jersey. The cowpea plant is similar to corn in its climatic adaptation except that it has a greater heat requirement. It is sensitive to frost both in the fall and spring. Severe drought generally prevents formation of seed in most varieties.[4] It can be grown in rows for hay or seed in the southern Great Plains where the average precipitation is as low as 17 inches, but the yields obtained scarcely justify the labor and expense involved in that method of production.

The cowpea is adapted to a wide range of soils. It grows as well on sandy soils as on clays. The plant thrives better than clover on either infertile or acid soils. There is a general tendency for it to produce a heavy vine growth with few pods on very fertile soils or when planted early. The primary soil requirements are good drainage, and the presence of, or inoculation with, the proper nitrogen-fixation bacteria cultures.

Botanical Description

The cowpea (*Vigna sinensis*) differs from the common bean (*Phaseolus* species) in that the keel of the corolla is only slightly curved instead of twisted or slightly coiled.[5] Two related subspecies are the asparagus bean (*Vigna sinensis* var. *sequipedalis*) and the catjang (*V. sinensis* var. *cylindrica*).

The cowpea is an annual herbaceous legume. The plants are viny or semiviny, and fairly leafy with trifoliate leaves (Figure 213). The leaflets are relatively smooth and shiny. The growth habit of the cowpea is indeterminate. It continues to blossom and produce seed until checked by adverse environmental conditions.

The white or purple flowers are borne in pairs in short racemes. The pods are smooth, 8 to 12 inches long, cylindrical, and somewhat curved. They are usually yellow, but brown or purple pods

FIG. 213. Plant of Victor cowpeas.

are found in some varieties. The seeds are generally bean-shaped but usually short in proportion to their width. The Crowder varieties produce seeds more or less flattened on the ends as a result of being crowded in the pods. The seeds are either uniformly colored or multicolored. The more common solid colors are buff, clay, white, maroon, purplish, or nearly black, with a second color usually concentrated about the hilum.[5] The multicolored seeds may be variously spotted, speckled, or marbled (Figure 214). The seeds weigh about 60 pounds per bushel. A pound contains 1600 to 4400 seeds.

The cowpea is largely self-pollinated. Natural crosses rarely occur in the field in most regions.

Catjang cowpeas are erect semibushy plants with small oblong seeds borne in small pods 3 to 5 inches long. The pods are erect or ascending when green, and usually remain so when dry. Varieties of this group are very late and not very prolific in this country so they are seldom grown here.

The asparagus bean or yard-long bean plants are very viny with pendant pods 12 to 36 inches long that become more or less inflated, flabby, and pale before ripening. The seeds are elongated and kidney-shaped. None of the varieties produces as much seed or forage as do the better cowpea varieties. Seedsmen offer the asparagus bean as a novelty vegetable, having pods so large that one suffices for a meal. It is not grown extensively because other beans are more palatable.

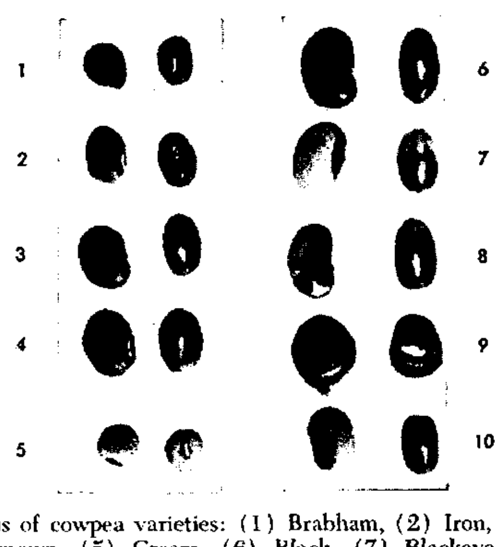

FIG. 214. Seeds of cowpea varieties: (1) Brabham, (2) Iron, (3) Whippoorwill, (4) Unknown, (5) Cream, (6) Black, (7) Blackeye, (8) Holstein, (9) Black Crowder, (10) Ayrshire.

Varieties

Good forage cowpea varieties are vigorous, erect, prolific and disease-resistant, bear the pods well above the ground, and retain their leaves late in the season.[4] Early maturity is important in the northern part of the cowpea region. The viny habit is considered desirable when the crop is planted in mixtures with corn or sorghum.

About 15 varieties are commonly grown in this country. The important forage varieties are Whippoorwill, Iron, New Era, Brabham, and Groit. Others grown to a lesser extent are Unknown (Wonderful), Clay, Red Ripper, Black, Victor, Taylor, Arlington, and Suwannee. Victor is the result of a cross between Groit and Brabham, whereas Brabham is believed to have originated from a cross between Iron and Whippoorwill; and Groit from a New Era-Whippoorwill cross. The white-seeded varieties such as Conch and Cream, the Blackeye sorts, and the Crowder varieties, are commonly grown for table use. The Crowder and Clay varieties are grown in the south for canning as green beans.

The late-maturing viny varieties, such as Clay, Iron, and Red Ripper are preferred in the Mississippi delta and nearby areas. Suwannee has given high forage yields in Florida.[3] In the northern part of the cowpea region the early varieties such as Whippoorwill and New Era are in demand. Brabham, Iron, and Victor have largely replaced other varieties in the wilt-infested areas of the south because of their resistance to wilt and nematode. Brabham is a popular variety in Texas and Oklahoma. The Chinese Red, an early dwarf erect, small-seeded variety, is preferred in the semiarid western part of Oklahoma. Improved strains of the California Blackeye variety include No. 5 and No. 6.

The characteristics of the leading cowpea varieties, prepared with the assistance of W. J. Morse, are shown in Table 1.

Crop Rotations

The cowpea is grown in corn and cotton rotations in the south to supply nitrogen and organic matter to the soil. Several widely-used cowpea rotations are given below: [4]

TABLE 1. CHARACTERISTICS OF LEADING VARIETIES OF COWPEAS

VARIETY	MATURITY	VINE HABIT	SEED SIZE	SEED COLOR
Whippoorwill (Shinney or Speckled)	Medium	Tall, suberect, half bushy	Medium	Buff, marbled with brown
New Era	Medium	Tall, erect, half bushy	Small	Buff, speckled with blue
Groit	Medium	Tall, erect, half bushy	Medium	Buff, marbled with brown, and sprinkled with blue specks
Brabham	Medium	Tall, erect, half bushy	Medium	Buff, marbled with brown
Iron	Late	Tall, suberect, half bushy	Medium	Cream buff to buff
Victor	Medium	Tall, erect, half bushy	Small	Buff, marbled with brown, and sprinkled with blue specks
Conch	Late	Low, trailing	Small	White
Rice	Medium	Low, trailing	Small	White
Suwannee	Late		Medium	Clay
Taylor (Gray Goose, Speckled Java)	Medium	Medium, trailing, half bushy	Large	Buff, with groups of blue specks
Early Buff	Early	Medium, erect, bushy	Medium	Buff or pinkish buff
Michigan Favorite (Revenue)	Medium	Low, prostrate, half bushy	Medium	Buff-pink (Crowder shape)
Chinese Red	Early	Low, erect, half bushy	Small	Pale red
Clay	Late	Tall, suberect, half bushy	Medium	Buff
Unknown (Wonderful)	Late	Tall, suberect, half bushy	Medium	Buff
Red Ripper	Late	Tall, suberect, half bushy	Large	Maroon
Black		Tall, suberect, half bushy	Large	Black
Blackeye	Late	Medium, erect, half bushy	Medium	White, with black eye
California Blackeye	Medium	Medium, erect, half bushy	Medium	White, with black eye
White Crowder	Late	Medium, suberect, half bushy	Large	White
Red Crowder	Medium	Medium, suberect, half bushy	Medium	Maroon
Brown Crowder	Medium	Medium, suberect, half bushy	Medium	Light brown
Virginia Blackeye	Medium	Medium, erect, half bushy	Medium	White, with black eye

ROTATION	REGION WHERE PRACTICED
(1) Cotton, cotton, cotton, corn and cowpeas	Cotton belt
(2) Wheat or oats, cowpeas	Missouri, Arkansas, Tennessee
(3) Cotton, corn with cowpeas, winter oats or wheat with cowpeas as catch crop	Missouri, Arkansas, Tennessee
(4) Wheat or oats, cowpeas, corn or sorghum, cotton	Black lands of Texas
(5) Cotton, cowpeas, sorghum or corn	Arkansas
(6) Corn, cowpeas, wheat or oats	Arkansas
(7) Tobacco, wheat, grass, grass, corn with crimson clover as cover crop, cowpeas, and red clover	Virginia

At the Arkansas Station, cowpeas were interplanted with corn to determine their effect on the yields of subsequent crops. They were planted: (1) in the same row with corn, (2) between normal 44-inch corn rows at laying-by time, and (3) before laying-by time in wide 58-inch rows. The 9-year average yields of oats following the three methods were 15.5, 9.5 and 5.9 per cent, respectively, higher than for oats following corn alone.[3] Cotton showed the greatest increase when it followed cowpeas planted in the same row and at the same time as corn.

Cultural Methods

Cowpeas succeed on a seedbed prepared as for corn. Sometimes they are seeded as a catch crop after small grains, with disking as the only soil preparation, especially where the land is free from weeds. Fertilizer requirements are the same as for soybeans. Inoculation is generally unnecessary, except possibly in new regions where the crop is being grown for the first time.

For best results, cowpeas must be planted in warm soil after all danger of frost is past. For hay or seed production the crop is usually planted at about the same time as for corn or up to 2 weeks later. The crop may be planted in the south for green manure, pasture, or hay as late as August 1, or up to 90 days before the first frost. Some data on time of planting cowpeas at Arlington Farm in Virginia,[4] are given in Table 2.

TABLE 2. YIELDS OF THE GROIT VARIETY OF COWPEAS IN A TIME-OF-SEEDING TEST AT ARLINGTON FARM IN VIRGINIA

DATE SOWN	YIELDS PER SCORE *Hay* *(tons)*	*Seed* *(bu.)*
May 1	1.39	28
May 15	1.55	28
June 1	1.58	29
June 15	1.80	19
July 1	1.74	12
July 15	1.10	5
August 1	0.41	2

Cowpeas may be planted with either a grain drill or a corn planter. For seed production, the crop is commonly planted in rows 24 to 40 inches apart with the seeds 2 to 3 inches apart in the row. The rate of seeding varies from 30 to 45 pounds of seed per acre. For forage or green manure, cowpeas are generally seeded in close drills at the rate of 75 to 120 pounds per acre. The average rate of planting cowpeas for all purposes in the United States is about one bushel per acre. Some results of a cultural method experiment[4] are given in Table 3.

TABLE 3. AVERAGE YIELDS IN A METHOD-OF-CULTURE TEST WITH BRABHAM COWPEAS AT ARLINGTON FARM IN VIRGINIA

METHOD OF CULTURE	AVERAGE YIELDS PER ACRE *Hay* *(tons)*	*Seed* *(bu.)*
Broadcast	1.83	3.9
18-inch rows	1.90	14.6
40-inch rows	1.66	16.0

HARVESTING FOR HAY

Cowpeas may be harvested for hay when the pods begin to turn yellow. The best quality of hay is obtained when the pods are full grown and a considerable number of them are mature. The vines are difficult to cure when harvested earlier. Delay beyond this stage results in tough woody stems as well as in excessive loss of leaves.

The mower is generally used to cut cowpeas for hay. The curing practices followed are similar to those used for soybeans. Triangular curing frames are sometimes used in humid sections of the south on which the hay is piled for better aeration. Hay yields range from 1 to 2 tons per acre under good growing conditions, a single crop being obtained in a season.

HARVESTING FOR SEED

Cowpeas should be harvested for seed when one-half to two-thirds of the pods have matured. Large fields are usually harvested with a combine after most of the seed is ripe. The mower with a bunching or windrowing attachment, the self-rake reaper, and the bean harvester are also satisfactory. The ordinary grain separator can be adjusted to thresh cowpeas. Pea-and-bean threshers also are used. Formerly much of the seed was gathered by hand-picking the pods, and this is still a common method where cowpeas are interplanted with corn. The pods are then threshed or flailed. Most of the cowpeas grown for food in the south also are picked by hand. Cowpeas in the pod have a threshing percentage of 65 to 75.

COWPEAS IN MIXTURES

About 35 per cent of the total cowpea acreage is grown in combination with other crops. Cowpeas often are grown in mixtures with corn for silage. They also are grown for hay in combination with such crops as the sorghum, Sudan grass, Johnson grass, soybeans, and foxtail millet. When grown for silage with corn, the cowpeas and corn are usually planted with the corn planter in one operation. Cowpeas grown in combination with other crops for hay produce a larger yield of hay that is more readily cured than that from cowpeas grown alone.

Utilization

Although high in feed value, cowpea seed is generally considered to be too valuable or too low yielding to grow for livestock feed. However, between 1 and 2 million bushels of seed are fed annually to livestock, consisting mostly of surplus seed as well as that damaged, immature, insect infested, or otherwise unsuitable for planting or for food. The seed of certain varieties is a popular food in the south, being used in the pod, shelled green, or shelled dried, in preference to other types of beans.[3]

Cowpea hay that has been well cured is considered equal to red clover hay in nutritive value. As a silage crop, cowpeas are commonly grown or mixed with corn or sorghum, and cut when the first cowpea pods begin to turn yellow. Cowpeas, although high in protein and low in carbohydrates, will make good silage alone when wilted to the proper moisture content of 60 to 68 per cent before putting them into the silo.[7]

Cowpeas are widely utilized for soil improvement in the southern states. They will make a good growth on soils too poor for soybeans. Often the cowpeas are pastured or some seed picked before being plowed under. On very poor soils it is advisable to plow under the entire crop in the green state. About 85 per cent of the fertilizing value is in the hay, and about 15 per cent in the roots and stubble.[3] Thus the soil is benefited even when the crop is cut for hay.

Diseases

The most serious diseases of cowpeas in this country are wilt and root-knot, especially on the sandy soils of the southern states.

COWPEA WILT

Cowpea wilt, caused by the fungus *Fusarium bulbigenum,* var. *tracheiphilum,* causes the leaves to yellow and fall prematurely,[4] and finally results in the death of the plant. The stems turn yellow, the plants become stunted, and seed setting generally fails. Diseased stems are brown to black inside. Wilt is generally observed about midseason, being spread by cultivation implements, drainage water, and other agencies. The most satisfactory control measure is the use of resistant varieties such as Iron, Brabham, and Victor. California Blackeye is susceptible, but strains of Calva Blackeye and Virginia Blackeye are resistant to wilt. Calva Blackeye was produced by crossing the California with the Virginia Blackeye.

ROOT-KNOT

Cowpea root-knot, caused by a nematode (*Heterodera radicola*), is identified by galls over the entire root system. The roots soon turn brown, decay, and often die. The most practical measure is the use of resistant varieties in combination with other immune crops in rotations. Iron, Brabham, and Victor are resistant to the disease. Suitable rotation crops that are immune include winter grains, velvetbeans, corn, sorghum, and Laredo soybeans.

OTHER DISEASES

Charcoal rot caused by *Macrophomina phaseola* (*Sclerotium bataticola*) damages cowpeas severely under certain soil conditions.

Other fungus diseases of the cowpea include zonate leaf spot, caused by *Aristastoma oeconomicum,* red leaf spot, caused by *Cercospora cruenta,* and mildew caused by *Erysiphe polygoni.* Strains of Blackeye resistant to mildew have been developed.

Most cowpea varieties have been developed through many years of natural hybridization and incidental selection. As a result, most American varieties are resistant to the bean rust caused by the fungus, *Uromyces phaseoli,* that attacks varieties introduced recently. New Era, Groit, and Chinese Red are resistant to bacterial canker caused by *Xanthomonas bignicola.*

Insects

The chief insect enemies of the cowpea are two species of weevil that damage the seed, viz., cowpea weevil (*Callosobruchus maculatus*) and the southern cowpea weevil or four-spotted bean weevil (*Mylabris quadrimaculatus*). These weevils lay their eggs on the pods or in the seeds in the field and later on the threshed seeds in storage. The larvae bore into the seeds and complete their life cycle there. New generations of the weevil continue to develop unless the temperature falls too low. Control of the weevils consists in fumigation or heat treatment of the stored seeds.[4]

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28 FIELD BEANS

Economic Importance

The common field bean is one of the important food plants, especially in time of war. The bean is a highly nutritious low-cost protein food. An average of about 1,840,000 acres were harvested as dry edible beans in this country annually from 1937 to 1946. The yearly average production was 16,680,000 bags of 100 pounds each. The average yield was more than 900 pounds per acre. The five leading states were Michigan, California, Idaho, Colorado, and New York.

More than half the American bean crop is produced west of the Mississippi River, being grown under both irrigated and dryland conditions. Over 90 per cent of the beans produced in the humid east are grown in Michigan and New York. The leading countries in field bean production are Brazil, United States, Egypt, Italy, and Spain.

History of Bean Culture

The common bean probably is native to tropical South America. Beans were being cultivated by the Indians when America was discovered. They were introduced into the Old World soon afterwards, being mentioned in Europe about 1542, where they became popular.

Adaptation

The bean plant is a warm-season annual adapted to a wide variety of soils. The optimum mean temperature is 65° to 75° F. High temperatures interfere with seed setting, while low temperatures are unfavorable for growth. Dry beans are produced most successfully in areas where the rainfall is light during the latter part of the season.

Beans require a minimum frost-free season of about 120 to 130 days in order to mature seed.[18]

In general, white beans are grown in the humid region and in the north, and mottled or colored beans in the dry and warm regions.[9] However, the colored Red Kidney and the mottled Cranberry beans also are grown in the east, small white beans are grown in California and Idaho, and the white-seeded Great Northern variety predominates in several of the northern irrigated intermountain regions. White varieties require a harvest period relatively free from rain to avoid discoloration of the seeds.

Hardshell, a form of dormancy caused by impermeability of the seedcoat to water, is prevalent in a large number of bean varieties.[5] The condition is accentuated by hot dry winds at harvest time, or by storage in a heated room.

Most types of field beans are short-day plants, but the Boston Yellow Eye and Cranberry types are day-neutral, i.e., they flower in 26 to 39 days after planting at all day lengths from 10 to 18 hours,[1] and the Red Kidney shows only a partial response to different day lengths. The lima bean (*P. lunatus*) and chickpea (*Cicer arietinum*) are day-neutral, the tepary bean, mung bean, velvetbean, and cowpea are short-day plants, whereas the scarlet runner bean, and yellow lupine, are long-day plants.

Botanical Description

Dry edible beans, including the common bean, lima, tepary, runner, and mung bean, belong to the genus *Phaseolus*.[12] All are more or less flat-seeded.

Plants of the common bean (*Phaseolus vulgaris*) may be either bushy or viny (trailing). Bush beans are determinate in growth habit, and stem elongation ceases when the terminal flower racemes have developed. Pole beans bear racemes in the leaf axils while the stem continues to elongate. Field beans are either the semipole or bush type. The leaves are pinnately trifoliate. Both leaves and stems are pubescent. The flowers are white, yellow, or bluish-purple. The pods are straight or distinctly curved, 4 to 8 inches long, and end in a distinct spur (Figure 23). The seeds may be white, brown, pink, red, blue-black, or speckled in color (Figure 215). The im-

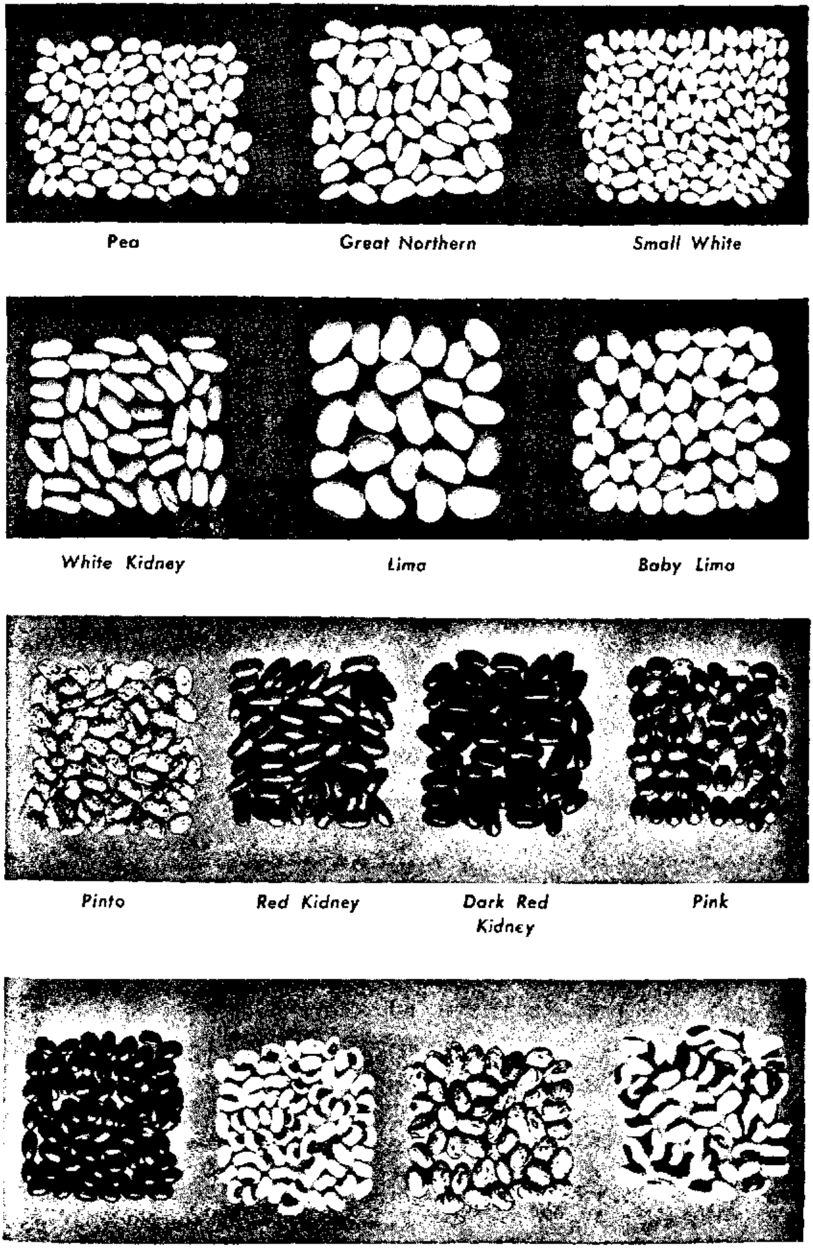

FIG. 215. Principal types of field beans showing relative sizes. (About ⅓ natural size.)

mature pods of snap beans are either yellow or green, but those of field varieties are green. The field varieties of the common bean are distinguished by their fibrous pods from the snap beans, which have very little or no fiber in the pods.[23] A satisfactory dry bean bears its pods above the ground, ripens uniformly, and does not shatter appreciably at maturity.

Beans are normally self-pollinated with less than one per cent of natural crossing.[16]

A classification of 4 species of beans commonly grown in this country, is as follows: [23]

A. Leaves glabrous
- B. Seeds with conspicuous lines radiating from the hilum to the dorsal region; perennial in tropics — *lima bean* [*Phaseolus lunatus* (*limensis*)]
- BB. Seeds without conspicuous lines radiating from the hilum to the dorsal region — *tepary bean* (*P. actifolius* var. *latifolius*)

AA. Leaves pubescent
- B. Roots tuberous, often perennial in warm climates, cotyledons not raised above the ground in the seedlings — *runner bean* (*P. multiflorus*)
- BB. Roots not tuberous, annuals, cotyledons raised above the ground in the seedlings — *common bean* (*P. vulgaris*)

GENERAL TYPES

The commonly recognized types of dry beans grown in United States are listed in Table 1, page 771.

Pea beans average about 2,300 seeds per pound; medium white 1,900; yelloweye and red kidney 1,100; and marrow and white kidney about 900 seeds per pound.[10] In order of length from the longest to the shortest are the kidney, marrow, medium, and pea beans, with lengths of 1.5+ cm., 1 to 1.5 cm., 1 to 1.2 cm., and <0.8 cm., respectively.

COMMON BEAN VARIETIES

More than 50 varieties of field beans are grown in United States.[12]

The White Pea (or Navy) and medium white beans are grown more extensively in the humid bean-growing areas than are any

TABLE 1. PRODUCTION OF DIFFERENT CLASSES OF BEANS IN THE UNITED STATES IN 1944

CLASS	PRODUCTION (UNCLEANED) (*millions of pounds*)
Field bean	
Pea and medium white	423
Pinto	360
Great Northern	270
Red kidney and dark red kidney	54
Small white	52
Pink	30
Small red	31
Cranberry	15
Yelloweye	10
White marrow	4
White kidney	1
Other and seed	97
Total	1347
Mung bean	11
Lima bean	
Standard lima	119
Baby lima	101
California Blackeye (culinary cowpea)	44
Chickpea	
Garbanzo (*Cicer arietinum*)	3

other varieties. Most of the pea bean acreage in New York and Michigan is planted to two improved varieties, Robust and Michelite. Pea beans mature in 110 to 120 days. The White Pea bean is a small semitrailing plant with white flowers and small white seeds. The Robust variety is a mosaic-resistant selection similar in general appearance but 4 to 5 days later than White Pea. The Michelite variety, resistant to common bean mosaic, is 3 to 5 days earlier than Robust. It also has a slightly smaller seed that is whiter, less veined, and more uniform than that of Robust.

The Red Kidney bean is important in California and it also ranks next to the white pea types of beans in importance in the east. It requires a frost-free season of at least 140 days to mature. Because of its red seed color, it is better adapted to areas of high rainfall than is the pea bean.[10] The Red Kidney bean plant is a bush type. The flowers are lilac in color. The seeds are large, flattened, pink when newly harvested and mostly dark red when old. The matured pods are often splashed with purple. The older strains are very susceptible to disease, especially to bacterial blight. The Wells strain is anthracnose-resistant.

The Great Northern variety leads in Montana [17] and in Idaho and is important also in Wyoming and Colorado. It is grown chiefly on irrigated land. The plants are short trailing, the flowers white and the seeds white, large and flattened. It is medium late in maturity. Selected strains of Great Northern beans grown in southern Idaho for their resistance to common bean mosaic [21] include U.I. No. 59, U.I. No. 81 and U.I. No. 123. Another selection, U.I. No. 15, which is resistant to the curly top virus as well as to common mosaic,[19] was selected from a hybrid.

Most of the bean acreage of New Mexico and Colorado is planted to the Pinto variety.[24] It is grown on both irrigated and dry land. The strains adapted to northern Colorado are earlier in maturity than are those grown in central New Mexico. The Pinto is a semitrailing variety with white flowers. The seeds are medium to large and somewhat flattened, and buff-colored, speckled with tan to brown spots and splashes.[14] It possesses a distinctive flavor not found in other dry beans.

The Red Mexican variety is adapted to irrigated and higher rainfall areas [19] of the Columbia and Snake river basins. The Red Mexican bean has bright red seeds. Improved strains of this variety, No. 3 and No. 34, are grown in Idaho and Oregon.

The Pink bean, grown chiefly in California, is a semitrailing variety with white flowers, and medium-sized pink seeds. It is very heat resistant. This variety is early to medium in maturity. Yelloweye beans are white with a splash of brownish-yellow around the hilum. The Marrow, Yelloweye, and White Kidney varieties are grown to a limited extent in the east. The Bayo bean, also grown in California, has bay or buff seeds.[13] The so-called cranberry bean has deep red splashes on a buff seedcoat. The cranberry varieties may be of the pole, semipole or bush type.

TEPARY BEAN

The tepary bean (*P. acutifolius* var. *latifolius*) has been grown by the Indians of Arizona and New Mexico since early times but was not tested by the white race before 1910.[7, 13] It has small leaflets and white seeds somewhat smaller than the navy bean. The beans are considered to be harder to cook and less palatable than the common edible beans and therefore have only a limited market. They appear to be very resistant to drought and outyield the Pinto bean in eastern New Mexico [5] and other southwestern areas. For hay, the tepary bean has outyielded cowpeas and other annual legumes by a considerable margin in tests in western Oklahoma.[6] It has been considered as a possible green-manure crop for southwestern dry lands if green manuring should ever prove to be advantageous under these conditions.

MUNG BEAN

The mung bean (green gram or golden gram) (*Phaseolus aureus*) is grown mainly for human food in the southern half of Asia and nearby islands and also in Africa. It is the source of the small canned bean sprouts found on the market and used in chop suey and similar foods. The mung bean has been known in the United States since 1835 under such names as Chickasaw pea, Oregon pea, Neuman pea, Jerusalem pea, or chop suey bean. Prior to World War II, nearly all of the mung beans used in the United States were imported. Production was begun in Oklahoma, California, and north Texas, and more than 24 million pounds were harvested on 110 thousand acres in Oklahoma in 1945. Previous experiments had shown the crop to be adapted to Oklahoma and other states especially for green manure. The beans are suitable for feed, and the plants make good silage and fair hay. The plants have glabrous leaves and are very similar to those of the cowpea except in being smaller and more bushy (Figure 216). The pale yellow flowers are borne in racemes or clusters of 10 to 25. The ripe black or brownish pods are 3 to 5 inches long and contain 10 to 15 small globose or oblong seeds. Most varieties have green, yellow, golden-brown, or marbled seeds. A variety called Selection No. 12 is most widely grown, but Green mung and Golden mung also are grown. Recommended varieties include the Korean and Indian mung.[27]

The urd, black gram, or mungo bean (*Phaseolus mungo*), which is grown chiefly in India for human food and for hay, is somewhat similar to the mung bean.

FIG. 216. Pods and leaflets of mung bean.

LIMA BEAN

The large lima bean (*Phaseolus limensis,* or *P. lunatus* var. *macrocarpus*) is a perennial grown as an annual. The small (baby) lima (*P. lunatus*) is an annual.

When allowed to mature, lima beans are handled in a manner similar to other dry edible field beans. The production, largely in California, exceeds that of any of the common field bean types except the White Pea, Great Northern, and Pinto. Improved strains of the small-seeded type of Hopi lima are becoming grown.

BROADBEAN

The broadbean (horse bean or Windsor bean), *Vicia faba,* is related botanically to the vetches but differs from them in having coarse erect stems, large leaflets, large pods, and large flattened seeds. It was grown by ancient Egyptians. This is a popular crop in Great Britain. In the United States, it is well adapted only to the coastal section of central California where it is grown to a limited extent for food, feed and green manuring. It is eaten either green or dry. In Europe, it is commonly grown for food and feed (chiefly for horses), or for green manuring.

CHICKPEA

The chickpea (*Cicer arietinum*) usually called garbanzo or gram, is grown on a commercial scale almost entirely in California. Some 700,000 to 5,000,000 pounds are produced annually. The leading countries in chickpea production are Spain, Turkey, Mexico, and Spanish Morocco. The chickpea is a native of Europe but was introduced to America many years ago. It is best adapted to warm semi-arid conditions. The plant is a low bushy annual with hairy stems and with each leaf comprised of several pairs of small rounded or oblong leaflets. The flowers are white or reddish, small, and borne singly at the tip of axillary branches. The seeds are roughly globular, flattened on the sides and somewhat wrinkled. The chickpea is grown and handled about like field beans. The threshed seeds are prepared for food in much the same manner as are dried lima beans They are relished by many foreign-born people. Roasted seeds have been used as a coffee substitute. The herbage is low in yield and also is toxic to animals.

OTHER BEANS

The culture of cowpeas including the California Blackeye variety is discussed in Chapter 27. The adzuki bean, *Phaseolus angularis,* is an important crop in Japan. In the United States it is grown only occasionally for home use.

LENTILS

Lentils (*Lentilla lens*) have been grown in the Mediterranean region since ancient times. They were introduced into the United States at an early date, but until recently were grown only to a limited extent chiefly in home gardens. Considerable quantities were imported chiefly for use in soups. Culture of lentils was stimulated by curtailment of imports during World War II. Lentils are adapted to the section of the Pacific northwest west of the Cascade Mountains extending from northwestern California to Washington and also to parts of eastern Washington.

The lentil plant is a weakly upright to semiviny annual with pinnately compound leaves, and having a general resemblance to vetch. The flowers are white, lilac, or pale blue. The seeds are thin and lens-shaped, usually smaller than pea seed and of various colors including brown and yellow. A pound contains 6,000 to 12,000 seeds. A bushel weighs about 60 pounds.

Crop Rotations

A rotation followed in New York bean areas[3] is: (1) beans, (2) winter wheat, (3) clover and timothy, and (4) timothy. In Michigan a common rotation is: (1) beans, (2) small grains seeded with clover, and (3) clover. Corn or potatoes may be fitted into such a rotation before or after beans. A rotation of alfalfa, potatoes, beans, sugar beets, and grain is popular in the irrigated intermountain regions.

In the Pacific northwest, beans replace summer fallow in the alternate wheat-fallow cropping system.[14] The yields of wheat after beans are almost as good as those after summer fallow. The beans usually are harvested in time for the fall seeding of wheat. In California beans may be grown continuously or in rotations following alfalfa or an intertilled crop. On the dry lands of Colorado and New Mexico beans may follow small grains or corn.

Cultural Methods

A deep, firm seedbed free from clods and coarse debris is essential for field beans. Heavy applications of commercial fertilizers are seldom necessary on land generally planted to beans. In Michigan, good yields have been obtained following sweetclover turned under with no direct application of fertilizer except to the small grain preceding sweetclover.[22] Those grown in the west usually are not fertilized. In New York[10] applications of 300 pounds per acre of superphosphate and 500 pounds of 2–12–4 or 4–12–4 have increased bean yields.

Beans should be planted in warm soil after all danger of frost is past. The time of planting in a locality is about the same as that for corn. In the northwest, the time varies from about May 20 to June 10, in Colorado from May 20 to June 15, in New Mexico from May 15 to July 1, and in California from April 10 to July 1. Cold, wet soil is likely to result in low germination when beans are planted in western New York before June 1.[18]

Beans are generally grown in rows 28 to 42 inches apart. In Michigan, pea beans in 21-inch rows yielded nearly 30 per cent more than those grown in 28-inch rows.[22] The seeds may be drilled in the row or planted in hills where the land is weedy. The crop may be planted with an ordinary grain drill with some of the feed cups stopped up to plant the rows the desired distance apart, or with a corn or bean planter. In New York,[10] yields favored the bean planter over the grain drill by a difference of 8.7 bushels per acre, or 57.6 per cent. The difference was ascribed to shallower planting, more compact surface soil, and closer placement of fertilizer by the planter.

Experiments with several bean types in New York[10] favor drill rather than hill planting. The data indicate that Red Kidney beans should be spaced six plants per foot and the Robust pea variety four plants to the foot. As the plant spacing increases, the number of pods per plant increases. Close spacing of plants does not increase the percentage of immature pods. Pea beans are planted at the rate of about 45 pounds per acre and Red Kidney beans at the rate of about 75 pounds per acre in New York.

Spacings under irrigation are similar to those under humid conditions. Dryland beans in Colorado and New Mexico are best planted in 42-inch rows with the plants spaced 18 to 24 inches apart.[4] The seed required ranges from 5 to 8 pounds per acre for the Pinto variety. Average rates of planting beans under all conditions in United States range from 17 pounds in New Mexico to 75 pounds in Idaho.

Mung beans are planted from May to July, often on land from which winter grain has been harvested. They may be drilled for hay or planted in cultivated rows for seed.[15]

Lentils are drilled at a rate of 30 pounds per acre or sown in 3-foot rows at a rate of 30 pounds per acre. They are sown about September 15 to October 15 and harvested in July in the mild sections west of the Cascade Mountains. In eastern Washington and other cold sections they are sown in the spring and harvested about August.

HARVESTING BEANS

Field beans are generally harvested when most of the pods are yellow but before they are dry enough to shatter from the pods. The vines are commonly cut below the soil surface with special 2-row or 4-row bean cutters that leave the plants in a windrow or in small bunches. After the vines have cured in the field the general practice in humid areas is to cock or stack them unless they can be threshed immediately. The crop may be threshed by a bean huller, a grain thresher (with alterations), or with a pickup combine. Most of the mung beans and many of the common beans are harvested with a combine, and nearly one-half of the latter are threshed from the windrow, stack or pile with a combine.

Harvesting with a bean cutter in semiarid regions leaves the soil pulverized so that it blows readily. Planting the beans in strips alternating with corn or sorghum helps to check soil blowing.

Diseases

The most serious losses from bean diseases occur in the humid and irrigated regions. More than 40 diseases attack the crop.[11]

BACTERIAL BLIGHTS

Blight is one of the most serious diseases in the important bean areas. The most striking symptoms appear first as water-soaked spots on the under side of the leaves. These spots may enlarge rapidly and produce dead areas on the leaf. On the stem a characteristic lesion known as stem girdle appears. This lesion may weaken the stem so that it breaks at the diseased node. Pod lesions, usually reddish, water-soaked, and very irregular in outline, may prevent the proper filling of the pods. The two causal organisms[26] are *Xanthomonas phaseoli* and *Pseudomonas phaseolicola.* The principal control measure is to plant blight-free seed, which can be obtained from certain sections of the intermountain region of the west and from the Pacific coast states.

ANTHRACNOSE

Bean anthracnose (*Colletotrichum lindemuthianum*) is a serious disease in the humid east. The disease is usually first noted on the leaves where dark-colored areas appear. The veins may be destroyed by the fungus, while the blade shows numerous cracks or holes with shriveled blackened margins. Large round dark-colored lesions finally appear on the pods. Large oval cankers may also be observed on the stem and may so weaken it that it is easily broken in cultivating or by a strong wind. The disease is most serious in wet seasons. It overwinters in the seed. The most satisfactory control measures are (1) use of disease-free seed grown in the semi-arid regions, and (2) resistant varieties. Geneva Red Kidney and York Red Kidney are resistant.[25]

COMMON BEAN MOSAIC

Common bean mosaic is a seed-borne virus disease that is also spread in the field by several species of aphids. The mottling of the leaves may form various patterns of dark and light green areas.[19] The dark green areas often occur along the midvein. The leaves of infected plants may be curled downward. Diseased plants are usually paler green and more dwarfed than healthy ones. Early infection may cause a complete failure to form pods. The use of resistant varieties is the only practical control. Some of these are Robust, Michelite,[20] the Great Northern strains (U.I. Nos. 15, 81 and 123), and Red Mexican strains U.I. 3 and U.I. 34.

OTHER DISEASES

Bean rust (*Uromyces phaseoli typica*) appears as small brown pustules on the leaves and to a less extent on the stems and pods. The pustules turn black for the winter stage. Control measures include (1) dusting the plants with sulfur, (2) crop rotation, and (3) use of resistant varieties. Resistant varieties now available are the pinto types 5 and 14.

Curly top is a virus disease that causes losses to beans in the area west of the continental divide. It is carried by the beet leafhopper (or "white fly") (*Eutettix tenellus*) from plants infected with the virus to other healthy plants. Bean plants are more subject to injury while in the younger stages of growth. The growing point may be killed by the virus and then drop off. The plant will then die. On larger plants the first symptom of curly top is the downward curling of the first trifoliate leaf. The curly top virus is not carried in the seed. Great Northern U.I. 15[19] and Red Mexican U.I. 3 and U.I. 34 are resistant to the disease.

Insect Pests

Beans are often damaged seriously in storage and in the field by the bean weevil (*Acanthoscelides obtectus*). It can be controlled by planting weevil-free seed, fumigation of infested seeds with methyl bromide as soon as possible after harvest, and by field sanitation. Carbon disulfide is commonly used as a fumigant. Weevils also may be killed by a temperature of 120 to 145° F. for several hours or by placing the infested seed in cold storage at 31 to 32° F. for 56 days.[2]

The Mexican bean beetle (*Epilachna varivestris*) (Figure 217) is a serious pest in many bean-growing areas. The larvae feed on the under sides of the bean leaves. They remove the epidermis but

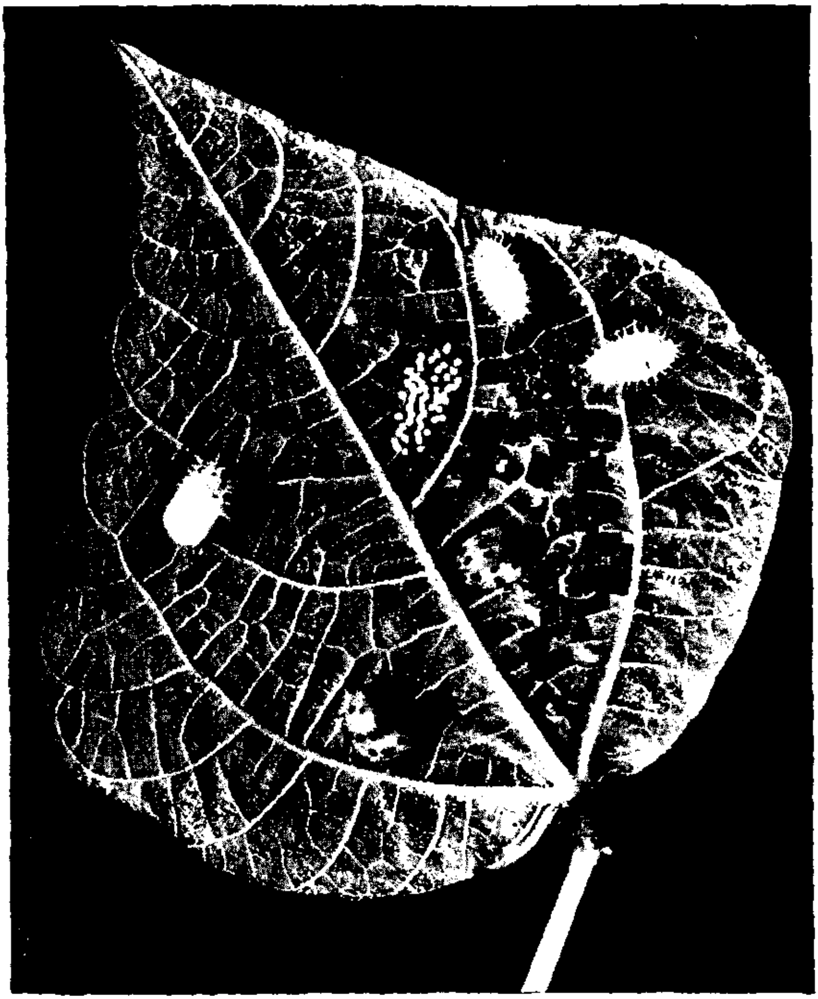

FIG. 217. Mexican bean beetle feeding on the under side of a bean leaf. Note the spotted adults, the hairy larvae, and the mass of eggs.

seldom cut through to the upper surface. This insect can be controlled by spraying or dusting with rotenone insecticides. Pyrethrum and cryolite also are useful. The insecticide is effective only on the under sides of the leaves. The first application should be made when the adult beetles are first seen in the field. Four treatments at 10-day intervals usually will protect the crop.

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29 PEANUTS

Economic Importance

The peanut, also called goober, pindar, groundnut, and earthnut, is the third most important cash crop in the south, being exceeded only by cotton and tobacco. The demand during World War II for vegetable oils and fats and for protein feeds and foods resulted in a record production in the United States. During the war period 3 to 3.5 million acres were harvested annually for the nuts, as compared with the prewar crops of 1½ to 2 million acres. About 3,600,000 acres of peanuts were grown annually from 1937 to 1946, of which 2,560,000 acres were threshed. The average production was 1,800 million pounds, and the annual value ranged from 40 to 170 million dollars. The average acre-yield was 705 pounds of nuts and 1,000 pounds of hay (straw or vines). Georgia, Texas, Alabama, North Carolina, Florida, Oklahoma, and Virginia led in acreage (Figure 218).

The world production of peanuts ranges from 16 to 21 billion pounds annually. The leading countries in peanut production are China, India, West Africa, and the United States.

Most of the crop not threshed in the United States, averaging 1,200,000 acres annually, was gathered by hogs turned into the field. Peanuts add nitrogen to the soil when utilized in this manner but they do not contribute appreciably to soil improvement when they are dug and threshed and the vines used for feed. The popularity of peanuts is enhanced by the fact that they require less fertilizer than do most other crops grown in the south.

The peanut is believed to be native to the tropics of South America. Peanuts were carried by the early slave ships to Africa from

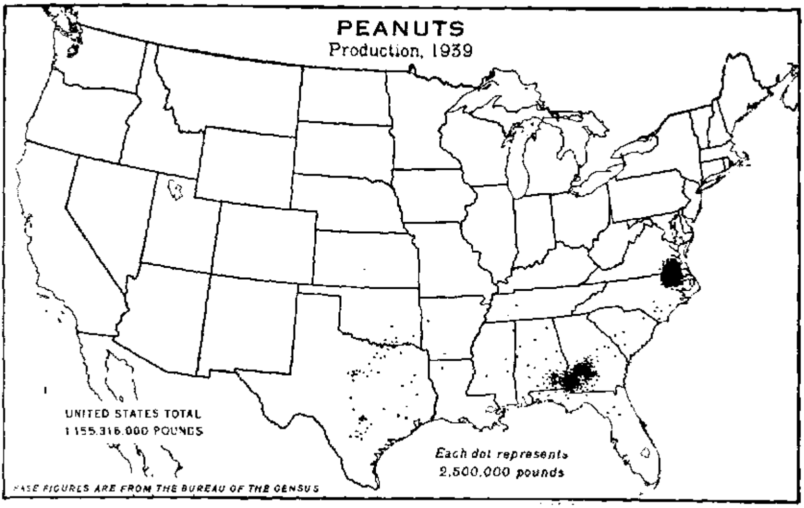

FIG. 218. Distribution of peanut production in 1939.

where they were introduced into the United States in Colonial days.[4] Commercial development of the peanut industry began about 1876. A rapid increase in production came in the cotton belt after 1900, when the boll weevil made serious inroads on the cotton crop.

Adaptation

The most favorable climatic conditions for peanuts are moderate rainfall during the growing season, an abundance of sunshine, and relatively high temperatures.[2] The best crops are obtained where the annual rainfall is between 42 and 54 inches, but peanuts for home use are grown where the precipitation is less than 19 inches. They are grown under irrigation in New Mexico. The peanut region has an average frost-free period of 200 days or more. The growing periods for different varieties range from 110 to 140 days.

The largest yields of the best quality of market peanuts are secured on well-drained light sandy loam soils. Dark-colored soils stain the hulls, which is objectionable for many commercial uses. For forage the crop can be grown on almost any type of soil except heavy clay soils low in organic matter. Peanuts produce the highest yields on soils with a *p*H above 5. Poorly-drained soils generally have been unsatisfactory. Light sandy soils offer less resistance to the penetration of the pegs that must enter the ground in order for the pods to develop.

The three major regions of peanut production are (1) southeastern Virginia-northeastern North Carolina, (2) the southeast and (3) the southwest (Arkansas, Louisiana, Oklahoma, and Texas).

Botanical Description

The cultivated peanut is a legume classified botanically as *Arachis hypogaea*. It is a pea rather than a nut. It is unknown in the wild state, but about 15 species that bear little resemblance to the cultivated form are found in Brazil and nearby countries.

The peanut plant is a low annual with a central upright stem. The numerous branches vary from prostrate to nearly erect. The pinnately compound leaf consists of two pairs of leaflets, and occasionally a fifth leaflet, borne on a slender petiole. Peanut varieties are readily separable into bunch and runner types. The nuts are closely clustered about the base of the plant of the erect or bunch type (Figure 219). The runner varieties have nuts scattered along their prostrate branches from base to tip. The peanut has a well-developed taproot with numerous lateral roots that extend several inches into the ground. Most roots have nodules but bear very few root hairs (Figure 219).

The flowers are borne in the leaf axils, above or below ground, singly or in clusters of about three. Under field conditions it is not uncommon to find the blossoms with their yellow petals three inches below the soil surface. The calyx consists of a long slender tube crowned with five calyx tips (Figure 220). The corolla is borne at the end of the calyx tube. After pollination takes place, the section immediately behind the ovary, the gynophore or peg elongates and pushes the ovary into the soil where the pod develops (Figure 221). Peanut flowers are perfect and self-pollination is the general rule, but natural crossing between varieties sometimes occurs.[17]

The peanut fruit is an indehiscent pod containing 1 to 6 (usually 1 to 3) seeds. The pods form only underground. The seed is a straight embryo covered with a thin papery seedcoat. The outer layer varies in color, but generally it is brick red, russet, or light tan, and occasionally black, purple, flesh-colored, or white. The weight per bushel

FIG. 219. A prolific peanut plant of the bunch type showing leaves above and nodule-bearing roots below.

FIG. 220. Portion of peanut plant showing blossom (b), calyx tips (c), gynophores or "pegs" (g), leaflets (l) and developing pod (p).

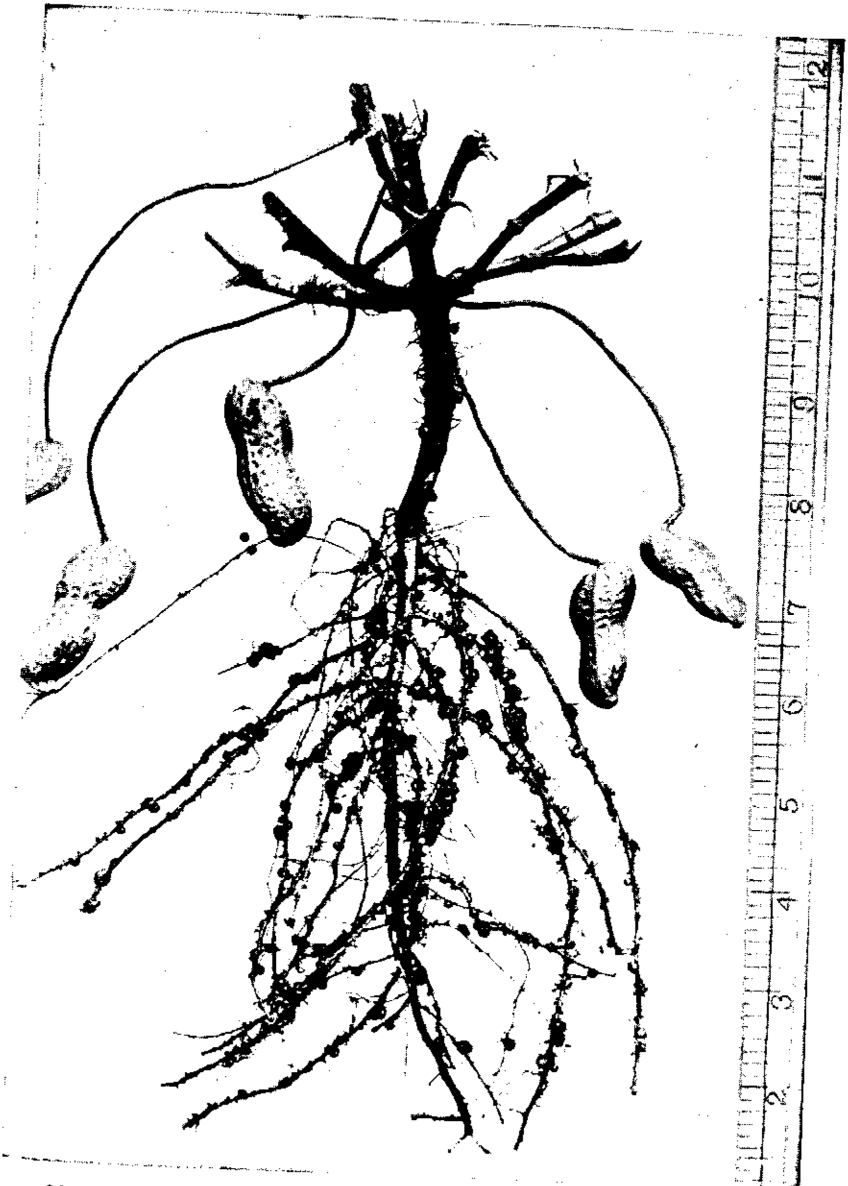

FIG. 221. Plant of the runner type showing attachment of the pods.

of unshelled peanuts is about 22 pounds for the Virginia type, 28 pounds for the Southeastern Runner types and 30 pounds for the Spanish type.

Seed dormancy is characteristic of the runner types.[19] Dormant peanuts planted soon after maturity frequently require rest periods ranging up to 2 years before germination occurs.[11] The average time for emergence of fresh seed of different strains from the Spanish and Valencia groups ranged from 9 to 50 days, while in a more dormant group that included runner peanuts it ranged from 110 to 210 days. The rest period is broken after several weeks or months in dry storage. The Spanish type shows no dormancy.

Peanut seed retains its viability for 3 to 6 years under proper storage conditions.[3]

Varieties

American peanuts are classified into three groups, viz., runner, Spanish (bunch type), and Valencia (bunch type).[11] Varieties of the bunch type, in general, mature earlier than those of the runner type.[2]

The runner group of peanuts includes Virginia runner and the common runner varieties which are definitely prostrate, except for the Virginia Bunch and North Carolina Bunch, which are semierect. This group has dark green foliage, large pods, occasionally three seeds in a pod, long seeds, and russet seedcoats. Improved varieties in this group include the Jumbo, Holland Jumbo, and Holland Virginia Runner.

The Virginia Bunch and Virginia Runner varieties are especially adapted to the commercial peanut area of southeastern Virginia and northeastern North Carolina. Peanuts of the runner type are grown extensively in Alabama, Georgia, and Florida. In the Alabama peanut belt, 85 per cent of the peanuts grown are North Carolina Runners and 15 per cent Spanish.[20] The North Carolina Runners are grown extensively for hogs, while the Spanish type is grown primarily for market. The yields and shelling percentages of varieties tested at Tifton, Georgia,[16] are shown in Table 1.

The Valencia group includes the Valencia as well as the Tennessee Red and Tennessee White varieties. This group is characterized by many pods with three and four seeds, and by very sparse branch-

TABLE 1. YIELD AND SHELLING PERCENTAGE OF PEANUT VARIETIES IN TESTS AT TIFTON, GEORGIA

VARIETY	ACRE YIELD OF NUTS (9-YEAR AVERAGE) (*lb.*)	SHELLING PERCENTAGE
North Carolina Runner	1967	70.4
McGovern (runner)	1921	70.
Virginia Bunch	1877	64.
Virginia Runner	1703	61.9
Dixie Giant (runner)	1686	61.
Spanish (bunch)	1616	76.2
Chapmans Pride (bunch)	1586	66.7
Improved Spanish (bunch)	1566	68.5

ing habits. The varieties named are all erect. The foliage is dark green, the seeds long or short, while the seedcoats may be purple, red, russet, or tan.

Any of the large-podded varieties grown in the southeast are likely to be hawked to sports fans in the athletic stadiums as *jumbo* or *California double-jointed* peanuts.

The Spanish group consists of erect types with light green foliage, rarely more than two seeds in a pod, short seeds, and tan seedcoats. Both pods and seeds are small.

The Spanish peanuts yield well west of the Mississippi River. In northern Arkansas Spanish produced 43.6 per cent more nuts and 15.1 per cent more hay than Valencia.[14] Some of the runner varieties produce satisfactory yields on the sandy soils of southwestern Arkansas where the season is longer than in the northern part of the state. Spanish is the most commonly-grown commercial type in Texas.[15] A selection known as Macspan, developed at the Texas Agricultural Experiment Station, is more vigorous in growth, produces higher yields, and bears longer and more uniform pods. On the Gulf coast prairie of Texas the Spanish types yielded more nuts but less hay than the runner types,[16] and more nuts and hay than the Virginia Bunch and Valencia types. The nuts comprised from 19 to 31 per cent of the total crop among the different varieties.

Crop Rotations

Peanuts harvested for nuts usually deplete the soil and depress the yields of crops following them in rotation because (1) fertilizers are usually omitted or are applied in inadequate quantities, (2) no crop residues are returned to the soil, and (3) clean row-cultivation hastens the decay of organic matter and the soil is left bare over winter. Fertilization of the land for peanuts and the planting of a legume winter cover crop help the yields of the following crop. Peanuts should occupy the land only once in 3 or 4 years, and the rotation should include at least two soil improvement crops, one of them being also a winter cover crop.[2] A Virginia rotation is: (1) corn with crimson clover as a winter cover crop; (2) early potatoes followed by cowpeas; and (3) Spanish peanuts followed by rye as a winter cover crop. Peanuts have yielded approximately three times the quantity of nuts in this rotation as in continuous culture, during the last 3 years of an experiment that extended over a 10-year period.

In Georgia, peanuts produce good yields when they follow cotton, tobacco, or truck crops.[9] A suggested 3-year rotation is: (1) cotton, fertilized; (2) Spanish peanuts (3–8–8 fertilizer) with the hay returned to the soil, and Austrian Winter peas or oats sown after the peanuts are harvested; and (3) corn interplanted with runner peanuts hogged off, or oats followed with cowpeas.

In the southern Great Plains peanuts should be planted in strips, alternating with strips of crops such as sorghum or corn to check soil blowing, because the removal of the peanut crop leaves the soil loose and bare.

Fertilizers

The peanut has a marked ability to utilize fertilizer residues not available to other crops. This explains the frequent failure of fertilizers to increase peanut yields on fertile soils. Only a small part of the peanut acreage of the United States is fertilized. Peanuts usually are grown on sandy soils that are often rather low in phosphorus and occasionally also in potash. Additions of nitrogen are seldom effective except on thin soils on which Spanish peanuts are grown. Peanuts remove large quantities of potash from the soil.[6] Combinations of lime and potash or phosphate and lime often increase the yield. Recommended fertilization for the eastern belt includes 200–300 pounds per acre of either a low-nitrogen mixed fertilizer or about equal ratios of N–P–K. Potash and dolomitic limestone also are advised. Gypsum is apparently necessary or helpful to the Virginia Bunch and Virginia Runner varieties. The nuts fail to fill out well on many soils low in calcium. Gypsum applied by dusting 300 to 500 pounds per acre on the tops at blooming time supplies the needed calcium.[5] A large proportion of the jumbo peanuts in Georgia are treated in this manner.

Cultural Methods

SEED PEANUTS FOR PLANTING

Either shelled or unshelled peanuts may be planted, but shelled seed gives quicker and often better stands. Machine-shelled seed often germinates lower than hand-shelled seed because of more or less seed-coat injury incident to shelling.[9] Peanut seed shelled as early as December gives practically the same germination and yield as that shelled just prior to planting.[1] Shelled seed should be stored in a dry (relative humidity about 60 per cent), moderately cool (between 32° F. and 70° F.) place. In Mississippi experiments Spanish peanuts germinated better when planted in the shell, while runner peanuts produced better stands when shelled, because the shell is tough and almost waterproof.[20] Consequently nearly all of the runner peanuts are shelled, whereas the Spanish types often are planted in the shell. Breaking the pod into two pieces gives practically the same results as shelling.[15]

Treating shelled seed with dust fungicides particularly Arasan, or New Improved Ceresan increases the assurance of satisfactory stands.[21]

SEED INOCULATION

Inoculation of peanuts with a culture of the proper nitrogen fixation bacteria is advisable unless inoculated peanuts, cowpeas, or velvet-beans have been grown on the soil previously. Spanish peanuts may bear a comparatively small number of nodules on certain soils in Alabama.[8]

Artificial inoculation of unshelled Spanish peanut seed has resulted in large increases in numbers of both total and large nodules, as well as a yield of 30 to 40 per cent more nuts per plant, when compared with noninoculated seed.[7] There appeared to be no benefit from inoculation of runner peanuts in the same experiments.

SEEDBED PREPARATION

Thorough seedbed preparation for peanuts is essential. A well-tilled soil aids the penetration of the pegs. Fall or winter plowing is generally practiced except where erosion is serious. Ordinarily the land should be plowed level rather than bedded. Growers often bed up peanut fields where there is a tendency for the soil to be wet.

SEEDING

Peanuts are planted generally after the danger of late spring frosts is past. In the commercial peanut area the main crop is planted between April 10 and May 10. Planting about March 15 is recommended for southern Georgia. Spanish peanuts will mature seed in the Gulf coast region when planted as late as July 1, but higher yields result from earlier plantings. In Texas, peanuts are planted about the same time as cotton or a little later. The actual dates of planting range from about March 1 in south Texas to May 15 or later in the northern part of the state.

Peanuts may be planted by machinery or by hand. In the commercial areas, the rows formerly were usually made with a single-shovel plow, the seed being planted in the rows with a peanut planter, or with a peanut plate on a cotton or corn planter. In recent years multiple-row tractor planters have come into common use.

The usual practice is to plant runner varieties in rows 30 to 36 inches and occasionally 42 inches apart with the seeds spaced 8 to 14 inches apart in the row. Spanish and similar sorts are usually planted in rows 24 to 30 inches apart with the seeds spaced 3 to 6 inches in the row. Under favorable growing conditions better yields are obtained from thick spacing, i.e., 6 to 8 inches apart in 30-inch rows for the larger types and 3 inches apart in 24-inch rows for the small type. About 10 to 15 per cent of the crop is interplanted, usually with corn. About 20 pounds of hand-shelled seed or 40 pounds of seed in the hull are required to plant one acre of the North Carolina runner variety in 30-inch rows with a 12-inch spacing in the row.[9] Some 30 to 40 pounds of hand-shelled Spanish or 60 to 70 pounds of the unshelled seed would be necessary for a 6-inch spacing in 30-inch rows. Consequently, these planting rates should be about doubled to produce the thick stands recommended above.

CULTIVATION

The cultivation of peanuts is similar to that of soybeans grown in rows. One or two early cultivations with a rotary hoe or a flexible-shank weeder are helpful. Later cultivation is done with row equipment.

HARVESTING

The proper time for harvesting peanuts is very exacting. The tops are kept green and growing late by the prevailing practice of dusting and spraying, so that the appearance of the tops is not a dependable guide. Peanuts are ready for harvest when the kernels are full grown, with the skins displaying a distinct texture and the natural color of the variety, and the inside of the shell has begun to color and show darkened veins. Peanuts shrink when harvested too early, and Spanish varieties will sprout in the ground if harvesting is delayed too long. Peanuts are generally harvested before the vines are killed by frost.

Most peanuts are loosened from the soil with special diggers, usually of the plow type. The potato digger also is satisfactory. The vines are then lifted, shaken to remove the soil, and left in small piles until thoroughly wilted before being stacked.

In all parts of the commercial peanut belt except the southwest, peanuts are almost always cured in small stacks around poles 6 to 8 feet high. Cross-pieces are placed 10 to 12 inches from the bottom of the pole to keep the vines off the ground (Figure 222). The peanuts are stacked around the pole with the pods to the center. Stacks may be topped with grass or with a canvas hay cap. About 14 to 30 poles per acre are needed for an average crop. The crop is allowed to cure in the stack for 3 to 6 weeks or longer before threshing. In Texas, Oklahoma, and New Mexico, where the rainfall is lower,

FIG. 222. Peanut poles and stacks.

a common practice is to dig the vines, rake them into windrows, or fork them into piles about 2 feet high and allow them to cure in the open without protection from the weather. This method is satisfactory in dry weather, but it often results in a large proportion of No. 2 or damaged peanuts in wet weather.

Modern types of special machines remove the pods from the vines satisfactorily if operated properly and if both the pods and vines are dry. The proper stage is reached when the stems and particularly the slender attachments of the pods to the stems are brittle. Some peanuts are threshed from the windrow, using a combine with a pickup attachment. Cylinder-type threshers, which formerly were frequently used, usually shell out more of the nuts than do the special pickers. Most of the machines have cleaning equipment. Market peanuts are generally bagged as they come from the machine. The threshed vines are often baled for hay, and if properly cured make an excellent feed.

Processing Peanuts

The operations incident to shelling remove rocks, sticks, and stems as well as the shells. The nuts are passed through various screens and then through a machine sheller. A pound of shelled nuts is obtained from about 1⅓ pounds of unshelled peanuts. Blanching gives a whiter and more homogenous appearance to the nuts. This treatment involves removal of the seedcoat by a combination of drying, heating, rubbing between soft surfaces, and blowing an air current through the nuts. Shelled nuts may become rancid after storage for 2 months or more. Rancidity is retarded when the nuts contain 5 per cent moisture or less, and the relative humidity of the storage room is about 60 per cent.

The most common method of preparing peanuts for human consumption is dry roasting until the nuts develop a brown color. Sometimes the nuts are roasted in oil, especially when they are to be salted. Peanut butter is made by grinding dry roasted salted nuts.[22]

For oil extraction the peanuts are shelled, cleaned, and crushed into a pulp to open the oil cells as much as possible. From the rollers the pulp goes to a cooker where the material is heated at about 235° F. in a humid atmosphere for 90 minutes. The oil is most commonly extracted by the hydraulic press plate method under a pressure of about 4,000 pounds. The expeller (cold pressed) method also is used. The crude peanut oil is collected in storage tanks, while the residual cake is ground into meal. The crude oil may be filtered to remove the foots (particles of meal), or the residue may be allowed to settle to the bottom of the tank and then removed.

An average ton of cleaned unshelled peanuts yields about 530 pounds of oil, 820 pounds of meal, and 650 pounds of shells.

Utilization

Peanuts either are harvested or they are used for livestock feed. Of those harvested previous to World War II about two-thirds were cleaned and shelled for food, more than 10 per cent were used for seed, 15 per cent or more were crushed for oil, and more than 3 per cent were retained on farms where they were produced. The remaining 5 per cent were fed, lost, or otherwise disposed of. During the recent war about 20 per cent of the crop, or 220 to 557 million pounds, were crushed annually.

Chemical Composition

Peanuts are high in both protein and oil.[15] In general, the vines with the nuts contain 10 to 12 per cent protein and, without the nuts, about 7 per cent protein. Unshelled peanuts contain about 25 per cent protein and 33 per cent fat. The nuts contain 40 to 48 per cent oil, and from 25 to 30 per cent protein. All of the embryo cells contain oil.[22] The nuts contain the amino acids, including cystine, that are essential for animal growth.[13] They are rich in phosphorus. Like other large legume seeds peanuts are an excellent source of the vitamins thiamin and riboflavin, and a good source of niacin. An average content of thiamin of 9.6 micrograms per gram has been reported.[10] In thiamin content the skins are highest, followed by the cotyledons and then the germ. The average nicotinic acid content is about 17.2 milligrams per 100 grams.

Diseases

Peanuts suffer some losses from leafspots. One of these is caused by *Mycosphaerella archidicola* (*Cercospora arachidicola*) and the other by *M. berkeleyii* (*C. personata*).[2, 12] The leafspot diseases appear as small brown spots on the leaves. They usually become severe in wet weather when the leaves may turn yellow and fall off. Leafspot often reduces the value of peanut hay and sometimes makes it unfit for feeding. Leafspot may be controlled with 325-mesh sulfur used as a dust at the rate of 15 to 20 pounds or more per acre for each of three or four applications about 14 days apart. Copper dusts also give satisfactory control. Root rots, chiefly that caused by *Sclerotium rolfsii*, often are serious diseases of peanuts, especially on Spanish and Valencia types. They rot the pegs and cause the nuts to drop off. No control method is known except that rotation with certain other crops has been recommended for reducing damage. Sulfur dusting may aid in keeping the nuts attached to the vines.

The Georgia Experiment Station has developed peanut hybrid selections that are promising for disease resistance and high yield.[10] A strain called Dixie Runner developed in Florida is resistant to the hidden damage disease, and the nuts keep in the ground for some time after they are ripe, thus making them adaptable to harvesting with hogs.

Insects

Insects damaging peanuts include leafhoppers and the velvet-bean caterpillar. The former insects are controlled by dusting with sulfur and the latter by dusting with cryolite or with a dust containing 5 per cent of DDT. Hay from peanuts that have been dusted with DDT should not be fed to dairy cows.

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30 MISCELLANEOUS LEGUMES

Legumes usually grown for forage, green manure, or as cover crops include field peas, vetches, velvetbeans, burclover, black medic, kudzu, crotalaria, trefoil, sesbania, lupines, guar, Florida beggarweed, roughpea, hairy indigo, and alyceclover. They may not occupy a large area in the country as a whole, but are important where they are well adapted. Except for field peas, these crops are grown almost entirely in the southern and Pacific coast states.

Field Pea

ECONOMIC IMPORTANCE

An average of about 260,000 acres of dry field peas are harvested for seed annually. The average yield is about 1,200 pounds per acre, and the production since 1936 has ranged from about 178 million pounds to 1,087 million pounds. In addition, 36 million to 74 million pounds of cleaned Austrian Winter pea seed, and 29 million to 113 million pounds of smooth-seeded vegetable pea seed have been harvested in recent years. About 100 million pounds of wrinkled pea seed is required annually for domestic planting. The leading states in field pea seed production, viz., Washington, Idaho, Colorado, Montana, Michigan, Wisconsin, and Oregon, also make the greatest use of field peas for hay, silage, and pasture. These, as well as other states, use field peas for green manuring. The most important seed pea area is the Palouse section of eastern Washington and northern Idaho. Statistics on the production of field peas for hay, silage, pasture, and green manure are not available.

Field peas are of greatest importance in northern and central

Europe, but they also are grown in India and other parts of Asia. Russia is the largest producer.

ADAPTATION

A cool growing season is necessary for successful production of field peas. High temperatures are more injurious to the crop than are light frosts, which are injurious only when the plants are in blossom. Climatic requirements limit field-pea production to the northern states as a summer crop, and to the southeastern states and the mild coastal sections of the Pacific northwest as a winter crop.

Field peas are most productive where rainfall is fairly abundant but they succeed in cool semiarid regions. Well-drained clay loam soils of limestone origin are best suited to field peas. Inoculation is essential or beneficial in practically all regions where the crop is grown.

BOTANICAL DESCRIPTION

The field pea is classified botanically as *Pisum arvense*. Garden and canning peas usually are classified as *P. sativum*. However, several canning and garden varieties also are grown as dry-field peas.[13] Garden peas tend to be sweeter and more wrinkled than do field peas, but, since this does not hold for all varieties, there can be no sharp distinction between the two species. The pea is an annual herbaceous plant with slender succulent stems 2 to 4 feet long. The foliage is pale green with a whitish bloom on the surface. The leaf consists of one to three pairs of leaflets and terminal branched tendrils. In most varieties, the blossoms are either reddish-purple or white. The pods are about 3 inches long and contain 4 to 9 seeds. These seeds may be round, angular, or wrinkled. The seed cotyledons are mostly yellow or green.

Field peas are generally self-fertilized, but some crossing is evident when varieties with white and colored blossoms are grown in alternate rows.[16]

VARIETIES

White Canada is the leading variety of field peas in the north central states. In this region the name Canada (or Canadian) field peas has been applied also to other yellow- or white-seeded varieties with yellow or orange cotyledons, such as Golden Vine, Canadian Beauty and Mackay (Figure 223). The leading varieties of dry edible peas include Alaska, Blue Bell (Blue Prussian), First and Best, Extra Early, and White Canada.[5, 41] Alaska, First and Best, and Extra Early are smooth peas grown for canning, as well as for dry edible peas. Alah, a wilt-resistant selection of Alaska, and Idabell, a selection of Blue Bell, also are grown.

Varieties with gray, brown, or mottled seed are grown for soil improvement or for feed. The most commonly grown varieties in the Pacific northwest are Austrian Winter, Blue Bell, and Alaska. The latter two varieties have bluish-green seeds and green cotyledons. Austrian Winter and French Grey have dark-colored seeds, i.e., gray speckled with purple or brown. The Austrian Winter variety is grown in the southeastern states as far north and west as Oklahoma where fall planting is practiced. It is winterhardy,[40] having been practically undamaged by a temperature of $-8°$ F.

French Grey, Canadian Beauty, Clamart, and Agnes for seed production and Canadian Beauty and Agnes for forage were recommended for spring planting in the mountain areas of Colorado. In the Great Lake states, Canadian Beauty, Multipliers, Marrowfat, Scotch, Chang, and the Chancellor varieties are recommended.[28]

CULTURAL PRACTICES

Field peas can replace summer fallow to advantage in wheat rotations in the Palouse area of Washington,[34] and to some extent in the more semiarid sections of the Pacific northwest. However, the harvesting of the two crops conflicts, the hay is not always needed, and greatly increased seed production there would result in national overproduction. Peas fit into hay, small grain, and corn rotations in most northern states.

Fall plowing is generally practiced for seedbed preparation in northern latitudes to facilitate early spring planting. Where grown as a summer crop, field peas are commonly sown with a grain drill as early in the spring as possible, usually in April. In the south and in the coastal section of the Pacific states, the usual practice is to seed winter peas from September 15 to October 15.

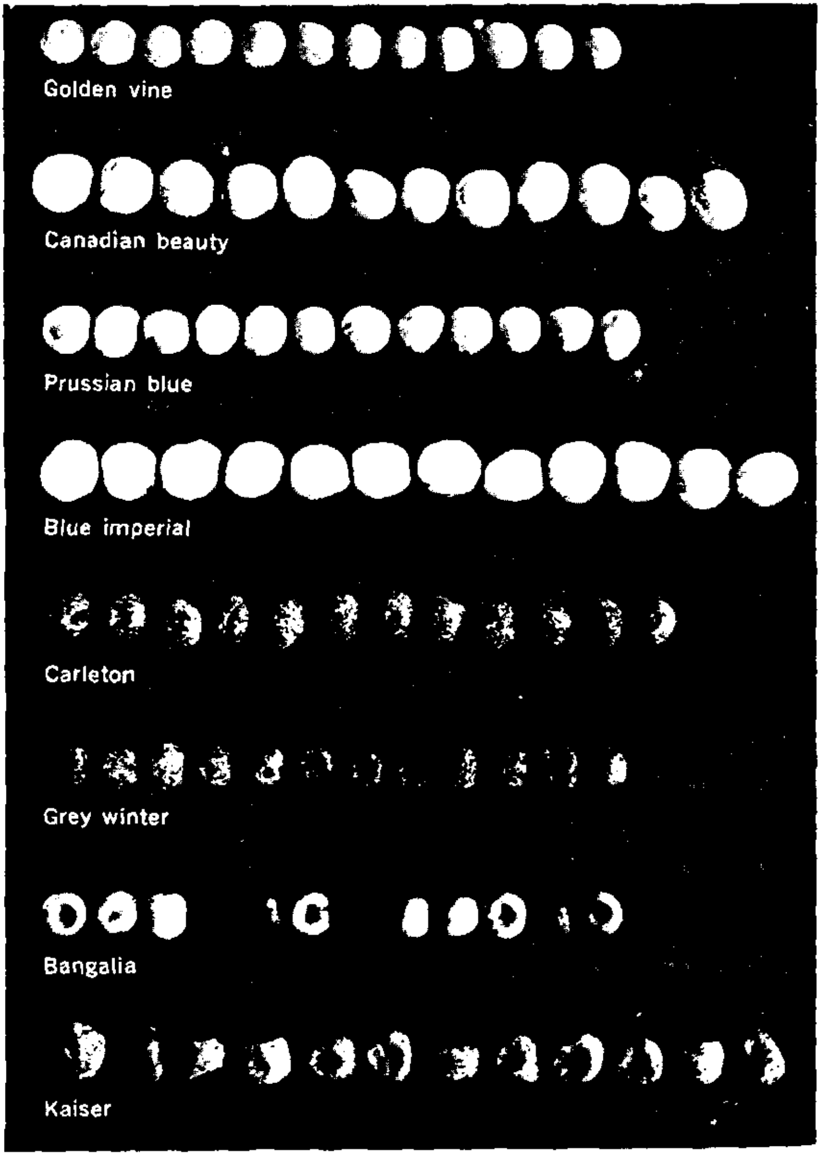

FIG. 223. Seeds of 8 varieties of field peas. (Natural size.)

In Idaho, 3.0 to 3.5 plants per square foot produce satisfactory yields regardless of the seed size of the variety. Optimum stands were obtained when six seeds per square foot were planted.[14] In sections of most northern states where moisture is abundant, small-seeded peas are planted at the rate of 60 to 90 pounds per acre, while large-seeded varieties are sown at nearly twice this rate. Under drier conditions the rate is 45 to 60 pounds for the small-seeded varieties and 80 to 100 pounds for the large-seeded ones. In the cotton belt, Austrian Winter peas are seeded at the rate of 30 to 50 pounds per acre.

For hay or silage, field peas often are sown in mixtures with oats or barley. The grain stems help to support the pea vines and reduce lodging and make a better balanced feed.

Field peas are harvested for hay when most of the pods are well formed. Since peas often lodge badly, they are usually cut with a mower equipped with special lifting guards and a windrow attachment. Field peas may be harvested for seed when the pods are mature in much the same manner, being threshed with an ordinary small grain thresher adjusted to avoid cracking of the seed. More than 60 per cent of the seed crop is combined directly. The pickup combine often is used to thresh the crop from the windrow or bunch. Also, special pea and bean threshers are used. Defective and weevil-infested seeds are separated from sound seed by floating them off in brine.

UTILIZATION

In the cotton belt the Austrian Winter pea often is planted as a fall-sown cover and green-manure crop in place of hairy vetch. Sufficient growth is generally made by March for the crop to be turned under. In the Pacific northwest field peas are used for hay, pasturage, and silage. For best results the peas should be allowed to mature before being grazed by hogs or sheep. Certain yellow and green varieties listed as dry edible peas are marketed largely as split peas for soups. Whole dry peas occasionally are soaked and then cooked as a substitute for canned peas.

Split peas are the separated cotyledons, with the seedcoats and most of the embryos removed. The process of splitting peas is a trade secret guarded as closely as the secret of splitting the atom for the release of atomic energy. Peas can be hulled and split in a burr mill, with the burrs set far enough apart to avoid serious cracking of the cotyledons. The hulls removed by aspiration, and the embryos and seed fragments screened out, are useful in mixed feeds. Field pea seed can be ground, mixed with grains, and fed to livestock. Peas and their by-products are popular pigeon feeds.

DISEASES

The Ascochyta blight of leaves and stems is caused by three different fungi, *Ascochyta pisi, Mycosphaerella pinodes,* and *Ascochyta pinodella.* It is most destructive in the humid regions, particularly in the south. The diseases are characterized by brown to black spots on all above-ground parts of the plant, which may be numerous enough to kill the leaves, petioles, and tendrils. The stem may be more or less uniformly blackened. The fungi live over from one crop season to the next principally in the soil or in pieces of diseased stems.[43] Losses are reduced to a minimum where peas occupy the land only once in 3 or 4 years. The use of seed produced in disease-free areas is recommended.[12]

Bacterial blight, caused by *Pseudomonas pisi,* produces olive-green to olive-brown, water-soaked areas on the stems, leaves, and pods. The infected plants may be killed. The bacteria that cause the disease can live over on the seed. Control measures involve the use of clean seed, and rotation.

Other diseases that attack field peas and the fungi which cause them include leaf blotch (*Septoria pisi*), powdery mildew (*Erysiphe polygoni*), downy mildew (*Peronospora viciae*), anthracnose (*Colletotrichum pisi*), fusarium wilt (*Fusarium oxysporium f. pisi*), various root rots, and mosaic. Strains resistant to fusarium wilt have been developed.

INSECT PESTS

The pea weevil (*Bruchus pisorum*) is the most serious insect enemy of the field pea. The adult weevil deposits its eggs on the pods while the peas are in the immature stage. The egg hatches and produces a larva that finally bores into the young seed where it feeds on the embryo. The principal injury is due to the destruction of the seed and its impairment for food. In regions where the pea-weevil is prevalent, the seed should be fumigated with cyanide gas or carbon disulfide as soon as it has been threshed. Crop rotation and the burning of pea residues also is helpful. Application of rotenone dusts when the weevils are emerging from hibernation, and after blooming and before pod formation in the peas, helps in controlling the pests. Dusting with 15 to 20 pounds per acre of 5 per cent DDT is useful for control of the weevils in peas grown for their seed where the straw is not desired for feeding to dairy cattle.

The pea aphid (*Illinoia pisi*), which attacks both peas and vetch, can be checked in Austrian Winter peas in western Oregon by delaying sowing until after October 16 to 20. Rotenone dusts containing 0.75 per cent rotenone, and 3 per cent nicotine sulfate dust (1 part 40 per cent nicotine sulfate to 14 parts by weight of hydrated lime), are effective against the pea aphid.

Other enemies of the pea include the pea moth (*Laspeyresia nigricana*), and the rootknot nematode.

Vetch

The total acreage planted to vetch probably exceeds 1,500,000 acres in the United States, of which nearly half is used for hay, pasture, silage, and soiling, and the remainder for a cover crop or for green manuring.

ADAPTATION

Vetch makes its best development under cool temperature conditions. The vetches vary in winterhardiness, but all are less hardy than alfalfa or red clover. Hairy vetch is the most winterhardy.[27] Hungarian vetch and smooth vetch survive temperatures as low as 0° F. in regions where temperature fluctuations are slight or where snow cover exists. Common vetch will not withstand zero temperatures, and was killed out completely at Stillwater, Oklahoma, as was monantha vetch.[15]

All vetches grow best on fertile loam soils. Hairy, smooth, and monantha vetches are productive on poor sandy soils, while Hungarian vetch is productive on heavy wet soils. As a group, the vetches are only moderately sensitive to soil acidity.

When grown for seed, some of the seeds shatter and volunteer. The volunteer vetch contaminates wheat grown on the land as long as the vetch continues to reseed itself. Wheat and vetch seed are not separated in the thresher or in a fanning mill, but only in special disk, cylinder, and spiral incline machines.

BOTANICAL DESCRIPTION

Most of the commonly grown vetches are annuals. Hairy vetch may be either an annual or a biennial. The common agricultural species are viny.[27] The stems may grow 2 to 5 feet or more in length. All the cultivated species have leaves with many leaflets. The leaves are terminated with tendrils in most of the species. The flowers are generally borne in racemes. The seeds of the vetches are more or less round, while the pods are elongated and compressed. Common vetch (Figure 224) is self-pollinated.[26] The flowers of most vetches are violet or purple, the purple vetch having reddish-purple flowers. Hungarian vetch has white flowers.

The most widely grown species of vetch are common vetch (*Vicia sativa*), hairy vetch (*V. villosa*), Hungarian vetch (*V. pannonica*), purple vetch (*V. atropurpurea*), and monantha vetch (*V. monantha*) (Figure 194). The so-called wild vetch or wild pea (*V. angustifolia*) occurs as an introduced weed in the north central states, where the seed contaminates wheat.

Hairy or sand vetch formerly was the most widely grown type in the south, but it has been replaced to a large extent by an improved variety known as smooth vetch. Smooth vetch was selected from hairy vetch in Oregon. The stems of hairy vetch are viny and ascend with support. This variety is characterized by pubescence on the stems and leaves as well as by the tufted growth at the ends of the stems. Smooth vetch is similar to hairy vetch except that it has less pubescence and lacks the tufted growth at the ends of the stems. Although winterhardy in the southern states, smooth vetch will not survive so far north as does hairy vetch.[24]

Common vetch, sometimes called spring vetch or tares, is a semiviny plant with slightly larger leaves and stems than those of hairy

FIG. 224. Branch of common vetch.

vetch. Three varieties are Oregon common, Williamette, and Pearl. The latter has a yellowish seed.

Hungarian vetch, grown commercially in Oregon, is less viny than either hairy vetch or common vetch. The plants tend to be erect when the growth is short or when they have support. They have a grayish color because of the pubescence on the stems and leaves.

Purple vetch is similar in growth habit to hairy vetch. The pods of purple vetch are hairy while those of hairy vetch are smooth. It is the best adapted vetch for the coastal sections of California.[8]

Monantha vetch has finer stems and leaves than hairy vetch. Single flowers are borne on long stems. It is grown safely as a winter legume only in Florida and other states bordering the Gulf coast, and in the Pacific coast states where it is grown for seed.

CULTURAL METHODS

Hairy vetch is planted in the fall wherever it is grown. In the north (north of latitude 40°), except on the Pacific coast, all other vetches are planted in early spring. In the cotton belt the crop is seeded in early fall, usually in September or October. Vetch is planted from about September 15 to October 15 in Washington and Oregon. The rate of planting depends largely upon the size of seed. but planting 12 seeds per square foot will give a satisfactory stand in California.[8] Rates of seeding for several species[27] are given in Table 1. The quantity of vetch seed should be reduced about one-fourth and that of small grain about one-half when they are grown in mixtures. A common practice is to plant vetch with small grain when it is grown for forage. The grain stems support the vetch vines,

TABLE 1. QUANTITY OF VETCH SEED TO PLANT PER ACRE WHEN SEEDED ALONE

VETCH SPECIES	SOUTHERN STATES (*lbs.*)	NORTHERN AND WESTERN STATES (*lbs.*)
Hairy or Smooth	20–30	30–40
Common	40–50	60–80
Hungarian	40–50	60–80
Monantha	30–40	60–70
Purple	——	60–70

which avoids damage from contact with the ground and also makes cutting easier.

Vetch is generally cut for hay when the first pods are well developed. It may be cut with a mower with a swather attachment. When grown as a seed crop, common, hairy, and smooth vetches are harvested when the lower pods are ripe to avoid shattering. Purple and Hungarian vetches are usually cut after 75 to 90 per cent of the pods are ripe. The seed may be threshed either with an ordinary grain thresher or with a pickup combine.

UTILIZATION

The vetches are most widely used in the southern states as cover and green manure crops, although occasionally they are cut for hay. In Alabama, vetch or Austrian Winter peas grown in a 2-year rotation (cotton-winter legume-corn) increased the corn yield 18 bushels per acre.[39] The second-year residue from these legumes increased the cotton yield by 213 pounds per acre. Large increases in the yields of corn and cotton were obtained when vetch was turned under in Alabama as early as March 15.[7]

In the Pacific northwest the vetches are used for hay either alone or in mixtures with small grains. Common and Hungarian are grown most generally for hay. The vetches have been used for soiling, and may be grazed during the winter, spring, and early summer.

DISEASES

Several fungus diseases attack vetch but they seldom cause serious damage. Leaf spot (*Ascochyta viciae*) is found on most species but it causes little damage.[27] Stem rot (*Sclerotinia trifoliorum*) causes some loss on the Pacific coast, particularly in warm wet springs. The disease can be controlled by a rotation where vetch is not seeded on the land more than once in 3 years. *Rhizoctonia* is damaging to vetch in the south. Nematodes likewise cause some loss.

INSECTS

Many insect pests of other forage legumes also attack vetch. Some of these are aphids, corn earworm, grasshoppers, cutworms, army worms, various weevils, and leafhoppers.

A specific pest, the vetch bruchid or vetch weevil (*Bruchus brachialis*) may cause heavy reduction in the seed yield of hairy, smooth, and woolly-podded vetch. It does not infest the seed of common, Willamette, or Hungarian vetch. It is found throughout the vetch-growing area of the middle Atlantic states and is also considered a serious pest in some of the western states. The bruchid in the seed can be killed by fumigation with hydrocyanic acid or carbon disulfide. This does not control the chief infestation which comes from hibernating weevils. Dusting the fields with 25 pounds per acre of 3 per cent DDT when the first pods appear is an effective control method.

Heavy infestations of the vetch or pea aphid (*Illinoia pisi*) destroy the seed crop and seriously damage the quality of the hay. Delaying the sowing of common vetch until after October 16 to 20, and of hairy vetch until after October 11, is recommended for the control of the aphid in western Oregon. The crop should be sown in fields free from volunteer annual legumes. In western Oregon cover or green manure crops of annual legumes should be plowed under by April 7 at which time the spring flight of the aphids begins.

Velvetbean

The velvetbean has been grown in this country as a field crop only since about 1890. An average of more than 2 million acres annually were devoted to the seed crop from 1936 to 1945. The average yield of threshed beans was more than 800 pounds per acre. The principal velvetbean states in order of production were Georgia, Alabama, Florida, South Carolina, and Mississippi (Figure 225).

ADAPTATION

The velvetbean is a warm weather crop requiring a long frost-free season to mature the seed. The crop was confined to Florida and other Gulf coast states until the introduction of early varieties extended its range to the northern limits of the cotton belt. The velvetbean is well adapted to the sandier, less fertile soils of the southeastern states, especially those of the coastal plain. It makes a poor growth on cold wet soils. It has been used extensively as a green-manure crop on newly cleared woodlands.

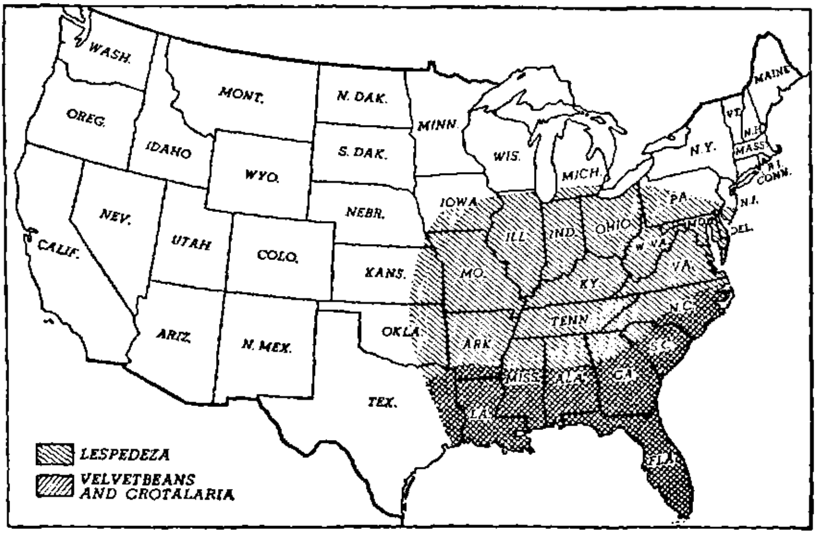

FIG. 225. Areas to which lespedeza, velvetbeans and crotalaria are adapted.

BOTANICAL DESCRIPTION

The velvetbean is a vigorous annual, and, with the exception of the bush varieties, the vines attain a length of 10 to 25 feet. The leaves are trifoliate, with large ovate membranous leaflets shorter than the petiole. The flowers are borne singly or in twos and threes in long pendent clusters. The numerous hairs on the pods of velvetbeans sting like nettles and make the crop unpleasant to handle. The pubescence usually sheds soon after maturity. The pods range from 2 to 6 inches in length. The seeds may be grayish, marbled with brown (Figure 226), white, brown, or black. The velvetbean has numerous fleshy surface roots that often reach 20 to 30 feet in length.

VARIETIES

The Florida velvetbean (*Stizolobium deeringianum*) was the only species grown in this country until 1906. It requires 240 to 270 days to mature. The purple flowers are borne in clusters 3 to 8 inches long.[32] The pods are 2 to 3 inches long, nearly straight, and covered with black velvety pubescence. The seeds are nearly spherical, grayish marbled with brown. The Georgia and Alabama varieties are

FIG. 226. Leaves, pod and seeds of the velvetbean.

early mutations from the Florida velvetbean.[3] The Georgia variety matures in 110 to 130 days and matures throughout the cotton belt. The Alabama velvetbean matures about 45 days later, being best adapted to the region south of central Georgia, Alabama, and Mississippi. The Arlington velvetbean is an early selection from the Georgia variety.

The Lyon velvetbean (S. *cochinchinensis*) is a long-season variety that matures about 10 days earlier than the Florida variety. It has white flowers borne in racemes sometimes 2 to 3 feet long. The pods are 5 to 6 inches long, covered with gray hairs, and have a tendency to shatter when mature. The seeds are ash-colored. The Chinese variety, similar to the Lyon, matures from 40 to 45 days earlier. It is adapted to about the same area as the Alabama variety.

The Yokohama velvetbean (S. *hassjo*) produces a smaller vine growth than the other species. It matures within 110 to 120 days. The flowers are purple. The pods are 4 to 6 inches long, flat and covered with gray pubescence. This variety is seldom grown at the present time.

The Osceola velvetbean was developed from a hybrid between the Florida and the Lyon varieties. The flowers are white, while the pods are 4 to 5 inches long and covered with a black velvety pubescence. It matures in 150 to 160 days, being adapted to about the same region as the Alabama variety.

CULTURAL METHODS

Seed yields are lower from continuous cropping than from the crop grown in rotation, but the vegetative growth is not adversely affected by continuous cropping. In general, the seedbed for velvetbeans should be prepared as for corn.

Velvetbeans are tender and should be planted in warm soils after all danger of frost is past. In the northern part of the cotton belt the planting time is about the same as for corn. Farther south, late varieties are planted as soon as the soil is in good condition, but the date of planting for early varieties may extend over a period of from 40 to 60 days.[32]

More than 90 per cent of the acreage of velvetbeans is planted with another crop, usually corn, to support the vines. Corn and velvetbeans are often planted in separate rows, every third row being planted to the latter. When planted in every row or in alternate rows, the velvetbeans are likely to form a tangled mass that makes it difficult to harvest the corn.

Velvetbeans are generally planted at the rate of about 7 to 11 pounds per acre when corn is the important crop. The rate is doubled for large bean yields. As a green-manure crop, velvetbeans are usually planted at the rate of 30 to 60 pounds per acre.

When grown for seed, velvetbeans are generally harvested soon after the pods have matured. Because of the tangled vine growth, it is necessary to pick the pods by hand. They may be threshed with a special bean huller or with a grain thresher. Late varieties grown for pasture may be left in the field all winter, but early varieties are pastured soon after the pods mature to avoid losses from shattering.

UTILIZATION

The velvetbean may be used for green manure, pasture, silage, or hay. In experiments in Alabama the yield of seed cotton after cotton was 918 pounds per acre; after velvetbeans cut for hay, 1,126 pounds; and after velvetbeans plowed under, 1,578 pounds. In southern Georgia, corn following velvetbeans plowed under in the winter has yielded about twice as much as when following corn. The crop is an important winter pasture in the south. The whole or ground beans are frequently used as feed, especially for cattle. As a rule, little benefit is derived from grinding them, and ground velvetbeans are likely to be unpalatable,[10] because they often become rancid in a short time. Thin-podded speckled beans similar to the Florida variety are much higher in feeding value than the thick-podded types like Osceola.

CROP PESTS

The velvetbean is remarkably free from disease or insect enemies.[32] The velvetbean caterpillar (*Anticarsia gemmatilis*) may cause serious injury to the crop south of central Georgia. They seldom attack the crop until the plants begin to bloom. The damage is caused by defoliation, especially on late varieties. The Florida Station has been able to control this pest by dusting the vines with arsenate of lead or zinc 10 or 12 days after the moth first appears. A mixture of 3 pounds with air-slaked lime is sufficient dust to treat an acre. There is little danger of stock poisoning with this amount of dust, especially after a rain. An application of 10 to 15 pounds per acre of cryolite dust also is effective.

Burclover and Black Medic

Burclovers, together with black medic, a related species, are valuable winter annual legumes that maintain themselves readily from year to year by natural reseeding.

ADAPTATION

The burclovers are primarily adapted to the mild moist winters of the cotton belt and the Pacific coast. Few legumes make more growth in the Gulf coast area in cool weather than does burclover. The crop will grow on moist soils, but it is most productive on well-drained loam soils. In California, burclover grows vigorously in adobe soils which are often poorly drained. The plant thrives on soils poor in lime as well as on slightly alkaline soils.[18]

Most soils on the Pacific coast are inoculated with the proper legume bacteria, but inoculation is essential in many southern states. In Alabama tests, nodule formation was greater when inoculation bacteria were applied to the unshelled seed than to the shelled seed.[6]

Black medic (often called yellow trefoil) is distributed naturally in pastures, waste places and meadows over much of the humid area of the United States. In certain sections of the southeast it furnishes valuable late winter or early spring pasturage when other pasture plants are largely dormant.[2]

BOTANICAL DESCRIPTION

Burclover plants branch at the crown and have 10 to 20 decumbent branches 6 to 30 inches long. The roots do not extend very deep into the soil. Burclover has small yellow flowers borne in clusters of 5 to 10. The coiled pods are covered with spines which form the so-called bur. A vigorous plant may produce as many as 1,000 pods. The seeds resemble those of alfalfa.

Spotted or southern burclover (*Medicago arabica*), widely grown in the cotton belt, has a purple spot in the center of each leaflet (Figure 227). The pods contain from 2 to 8 seeds. California or toothed burclover (*M. hispida*) is the most common species on the Pacific coast. It lacks the spots on the leaflet. The pods have three and sometimes five seeds. The California burclover is less winter-hardy than spotted burclover. Tifton burclover (*M. rigidula*), a recent introduction to the coastal plain of Georgia, is more resistant to extremes of temperature, more resistant to disease, and produces more seed than the other common burclovers.[4] There is a variety of spotted burclover with spineless pods. All burclovers are native to the Mediterranean region.

Black medic (*M. lupulina*) has slender, finely-pubescent, procumbent stems, one to two feet long. The leaves are pinnately trifoliate with long petioles (Figure 228). The leaflets are finely pubescent, obovate, rounded, and slightly toothed at the tips, and are one-half inch or less in length. The small bright yellow flowers are borne in dense heads about one-half inch long. The seeds (Figure 194) closely resemble those of alfalfa, and formerly were imported from Europe as an adulterant of alfalfa seed.

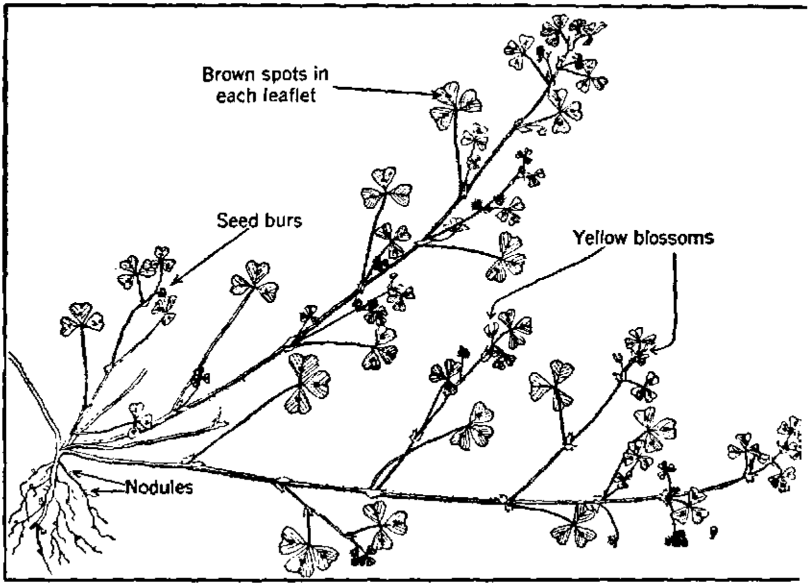

FIG. 227. Spotted burclover. One-third natural size.

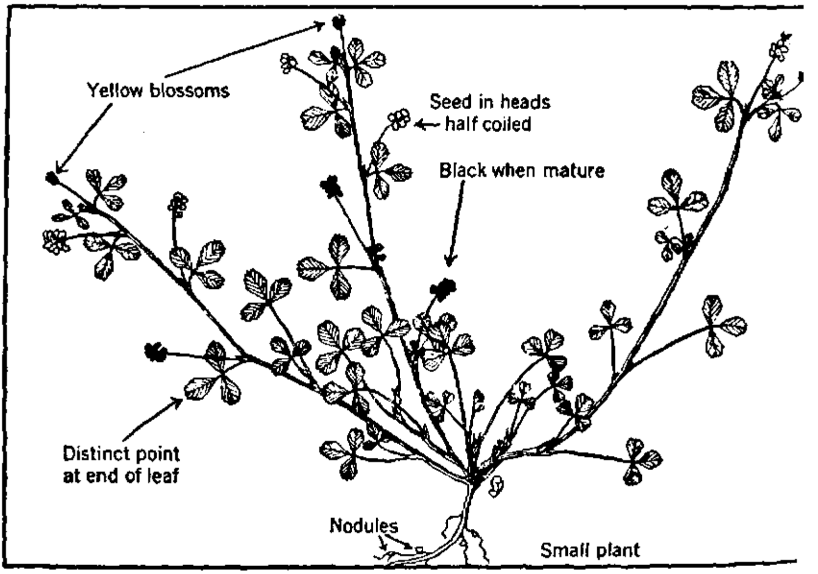

FIG. 228. Black medic.

CULTURAL METHODS

Burclovers and black medic are seeded in the fall from September to December, but sufficiently early for the plants to become established before winter.

Seed in the bur is generally broadcast at the rate of 3 to 6 bushels per acre, while the shelled seed may be drilled at the rate of 15 pounds per acre.[18] Good stands are obtained thereafter without additional seeding, provided the land is plowed after the burs are ripe. The plants reseed indefinitely on established pasture lands. When harvested for seed, the burs are allowed to mature and drop to the ground. The burs are swept together with large barn brooms and hauled from the field.

UTILIZATION

Burclover is used primarily as a pasture crop. It is valuable on California range lands where animals graze the pods, particularly after they are softened by rains, and where the burclover cures and dries after the rainy season is over.[11] Weathering of the cured forage reduces its digestibility. A combination of burclover and Bermuda grass is often used as a permanent pasture in the south.

Burclover alone has been widely used in California orchards or rice fields as a green manure crop. It has proved to be a valuable cover and green manure crop in the south. It is often seeded in cotton and corn to control soil erosion. Burclover is seldom used for hay.

Black medic sown with locally adapted (Florida or Alabama) seed is recommended for Florida pastures.[2] Imported (European) seed produces slow-growing, prostrate plants that fail to produce seed under high-temperature, short-day conditions. It is adapted to well-drained, open, limed or calcareous soils. It is sown at a rate of 7 to 12 pounds per acre.

Kudzu

Kudzu (*Pueraria thunbergiana*) has recently become an important legume in the southeastern states, occupying probably 400,000 acres in 1946.

ADAPTATION

Kudzu is a warm weather plant that is somewhat drought resistant. The leaves and stems are sensitive to frost. Kudzu makes its seasonal growth from the time the soil becomes warm in the spring until the first frost in the fall. The plant will grow on many soil types, being able to thrive on soils too acid for clover. It is well suited as a cover crop for rough, cultivated lands. Kudzu is not adapted to soils with a high water table, nor to the lime soils of the black belt in Alabama.

BOTANICAL DESCRIPTION

Kudzu is a perennial leguminous vine native to Japan. The plant has many stems or runners that may grow as much as 70 feet in one season. The stems have nodes that send out roots wherever they come in contact with the soil. The internodes die and the rooted nodes become separate plants called crowns. The leaves resemble those of the velvetbean except that they are hairy. The deep purple flowers are borne in clusters (Figure 229). Seed production usually is very poor. More seed is set on old than on young vines,[37] and on climbing than on prostrate vines. The seeds are mottled and about one-fifth as large as those of peas.

CULTURAL METHODS

Kudzu can be propagated by seedling plants, crowns, or vine cuttings. Rooted vine cuttings are commonly used. Seedling plants occasionally are reproduced in special seedbeds, the seed being planted from May to July.[38] The plants should be set on well-prepared land in the winter or spring before growth begins, but usually in February or March in the south. They may be set in furrows or in holes dug for the purpose. A stand will be established in from one to five years, this being dependent upon the number of crowns set, soil fertility, and the amount of cultivation. Kudzu covers the area more rapidly where the plants are set 5 to 6 feet apart each way than by setting them 5 feet apart in 10-foot rows.[36] Where the rows are 10 to 12 feet apart, some crop such as soybeans may be interplanted the first year.

FIG. 229. Leaves and flowers of kudzu.

Kudzu may be cut for hay after the plants are well established, which is usually 2 or 3 years, but may be 5 years if planted on poor eroded soils. Phosphorus fertilization often hastens the development of the plants. Kudzu may be cut at any time during the season, but should be cut high and not more than once or twice in a season. The root reserves are decreased by excessive cutting.[31]

UTILIZATION

Kudzu is utilized either for hay or pasture. Its feeding value compares favorably with that of other legumes. Kudzu furnishes grazing during the summer drought period when many other pastures are unproductive. Close grazing usually kills the crop.[30]

Kudzu is also an important soil improvement crop. In an Alabama experiment kudzu plowed under increased the average yield of two crops of sorghum hay by 2,536 pounds per acre, four crops of corn by 19.3 bushels, and seven crops of oats by 7.9 bushels.[36]

Kudzu is widely used in the south as an erosion-control plant because of its rank vegetative growth. It does well in gullies, roadside cuts, and in areas destroyed by sheet erosion.[1] It will not thrive on very infertile soil unless phosphate fertilizers are applied. When planted as an ornamental, it often covers an entire yard and climbs to the tree tops. Close, frequent mowing will eradicate it.

Crotalaria

Crotalaria is grown extensively in the southeastern states as a summer annual cover crop. The five species of agricultural importance in the United States are *Crotalaria intermedia, C. mucronata* (*striata*), *C. spectabilis, C. lanceolata,* and *C. juncea.*[22] *Crotalaria juncea* is called Sunn hemp in India where it is grown frequently as a fiber crop.

ADAPTATION

Crotalaria is native to tropical regions of heavy rainfall. It requires a warm season for vigorous plant growth. The plant is sensitive to frost, being killed or seriously injured at 28° to 29° F.[22] Showy crotalaria (*C. spectabilis*) (Figure 230) will mature seed farther north than does striped crotalaria (*C. striata*), i.e., as far north as North Carolina.[21] Crotalaria is adapted to light sandy soils, especially to those of the coastal plains area of the southeastern states (Figure 225). Well-drained soils are essential to growth. The soils in this region usually are naturally inoculated with the proper legume bacteria.

BOTANICAL DESCRIPTION

The above species of *Crotalaria* are moderately branched, upright annuals that attain a height of 3 to 6 feet. The leaves are large and numerous. *C. striata* has numerous yellow flowers borne on long terminal racemes.[35] From 40 to 50 seeds are borne in pods similar to those of peas. The seeds are kidney-shaped and vary in color from olive green to brown. The leaves are trifoliate in this species, but monofoliate in *C. spectabilis.* Both species have a bitter taste in the green state.

CULTURAL METHODS

All types of crotalaria should be planted late in the spring. When used as a cover crop, crotalaria is generally planted from March 15

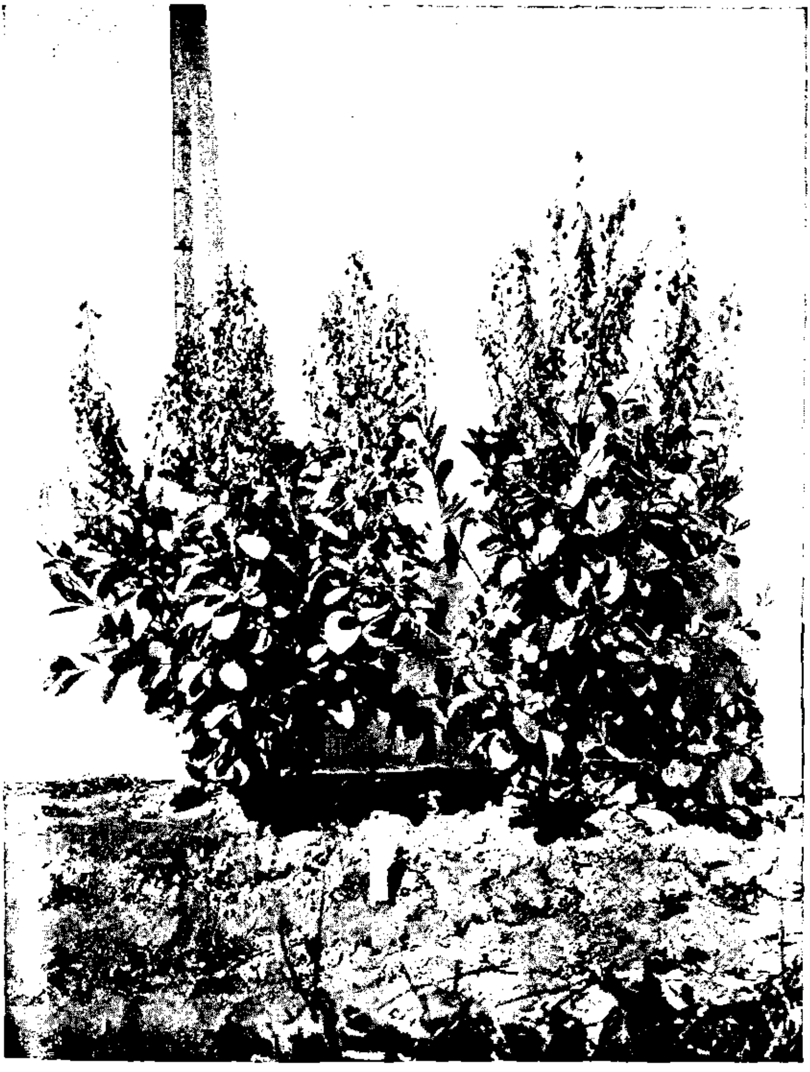

FIG. 230. Showy crotalaria.

to April 15 in Florida and from April 1 to 30 in other Gulf coast states.[21] As a hay crop, it is often planted in June so as to be ready for harvest by October 1. Crotalaria may be sown broadcast or in close drills at the rate of 15 to 30 pounds of seed per acre. The higher rate is generally followed for unscarified seed, or when seeding conditions are poor. Crotalaria can be seeded in oats in the lower south,[17] where it makes a rapid growth after the oats are harvested. Where crotalaria is grown for seed it is commonly planted at a rate of 2 to 6 pounds per acre in cultivated rows.

Crotalaria should be cut for hay at least by the bloom stage. The best quality of *C. intermedia* is obtained when cut in the bud stage or earlier.[33] To obtain a satisfactory second growth, it is necessary to leave a stubble of at least 8 to 10 inches. Seed may be harvested as it matures, or left to fall on the ground and reseed the crop. The seed usually is harvested with a combine. Much of the seed requires scarification before it will germinate promptly.

UTILIZATION

The greatest use of crotalaria is as a cover and green-manure crop. Seeding of striped crotalaria in Florida citrus orchards has been discontinued because it harbors insects injurious to citrus. Showy crotalaria is often planted in pecan groves. In Florida greatly increased yields of corn and sweetpotatoes were obtained after striped crotalaria in comparison with yields after a nonlegume.[35] For a rapid accumulation of nitrates, crotalaria should be plowed under in the early growth stages.[17] To retard the accumulation of nitrates for use in the spring, the crop should be turned under at an advanced stage of growth.

Crotalaria is used only slightly as a forage crop because it is not very palatable and because the coarse fibrous stalks make a poor quality of hay. A fair quality of hay and silage can be made from *C. intermedia* when the plants are cut early.[33] The green forage, hay and silage of *C. spectabilis* and *C. juncea* may cause death when fed to livestock. They contain an alkaloid called monocrotaline. *Crotalaria intermedia, C. lanceolata* and *C. striata* are not poisonous.

Trefoil

ECONOMIC IMPORTANCE

Two species of trefoil, viz., birdsfoot trefoil (*Lotus corniculatus*) and big trefoil (*L. uliginosus* or *L. major*), have become naturalized in the United States and are being sown in pasture mixtures. Seed of these legumes has been imported from Europe, where they are native, but seed is now being harvested in this country. The value of birdsfoot and big trefoil for pasture, and in some cases for hay, is becoming well recognized, particularly in New York and other northeastern states, the Pacific coast states, and in parts of Iowa and Nebraska.[29]

BOTANICAL DESCRIPTION

The trefoils appear to be best adapted to the northern states. Both species are long-lived perennials with a well-developed branching root system. In general, they have the appearance of fine-stemmed alfalfa, with cloverlike leaflets and yellow flowers. The stems are partly erect, 12 to 30 inches long, slender, somewhat branched, and moderately leafy. Each leaf consists of five obovate to linear leaflets, three of which are petiolate and two sessile. The seeds weigh about 60 pounds per bushel. Birdsfoot trefoil usually has five flowers in a raceme and nonspreading rhizomes, whereas big trefoil usually has eight to twelve flowers in a raceme and spreading rhizomes. Both species are largely cross-pollinated and each requires a specific culture of nitrogen-fixation bacteria for inoculation, and likewise distinct from those for other cultivated legumes.

BIRDSFOOT TREFOIL

Birdsfoot trefoil was introduced into the United States before 1876. It appears to be adapted to a wide range of soil conditions but is not particularly resistant to drought. Although thriving on rich soils, it will grow on gravelly loams, and on soils low in available calcium.

Birdsfoot trefoil is a highly variable species. The seeds (Figure 194) are light to dark brown in color, with about 375,000 in a pound. Two botanical varieties are of some importance in the United States. These are *L. corniculatus* var. *arvensis* recommended in New York and other northeastern states, and var. *tenuifolius*, becoming important in Oregon and California. The *arvensis* type has rather large obovate to oblong leaflets, with stems nearly free from hairs. The *tenuifolius* type has smaller lanceolate or linear leaflets and hairy plants. It is extremely tolerant to soil salinity.

BIG TREFOIL

Big trefoil, *L. uliginosus,* is of two types: (1) plants smooth or nearly so, var. *glabriusculus,* and (2) plants hairy, var. *villosus.* Big trefoil occurs in pastures or meadows in Oregon, California, and Wisconsin. It is adapted to moist or even swampy land and peat or muck soils. It thrives in an acid soil of *p*H 4.5 and does not respond to liming. The seeds are greenish-yellow to yellowish-green in color but become brown with age. A pound contains about one million seeds.

CULTURE

Both birdsfoot and big trefoil are recommended for growing in mixtures with grasses and other legumes, with timothy and red clover in both New York and Oregon and also with alsike clover and orchard grass in New York, and with bentgrass and perennial ryegrass in Oregon. About one pound of seed per acre of trefoil is used in the mixtures.

When grown alone, birdsfoot trefoil is sown at 8 to 12 pounds and big trefoil at 4 to 6 pounds per acre. Seeding should be in the late summer or early fall, or late fall if unscarified seed is used, in the northeast. Hay yields are comparable to those of red clover under the same conditions. Clean seed yields of only approximately 100 pounds per acre are typical because of the shattering of seed soon after the pods are ripe. The hay has a composition and quality similar to that of clover and alfalfa. Its value for pasture lies chiefly in its succulent growth in midsummer and late summer when other herbage has nearly ceased growth.

INSECTS

Birdsfoot and big trefoil are injured by insects that attack alfalfa and clover, but the only serious injury reported thus far in the United States is from the potato leafhopper.

Sesbania

Sesbania *[Sesbania macrocarpa (exaltata)]* * is a coarse-growing, upright annual legume, native to America, and found in various

* *New Mexico Agr. Expt. Sta. 46th Ann. Rpt.,* 1934–35, p. 18.

localities in the southern part of the United States from California to Georgia, extending as far north as Arkansas. It is abundant on the overflow lands of the lower Colorado River in Arizona and California where it is referred to as wild hemp or Indian hemp. The Indians there use the fiber for making fish lines and other twines. It also occurs as a weed in the rice fields of southern Texas and Louisiana under the name *tall indigo*. In hot weather, with ample rainfall or irrigation, and good soil, it grows to a height of 6 to 8 feet in a few weeks. The yellow flowers borne in racemes arising from the leaf axils later produce long slender seed pods. Sesbania is not relished by livestock. It is grown for green manure in the irrigated valleys of southern California, and southern Arizona and the lower Rio Grande Valley of Texas. Seeded in June, it provides a heavy growth of green manure to be turned under in late August, in preparation for fall-planted vegetable crops. It should be sown at the rate of about 20 pounds per acre. The seed usually is gathered from wild stands. Sesbania roots are attacked by nematodes, and the seed by a small weevil. Soil disinfection controls the nematode and seed fumigation controls the weevil.

Lupines

Lupines, although known for some 2,000 years and used in Europe for 200 years, have only recently been established in this country. From about 10,000 acres planted in 1942, the acreage increased to 250,000 by 1945. Lupines are grown for green manuring. Although occasionally fed to livestock in Europe, New Zealand, and Australia, such use is not recommended in the United States because the plants, particularly the seeds and pods, contain poisonous alkaloids. Nonpoisonous strains of lupines have been developed that may come into use for feed.[23]

Many perennial and annual species of lupines, including the bluebonnet, the state flower of Texas, *L. subcarnosus*, are native to America. The three species now grown commercially in the Gulf coast area, white lupine (*Lupinus albus*), yellow lupine (*L. lutens*), and blue lupine (*L. angustifolius*) were introduced from Europe. The value of these lupines lies in the fact that the seed can be produced in the south[42] and they make a heavy winter growth for turning under. The lupines are upright annuals having coarse stems and medium-sized digitate (fingered) leaves and large attractive flowers of the respective colors indicated by the names (Figure 231).

The lupines are drilled 1 to 2 inches deep in the fall in the southeastern states, where the temperatures do not go below 15° F., at the rate of 120 to 160 pounds for white lupine, 70 to 90 pounds of blue

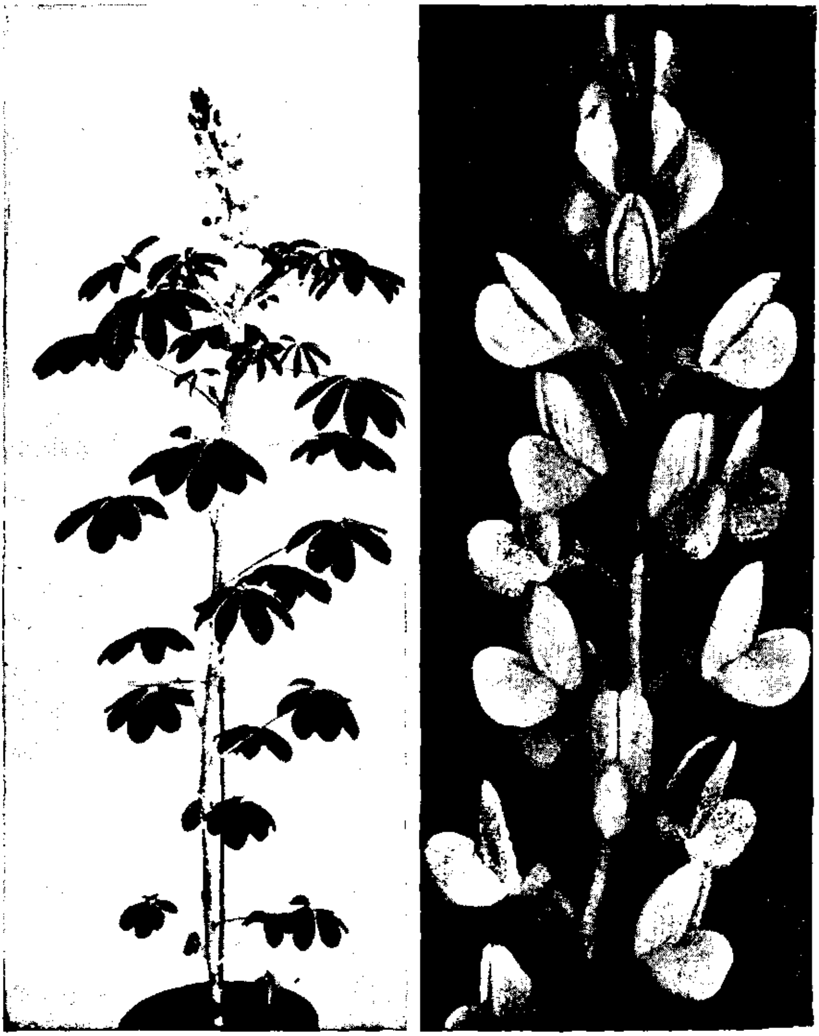

FIG. 231. White lupine: plant (*left*), flower spike (*right*).

lupine, and 45 to 60 pounds of yellow lupine.[20] The seed can be harvested with a combine.

Guar

Guar (*Cyamopsis psoralides*), or *C. tetrogonolobus*, introduced from India in 1903 has been used to some extent as a leguminous green-manure crop in southern California and Arizona, and in Texas. It is the most resistant of all legumes tested to the Texas (or cotton) rootrot disease fungus (*Phymatotrichum omnivorum*), and is partly resistant to the rootknot nematode. Consequently, guar is the best leguminous summer green-manure crop on cotton lands badly infested with the former organism. Recently, guar has been grown in California and Arizona on 2,000 acres or more for production of a mucillage that is extracted from the seed. The mucillage, which is composed of mannogalactans, is used in paper manufacture to bind the fibers of cellulose strands together. The plant is a coarse, summer-annual, upright, drought-resistant herb, 2 or 3 feet in height, with angular toothed trifoliate leaves (Figure 232), small purplish flowers borne in racemes, and long leathery pods. Guar, sometimes called cluster bean, is a native of India where it is grown principally for its green fodder and for the pods that are used for food and feed. It is too coarse and woody for hay.[9] In the United States, it is sown in late spring at the rate of 40 to 60 pounds per acre drilled or 10 pounds per acre in rows. The seeds, 2,000 per pound, weigh 60 pounds per bushel.

FIG. 232. Guar plant.

Florida Beggarweed

Florida beggarweed (*Desmodium purpureum*) has been cultivated on a small acreage in the southern states for more than 50 years. It is a native of tropical America and southern United States. It is found chiefly in cultivated fields where it volunteers freely. Florida beggarweed is adapted to the southern coastal plain. When sown in the north it makes a fair vegetative growth but will not produce seed. It is best adapted to rich sandy loams and silt, but tolerates acid soils, and is resistant to the rootknot nematode. The plant is an upright, herbaceous, short-lived perennial legume attaining a height of 4 to 7 feet. It usually lives as an annual in most of the United States. The pubescent main stem is sparsely branched. The leaves are trifoliate with large ovate leaflets that are pubescent and often reticulate on the lower surface. Racemes of inconspicuous flowers terminate the main stem and lateral branches. The seeds are borne in jointed pods, segments of which adhere to cotton lint and clothing. The seeds, which number about 190,000 per pound, weigh about 60 pounds per bushel when freed from the hull.

The seed is sown in late spring or early summer following a cultivated crop or at the last cultivation of early-planted corn. About 10 pounds of hulled or scarified seed to 30 to 40 pounds of unhulled seed are sown on a compact seedbed. Fertilizer usually is not needed on fertile soils or when seeding on corn or cotton land that has been fertilized. Otherwise 200 pounds per acre of superphosphate, 75 pounds of muriate of potash, and 8 to 10 pounds of available nitrogen in some form may be applied. Lime seldom is needed and inoculation is unnecessary. It is harvested for forage between early bloom and the formation of the first pods. The hay is difficult to cure.

The chief uses of Florida beggarweed are pasturage, hay, and green manure, and to produce seeds for quail feed. It cannot be maintained in permanent pastures.

Roughpea

Roughpea (*Lathyrus hirsutus*), also known as wild winter pea, caley pea, and singletary pea, occupies possibly 50,000 acres of cultivated and pasture land. It is sown occasionally for pasturage, hay, or green manure. The plant, a native of Europe, long ago escaped to cultivated land and pastures in humid sections of the southern half of the United States, where it is adapted. The plant is a winter annual resembling the sweetpea (*Lathyrus odoratus*). It has weak stems that are decumbent except in thick stands, where they are partly upright. The plants mature at or before wheat harvest. After the plants come up naturally or from seeding, the growth is slow until late winter or early spring when rapid growth begins. Because of this delayed growth, it is inferior to the Austrian Winter pea or smooth vetch as a green manure crop to precede early-planted spring crops such as cotton. The seeds (Figure 194) are about the size of vetch seed, i.e., 14,000 per pound, and they weigh about 55 pounds per bushel.

The rough pea is sown about October 1 at a rate of about 20 pounds per acre. The plants volunteer when once established. It requires inoculation when seeded for the first time. Fertilization with 200 pounds per acre of superphosphate is beneficial on most soils. Its lime requirements appear to be low. For hay the roughpea should be cut before seed is formed because the seeds appear to be injurious to livestock. The crop is cut and cured for hay and harvested and threshed for seed about as vetch and field peas are handled. The seed sometimes is harvested from the wild or is salvaged from the cleaning of grain from fields where roughpea is growing. The roughpea should not be pastured after the seeds have developed.

Hairy Indigo

Hairy indigo (*Indigofera hirsuta*) was first introduced into cultivation in Florida in 1945 after experiments had shown its value as a hay and green manure crop on sandy soils low in calcium. It is adapted to the coastal plain area from Florida to Texas. The plant is a summer annual legume that attains a height of 4 to 7 feet. The somewhat coarse stems become woody with age. The pinnately compound leaves resemble those of vetch. A late strain of hairy indigo is adapted to the southern half of Florida. The seeds which weigh about 55 pounds per bushel require about 200,000 to make a pound. Hairy indigo is resistant to rootknot nematode.

Hairy indigo is sown without inoculation from March to late May at a rate of 3 to 5 pounds per acre when drilled or 6 to 10 pounds per acre when broadcast. It responds to applications of phosphorus and potash when grown on coastal plains soils. It is cut for hay in August or September while still young. If cut high in August, a second growth follows which furnishes pasturage. Seed of the early strain matures in October, while the late strain is ripe in November. It can be harvested for seed with a combine or mower.

Alyceclover

Alyceclover (*Alysicarpus vaginalis*) is a summer annual, native to tropical Asia, grown in the gulf region for hay and soil improvement, and occasionally for pasture. It is not adapted to wet or very infertile soils, or to lands infested with rootknot nematode. The plants are 3 feet or less in height, with coarse leafy stems and broadly oval unifoliate leaves. Uninoculated seed is sown in May at the rate of 15 to 20 pounds per acre. The seed shatters quickly after it is ripe.

Miscellaneous Forage Legumes

Several other legume crops listed below have been grown experimentally in this country.[25] Those marked with asterisks also have been used on farms occasionally, chiefly for green manure. They are not described here because of their limited importance. The pigeon pea is grown on about 10,000 acres in Hawaii. Ground fenugreek seed is used in food condiments and horse-conditioning powders.

Bonavist or hyacinth bean (*Dolichos lablab* L.)
* Fenugreek (*Trigonella foenumgraecum* L.)
Kidney vetch (*Anthyllis vulneraria* L.)
* Milk vetches (*Astragalus* species)
Pigeon pea (*Cajanus indicus* Spreng)
* Sainfoin or esparcet (*Onobrychis viciaefolia* Scop.)
Serradella (*Ornithopus sativus* Brot)
* Sulla (*Hedysarum coronarium* L.)
* Tangier pea (*Lathyrus tingitanus* L.)
* Crown vetch (*Coronilla varia*)

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PART IV CROPS OF OTHER PLANT FAMILIES

31 MISCELLANEOUS FORAGE CROPS

Several forage crops that are neither grasses nor legumes are grown on limited acreages in the United States. These include the sunflower, Jerusalem artichoke, mangel, rutabaga, turnip, carrot, rape, kale, pumpkin, and squash. A few others [28] are grown so sparingly that mere mention is considered sufficient. Among these latter are cassava (*Manihot utilitissima*), a root crop (Figure 233) grown occasionally in Florida and adjacent states. It is native to Brazil, propagated from root or stem cuttings, and used for food in the tropics. It is grown mostly in the Netherlands Indies for the extraction of tapioca starch which is used for textile sizing, adhesives, and

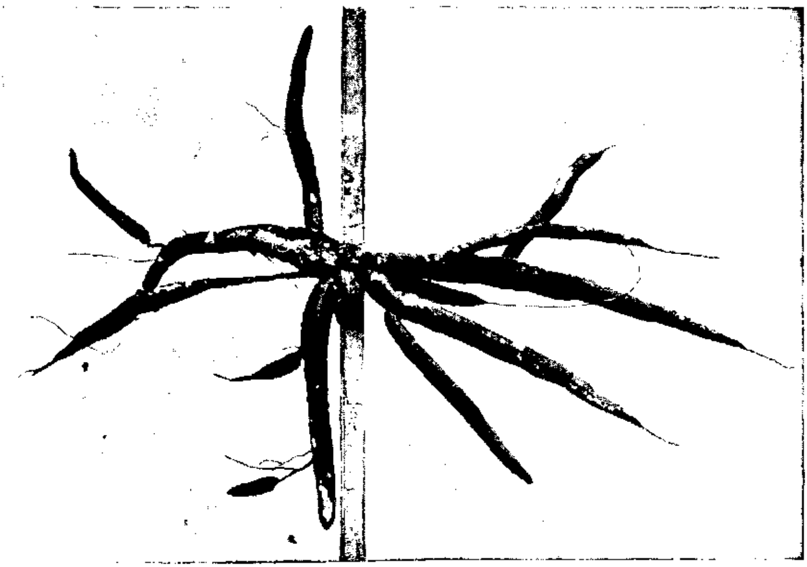

FIG. 233. Cassava roots.

food. About 300 million pounds of tapioca starch were imported annually before World War II. A plant called burnet (*Sanguisorba minor*), a deep-rooted perennial native to Europe, is utilized occasionally in pastures in California and Oregon. Sacaline (*Polygonum sachalinense*), a member of the Polygonaceae (buckwheat) family and grown as an ornamental, is occasionally exploited as a forage crop, often under some other name such as Eureka clover. Its tall branched growth and coarse hard stems make it less desirable for forage than corn and sorghum, which also outyield sacaline. Spineless cactus seldom is planted for forage because of its recognized slow growth and limited feeding value. Nearly spineless forms of the prickly pear cactus (*Opuntia species*), native to Mexico, have long been observed. A mediocre strain of a nearly spineless cactus, was introduced by a plant wizard early in the twentieth century. The wild spiny prickly pear is gathered, the spines usually singed off, and then fed to livestock in emergencies, chiefly in south Texas. The pears are watery and high in crude fiber but are satisfactory for feed.[14]

The chufa (*Cyperus esculentus*) was grown on about 2,000 farms in the United States in 1944, mostly in Florida. In 1941, 7,072 acres were hogged-off in Florida and 3,341 bushels of nuts were dug from 172 additional acres.[24] The nuts weigh about 44 pounds per bushel. The chufa is a sedgelike plant, with creeping rootstalks, that produces small tubers or nuts. In some places it is a pernicious weed called yellow nutgrass. Chufas are planted from late spring to midsummer by dropping the nuts 6 to 12 inches apart in rows spaced 2½ to 3 feet apart. The planting rate is about 15 to 40 pounds per acre. The crop is dug with a plow or potato digger, the plants allowed to dry, and then the nuts are rubbed off through a screen. The tops are used for hay. Chufas suffer little loss from diseases but the nuts are infested by a so-called Negro bug.

Sunflower

ECONOMIC IMPORTANCE

Sunflower seed production in the United States averaged about 4½ million pounds annually from 1936 to 1944. The yield of seed in

1939 was about 25 bushels or 700 pounds per acre on 4,235 acres. Most of the domestic seed crop is produced in California, Illinois, Missouri, Oregon, Indiana, and North Dakota. In addition, a limited acreage is grown for silage in the northern and intermountain states. Sunflowers also are grown in many gardens and yards for ornamentation or poultry feed, or to furnish shade for the poultry flock. The world production of sunflower seed is about 4 million tons annually. The leading countries in sunflower seed production are Russia, Argentina, Rumania, Bulgaria, Hungary, and Uruguay. About 5 million acres are grown in Russia, mostly in the Ukraine. Sunflower seed also is produced in Canada, Mexico, Spain, India, China, Africa, and elsewhere. In recent years, it has become an important export crop in Argentina under the name girasol. Sunflower seed and oil have been imported into the United States. The imports of oil previous to World War II averaged 16 million pounds annually.

ORIGIN AND HISTORY

The cultivated sunflower is a native of America and was taken to Spain from Central America before the middle of the sixteenth century. It was being grown by Indians for food at Roanoke Island in 1586, and in New England for hair oil in 1615.[6, 42] Established culture of the sunflower in the United States followed introduction of improved varieties that had been developed in Europe before 1600.[42]

The wild sunflower, the state flower of Kansas, flourishes in overgrazed pastures, and in fields, and waste places over western United States, particularly in the Great Plains states, strictly as a weed. The wild sunflower dramatically took possession of the wind-eroded fields and pastures of the southwestern dust bowl where man's efforts had failed, when the rains came in 1940 and 1941. Its rank-growing branched stems protected the lands from further wind injury while perennial vegetation became reestablished.

ADAPTATION

The sunflower is adapted for seed production where corn is successful in the northern two-thirds of the United States. It has been grown for silage in cool northern and high altitude sections where corn does not thrive. The young plants will withstand considerable freezing until they reach the 4 to 6-leaf stage, and the ripening seeds likewise suffer little damage from frost. Between those stages the plants are more sensitive to frost. The plants show relatively little photoperiodic response.

BOTANICAL DESCRIPTION

The sunflower (*Helianthus annuus*) belongs to the family *Compositae,* the thistle family. Plants of this family bear heads in which the fertile flowers are aggregated and which are bordered by rays, the corollas of sterile flowers.

The cultivated sunflower is a stout erect annual, 5 to 20 feet in height,[42] with rough hairy stems 1 to 3 inches in diameter, terminating in a head or disk 3 to 24 inches in diameter. The top of the disk is brown to nearly black. The rim of the disk is surrounded by pointed scales and 40 to 80 yellow rays. The seed is an elongated rhomboid achene. The stalk may produce several branch heads. The flowers are almost entirely cross-pollinated. The stalk of wild sunflower (also called *H. annuus*) usually is one inch or less in diameter, much branched, and bears numerous heads. The wild sunflower seeds are too small and chaffy for economic utilization.

A noticeable characteristic of the sunflower heads of facing toward the sun throughout the day accounts for both the common and botanical names for the plant. Schaffner[30] watched wild and cultivated sunflowers during the day and night. The heliotropic movement results from a bending of the stem, a process called nutation, which tilts the head to the west in the afternoon. After sunset the stem gradually straightens until it becomes erect about midnight. Thereafter the stem gradually bends in the opposite direction up to as much as 90 degrees, so that the head faces east by sunrise. Soon thereafter the stem starts to straighten until the head is erect again at noon. The leaves likewise face east in the morning and west in the evening and upward at noon and midnight. At 10 P.M., however, the leaves are drooping downward. Stripping the leaves from the stalk stops all bending of the stem. Nutation ceases when anthesis (pollen shedding) begins, or shortly thereafter, leaving fully 90 per cent of the heads facing east or northeast as they hang at maturity except during strong winds. Growers often take advantage of this eastward nodding habit by planting the rows north and south. At harvest time they drive a wagon along the east side of each row and cut off the overhanging heads.[17]

VARIETIES

The variety of sunflower best known in the United States for more than 50 years is the Mammoth Russian, but the varieties usually grown for commercial seed production are Greystripe and Manchurian. They are tall, large-headed, late-maturing varieties, 8 to 15 feet in height, Manchurian being the shortest and earliest of the three. Other varieties are Black Giant and White Beauty. Two dwarf early varieties, Mennonite and Sunrise, and a topcross hybrid named Advance are grown for seed in Canada and North Dakota. They grow to a height of 3½ to 6 feet, with small heads, and are harvested with a combine.[41] They do not produce large yields of seed because of their small quick growth. Mennonite is smaller and earlier than Sunrise. Sunflower hulls may be all white as in White Beauty, white with grey stripes as in Mammoth Russian and Greystripe, dark with black stripes as in Manchurian, or dark brown to black as in Black Giant. The seed weighs 21 to 32 pounds per bushel. A pound of seed contains 3,000 to 9,000 seeds.

CULTURAL METHODS

The seedbed for sunflowers should be prepared as for corn, and planting is done with a corn planter, equipped with special sunflower plates, or with a grain drill with most of the feed cups closed off. Planting usually is done in May[20] except in the central latitudes of United States where April planting seems to be more favorable.[32] Three to seven pounds per acre in drills or hills give an ample stand except when grown for silage under irrigation, in which case up to 10 pounds are planted. Plants of large varieties should be about 12 to 14 inches apart in rows 36 to 42 inches apart for grain production, and somewhat closer for silage. The small Mennonite and Sunrise varieties require closer spacing.

HARVESTING

Sunflowers are mature when the backs of the heads are yellow and the outer bracts are beginning to turn brown. The seeds are ready to thresh and store when they contain not more than 8 to 9 per cent moisture. The large varieties of sunflowers are harvested by hand. Dwarf sunflowers are cut with a combine. The cut heads can be threshed by hand, with a special sunflower thresher, a pea-and-bean thresher, a grain thresher, or a combine. These two latter machines should be adjusted to about one-half normal cylinder speed and an open concave setting. Extra slats or screening on the reel arms of combines and grain binders are necessary to avoid catching and throwing out the crook-necked heads. Whole heads are fed to chickens without threshing.

The use of sunflowers for silage began with a combination of corn, sunflower heads, and horse beans called the Robertson mixture recommended by the Dominion Experimental Farms in Canada in 1893.[1] For silage, sunflowers should be cut in the late bloom to early milk stage at which time the seeds have attained only about 10 per cent of their normal mature dry weight. Increases in acre yields of dry matter after this stage are offset by decreases in the percentage of digestible nutrients.[13] The stalks become woody and high in crude fiber as they approach maturity. Since the plants contain about 85 per cent water at the stage of maturity for silage harvest, they should be permitted to dry to the proper condition of 65 to 70 per cent moisture before being ensiled.[13] Sunflower silage contains nearly 2 per cent of ash, an appreciable portion of which consists of potash.

The resinous odor and taste of sunflower silage is not particularly pleasing to livestock. The digestible nutrients in typical watery sunflower silage are about 19 to 28 per cent less than in corn silage. In general, it might be advantageous to grow sunflowers for silage where the acre yield of dry matter exceeds that from corn silage by 50 per cent or more, as it has in certain cool northern sections.[13, 15, 20, 37] The handling of extra silage required to supply the same amount of digestible nutrients as in corn silage should be considered.

USES

The head of the matured sunflower contains about 50 per cent of the dry matter of the whole plant.[42] Nearly one-half the weight of dried heads is seed. About 35 to 50 per cent of the seed consists of hull. The whole seed contains 24 to 35 per cent of oil, and the hulled kernel about 45 to 55 per cent. The expressed oil yield from whole seed ranges from 20 to 25 per cent and from the hulled kernel about 35 per cent. The residue is oil cake which contains about 35 per cent protein when made from whole seed.

In most countries sunflowers are grown primarily for the production of oil. In Russia and elsewhere the seeds are eaten as a confection, either raw or roasted. Sunflower seed constitutes about one per cent of the ingredients of most commercial scratch feeds for poultry, and also is fed to parrots and wild song birds.

Sunflower oil is used mostly in shortening, cooking and salad oils, and margarine. It smokes at about 150° C. which is too low for deep-fat frying at the usual temperature of about 200° C.[12] Sunflower oil is used also for making soaps and paints. It is a semi-drying oil with an Iodine Number of about 130. The oil cake is mostly fed to livestock, but some is used for fertilizer.

DISEASES

Sunflowers are attacked by rust, charcoal rot, downy mildew, powdery mildew, and leaf-spot wilt.[16]

Sunflower rust, caused by the fungus (*Puccinia helianthi-mollis*) is the most common disease. It develops numerous brown (and later black) pustules on the leaves, causing them to dry up. Destruction of so much leaf tissue checks the development of the stalk and head. Dusting with sulfur and crop rotation are the most effective remedies. Certain European varieties, and also the ornamental sunflower (*Helianthus agyrophyllus*) [37] are resistant.

The charcoal rot disease causes wilting and lodging following the decay of the pith in the stalk. Control consists in late planting, an ample soil moisture supply, and avoidance of severely-infested soils. A wilt or stem rot caused by the fungus (*Sclerotina sclerotiorum*) has been reported in Minnesota.

INSECTS

The insect enemies of the sunflower include cutworms, wire worms, white grubs, grasshoppers, aphis, thrips, sunflower beetle, seed weevils, sunflower moth, sunflower budworm, and webworms.

Jerusalem Artichoke

ECONOMIC IMPORTANCE

The Jerusalem artichoke is grown only to a limited extent in the United States, although it has been advocated [3] as having great possibilities for food, feed, sugar, or alcohol. It has been grown in the Pacific coast states for many years. An estimated production of 2,000 acres was reported in Nebraska in 1935. The Jerusalem artichoke, native to America, was used for food by Indians who gathered the tubers in the wild or grew them in their clearings. It was found by Champlain at Cape Cod, Mass., and taken to France in 1605. Its culture in France has ranged from 200,000 to 330,000 acres annually.

ADAPTATION

The highest yields of Jerusalem artichoke tubers in the country have been obtained in cool, mild humid sections of the Pacific northwest. The tops are killed by the first frost in the fall. The crop responds to a good supply of moisture.[23] The plants require a growing season of 125 days and do not develop flowers or tubers until the approach of shorter days in August. It is a short-day plant.[31] The crop is best adapted to rich light or medium loams. Heavy soils make digging of the numerous small tubers rather difficult.

BOTANICAL DESCRIPTION

The name artichoke was early applied to the tuber because its taste resembled that of the edible bracts of the vegetable, the globe. French, or bur artichoke (*Cynara scolymus*). The Jerusalem part of the name has no reference to the Holy Land but arose from a corruption of the word girasol, the Italian name for sunflower. The Jerusalem artichoke (*Helianthus tuberosus*) grows to a height of 6 feet and is similar to the wild sunflower except that the center

FIG. 234. Tubers of Jerusalem artichoke.

of the head (disk) is light yellow instead of dark brown. The flower heads usually are about 2 to 3 inches across. The tubers (Figure 234), resembling hand grenades, are ovoid but irregular due to knobs and to rings or sections of different diameter. The skin is much thinner than that of the potato and not corky. Well-developed tubers weigh 1 to 5 ounces. The tubers remain alive in the ground over winter and thus maintain the crop as a perennial. Since it is extremely difficult to gather all of the tubers, the Jerusalem artichoke easily becomes established as a weed.

VARIETIES

Many varieties of the Jerusalem artichoke, having tubers with white, yellow, or red skin, are grown in Europe. The white-skinned French variety, Blanc Ameliore (White Improved), is the most promising in the United States.[4]

CULTURAL METHODS

The Jerusalem artichoke may follow a legume hay or grazed crop in rotations.[5] The fertilizer requirements and cultivation methods are similar to those for potatoes. The New Jersey Agricultural Experiment Station recommended an application of 500 pounds of a complete mixed fertilizer. Liming increased the yield of sugar per acre.[33] Either whole or cut tubers, preferably the former, may be used for planting. Some recommended planting rates are 5½ to 8 bushels (275 to 400 pounds) of tubers per acre in hills 18 to 24 inches apart in 42-inch rows.[22, 23, 31] In Wyoming, Minnesota, Illinois, and Maryland[4] the best yields were secured from whole or cut pieces weighing about 2 ounces, planted 1 foot apart in rows 4 feet apart, or 1,360 pounds per acre. The best yields in Oregon were obtained from 3-ounce tubers planted 2 or 4 feet apart in rows 5 feet apart or about 400 to 800 pounds per acre. Large seed pieces produce more stems but do not increase the size of tubers.

The tubers should be planted 4 inches deep as early in the spring as the land can be prepared. If some of the tubers are left when digging, a crop will develop the following year. The best method of eradicating the Jerusalem artichoke is to plow the land in late spring or early summer when the tops are about 1½ feet high and then immediately plant some smother crop.

HARVEST

The digging of tubers starts after frost. Digging with a plow or ordinary potato digger leaves many tubers in the soil, and usually the tops must be mowed and removed before a potato digger will operate satisfactorily. Picking up the tubers is laborious because they are much smaller than average potato tubers. About 20 pickers are required to keep pace with the mechanical digger.

A modified elevating potato digger which breaks down the stalks, reduces the size of the crew about two-thirds and also permits the pickers to ride on the machine while sorting and bagging the tubers.[25]

When grown for hog feed, the hogs often are allowed to gather the tubers, in which case they leave enough seed tubers in the ground for a stand the following year. This harvesting method is somewhat uncertain because often the soil either is frozen or is too wet for effective rooting during much of the late fall and winter. Tubers for planting often are not dug until spring because they keep better in the ground than in storage.

Fresh green tops are suitable for feed, but when mature they are harsh, woody, unpalatable, low in digestible nutrients, and seldom harvested. When the tops are cut early enough to secure the maximum yield and quality of forage the yield of tubers is reduced 40 to 60 per cent.[4] The green weight of tops at maturity is about equal to the tuber yield.

On farms the yield of tubers may be expected to range from about one ton per acre on semiarid lands up to 10 tons under favorable irrigated or humid conditions. Occasionally yields are much higher. Average yields in the middle west and east will not exceed 5 or 6 tons per acre. The cost of production is similar to that for potatoes, harvesting being more expensive, but spraying costing less or being omitted.[5]

The tubers keep best in cold storage at a temperature of 31° to 32° F., with a relative humidity of 90 to 95 per cent. Considerable shriveling occurs in a root cellar, and heavy decay in a common storage house after 5 months.[21] They also can be piled on the ground and covered with earth and straw.

USES

The Jerusalem artichoke tuber is used chiefly for feed to replace silage, root crops, or potatoes in the ration. The tubers also may replace potatoes for human food, but they are very low in digestibility, and are watery when cooked. In gross chemical composition the Jerusalem artichoke tuber is similar to potatoes, but it contains no starch. The carbohydrates are mostly several polysaccharides, chiefly synanthrine,[2] which when hydrolized by acids or enzymes produce a simple very sweet sugar called levulose, fructose, or fruit sugar. Levulose often is prescribed for diabetics. Hydrolized starch produces dextrose (glucose, or grape sugar). When cane sugar is hydrolized, or partly digested, it produces the sweet invert sugar that consists of equal quantities of dextrose and levulose. Honey is composed chiefly of invert sugar. Levulose is 3 to 73 per cent sweeter than cane sugar, depending upon who does the tasting.[31] Dextrose is 20 to 50 per cent less sweet than cane sugar. Equal mixtures of levulose and dextrose therefore should be sweet as honey. This is the basis for the hope that by producing levulose from artichokes and dextrose from grains or potatoes, and mixing them, our domestic sugar requirements could be supplied at home. Methods of producing and crystallizing levulose from Jerusalem artichoke tubers and dahlia roots have been developed.[19] Up to the present time the Jerusalem artichoke has not been able to compete with other crops as sources of sugar and alcohol, but a plant for processing them is now in operation in the Pacific northwest.

The tubers yield an average of about 13 per cent levulose and 2.5 per cent glucose, or roughly 16 per cent of total sugar. Thus, a 6-ton acre yield of tubers would produce less than a ton of total sugar or 130 to 150 gallons of alcohol per acre.

Root and Leaf Crops

The chief root crops grown for forage include the mangel (or mangelwurzel, mangold, or stock beet) (*Beta vulgaris*), turnip (*Brassica campestris* var. *rapa*), rutabaga or swede (*Brassica napus* var. *napobrassica*), and carrot (*Daucus carota*).[38] The chief leaf crops for forage are rape (*Brassica napus* var. *biennis*) and Thousand-headed kale (*Brassica oleracea* var. *acephala*). All these crops combined were harvested on less than 10,000 acres in 1939. An additional but unknown acreage was grazed or dug by livestock. They are grown mostly in cool sections of the northern border states. Their chief value is in supplying succulent feed during the fall, winter, and spring, mostly on farms too small to afford a silo. Rape is chiefly a pasture crop. In northern Europe and parts of Canada where corn does not succeed, the root crops are an important source of winter feed.

The chief handicaps to the growing of root crops are the labor involved in growing, harvesting, and slicing them, and the limited period of storage as compared with corn silage.[10] Under favorable conditions, mangels, rutabagas, and turnips yield 20 to 30 tons per acre, whereas carrots yield about one-half as much, and sugar beets two-thirds as much. Corn silage is higher in digestible nutrients.[3]

ADAPTATION

The root crops thrive where the mean summer temperature is 60° to 65° F. They do not succeed as summer crops where the mean temperature is much above 70° F. Mangels, turnips, rutabagas, kale, and rape will withstand light freezes. A moist climate, together with deep loam soils and soils high in organic matter are favorable for most root crops. Carrots thrive in rather light friable soils.

ORIGIN AND HISTORY

The beet, of which the mangel is a representative, like the turnip, rutabaga, and carrot, is native of Asia. The varieties grown in the United States are mostly of European origin or were developed from European varieties. Rape and kale are native to Europe.

BOTANICAL DESCRIPTION

Mangels differ from sugar beets (Chapter 36) chiefly in their larger roots, larger acre yields, and a sugar content only about one-third or one-half as much. Mangel roots usually extend up above the surface of the soil for about two-fifths their length.

The turnip and rutabaga belong to *Cruciferae,* the mustard family, and the genus *Brassica,* which includes also rape and kale. The plants of this family are biennial or annual herbs, with a pungent taste and bearing flowers with four petals arranged in the form of a cross. The genus *Brassica* has yellow flowers, six stamens, and globose seeds borne in two-celled pods. The rutabaga can be distinguished from the turnip because it forms a neck on the top of the root to which the leaves are attached. Also, the older leaves of the rutabaga are smoother and of a lighter bluish color, and the roots of most varieties have yellow flesh in contrast with the white flesh of most turnip varieties.

Rape is of two general types, the annual grown for seed, and the biennial grown for forage. The plants resemble cabbage when young but later they grow to a height of 1½ to 2½ feet, producing only leaves and branches without forming a head. Kale plants likewise are branched and leafy but are larger than those of rape.

VARIETIES

The leading varieties of mangels[26, 39] include Mammoth, Long Red (red-fleshed), Golden Tankard (yellow-fleshed), Giant Half Sugar (white-fleshed), and Heavy Cropper or Gatepost. The first-named variety is capable of producing the largest tonnage, but because of its long roots is not well suited to shallow soils. The most popular varieties of rutabaga for feed include American Purple Top, Improved Purple Top, and White Sweet Russian. Common varieties of turnip for feed are Purple Top, White Globe, and Cowhorn. The most popular carrot varieties for feed include White Belgian (white) and the yellow varieties Improved Long Orange, Mastodon, and Ox-heart.

The rape grown for pasture and soiling in the United States is nearly all of the Dwarf Essex variety. Thousand-headed kale is a single variety. A similar crop, but with thick fleshy stems, is called marrow kale or marrow cabbage.[8]

FERTILIZER PRACTICES

For mangels, as well as other root crops, heavy applications of manure and 300 to 400 pounds of superphosphate alone or in addition to manure have been recommended.[9, 39] A complete fertilizer such as 400 to 700 pounds of 4–16–4 or 4–16–8 can be used where manure is not available. Acid soils may require lime.

CULTURAL METHODS

The seedbed for root crops should be prepared as described for sugar beets in Chapter 36. On wet low lands planting the crops on ridges or beds is recommended.[9] A fine compact seedbed is essential to good stands.[11]

Where special planters, or sugar beet drills, and cultivators are at hand the rows can be spaced at the desired distance of 18 to 24 inches apart. Otherwise, a grain drill is used, spacing the rows at distances from 30 to 42 inches adapted to the ordinary cultivator. Small acreages may be planted with a garden planter. The seeds should be planted in a seedbed of good tilth, about ½ to ¾ inches deep, except for carrots which should be ¼ to ½ inch deep, the shallower depths applying to heavy soils. The usual rates of planting [39] are 6 to 8 pounds per acre for mangels, 1½ to 2 pounds for carrots, and 1 pound for rutabagas or turnips. When labor is available for thinning, the final desired spacing is mangels, 12 inches; rutabagas, 10 to 12 inches; turnips, 10 inches; and carrots 6 to 8 inches. Broadcast turnips are planted at a rate of 4 to 5 pounds per acre.

Rape is planted at a rate of 2 to 3 pounds per acre in rows and 4 to 5 pounds when broadcast. Thousand-headed kale usually is sown in a bed or cold frame, and later the plants are set out about 1½ to 3 feet apart in rows about 3½ feet apart. A pound of seed is sufficient for 4 or 5 acres.[34] When sown directly in the field to be thinned later, 8 to 12 ounces of seed per acre usually are ample.

Mangels and carrots should be planted in the spring as soon as the danger of heavy freezes is past or a little before corn-planting time. Turnips and rutabagas may be planted in early spring for a summer crop, in the summer for a fall crop in cool climates only, and in early fall in the milder sections of the south and Pacific coast when a winter crop is desired. Rape likewise may be sown in the spring, summer, or fall, depending upon the region and the period in which the crop is to be pastured or fed. Early spring planting is recommended in Missouri.[18] In cool sections, rape often is sown in the summer as a catch crop or is sown with grain in the spring and then is pastured in the fall or late summer. Thousand-headed kale seed is planted in the spring, the plants are set out usually in June and are cut during the fall and winter as needed for feeding in a fresh condition. Rape sometimes is used as a soiling crop in a similar manner.

HARVEST AND STORAGE

The root crops are harvested usually before a heavy freeze, or as soon as the leaves wither and turn yellow indicating that growth has ceased. They are pulled by hand either directly or after they have been loosened with a beet lifter or plow. The tops can be twisted or cut off after pulling, or topped with a sharp hoe before pulling. The crown is not cut off as with sugar beets. The harvested roots usually are stored in root cellars or outdoor pits. The best storage conditions are those described for potatoes, viz., 36° to 40° F. temperature, ample ventilation, and humidity high enough to avoid excessive shrinkage. Turnips do not keep so long as mangels, rutabagas, and carrots, and therefore should be fed up first. When kept for 3 months in a root cellar in West Virginia without any special control of temperature, ventilation, or humidity, mangels lost considerable water and protein, while rutabagas lost water, carbohydrates, and some protein.[27]

USES

Root crops replace silage as a succulent winter feed. They may be fed in quantities of 1 to 2 pounds daily per 1,000 pounds of live weight of the animal.[39] Large roots may be fed whole to poultry but should be sliced or chopped for livestock. Mangels, rutabagas, turnips, and carrots contain roughly 90 per cent water. In mixed rations for hogs, 100 pounds of grain are saved by each 440 to 780 pounds of roots fed.

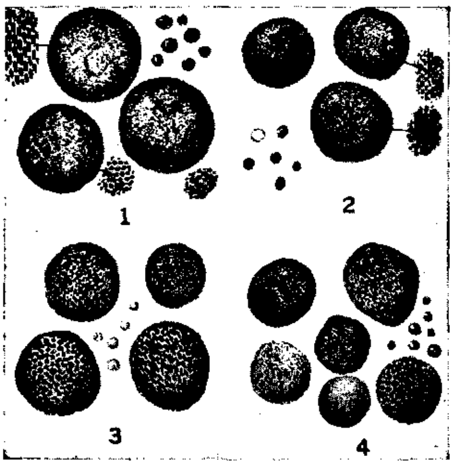

FIG. 235. Rape seeds: (1) Dwarf Essex (winter) rape (*Brassica napus* var. *biennis*). (2) Oilseed (summer) rape (*B. napus* var. *annua*). (3) Annual turnip-rape or bird rape (*B. campestris*). (4) Biennial turnip-rape or bird rape (*B. campestris* var. *autumnalis*).

The turnip-rapes, which also are processed for oil, are closely related to the turnip and the mustards.

Rape is used largely as pasture for hogs or sheep, being nearly equal to alfalfa for that purpose. Thousand-headed kale is used mostly as a fall and winter soiling crop for dairy cattle, but also is fed to other livestock and poultry. In 1939, 124 acres or 446 bushels of rapeseed were harvested in United States, chiefly for oil production. Rapeseed also is fed to cage birds (Figure 235). Before World War II, 7 to 28 million pounds of rapeseed and 1 to 10 million gallons of rapeseed oil were imported annually chiefly from Japan, Argentina, India, and western Europe. China, India, western Europe, Japan, Poland, Mexico, and Canada have been the leading producing countries. The world production of rapeseed exceeds 4 million tons. The oilseed and the oil sold as rapeseed often include other cultivated species of the genus *Brassica* which have similar properties. Refined rapeseed oil is called colza oil. The oil is extracted by cold pressing or by volatile solvents. The by-product meal is used for feed. Rapeseed oil is classified as nondrying, having an iodine number of about 80 to 110. It is used chiefly in mixtures of mineral oils for lubrication, or alone for tempering steel plates. In other countries, rapeseed oil is used for edible purposes and in lamps and also for soap.

Seed of the Frenchweed (*Thlaspi arvense*), a waste product too unpalatable for grinding in mixed feeds, produces an oil that can replace rapeseed oil for certain uses.

The culture of rapeseed is similar to that of mustard seed (Chapter 39).

DISEASES

Root crops suffer relatively little damage from diseases in the regions where they are generally grown. The chief damage is from rots in storage.

INSECT PESTS

While the root crops usually suffer relatively little damage from insects in the chief producing areas, they occasionally are attacked by cutworms, grasshoppers, aphids, flea beetles, cabbage worms, and root maggots. The spreading of poisoned bran mash to destroy cutworms and grasshoppers is justified when these pests appear in damaging numbers. Likewise, spraying or dusting with arsenicals, cryolite, or DDT may control flea beetles and cabbage worms.

Pumpkin and Squash

ECONOMIC IMPORTANCE

Large varieties of pumpkin and squash were harvested for stock feed on about 10,000 acres in 1939. In addition large quantities were produced in corn fields.

ADAPTATION

The field or stock varieties of pumpkin and squash are grown most commonly in humid regions, particularly the central corn belt and in Kentucky and Tennessee.[36] The pumpkin and squash are adapted to a wide range of temperature but are not tolerant to frost or prolonged exposure near freezing. The large varieties require 110 to 120 days to reach maturity. Since they cannot be planted safely until about the time of the latest spring frost, a frost-free season of some 4 months is essential. They thrive in rich, well-drained light soils. They prefer full sunlight but develop satisfactorily in a corn field.

BOTANICAL DESCRIPTION

The pumpkin and squash belong to the genus *Cucurbita,* of the family *Cucurbitacea,* the gourd family, which bears a fleshy fruit called a pepo. The large, showy yellow flowers are monoecious.

The common pumpkin belongs to the species *Cucurbita pepo,* the Cushaw (or crookneck) pumpkin is *C. moschata,* and the winter squash is *C. maxima.*[7] Both the pumpkin and squash are of American origin and were cultivated by the Indians.

The distinction between a pumpkin and squash is rather confusing because some varieties of both pumpkins and squashes occur among each of the three species. The stem attachment of *C. pepo* is five-angled but not expanded next to the fruit. That of *C. moshata* is not angled but much expanded, while that of *C. maxima* is swollen and fleshy but neither expanded nor angled.[40]

These species are normally cross-pollinated but do not show a loss of vigor when inbred. They usually are insect-pollinated. The different species do not intercross readily except with *C. moshata*, and they do not cross with other cucurbits.

The distinctions between the seeds of the three species are as follows: [29]

Scar obliquely truncate; face of seed pure white or clear brown — *C. maxima*

Scar normally squarely truncate or rounded; face of seed ashy gray or dirty white

- Margin agreeing in color with face of seed, usually smooth and not swollen — *C. pepo*
- Margin darker than face of seed, rarely smooth, often swollen and corky, or roughened and stringy — *C. moschata*

VARIETIES

The leading pumpkin varieties grown for feed are the large types with yellow skin, such as Connecticut Field, Large Cheese, and Mammoth Cushaw, or Golden Crookneck. A striped Cushaw variety, having creamy skin with green stripes, also is grown. The varieties above mentioned all are of the trailing-vine type.[35]

Large coarse varieties of squash, grown especially for exhibition purposes, also are used for feed. These include the orange-yellow-skinned varieties with a pumpkin shape, such as Mammoth, King of the Mammoths, and Mammoth Chili, and a greenish-gray variety, Mammoth Whale. These varieties are less sweet than the favorite table sorts.

CULTURAL METHODS

Field varieties of pumpkin and squash are planted in hills 10 to 12 feet apart, three to six seeds per hill, and later thinned to 1 or 2 plants. On soils of low or moderate fertility, it is helpful to stir in a forkful of manure at each hill, leaving a cover of about two inches of unmixed soil in which the seed is planted. Planting is done after the danger from frost is past. Often they are planted in the missing hills in a field of corn or at regular intervals in the corn rows. In corn fields, the seeds usually are planted by hand at corn-planting time or after one or two cultivations of the corn. The crop requires clean cultivation until the trailing vines start to run and the ground is partly shaded by the large leaves.

HARVEST

For best keeping quality, field pumpkins and squash should be harvested upon the approach of the first frost. Light frosts kill the vines, but do not damage the fruits appreciably. They keep best if a short section of the stem is left on the fruit when cutting from the vine. Careful handling at harvest is essential to prevent decay in storage. The best storage conditions for pumpkins and squash are a temperature of 50° to 55° F. and a relative humidity of 70 to 75 per cent. Such conditions often are available in a livestock barn or a house cellar. A preliminary curing for about 2 weeks at 80° to 85° F. will ripen immature specimens and aid in healing mechanical injuries. Field pumpkins and squash often do not keep more than 2 or 3 months.

USES

Pumpkins and squashes are sliced or chopped, and fed as succulents during late fall and early winter. Yields of squash in the United States average about 9 tons per acre. Pumpkins grown among cornstalks yield about 1½ tons per acre.

DISEASES

Diseases of pumpkins and squash include anthracnose, downy mildew, bacterial wilt, and mosaic. Treating the seed with mercury compounds helps to check anthracnose. Bordeaux mixture sprays and copper dusts check anthracnose and downy mildew. Control of insects such as cucumber beetles and aphids retards the spread of bacterial wilt and the mosaic diseases.

INSECTS

The chief insects attacking pumpkins and squash are the squash vine borer, squash bug, melon worm, pickleworm, striped cucumber beetle, spotted cucumber beetle, and aphids. Insecticides used in controlling these pests include sabadilla for the squash bug, cryolite or rotenone for the melon worm, pickleworm, and the cucumber beetles, and nicotine dusts or nicotine sulfate sprays for aphids.

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32 BUCKWHEAT

Economic Importance

Buckwheat was harvested on 56,897 farms in the United States on less than 11 acres per farm in 1939. The average production from 1937 to 1946 was 7 million bushels on 416,000 acres, or a yield of 16.8 bushels per acre. The farm value of the crop ranged from 3½ million to 11 million dollars annually. The buckwheat acreage remained relatively stable between 1876 and 1919 when it began to decline. The average acreage from 1916 to 1925 was 773,000, and more than a million acres were grown in 1918.

About two-thirds of the domestic buckwheat is grown in Pennsylvania and New York. Other states growing appreciable quantities are Ohio, West Virginia, Michigan, Wisconsin, and Minnesota. Russia leads all other countries in buckwheat production, followed by France, Poland, Canada, and the United States. Other producing countries include Japan, Austria, Germany, and Rumania.

Adaptation

Buckwheat makes its best growth in a cool, moist climate, and is grown in the north and in the higher altitude areas of the east. It is sensitive to cold, being killed quickly when the temperature falls much below freezing. Buckwheat requires only a short growing season of 10 to 12 weeks. The crop is sensitive to high temperatures and dry weather when the plants are in blossom. For this reason, seeding generally is delayed to allow plant growth to take place in warm weather and seed to form in the cool weather of late summer.

Buckwheat will produce a better crop on infertile, poorly-tilled land than other grain crops when the climate is favorable. Its response to fertilizer applications is less than for other crops.[11] Also, it is able to extract more nutrients from raw rock phosphate than are other grain crop plants.[10] It is well suited to light well-drained soils such as sandy loams or silt loams. It grows satisfactorily on soils too acid for other grain crops. Buckwheat usually produces a poor crop on heavy wet soils. The crop is likely to lodge badly on rich soils high in nitrogen.[5] Buckwheat is often sown as a catch crop with little regard for the best conditions for its growth. This accounts for the low average yield in the United States.

History

Common buckwheat appears to have been cultivated in China for at least 1,000 years. It probably originated in the mountainous regions of that country. During the Middle Ages the crop was introduced into Europe from where it was brought to this country. It was grown by Dutch colonists along the Hudson River before 1625.

Buckwheat is not a cereal, nor, strictly speaking, is it a grain, because it does not belong to the grass family. Because the fruits or seeds are used like grain, buckwheat is commonly regarded and handled as a grain crop. The name buckwheat was coined by the Scotch from two Anglo-Saxon words, *boc* (beech), from the resemblance of the achene or fruit to the beechnut; and *whoet* (wheat), from its use like wheat. In Germany, the name is Buchweizen, likewise meaning beech wheat.[11]

Botanical Description

Buckwheat belongs to the *Polygonaceae* or buckwheat family. Common buckwheat (*Fagopyrum esculentum*), the most important species, appears to have been derived from *F. cymosum,* a wild species of Asia. Two other species, *F. tataricum* (Tartary buckwheat) and *F. emarginatum* (winged buckwheat), are grown.

The buckwheat plant is an annual, 2 to 5 or more feet in height, with a single stem, and usually several branches.[4, 6] The stems are strongly grooved, succulent, and smooth, except at the nodes (Figure 236). The stems range from green to red, but turn brown with age. More reddening is evident when the plants have a poor seed set.

FIG. 236. Plant of Japanese buckwheat.

The leaf blades, 2 to 4 inches long, are triangular heart shaped.

The plant has a taproot with numerous short laterals, and may extend 3 to 4 feet in the soil. The root system comprises only about 3 per cent of the weight of the plant, compared with 6 to 14 per cent in the cereal grains.[11]

The inflorescence of common buckwheat consists of axillary or terminal racemes or cymes with more or less densely clustered flowers (Figure 237). The inflorescence is indeterminate. The flowers, i.e., the petal-like sepals, are white or tinged with pink. They have no petals. There are eight stamens, and a triangular one-celled ovary containing a single ovule.

FIG. 237. Branch bearing flowers, immature seeds and leaves of Japanese buckwheat.

The buckwheat plant begins to bloom 5 to 6 weeks after seeding.[3] The flowers are dimorphic, i.e., some plants bear flowers with stamens shorter than the styles, while in others they are longer.[9] The few flowers that have styles and stamens of the same length are sterile.

Common buckwheat is naturally cross-pollinated and self-sterile.[5] Bees and other insects distribute the pollen. Tartary buckwheat is self-fertile.

The fruit is an achene that is brown, gray-brown, or black in color. The point of the grain is the stigmatic end, while the persistent calyx lobes remain attached at the base. The hull is the pericarp. The seed (groat) or matured ovule inside the hull has a pale brown testa, being triangular like the fruit.

The endosperm is white, opaque, and more starchy than cereal grain endosperms. The embryo, embedded in the center of the endosperm,[8] possesses two cotyledons which are folded in the form of a letter S.

Varieties

The Japanese variety probably is the most extensively grown. The seed is brown and usually large (7 mm. long and 5 mm. wide; 15,000 per pound). It is nearly triangular in cross section. The plants are tall with large leaves and coarse stems.

Silverhull has smaller, glossy, silver-gray seeds, 20,000 per pound. The sides of the seed are rounded between the angles and thus appear less triangular. The stems and leaves are smaller than those of Japanese and the stems are more reddened at maturity. Common Gray is like Silverhull [5] but may have smaller seeds. Lots designated as common buckwheat are mechanical and hybrid mixtures of Japanese and Silverhull.[11]

Winged or notch-seeded buckwheat occurs only as a mixture. It is merely a type of common Japanese buckwheat in which the angles of the hulls are extended to form wide margins or wings,[5] making the seeds look large.

Tartary or mountain buckwheat (*F. tataricum*) is grown occasionally for feed in the mountains of North Carolina and Maine and in certain other areas. It has escaped from cultivation and become a weed, particularly in the prairie provinces of Canada. It is sometimes called India wheat, duck wheat, or rye buckwheat. Tartary buckwheat is distinguished from the common species by its more indeterminate habit, simple racemes, and by smaller seeds (26,000 per pound) that are nearly round in cross section and usually pointed. The seed color ranges from dull gray to black, while the pericarp (hull) varies from smooth to decidedly rough and spiny. The plants are somewhat viny. The flowers are very small and inconspicuous with greenish-white sepals.[5, 11]

Common Gray and Silverhull complete terminal growth in 8 weeks after planting, Japanese in 6 to 7 weeks, and Tartary in 10 weeks in Pennsylvania.[11] The percentages of hull in the grain were: Common Gray, 19.1; Silverhull, 18.4; Japanese, 21.0; and Tartary, 21.6.

Cultural Methods

Early plowing is advantageous in West Virginia. The soil preparation and seeding depth are about the same as for small grains.[2, 3, 5, 7, 11] Buckwheat land usually is not fertilized but sometimes 100 to 150 pounds per acre of superphosphate is applied. An application of 200 to 300 pounds per acre of superphosphate is recommended in Pennsylvania.[11] Moderate applications of lime have shown some benefit.

Buckwheat is generally seeded in the northeastern states between June 24 and July 1. It is seldom advisable to seed after July 15. Seeding time in a locality can be calculated fairly accurately by allowing a period of 12 weeks for growth before the average date of first fall frost. Buckwheat germinates best when the soil temperature is about 80° F., but it will germinate at any temperature between 45° and 105° F. The rate of seeding varies from 3 to 5 pecks per acre for common buckwheat while 2 pecks is sufficient for the smaller-seeded Tartary buckwheat. The crop may be either drilled or broadcast.

Since buckwheat is rather indeterminate in its flowering habit the plants usually bear some flowers and immature seeds when the majority of the seeds are ripe. Consequently, the crop often contains considerable green and damp material when it is ready for harvest.

Buckwheat is harvested with a combine on about one-third of the acreage. It is usually necessary to dry grain harvested by a combine before it can be stored safely, because the plants do not bloom or ripen uniformly. On small farms or rough lands buckwheat is harvested with a binder, cradle, scythe, or self-rake reaper. Shocked or cocked buckwheat can be threshed with the ordinary grain separator, provided the spiked concave is replaced by a blank concave.

Injurious effects of buckwheat on subsequent crops on unfertilized land are attributed to excessive removal of mineral plant foods by the rapidly-growing, shallow-feeding plants.[11] A winter cover crop should follow buckwheat to increase organic matter and to reduce erosion.[11] Buckwheat stubble land is more subject to erosion than small grain land, due to the loose friable condition of the soil.

Chemical Composition

The chemical composition of the whole grain of buckwheat is as follows: [1]

VARIETY	WATER (%)	ASH (%)	FAT (%)	PROTEIN (%)	FIBER (%)	N-FREE EXTRACT (%)
Japanese	10.05	1.71	2.36	10.69	11.37	63.82
Silverhull	10.01	1.81	2.43	11.81	9.92	64.02
Tartary	11.06	1.64	2.32	10.19	15.21	59.58

Uses

About 95 per cent of the buckwheat is harvested for grain and the remainder is abandoned or turned under for green manure.

Buckwheat for the market is grown primarily for human food, but since only the grain of better quality is bought by the millers, about 50 to 60 per cent of it remains on the farm for feeding to livestock. About 6 to 7 per cent is used for seed. Buckwheat flour is consumed largely in the form of buckwheat cakes. A continued heavy diet of buckwheat cakes results in development of a skin rash in those who are allergic to buckwheat protein. Animals fed a buckwheat ration also develop a rash, but the effect is confined to white animals that are exposed to light.[5]

Buckwheat is one of the best temporary honey crops, since it produces blossoms for 30 days or more. It will supply enough nectar on one acre for 100 to 150 pounds of honey.[2] Buckwheat honey is dark, with a distinctive flavor that some people do not relish. Bees ordinarily do not collect nectar from Tartary buckwheat.

The leaves and flowers of buckwheat are the commercial source of rutin, a glucoside used medicinally to check capillary hemorrhages, help reduce high blood pressure, prevent frostbite gangrene, and as a protection against the effects of subsequent atomic bomb radiations.

The whole grains are fed to poultry, but the grain often is hulled for other stock. Buckwheat is a valuable green-manure summer cover, a smother or catch crop.

Buckwheat shorts or middlings are valuable feed for livestock. Buckwheat hulls have very little feeding value. Most mills burn the hulls but some are sold for packing.

Milling

Millers prefer Japanese buckwheat because the hulls are easier to remove. It may be milled either for flour or for groats (hulled grains).[1] Tartary buckwheat is not used for milling because the flour has a dark color and a bitter taste.

In flour milling the buckwheat is cleaned, dried to 12 per cent moisture, then scoured and aspirated, to remove dust, fuzz, and the calyx that adheres to the fruit. The grain is then passed through break rolls where the hulls are cracked and loosened. Some moisture may be taken up during this process, so the material is again dried to 12 per cent moisture to aid in the separation of the hulls from the kernels. The broken grain, after sifting out the hulls, is further ground and sifted. Some buckwheat flour is milled so fine that it is as white as wheat flour. However, coarser bolting cloths are generally used, through which small particles of hulls pass and remain in the flour. These particles give the flour a characteristic dark color. The dark coarse-particled residue from flour extraction is called middlings or shorts.

About 100 pounds of clean buckwheat may yield 60 to 75 pounds of flour, 4 to 18 pounds of middlings, and 18 to 26 pounds of hulls,[5] but only about 52 pounds of pure white flour are obtained.

In milling for groats separated uniform medium-sized kernels are passed between two mill stones adjusted to crack the hull without a grinding action. The purified whole groats are used in porridge, soups, and breakfast food, mostly by European immigrants. Broken groats are eaten as roasted broken kernels and farina.

Diseases and Insects

Buckwheat suffers relatively little damage from either diseases or insects. The diseases most frequently reported are a leaf spot caused by the fungus, *Ramularia* sp. and a rootrot caused by *Rhizoctonia*. Wireworms and aphids attack buckwheat occasionally.

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33 FLAX

Economic Importance

Flax (*Linum usitatissimum*) is grown both for seed or fiber on more than 80,000 farms in the United States. An average of nearly 3 million acres annually were harvested for seed from 1937 to 1946. The average seed production was more than 27 million bushels or 9 bushels per acre. The leading states in flaxseed production are Minnesota, North Dakota, South Dakota, California, Montana, Texas, Iowa, and Kansas (Figure 162). An average of 9,000 acres annually of fiber flax are grown in this country. The average production is 15,000 tons of pulled and threshed straw, most of it being produced in the Willamette Valley of Oregon under various forms of subsidy. More than 250,000 tons of seed flax straw are sold annually for making some 60,000 tons of tow that is used for making paper.[18]

The leading countries in flaxseed production are Argentina, Russia (U.S.S.R.), India, United States, Uruguay, and Canada. More than 140,000,000 bushels are grown annually. The countries leading in fiber production are Russia (U.S.S.R.), Poland, Belgium, France, and the Netherlands.

History

Flax was cultivated long before the earliest historical records. Remnants of flax plants were found in the Stone Age dwellings in Switzerland. The art of making fine linen from the fibers was practiced by the ancient Egyptians. Primitive man probably used the seeds of wild flax for food.[6]

Flax is an Old World crop that was probably cultivated first in southern Asia and in the Mediterranean region. It may have originated from the wild flax (*Linum angustifolium*),[6] native to the Mediterranean region, and the only species with which cultivated flax crosses readily.

Cultivation of fiber flax began in America during the Colonial period, being used to supply linen for hand spinning in the home. The manufacture of linseed oil began about 1805. Flax production moved westward with the settlement of new lands because it was a good first crop on nearly broken sod, and also because of the damage from flax wilt on old cultivated fields. The development of wilt-resistant varieties in recent years has made flax a dependable crop on old cultivated lands.[11]

Adaptation

Flax requires moderate to cool temperatures during the growing season. Seed flax is generally grown where the average annual precipitation ranges from 18 to 30 inches, and also under irrigation in dry climates. Drought and high temperatures, about 90° F., during and following the flowering stage reduce the yield and the size and oil content of the seed as well as the quality of oil.[10] The fiber flax plant requires adequate moisture and a cool temperature during the growing season; but after maturity, dry weather facilitates harvesting, curing, and drying after retting. Cool weather from March to June, followed by warm dry weather in July, affords excellent conditions for fiber flax production.[23]

Flax may be damaged or killed at temperatures of 18° to 26° F. in the seedling stage, and a light freeze of 30° F. may cause injury in the blossom or green boll stage, but between these stages the plants may survive temperatures of 15° F. or even lower.[3] Frost injury may occur in the northern states, either when the flax is sown too early in the spring, or when sown so late that it is frosted in an immature stage in the fall. Flax sown in early October in California or southern Texas may be damaged by a sudden freeze in February when it is in the blossom stage. That sown in late November or in December may be damaged in the seedling stage. The Turkey variety recently released in Texas is a distinctly winter type resistant to cold.

Flax makes its best growth on well-drained medium-heavy soils, especially silt loams, clay loams, and silty clays. Light soils are unsuited to seed flax, particularly in regions of deficient rainfall.[17] Since flax has a relatively short root system, it is dependent on moisture largely in the surface 2 feet of soil. Fiber flax grown on the heavier soils consistently outyielded that grown on the lighter soils.[24] Weedy land should be avoided.

Botanical Description

Flax is an annual herbaceous plant that may be grown as a winter annual in warm climates. The plant grows to a height of 12 to 48 inches. It has a distinct main stem and a short taproot. Two or more basal branches may arise from the main stem just above the soil surface unless the stand is thick. The main stem and basal branches give rise to the primary, secondary, and tertiary branches that bear the leaves, flowers, and bolls (Figure 22). Three principal tissue areas are recognized in the stems, viz., pith, wood, and bark. The bark contains the comparatively long bast or flax-fiber cells that constitute the linen fibers.

The flax flower has 5 petals and a 5-celled boll or capsule that contains 10 seeds when each of the cells contains the complete number of 2 seeds (Figure 238). The flowers open at sunrise on clear warm days, the petals falling before noon. Flowering is indeterminate and continues until growth is stopped. The petals are blue, pale blue, white, or pale pink in different varieties. The bolls are semi-dehiscent in most varieties grown in the north central states.[4] The bolls of this type rarely dehisce so far as to allow the seeds to fall out (Figure 239). Most varieties of Indian and Argentine origin are indehiscent. This includes the Punjab variety grown in California and the Rio variety grown in Texas.

Flax seeds vary from one-seventh to one-fifth inch in length. A thousand seeds weigh 3.8 to 7.0 grams, or 65,000 to 120,000 per pound. The seeds are usually light brown in color, although in certain varieties they are yellow, mottled, greenish-yellow, or nearly black (Figure 240). The seeds have a smooth, shiny surface resulting from a mucilaginous covering. The embryo is surrounded by a thin layer of endosperm that contains starch in the immature seed.

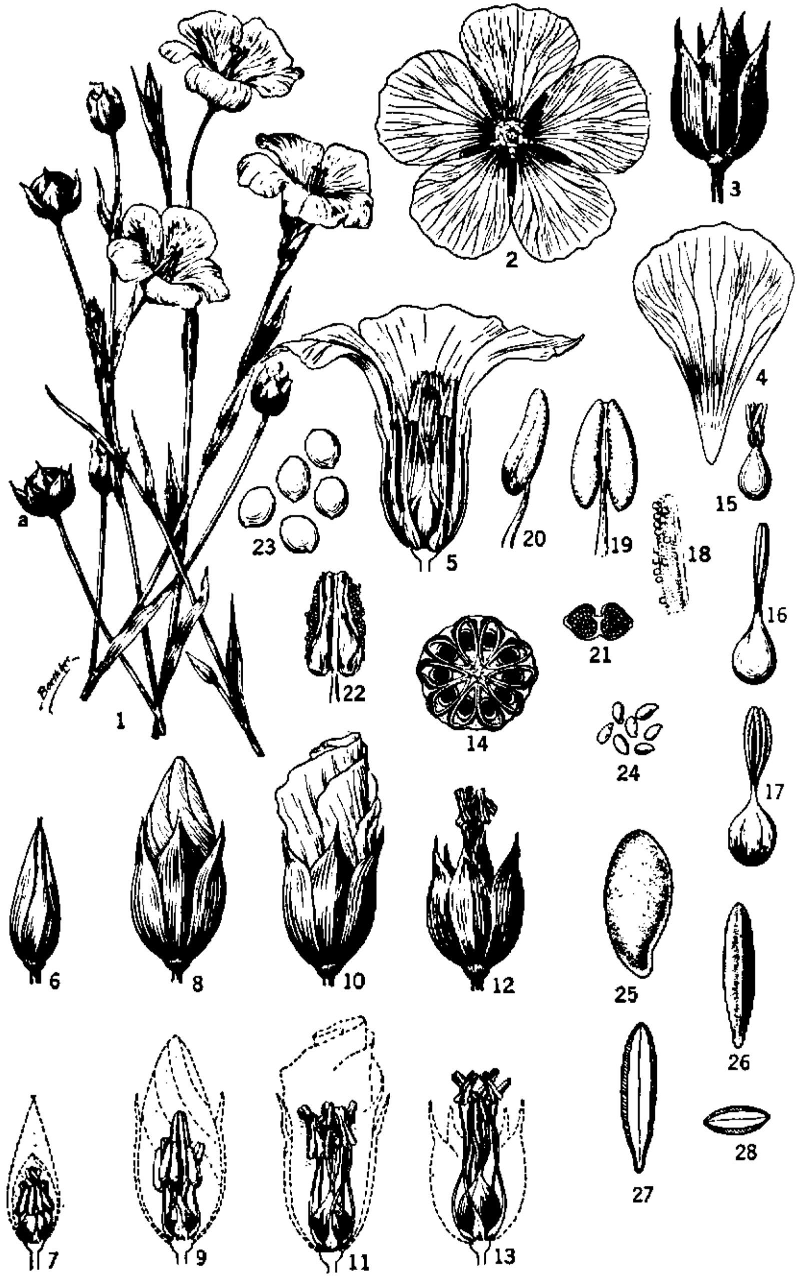

FIG. 238. Flax inflorescence. (1) upper stems showing leaves, flowers, and boll (a), about natural size; (2) expanded flower; (3) calyx after anthesis and the shedding of petals; (4) upper surface of a petal; (5) section of a flower show-

FIG. 239. Shape, size and type of bolls among flax varieties. Nos. 1 and 2 are a fully dehiscent European type that must be pulled as soon as the first bolls are ripe to avoid shattering. Nos. 3, 4 and 5 are semi-dehiscent American types. Nos. 6, 7, 8, and 9 are indehiscent Indian and Argentine varieties.

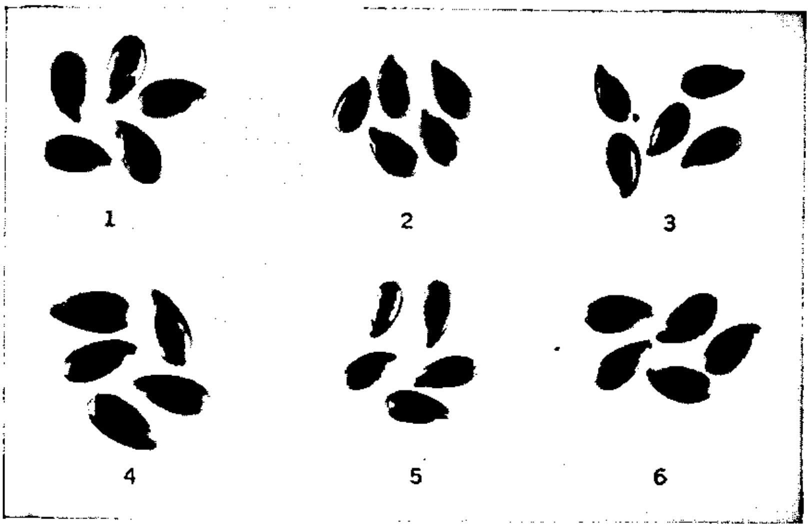

FIG. 240. Seeds of six varieties of flax: (1) Bison, (2) Redwing, (3) Linota, (4) Argentine, (5) Buda, (6) B. Golden (yellow-seeded).

ing calyx, corolla, the five stamens and the five stigmas; (6 to 13) four stages of flower opening and anthesis, (6 and 7) 2 days before anthesis, (8 and 9) late afternoon of day before anthesis, (10 and 11) anthesis occurring at sunrise, (12 and 13) three to six hours after anthesis; (14) cross section of boll, showing the 10 ovules (seeds) developed in the five carpels; (15, 16, 17) pistil before and during anthesis; (18) portion of stigma, greatly magnified, showing adhering pollen grains; (19) dorso-ventral view of anther with a portion of the filament; (20) lateral view of anther; (21) cross-section of anther; (22) dehiscing anther; (23) pollen grains, greatly magnified; (24) seeds, natural size; (25 and 26) seed magnified; (27) seed dorso-ventral longitudinal (sagittal) section, showing cotyledons and surrounding endosperm; (28) cross-section of seed, showing cotyledons and surrounding endosperm.

Flax seed gives satisfactory germination when stored from 5 to 10 years under dry conditions, but that stored from 15 to 18 years shows low viability.[12]

Pollination

Flax is normally self-pollinated, but 0.3 to 2 per cent of natural crossing may occur.[7, 14] Insects seem to be important agents of natural crossing. Large-flowered varieties with flat petals show the greatest percentage of crossing.[7] Weather conditions and the distance between plants also influence the amount of outcrossing.[14]

Varieties

The leading seed flax varieties in the northern states are Koto, Victory, Royal, Crystal, Arrow, Minerva, Sheyenne, and Dakota. The leading varieties in California are Punjab, Rio, and Calar, while Golden, B–5128, and Rio lead in Texas, and Dakota is the chief variety in Kansas. Royal is a rust-resistant blue-flowered variety that is important also in Canada where it originated.

The seed flaxes are shorter, more branching, and produce more seed than the fiber flaxes, ranging in height from 15 to 30 inches, while fiber flax ranges from 30 to 48 inches. Seed flax seeds may be either large, medium, or small, but those of all fiber varieties are small. The fiber in seed flax is short, and sometimes harsh, and consequently is not used for production of fine linen yarn. The small stems and the absence of basal branches of fiber flax are merely a result of a thick seeding.[6]

Several more or less distinct groups of seed flax are recognized.[9] These are: (1) wilt-resistant, short-fiber flaxes, (2) common or Russian, (3) Argentine, (4) Indian, (5) Abyssinian, and (6) Golden or yellow-seeded. Bison, formerly the leading flax variety in the United States, does not fall strictly within any of the above defined groups.

The wilt-resistant so-called short-fiber flaxes are grown only for seed production. Buda, Linota, and Redwing belong to this group. These varieties are much shorter than the fiber flaxes, and have small brown seeds, slender stems, and moderate wilt resistance. Redwing, a very early variety that seldom lodges, is well adapted to southern Minnesota and Iowa.

Varieties of the common or Russian group have largely disappeared from cultivation because of their susceptibility to wilt. These varieties have taller stems and larger seeds than those of the short-fiber varieties.

Varieties of the Argentine group of seed flax, including Malabrigo, Rio, and Walsh, have large open blue flowers, tightly closed bolls, and large brown seeds.

The Indian flaxes such as Punjab are adapted to a long growing season, particularly for fall seeding in mild climates. Punjab has blue flowers, indehiscent bolls, and medium-large brown seeds of high oil content.

The Abyssinian seed flaxes are short, fine-stemmed, much branched, and leafy. They have blue flowers and small brown or yellow seeds. Abyssinian Yellow-seed has yielded well in California.

The typical Golden flaxes have pale pink flowers and medium to large yellow seeds. Viking and Bolley Golden, similar or identical varieties of this group, are grown in North Dakota. They are moderately wilt resistant and almost immune to rust, but very susceptible to pasmo.

The typical fiber-flax varieties are characterized by tall stems, few seed branches, small funnelform flowers, and small brown seeds. Those grown in this country are at most only moderately resistant to wilt, while Cirrus is rather susceptible. Of varieties grown in the United States—J.W.S., Pinnacle, Cirrus, Cascade, and Concurrent—Pinnacle was originated in Michigan and Cascade in Oregon, but Concurrent was introduced from Holland and the other two are from north Ireland. Pinnacle has white petals but those of the other varieties are blue. Cascade, J.W.S., and Cirrus are the principal varieties grown in Oregon.

Crop Rotations

Flax is most productive on clean land because it is a poor competitor with weeds. Flax is a good crop to follow newly broken pastures or meadows (Figure 241). It is best grown following either a clean-cultivated row crop or a legume. In the north central states, flax grows well when it follows corn. A satisfactory sequence of crops includes a small grain, a legume, corn, and flax. In southeast

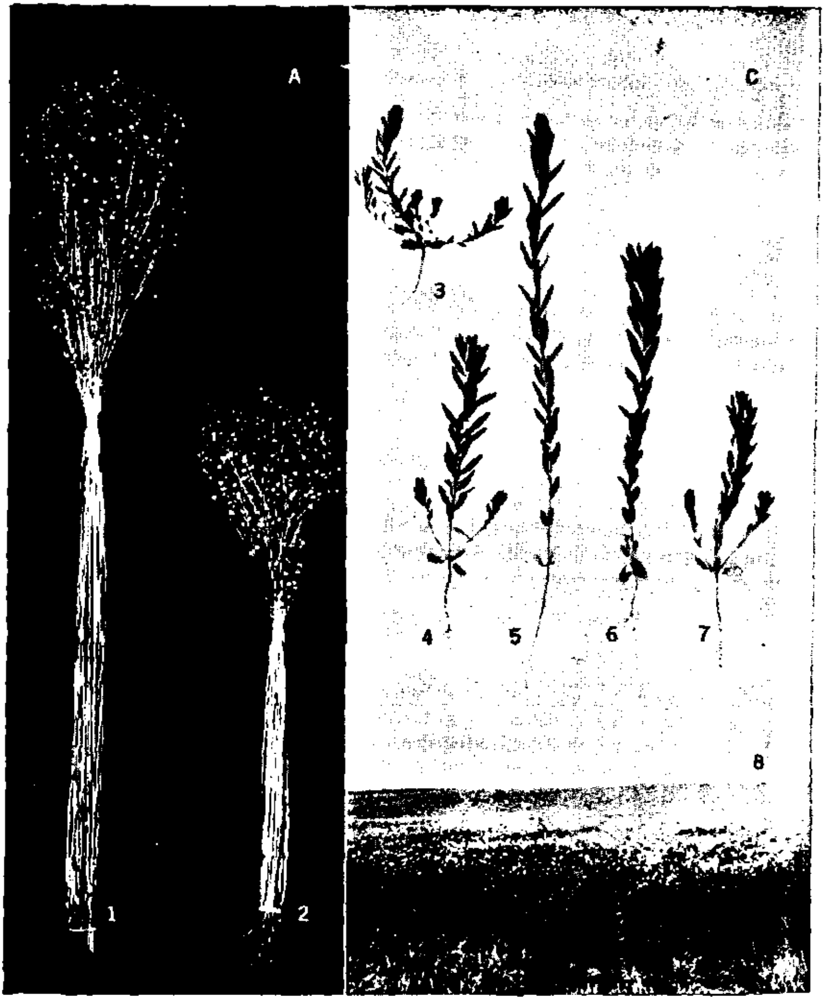

FIG. 241. Flax: (A) ripe bundles of (1) fiber type; (2) seed type; (B) field in bloom; (C) young plants of five varieties; (3) Roman Winter; (4) Punjab; (5) Cirrus; a fiber type; (6) Bison; (7) Rio. Cotyledons are still attached at the base of the branches of (4) and (7).

Kansas[2] flax after soybeans yielded much better than that following corn, kafir, or oats. Where it is adapted, flax has proved to be a good companion crop for alfalfa, clover, or grass because it offers less competition for light than do small grain crops. Flax rarely does well after small grains because of the abundance of weeds, unless the grain stubble is plowed early and then worked to stimulate germination of weed seeds. The weeds then are killed by winter freezes and the flax is sown in the spring after a shallow disking.

Fiber flax may follow sod or corn.[23] Because of the disease problem, fiber flax should not be planted on the land oftener than once in 5 or 6 years.

Seed Flax Culture

Flax requires a firm weed-free seedbed. Clean-cultivated row-crop land usually is disked instead of plowed in preparation for flax. Except in the drier areas, fall plowing is generally practiced where plowing is necessary. Commercial fertilizers are seldom applied to flax lands in the north central states. Manure and nitrogen fertilizers increase flax yields appreciably in southeastern Kansas, and phosphates and lime also are beneficial. Nitrogen fertilizers are often used on irrigated lands in California. Liquid ammonia is added to irrigation water.

SEEDING

Flax is generally sown in the spring as early as possible after the seeding of spring small grains is completed. The highest yields are obtained when the crop makes its growth during comparatively cool weather. In the northern Great Plains flax produces well when sown early in May. It is sown in April in Iowa, Idaho, and Washington. Fall seeding between October 20 and November 20 is the usual practice in southern Texas and California. Flax sown in the Imperial Valley of California on September 20, when the soil temperature was above 100° F., gave poor stands.[12]

The general practice is to sow flax with a grain drill at a depth of one inch or less. It is sown at the rate of 3 pecks (42 pounds) or slightly more under humid conditions in Minnesota, Iowa, Kansas, or elsewhere[15] or under irrigation in the western states. Large-seeded varieties like Bison are sometimes sown at a rate of 4 pecks (56 pounds).[20] Under drier conditions in Montana and the Dakotas, 2 pecks is a common rate of seeding.

Flax-Grain Mixtures. Flax-grain mixtures are sometimes sown on weedy land where soil moisture is ample, the flaxseed and grain being separated with a fanning mill after threshing. Spring wheat is the best grain for growing in the mixture because oats and barley often grow too rank. Flax-wheat mixtures [1] yielded 4 to 9 per cent more flax than flax alone over a 3-year period in Minnesota. The usual rate of seeding for this mixture is 25 to 40 pounds of flaxseed and 30 pounds of wheat per acre. Flax is sometimes sown on clean fields of winter wheat where the stand has been thinned by winter killing.

HARVESTING SEED FLAX

Seed flax is generally harvested after a majority of the bolls are ripe. The bolls of most varieties are semidehiscent when dry enough to thresh readily with a combine. Partial dehiscence occurs when the seeds contain 9 to 11 per cent moisture.[4]

Seed flax may be harvested with a combine where the crop is thoroughly dry and free from weeds. Nearly two-thirds of the crop is combined. Fields that ripen unevenly or contain green weeds may be cut with a windrower and pickup combine (Figure 53) or with a binder. A relative humidity well below 75 per cent appears to be necessary for effective drying.[5] Air-dry flaxseed usually contains about 6 to 10 per cent moisture compared with 10 to 14 per cent in wheat under the same conditions. The lower water absorption of flaxseed, as compared with wheat and other starchy seeds, is characteristic of oleaginous (oil-bearing) seeds. Flaxseed containing more than 11 per cent moisture is likely to deteriorate in storage.

Linseed Oil Extraction

Flaxseed contains 32 to 44 per cent of oil, based on dry weight. Large seeds are highest in oil content. In commercial crushing about 2½ gallons or 18 to 20 pounds of oil are obtained from a bushel (56 pounds) of cleaned flaxseed. A gallon of linseed oil weighs about 7½ pounds. The oil content of flax continues to increase until 18 to 25 days after flowering, but total oil per seed and total dry weight continue to increase until the seeds are mature.[3, 16] The oil content usually is low when drought occurs at the filling stage, i.e., within a period of about 30 days after flax blossoms. Shriveled seeds are low in oil. The iodine number is a chemical test for the drying quality of the oil. It is a measure of the quantity of oxygen the unsaturated chemical bonds in the oil will absorb in drying to form the characteristic paint film. The iodine number may be defined as the number of grams of iodine that 100 grams of oil will absorb. The iodine number of linseed oil usually ranges from 160 to 195. Linseed oil must have an iodine number of not less than 177 to meet standard specifications. The unsaturated fatty acids in linseed oil are oleic with one double bond, linoleic with two, and linolenic with three double bonds.

A comparison of the principal vegetable oils is shown in Table 1.

TABLE 1. CHARACTERISTICS OF THE MORE COMMON VEGETABLE OILS

CROP	BOTANICAL NAME	OIL CONTENT %	IODINE NUMBER	WORLD PRODUCTION 1948 (1000 TONS)
Drying oil				
Perilla	*Perilla frutescens*	40–58	182–206	10
Flax	*Linum usitatissamum*	35–45	170–195	1252
Tung (China wood)	*Aleurites fordii*	40–58	160–170	145
Hemp seed	*Cannabis sativa*	32–35	145–155	
Safflower	*Carthamus tinctorius*	24–36	140–150	
Oiticica	*Licania rigida*	60–75	140–148	20
Drying or semi-drying oil				
Soybean	*Glycine max*	17–18	115–140	1712
Semidrying oil				
Sunflower	*Helianthus annuus*	29–35	120–135	965
Corn (germ)	*Zea mays*	50–57	115–130	
Cottonseed	*Gossypium hirsutum*	15–25	100–116	1547
Rapeseed	*Brassica napus*	33–45	96–106	1629
Nondrying oil				
Sesame	*Sesamum indicum*	52–57	104–118	697
Peanut	*Arachis hypogeae*	47–50	92–100	1915
Castorbean	*Ricinus communis*	35–55	82–90	230
Coconut (meat)	*Cocos nucifera*	67–70	8–12	1200

The plants producing tung, oiticica, and coconut are trees. The others are from field crops discussed elsewhere in this book.* The specific

* For further reference regarding vegetable oils see:
Francis Scofield, "Drying Oils," *Flax Facts*, Flax Development Committee, Minneapolis, Minn., 1944.
Laboratory Letters, Spencer Kellogg & Sons, Inc., Buffalo, N. Y., 1940.
G. S. Jamieson, *Vegetable Fats and Oils*, Reinhold Publishing Corp., New York, 1943.

gravity of the above oils ranges from 0.91 to 0.93 except for castor oil, 0.96; tung oil, 0.94; and oiticica, 0.97.

The manufacture of linseed oil is as follows: [11]

"The flaxseed is ground to a fine meal by being passed through a battery of revolving steel rolls. The ground meal is then transferred to a steam-jacketed cylinder or 'cooker,' live steam being added if the meal is very dry, and heated to near the boiling point. This heating process facilitates the expression of the oil when the meal is subjected to pressure. After being heated, the meal is pressed firmly into a mold about 13 by 22 inches on a press cloth, which is folded over the cake. From 24 to 30 of these meal cakes are placed in a hydraulic press and subjected for about an hour to increasing pressure . . . The residue left after the oil is expressed is known as linseed cake, or, if ground, as linseed meal. The cake contains from 3 to 6 per cent of oil, depending on the efficiency of the pressing."

The protein content of the oil meal is about 35 per cent.

The cage type press and the expeller press also are used for oil extractions.

Fiber Flax Culture

The seedbed requirements for fiber flax are essentially the same as for seed flax. With some exceptions, phosphorus increases the fiber percentage and nitrogen decreases it.[21] A 4–16–8 fertilizer mixture usually is recommended for fiber flax where little is known regarding the particular soil conditions.

SEEDING

Fiber flax should be sown early in the spring so that it can complete its growth during cool moist weather. In Oregon this necessitates seeding before April 15, because if sown later, dry weather is likely to occur before the plants are mature. Flax for fiber usually is sown with a drill in 4-inch or 7-inch rows at the rate of 75 to 85 pounds per acre. Such thick seeding produces tall, nonbranching plants. Lodging frequently occurs when the seeding rate is appreciably heavier.

HARVESTING

The fiber flax crop generally is harvested when one-third to one-half the seed bolls are brown or yellow with fully developed brown seeds. At this stage the stems usually have turned yellow and the leaves have fallen from the stems two-thirds the distance from the ground.[22, 23] The fibers of flax plants harvested too early tend to be fine and silky but lacking in strength; fibers of late-harvested flax are coarse, harsh, and brittle, with poor spinning qualities.

In Europe, fiber flax usually is pulled by hand, but in the United States pulling machines are being used to harvest most of the crop. The Vessot pulling machine was introduced into Oregon in 1923. The pulled flax is shocked in the field to cure, after which it is stacked or placed in a shed to await processing. For upholstery tow, the crop generally is cut with a mower, left on the ground several days to cure, and then hauled to the mill. Yields of about 1¾ tons cured pulled flax per acre are typical in the United States. Such a quantity yields about 400 pounds of scutched fiber (including tow) and about 300 to 500 pounds of seed.

Processing Fiber Flax

In the mill, fiber flax is first threshed or deseeded. The next steps are retting, breaking, and scutching.

Retting (or partial rotting) dissolves gums that bind the fibers to the wood, and destroys the thin-walled tissues that surround the fibers. Retting is brought about chiefly by common soil-inhabiting bacteria that are present on the straw when it is harvested.

Two common methods of retting are practiced in this country, viz., dew retting and water retting. Water retting is most satisfactory because of more uniformly favored conditions. Chemical methods of retting are not yet generally feasible from the economic standpoint. In dew retting, the flax is spread on the ground where it is grown. It is retted by molds and bacterial action promoted by frequent rains and dews. Retting usually is completed in 14 to 21 days. The straw must be thinly and evenly spread on the ground for uniform retting. In water retting the straw is placed in tanks which are then filled with water.[22] The retting is accomplished in 6 to 8 days when the water is free of impurities and kept at 80° F. The water in the tank should be circulated for uniform retting.[25] The bundles of retted straw are then taken to a field where they are stood up to dry (Figure 242).

FIG. 242. Retted flax standing on the drying field near the fiber-extracting plant. The stacks in the background contain low-grade stalks to be processed for tow.

The breaking process consists of breaking the woody portions of straw into fine pieces called "shives" by passing the dry retted straw between fluted rollers. At the same time the shives are broken or loosened from the fiber. The shives are then beaten off by a cylinder or wheel in a process called "scutching." The long fibers are strong and flexible enough to resist breaking during these processes. The cleaned fiber resembles the unbobbed tresses of a "flaxen-haired" blonde of the Nordic type. Good fiber averages 20 inches long. Single cells average 1 inch long and 0.009 inch in diameter.

Uses of Flax

About 81 per cent of the linseed oil is used in paints and varnishes, 11 per cent in the manufacture of linoleum and oil cloth, 3 per cent in printers' inks, and the remainder in soaps, patent leather, and other products. Linseed cake or meal is used as feed for livestock. Animals that are fed with it have glossy coats. Seed flax straw has had a limited market for the manufacture of upholstery tow, insulating material, and rugs. Recently, fiber from flax straw has been used extensively in the making of cigarette, Bible, currency, and other high-grade papers. This new industry supplied all of the domestic requirements for cigarette paper with some surplus for export during World War II when the supply of linen rags from Europe for this purpose was unavailable. The feeding value of flax straw compares favorably with that of wheat or oat straw. A flaxseed placed in the eye usually will remove a cinder. Ground flaxseed has long been used in medicine as a conditioner or for making a poultice. Processed edible linseed oil was shipped to Russia during World War II.

Flax fiber is spun into linen yarns, which are used in threads and twines of various kinds. The yarn is also woven into toweling, clothing fabrics, table linen, handkerchiefs, and other textiles. The short tangled fibers, called tow, usually a by-product, are used for upholstering, paper manufacture, and packing. Surplus seed of fiber flax is sold to oil mills for crushing.

Diseases

FLAX WILT

Wilt (*Fusarium lini*) is a fungus disease that generally causes infected plants to wilt and die. It grows upon the live plant as well as upon the dead plant material in the soil. The fungus may remain in the soil for as long as 28 years. The use of resistant varieties is the only satisfactory control on wilt-infected soil. The resistant varieties formerly most widely grown are Bison, Buda, Linota, and Redwing.[6] New wilt-resistant varieties include Biwing, Sheyenne, Victory and Koto.

FLAX RUST

Flax rust caused by the organism, *Melampsora lini*, frequently damages flax in wet seasons such as that of 1942. Bright orange pustules, the uredineal stage on the leaves, are followed by black shiny areas on the stems (the telial stage) late in the season. The fungus is carried over winter on infected stubble and straw.[13] Crop rotation aids in reducing damage from the disease but resistant varieties are the only effective means of control. Viking, Rio, Newland, and Cirrus are resistant to the more common races of the flax rust fungus.

OTHER DISEASES

Anthracnose or canker, caused by the organism *Colletotrichum lini,* has damaged Punjab flax seriously in California. For many years it has caused some loss (as a seedling disease) in North Dakota. Seed treatment checks the spread of the disease. Indian varieties, including Punjab, are very susceptible to anthracnose, whereas Argentine varieties such as Rio and the new California variety, Calar, are fairly resistant to the disease.[19]

Heat canker is caused by high temperatures at the soil surface when the plants are small. The young stems, girdled at the soil line, finally break over and die. The damage is prevented by early seeding.

Pasmo (*Phlyctaena linicola*) appears on the foliage of young plants as yellow-brown circular lesions. As the plant reaches maturity, brown to black blotches are observed on the stems. The disease is seed-borne. Some control measures are crop rotation, seed treatment, and use of resistant varieties.

Seed treatments improve stands and yields and check damage from seedling blight, particularly if the flaxseed has been damaged during threshing, as is usually the case.

Insects

The most common insect injury to flax is from various species of grasshoppers and crickets that chew off the pedicels and allow the bolls to drop to the ground. These pests are controlled with poison baits. Other insects that sometimes damage flax include cutworms, particularly the pale western cutworm in Montana and the western Dakotas; army worms, especially the Bertha army worm in North Dakota, and the beet army worm in California; false chinch bugs in California; stink bugs in Texas; and the flax worm, *Cnephasia longana,* in Oregon. The latter pest is partly controlled by crop rotation. The corn earworm damages flax in Texas.

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34 COTTON

Economic Importance

Cotton * comprises about 56 per cent of the fiber used by man and is the most important fiber crop in the United States. It is grown on about 1,200,000 farms. The cotton belt of the United States is the largest continuous area of land used for cotton production (Figure 243) in the world.[17] The cotton belt has gradually expanded westward, more than one-half the crop now being produced west of the Mississippi River. With the spread of the boll weevil, cotton declined in the older regions while it expanded in western Texas, New Mexico, Arizona, and California, where the boll weevil is absent. Price and production controls of cotton in this country since 1929 have restricted cotton exports,[28] and other countries increased their production.

The average area harvested in the United States from 1937 to 1946 was nearly 23 million acres, and the average production was about 12 million bales of lint. The acre yield was 254 pounds, or slightly more than one-half bale. From 1923 to 1932, the average acreage exceeded 40 million but the production was only 14,400,000 bales because of a yield of only about 180 pounds. The average annual cottonseed production from 1937 to 1946 was about 4,900,000 tons. The seed production in pounds is nearly double that of the lint,

* For a more complete discussion of cotton, readers are referred to the following books:

W. H. Johnson, *Cotton and Its Production*, Macmillan and Company, Ltd., London, 1926.

H. B. Brown, *Cotton History, Species, Varieties, Morphology, Breeding, Culture, Diseases, Marketing and Uses*, McGraw-Hill Book Company, Inc., New York, 2d ed., 1938, pp. 1–592.

G. H. Collings, *Production of Cotton*, John Wiley and Sons, Inc., New York, 1926, pp. 1–256.

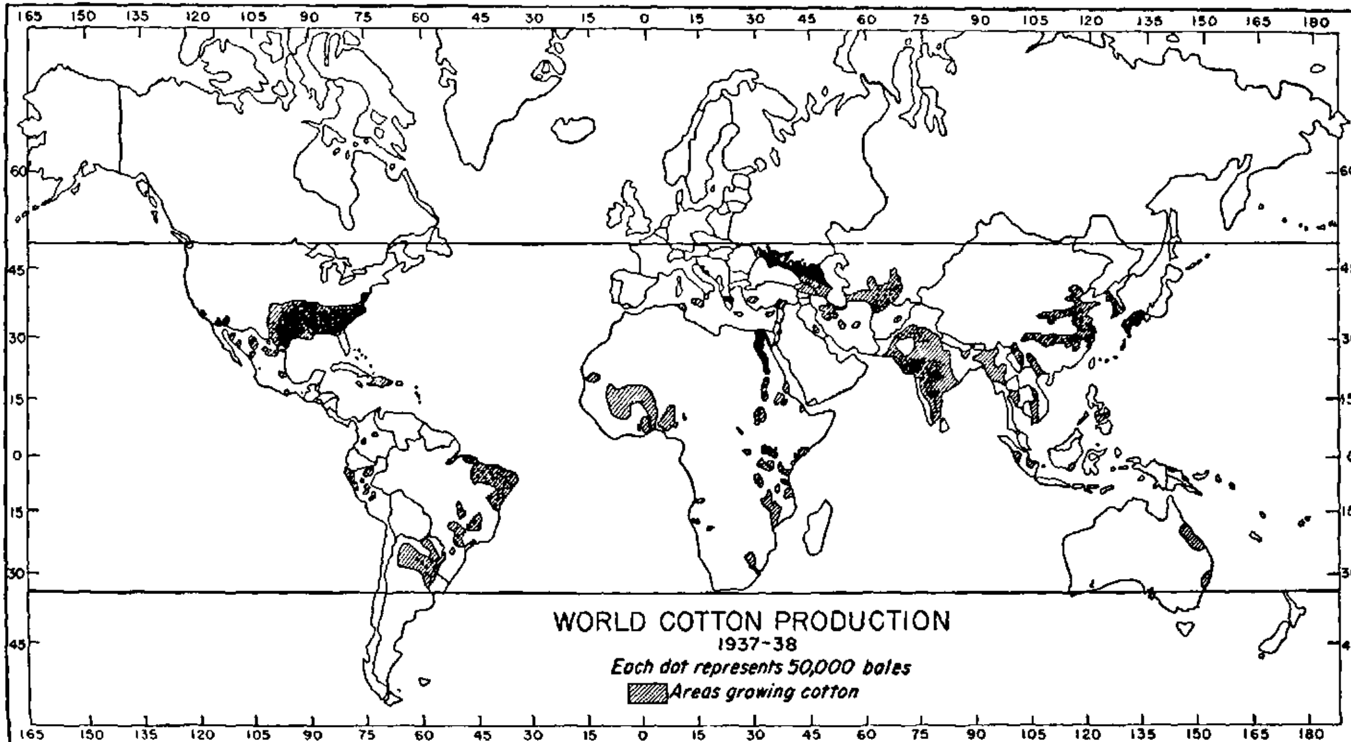


FIG. 243 (a). World cotton production.

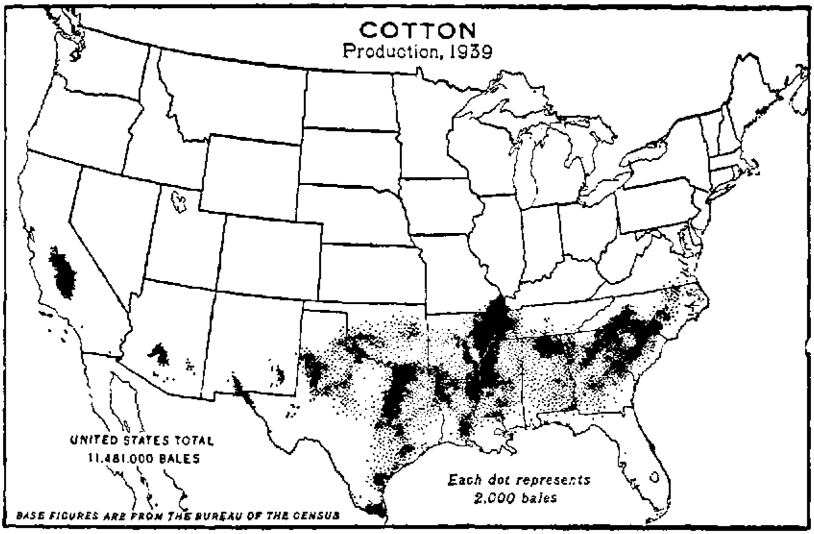


FIG. 243 (b). Distribution of cotton production in the United States.

the average ratio being about 65:35. The leading states in cotton production are Texas, Mississippi, Arkansas, Alabama, Georgia, South Carolina, North Carolina, Louisiana, Oklahoma, and California. The leading countries are the United States, India, Russia (U.S.S.R.), China, Brazil, and Egypt (Figure 244).

History of Cotton Culture

Cotton has been grown in India for making clothing for more than 2,000 years, and in certain other countries for several hundred years. Early European travelers returned from southern Asia with weird tales of seeing wool growing on trees. Early herbalists sometimes illustrated the cotton plant by drawings of sheep hanging from the branches of a tree. Apparently tree types of cotton were grown to a considerable extent at that time. Even today cotton is called Baumwolle (tree wool) by the Germans.

Columbus found cotton growing in the West Indies. Cotton fabrics, probably 800 years old, have been found in Indian ruins in Arizona. The crop was grown in the Virginia Colony in 1607.[7] Its culture soon spread throughout the south, but large-scale production began after the invention of the cotton gin in 1794.

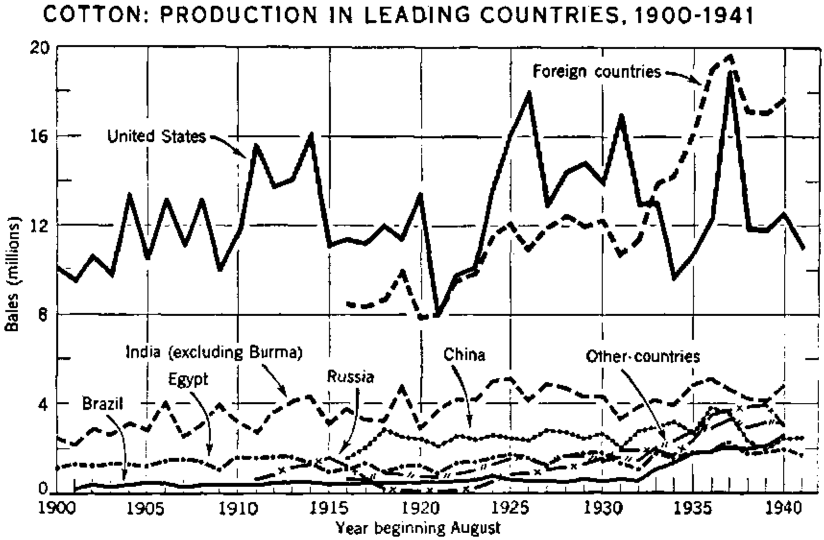


FIG. 244. Cotton production in leading countries.

There probably are two general centers of origin of the cotton plant, Indo-China and tropical Africa in the Old World, and South and Central America in the New World.[53] Separate origins are indicated by the fact that consistently fertile hybrids have not been obtained from crosses between the 26-chromosome American cottons and the 13-chromosome Asiatic cottons.[54] The three distinct types of cotton grown in the United States, Sea Island, American-Egyptian, and Upland, probably are of American origin. The first two are believed to have come from South America originally. Upland cotton is assumed to have descended from Mexican cotton, or from crosses of Mexican and South American species.

Adaptation

Climatic conditions are favorable for cotton where the mean temperature of the summer months is not less than 77° F. The zone of cotton production lies between 37° north and 32° south latitude, except that in Russian Ukraine cotton is grown up to 47° north latitude. Three climatic essentials are freedom from frost for a minimum growing and ripening season, an adequate supply of moisture, and abundant sunshine.[14] General requirements are:

> "(1) a mean annual temperature of over 60° F., though where the distribution of rainfall, sunshine, and temperature is favorable, a mean of over 50° F. probably would be sufficient; (2) a frostless season of 180–200 days; (3) a minimum rainfall of 20 inches a year with suitable seasonal distribution—a maximum of 60 inches, or up to 75 inches, would not be excessive if distribution were favorable; (4) open sunny weather; areas recording 'half cloudiness' annually have too little sunshine to be safe, and areas over three-fifths cloudy are unsuitable for cotton." [14]

The Sea Island and Egyptian types require about 6 months to mature, whereas the period for Upland varieties is about 5 months. In the United States, cotton is limited to sections having 16 inches or more of rainfall without irrigation, but in parts of the irrigated southwestern cotton region the average annual rainfall is less than 6 inches.

The growing conditions most favorable for cotton are a mild spring with light frequent showers; a warm moderately moist summer; and a dry, cool, prolonged autumn. Rainy weather when the bolls begin to open retards maturity, interrupts picking, and damages the exposed fiber. Irregular growth in irrigated cotton causes nonuniformity and lack of strength in the fiber.[32] Early killing frosts in the fall and high evaporation during the flowering period limit the yields of American-Egyptian cotton in Arizona.[19] American Upland cotton, being of indeterminate growth habit and very insensitive to length of day,[17] will produce flowers throughout the year under warm greenhouse conditions.

Cotton grows well on moderately fertile soils. The soils in the cotton regions range from sands to very heavy clays with ranges in acidity from *p*H 5.2 to *p*H 8+. The best cotton lands are mixtures of clay and sandy loam, containing a fair amount of organic matter and a moderate amount of available nitrogen, phosphorus, and potash.[7] The heavier soils promote later maturity, larger vegetative growth, and greater boll-weevil damage. The best cotton regions from the standpoint of both yield and quality are perhaps the Mississippi delta and the irrigated valleys of the southwest.

Environmental conditions that promote earliness in Mississippi are important in avoiding excessive shedding due to mid- and late-season stress conditions, in avoiding boll weevil infestation, and in having the crop ready to pick before the onset of fall rains and cold weather.[41] Maturity is not affected by application of nitrates or by stripping off young bolls. Potash-deficient fertilizers, low soil moisture, and other environmental contributions to earliness usually result in decreased yields. Thick spacing rarely reduces yields and is the most practical way of obtaining earliness. Thick spacing does not advance initial flowering appreciably but merely provides more plants to produce a proportionally larger number of early bolls, and restricts later branching and flowering.

Botanical Description

Cotton belongs to the family Malvaceae, or mallow family.

Upland cotton (*Gossypium hirsutum*) fibers range from ¾ to 1¼ inches or more in length and are of medium coarseness. The flowers are creamy white when they first open but soon turn pink or red. The lint fibers adhere strongly to the seed. The bolls usually contain four or five locks.

Sea Island and American-Egyptian cottons (*G. barbadense*) have extra long, fine fibers, 1½ to 2 inches long or longer in some cases. The lint is readily detached from the seed. The petals are yellow with a purple spot at the base or claw. The bolls usually contain three locks.

The Asiatic cottons are classified as *G. arboreum* and *G. herbaceum*. The fibers are coarse and short, their length being mostly from ½ to ⅞ inches. Native cottons of the American aborigines, such as the Hopi Indians, likewise have short fibers. Upland and Asiatic cottons have shorter boll periods than the Egyptian and Sea Island cottons.[36]

The cotton plant usually is considered an annual, although it is a long-lived perennial in the tropics where the mean temperature of the coldest months does not fall below 65° F. The plant is herbaceous, with a long taproot, and attains a height of 2 to 5 or more feet, with a main stem from which many branches arise. The leaves arise on the main stem in a regular spiral arrangement. At the base of each cotton leaf petiole are two buds, the true axillary bud which continues to make a vegetative growth, and an extra-axillary bud which produces the fruiting branch.[23] The leaves are petioled, stipulate,

FIG. 245. Cotton leaves, flowers, square (*upper right*) and unopened boll (*right*).

and 3, 5, or 7-lobed (Figure 245). The leaves and stems are usually covered with fine hairs. The leaves are green except in a few red leaf varieties.

The flowers may appear arranged on alternate sides of the fruiting branch. There are three relatively large leaflike bracts at the base of the flower, above which is a true calyx consisting of five unequally

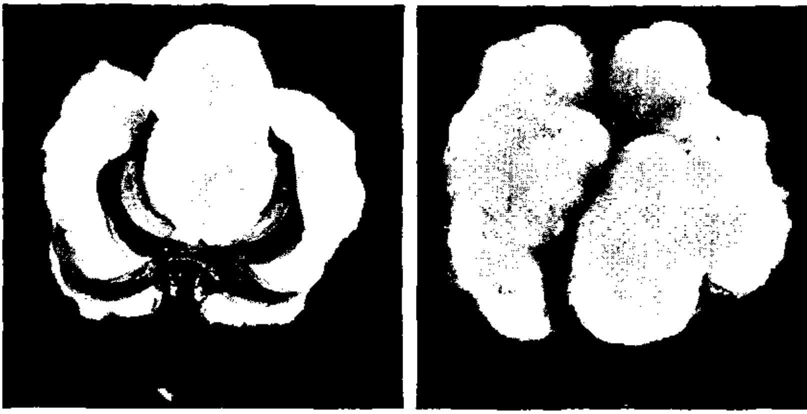


FIG. 246. Open cotton bolls.

lobed sepals. The corolla consists of five petals which range in color from white to yellow to purple in different types. The staminal column bears 10 more or less double rows of stamens, while the pistil is made up of from 3 to 5 carpels. The fruit (Figure 20) is the enlarged ovary that develops into a three- to five-loculed capsule or boll. The bolls are 1½ to 2 inches long among the common varieties, and it requires about 60 to 80 bolls to produce a pound of seed cotton.[38] Other types have bolls not over an inch long. The boll dehisces or splits open at maturity (Figure 246). Late unopened bolls are called "bollies." The seeds are covered with lint hairs, i.e., the fibers,[21] and usually also with short fuzz.

Flowering in the cotton plant begins from 8 to 11 weeks after planting and continues until growth is stopped by frost, drought, insect attack, or other causes. In certain perennial types flowering awaits a suitable photoperiod. The fruit bud or square usually is discernable 3 to 4 weeks before the flower opens. Many more bolls are produced than the plant is able to mature. As many as 50 per cent of the immature bolls may be shed under normal conditions within 8 to 10 days after flowering.[8] The period between flowering and the opening of the mature boll is about 6 to 8 weeks, being longer as the season extends into cool autumn weather. The cotton plant shows a remarkable adjustment to moisture supply. Under severe drought conditions the plant may be 6 inches high and bear one boll. The same variety under irrigation may be 5 feet high and produce 40 bolls per plant.

Pollination

Cotton is often cross-pollinated, but natural hybrids seldom exceed 20 per cent and often are much less.[31] Upland cotton produces more vicinists (natural hybrids) than does Egyptian cotton when two types are grown in proximity. Cross pollination probably is effected by insects attracted to the large showy flowers laden with nectar and pollen.

Metaxenia, or the immediate effect of foreign pollen on the fertilized ovules, has reduced the lint length of Pima (long staple) cotton when pollinated with Hopi (short staple).[24]

Lint or Fiber

Cotton fibers are slender single-cell hairs growing out from certain epidermal cells of the cotton seed.[5] Their growth starts on the ovules about the time the flower opens. The fibers lengthen rapidly and attain full length in 20 to 25 days when the seed has attained full size. For an additional period of 25 days, the cell walls of the fiber thicken. Thickening occurs by laying down two additional spiral growth rings each day. The fiber is cylindrical before the boll opens, but collapses and becomes more or less flattened and twisted (with convolutions) with the opening of the boll (Figure 247). It is thin-walled, weak, and poorly developed when unfavorable conditions prevail during the time the fiber is thickening. A pound of lint may contain 100 million or more fibers. The fiber may be 1,000 to 3,000 times as long as thick. The fibers range in length from ¼ inch to over 2 inches (Figure 248) and in thickness from 0.0006 to 0.0008 inch. Varieties with long fibers tend to have a low lint percentage in seed cotton, whereas those with short fibers have the highest percentage of lint.

The fiber length is enhanced by ample rainfall while the bolls are developing.[45] Thin-walled or so-called immature fibers produce yarns that are unduly neppy or full of knots and snarls which cannot all be removed by the spinner. Dark-colored, plump, well-developed seed yields a high percentage of mature fibers.[26] Yarn strength is

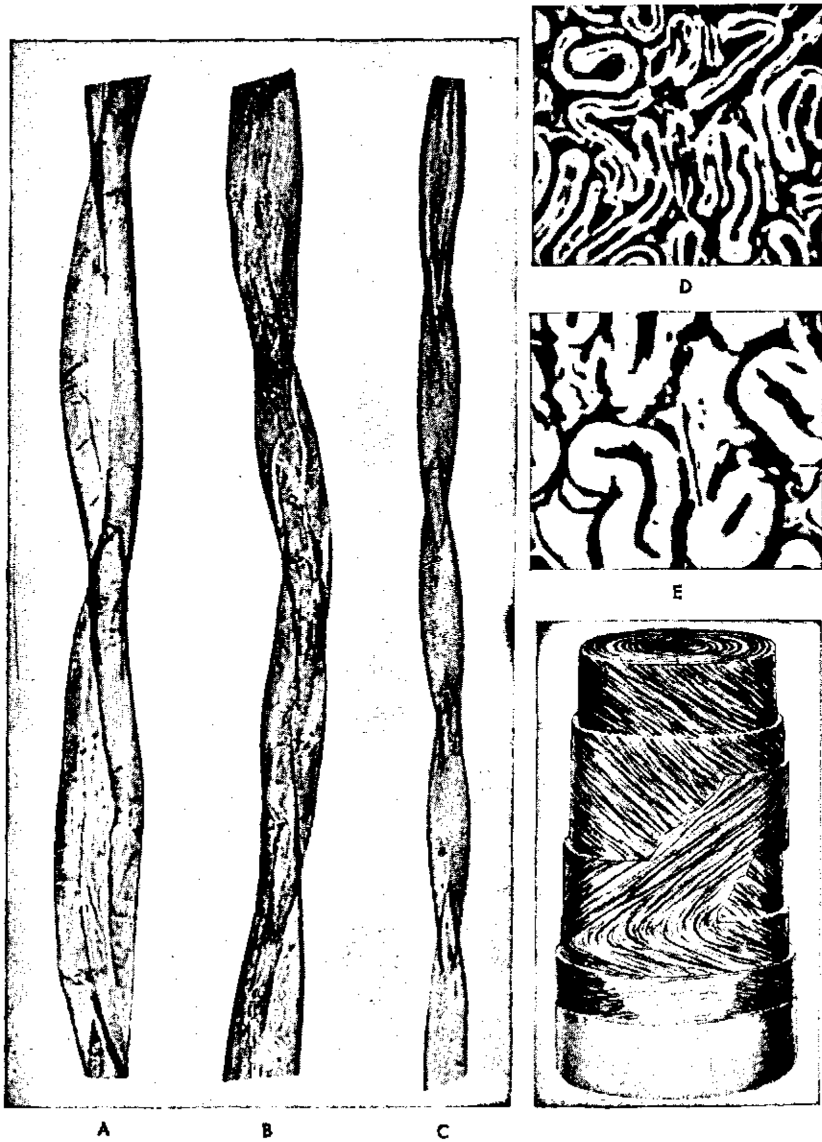


FIG. 247. (*Left*) Short portions of single cotton fibers magnified 400 diameters. (a) Coarse fiber of the Garo Hill variety with ⅜-inch staple, (b) medium fiber of American Upland with 1⅛-inch staple, and (c) fine fiber of Sea Island cotton with 1¾-inch staple, the section shown representing about 1/136 of the total fiber length. (*Upper right*) Cross sections of dry cotton fibers, (d) four weeks after pollination, and (e) at maturity showing thickened walls, all highly magnified. (*Lower right*) Diagram of a mature cotton fiber showing the slope of the strands comprising the daily growth rings within the cell wall.

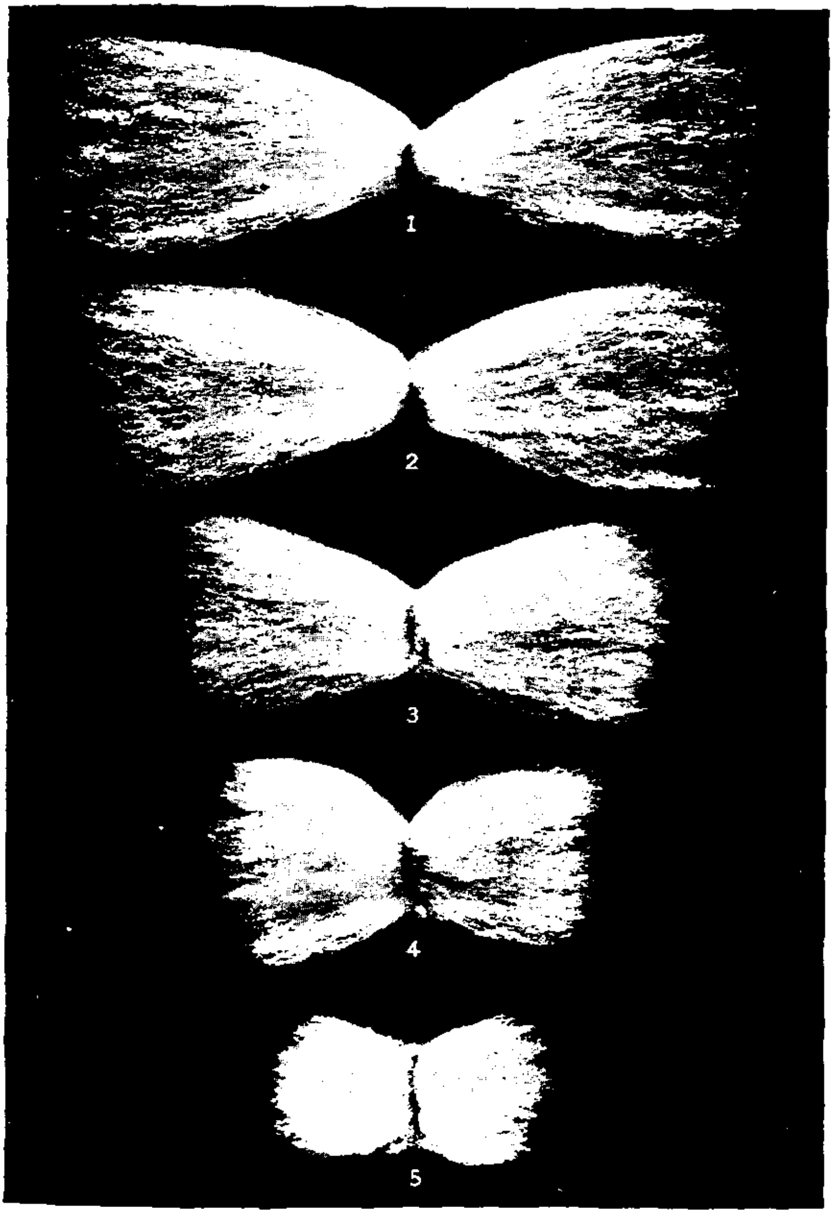


FIG. 248. Combed fibers attached to the seeds of 5 types of cotton: (1) Sea Island; (2) Egyptian; (3) American Upland long-staple; (4) American Upland short-staple; (5) Asiatic. All natural size.

about equally dependent upon fiber length and fiber strength. In very fine yarns fiber fineness, small diameter, and thin fiber walls contribute to yarn strength. Although long, fine fibers are desired for yarn strength, such fibers tend to cause neppy or poor yarn appearance unless a combing process is used in spinning. Other things being equal, long fibers give a smoother and stronger yarn than do short fibers. Consequently, long-staple cotton is used in making the better grades of yarn and the cord for rubber tires. Short-staple varieties are grown in certain localities because they are more profitable. For example, the short-staple Half and Half, Hi-bred, and Macha varieties are grown in western Texas and Oklahoma because they yield more or are easier to pick and clean than are the longer-stapled types. Furthermore, the cost of picking a pound of lint is lower because many of the short-stapled varieties have a high lint percentage.

Cottonseed

Normally, there should be 9 cotton seeds in each lock, or 27 to 45 per boll. However, a lock usually contains one or two undeveloped (aborted) seeds called motes. The seeds are usually ovoid in shape (Figure 249). Most of the Upland cotton varieties have dark brown seeds covered with fuzz, while Sea Island and American-Egyptian seeds are black and practically free from fuzz. A pound contains 3,000 to 5,000 seeds. Large-bolled varieties tend to have large seeds. The seedcoat is a tough leathery hull constituting about 25 to 30 per cent of the weight of the seed. The oil content of the hulled kernel (or *meat*) varies from 32 to 37 per cent.

Cottonseed stored in tight containers at a moisture content below 8 per cent has retained its viability with only slight impairment for 7 years.[47]

Cottonseed is often delinted before planting to cause it to pass through the planter box more freely and germinate more rapidly. Cottonseed is delinted mechanically with delinting saw gins or by stirring two bushels of seed in 5 quarts of concentrated sulfuric acid.[22] Cottonseed may be delinted very closely with not over 1 per cent of saw-cut injury, and 100 to 150 pounds of linters per ton of seed may be removed with safety.[2] The sale value of the linters helps defray the cost of mechanical delinting. Mechanical delinting is fre-

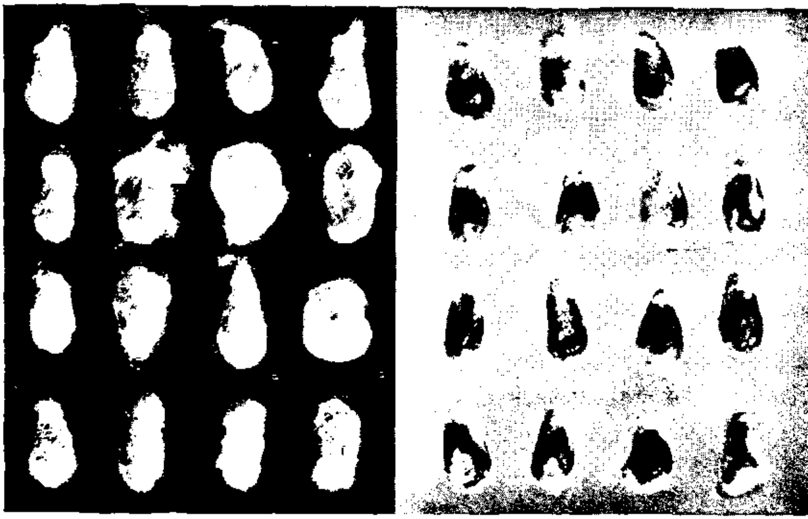


FIG. 249. Cottonseed: gin run (*left*); delinted (*right*).

quently done at oil mills. Often the seed is treated after delinting, or without delinting, with a mercury dust fungicide to control seedling diseases.[10]

Varieties

The great number of cotton varieties grown is due to the ease with which new ones arise by natural hybridization. Most varieties come and go within a rather brief period.[53] Considerable progress has been made in standardizing on the production of a few of the better varieties.[6] The one-variety-community plan proposed by O. F. Cook in 1911 has been widely accepted in the United States. About 40 per cent of the cotton is produced in one-variety communities. Under this plan, a single good variety is grown in a community so as to maintain a uniformly good quality in the local market and to avoid admixtures with inferior kinds.

Since 1936 improved strains of the older varieties have replaced poorer strains, and certain better strains are grown on a much more extensive scale. In 1946 probably 40 to 50 per cent of the cotton acreage in the United States was devoted to strains of five good varieties, Deltapine, Mebane, Acala, Stoneville 2 B, and Coker 100.

The change in varieties has brought about an increase in proportion of the crop having a more satisfactory staple. In 1944, 84 per cent of the cotton crop had a staple length of $^{15}\!/_{16}$ inch or longer, as compared with 44 per cent in 1928. The leading types, varieties, and strains of cotton grown in the United States in 1946 are shown below in Table 1, prepared with the assistance of C. B. Doyle and J. O. Ware, cotton specialists of the Bureau of Plant Industry, Soils and Agricultural Engineering, U. S. Department of Agriculture. The boll size classes based upon the number of bolls required to yield one pound of seed cotton are as follows: large, 65 or less; medium, 65 to 75; small, 75 or more. The staple lengths indicated are approximate averages determined on samples from experiment station tests.

Lint length, percentages of oil and protein in the seed, and percentage of fuzz on the seed are distinct varietal characteristics,[43] but are modified greatly by environment.

Small non-storm-resistant bolls and soft staple have prevailed in many eastern varieties, probably because of selection under humid conditions. The western cottons have large bolls and coarse fiber and are more storm resistant. Early short-staple cottons were substituted in many parts of the cotton belt after the boll weevil became prevalent. These prevailed until earlier varieties with better lint qualities could be bred. Acala is widely grown in the southwestern states, while Half and Half has long been popular in western Oklahoma and western Texas. Acala 4–42 is grown widely in California.

American-Egyptian cotton is not adapted to the humid cotton belt, but is grown under irrigation in southern Arizona.[25] The principal variety S × P has replaced Pima. The production of Sea Island cotton was limited to the islands off the coast of South Carolina and Georgia, and to a narrow strip along the coast of those states and Florida. It is very susceptible to boll weevil damage.[9] Very little Sea Island cotton has been grown since 1943, largely because of labor shortages and previous adverse growing conditions.

Fertilizers

Increased use of fertilizers, confinement of the crop largely to the better lands, and more extensive use of better varieties have been potent factors in increasing cotton yields from 180 pounds up to 260

TABLE 1. LEADING TYPES, VARIETIES AND STRAINS OF COTTON IN THE UNITED STATES IN 1946

TYPE	BOLL SIZE	STAPLE LENGTH (*inches*)	VARIETIES AND STRAINS
Stoneville	Medium	$1\frac{1}{16}$	Stoneville 2B, Stoneville 5A, Stoneville 62, Stoneville 4A (Ambassador), Stonewilt, White Gold, Empire, Bobshaw
Coker 100	Medium	$1\frac{1}{16}$	Coker 100 strain 9, Coker 100 Staple, Coker 100 strain 5 (Wilt Resistant), Coker 200 Strain 2
Deltapine	Medium	$1\frac{1}{32}$	Deltapine 14
Delfos	Small	$1\frac{1}{8}$	Delfos 531A, Delfos 425 (Wilt Resistant), Delfos 651, Delfos 719 (Washington)
Rowden	Large	1	Rowden 40, Rowden 41A, Rowden 41B
Acala 8	Large	$1\frac{1}{16}$ to $1\frac{1}{8}$	Shafter, Santan, Rogers, Texacala
Acala 5	Medium	1 to $1\frac{1}{8}$	Acala 1517 (Wilt Resistant), Nucala, Acala 18, Acala 892
Mebane Triumph	Large	$\frac{7}{8}$ to 1	Mebane Estate, Texas Special, Ferguson, New Boykin, Harper, Watson, Kasch, Floyd, Oklahoma Triumph 92 or Early Triumph. Qualla, Mebane 140, Western Prolific, Lockhart 140
Lone Star	Large	$\frac{15}{16}$ to $1\frac{1}{16}$	Lockhart, Lockhart 57, Northern Star
Wilds	Medium	$1\frac{1}{4}$ to $1\frac{3}{8}$	Wilds 18
Cook	Medium	$\frac{15}{16}$ to 1	Cook 144 (1 to $1\frac{1}{32}$ staple), Cook 912, Rhyne Cook
Dixie Triumph (Wilt Resistant)	Large	1 to $1\frac{1}{32}$	Dixie Triumph 12, Dixie Triumph 25, Station 21, Dixie Triumph 366
Cleveland	Medium	1 to $1\frac{1}{32}$	Wannamaker Cleveland, Marett Cleveland, Cleveland Wilt Resistant, Clevewilt 7 strain 2, Cleveland 54, White Gold
Half and Half	Medium	$\frac{3}{4}$ to $\frac{7}{8}$	Half and Half, Macha or Stormproof
Hi-bred	Medium	$\frac{3}{4}$ to $\frac{7}{8}$	Hi-bred
American Egyptian	Small	$1\frac{7}{16}$ to $1\frac{9}{16}$	Amsak ($1\frac{9}{16}$ inch staple), S × P, Earlipima
Sea Island	Small	$1\frac{1}{2}$ to $1\frac{5}{8}$	Seabrook 12B 2, Seabrook 10, Seaberry

pounds per acre since 1932. Since the soils in most of the southeastern cotton belt are deficient in available nitrogen, phosphorus, and potassium, a balanced mixed fertilizer usually is needed. In the semiarid regions, little or no fertilizer has been used.

The usual application of fertilizer to cotton in the United States in 1938 (Table 1, Chapter 6) was about 300 to 400 pounds per acre of a 4–8–4 or similar mixture. Frequently, a side dressing of nitrogen is also applied. For the 1943 crop, in the southeastern states about 93 to 99 per cent of the growers fertilized their cotton.[43] The average application was about 412 pounds per acre. In the south central states 58 to 78 per cent of the crop was fertilized. About 70 per cent of the cotton acreage in Missouri received fertilizer. In Texas and Oklahoma, on the other hand, only about 5 per cent and 1 per cent, respectively, of the cotton acreage was on fertilized land.

In North Carolina, the use of 500 pounds of 5–7–4 fertilizer or its equivalent increased the yield of seed cotton about 568 pounds per acre.[48] In more than 150 experiments with cotton fertilizers conducted cooperatively by the United States Department of Agriculture, the yield of lint was increased about 40 pounds for each 100 pounds of fertilizer applied. The best results were secured when one-half the total nitrogen was applied in the mixed fertilizer and the remainder applied later as a side dressing. About 12 per cent of the total seasonal intake of mineral nutrients occurs during the stage between seedling emergence and formation of squares. About 58 per cent of the mineral soil nutrients are taken up by the plant between the stages of square formation and boll formation. The remaining 30 per cent is taken up thereafter. For best results, fertilizer should be placed in bands 1½ to 3½ inches to each side and 1 to 3 inches below the level of the seed.[46] The material can be placed in such bands with a combination planter and fertilizer distributor.

The cotton plants on an acre producing 700 pounds of seed cotton absorb the following quantities of mineral nutrients from the soil:

NUTRIENT	TOTAL ABSORBED (*pounds*)	IN SEED COTTON (*pounds*)
Nitrogen (N)	77	15
Phosphoric acid (P_2O_5)	23	7
Potash (K_{20})	67	7
Lime (CaO)	79	1½
Magnesia (MgO)	26	2
Total	272	33½

Thus, only about one-eighth of the nutrients absorbed by the cotton plant is contained in the harvested portion of the crop. When the burs remain on or are returned to the field, and the seed produced or its equivalent is used for feed or fertilizer, loss of nutrients from the farm from the sale of lint is negligible. Cotton lint is nearly pure cellulose consisting of carbon, hydrogen, and oxygen manufactured by the plant from air and water.

Rotations

Winter legumes are often grown on cotton land as a means of reducing the amount of fertilizer needed for satisfactory cotton yields. Rotation is essential in some areas in order to reduce some cotton diseases such as root rot. A good 3-year rotation is: (1) cotton; (2) summer legumes (cowpeas or soybeans) for hay or seed, followed by winter legumes for cover crop and green manure; (3) corn, interplanted with cowpeas, soybeans, or velvetbeans. A suggested 4-year rotation is: (1) cotton, followed in part by a winter legume; (2) cotton; (3) summer legumes for hay or seed followed by winter legumes; (4) corn, interplanted with summer legumes.[35] The yields of seed cotton in six southern states were increased 200 pounds per acre by crop rotation as compared with continuous culture.[48] Growing a winter legume preceding cotton increased the yield of seed cotton an average of 270 pounds per acre.

In western Texas, cotton often is grown continuously, because it does not fit in well with wheat or sorghum, the other two important crops.

Seedbed Preparation

The first step in seedbed preparation for cotton is stalk disposal, i.e., the stalks are cut up by a machine known as a stalk cutter (Figure 48). The land may then be plowed and later thrown up into beds for the cotton rows. Sometimes it is bedded directly by a lister run in the ridge of the old row so as to make new ridges or beds between the old ridges. Fertilizers often are applied in the old middle before it is bedded.[7] Cotton is planted on ridges or beds in most of the humid cotton belt, while level and furrow planting are more common in the western half of the cotton belt. Much of the cotton land in western Texas and Oklahoma is listed instead of being plowed.

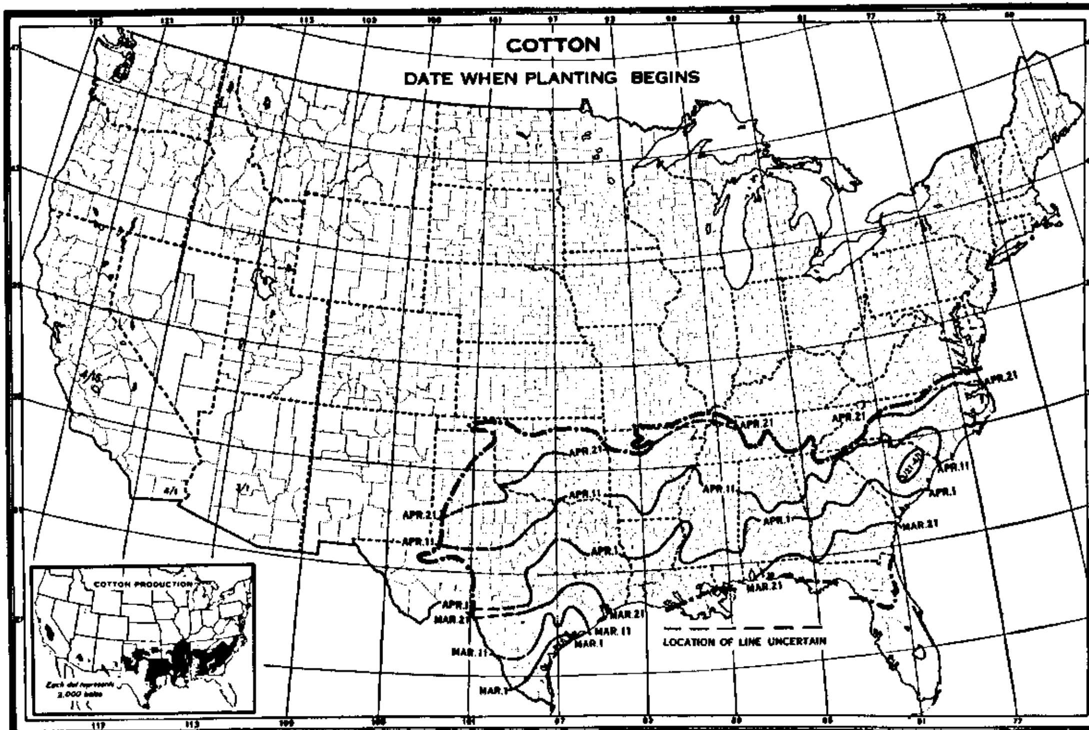


FIG 250 (a). Date when cotton planting begins in the United States.

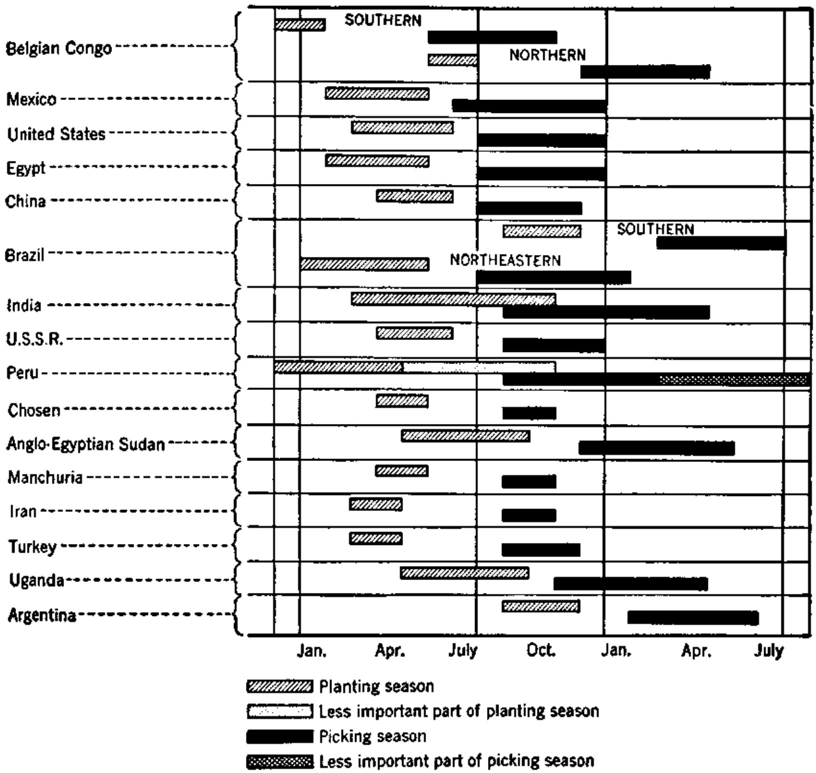


FIG. 250 (b). Dates of planting and picking cotton in different countries.

Planting

Cotton is planted after the soil is warm, i.e., when the temperature is 60° F. or higher. Most of the crop is planted in March, April, or May, the later dates being applicable to the northern part of the cotton belt (Figure 250).

The seed usually is planted shallow (1 to 1½ inches), at a rate of 1 to 2 bushels (30 to 40 pounds) per acre in the humid and irrigated regions. An excess of seed is thought necessary usually to insure an adequate stand. However, by seed treatment with organic mercury dusts the quantity of planting seed can be reduced safely. The rows are generally 3 to 4 feet apart. Single-row planters are common in the southeast, particularly on hilly land, but multiple-row planters

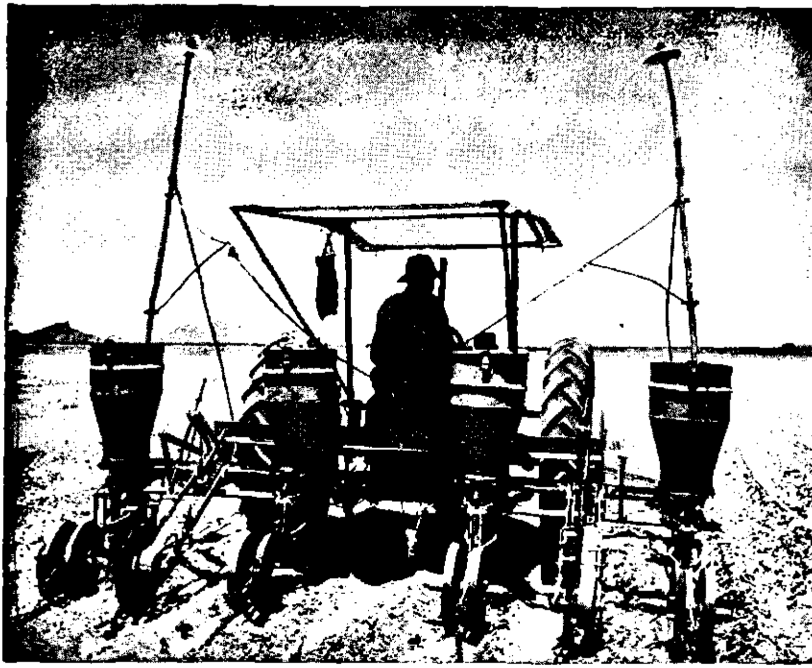


FIG. 251. Planting cotton with a 4-row planter.

are used in the large river valleys and in the southwest (Figure 251). After the plants develop two or three true leaves they are thinned (or chopped) with a hoe to the desired spacing. Most of the cotton grown in the semiarid regions is planted at a rate of about 20 to 30 pounds per acre and not chopped. Delinted seed in semiarid regions is planted at a rate of only 7 to 10 pounds per acre because of better germination. In number per pound, delinted seed is equivalent to 1.18 pounds of fuzzy seed.

The best depth of planting is 1¼ inches in Lufkin fine sandy loam in Texas,[49] where variable-depth planting was not advantageous. The latter planting method is recommended for soils in which uncertain moisture or temperature conditions might favor either shallow or deep (2 to 3 inch) planting, so that a stand would be secured in either case. Press wheels on the planter help to compact the soil around the seed and improve stands.[49] The fuzz on cotton seed prevents close contact with the soil unless the soil is pressed around the seed. A knife type of furrow opener that leaves a smooth narrow opening for the seed likewise has favored good stands on a sandy loam soil.

Spacing

Although the cotton plant is sufficiently adaptable to produce satisfactory yields over a wide range of field stands, moderately close spacing has given the best yields. The most satisfactory spacing between plants in the row is 12 to 16 inches in most of the cotton belt,[39] but in Texas it ranges from 12 to 21 inches.[51] A spacing of 12 to 18 inches gave the highest yields under semiarid conditions in southwestern Oklahoma.[42]

In general, close spacing has resulted in better yields on less fertile land, while wide spacing produced more satisfactory crops on fertile land.[4, 52] In southern Louisiana where the soil is generally fertile and the rainfall rather heavy, the best yields were obtained with a spacing of two stalks 20 inches apart in rows 4 feet apart.[12] Boll rot was somewhat prevalent in closely spaced plants.

Although uniform earliness has been favored by close spacing, extremely thick stands may result in a reduced first picking. Uniform earliness is important under boll weevil conditions. In the irrigated Mesilla Valley of New Mexico, 6- to 12-inch spacings were the most favorable for maximum early production as well as for large yields.[34] A comparison of 1 and 2 plants per 12 inches of row favored the heavier stand.

Methods being developed for thinning and weeding cotton with flaming machines appear to be meeting with considerable success. Such a machine, together with the mechanical picker, tractor-mounted tillage and planting equipment, and airplane dusting, offer promise of making cotton a completely mechanized mass-production crop.

Harvesting

In the eastern cotton belt, cotton is nearly all picked by hand, i.e., keeping both hands busy, the seed cotton is pulled with the fingers from the locks of the open bolls. When both hands are full, the cotton is dropped into a sack. In the southeast, short sacks often are suspended from the shoulder. In the Mississippi Valley and the southwest, sacks up to 12 feet in length with a shoulder strap are dragged along the rows (Figure 252). Where the plants are short and the fruiting is heavy and thick near the ground cotton pickers often move along the row on padded knees. Several (usually two or three) pickings are necessary as the bolls continue to open. Most of the American crop is picked from August to December (Figure 253). When a machine is used, picking is delayed until nearly all the bolls are open. Unfavorable weather conditions sometimes result in cotton being harvested in a green or damp condition. Sun-drying during the day is effective in removing excess moisture when the cotton is spread out in layers about 8 inches deep.[20]

In much of the high and low plains of Texas and Oklahoma cotton is snapped by hand, the entire boll being pulled from the stem. The burs and seed cotton are separated at the gin with a special extractor.[37] Although snapping is faster and cheaper than picking, it increases the amount of trash gathered with the cotton. About 40 to 75 man-hours are required for an adult to pick a bale of cotton, whereas snapping requires about two-thirds of that time. A usual day's picking is about 200 pounds of seed cotton, or 250 to 300 pounds where plants are small, fields clean, and picking easy. The picking of American-Egyptian cotton is much slower. The need for cleanliness in this premium cotton does not permit either snapping or stripping.

In western Texas and Oklahoma, mechanical stripping is practiced to a considerable extent when labor is scarce or cotton is cheap. It is done by either a stripper or sled pulled along the row while rolls or fingers, respectively, strip the bolls from the plant (Figure 254). Two men operate the tractor and machine while a third man hauls the cotton to the gin. Such a crew, with a two-row machine, harvests a bale of cotton in less than two hours. Bollies (immature unopened bolls) gathered are opened with a boll breaker at the gin.

In 1944 a modified grain combine, developed at Frederick, Oklahoma, was used successfully for stripping cotton.[16] The reel and sickle were removed, and 30-inch fingers attached to the cutter bar stripped the bolls from the stalks. Cotton usually is not stripped until after frost and when nearly all leaves have fallen from the

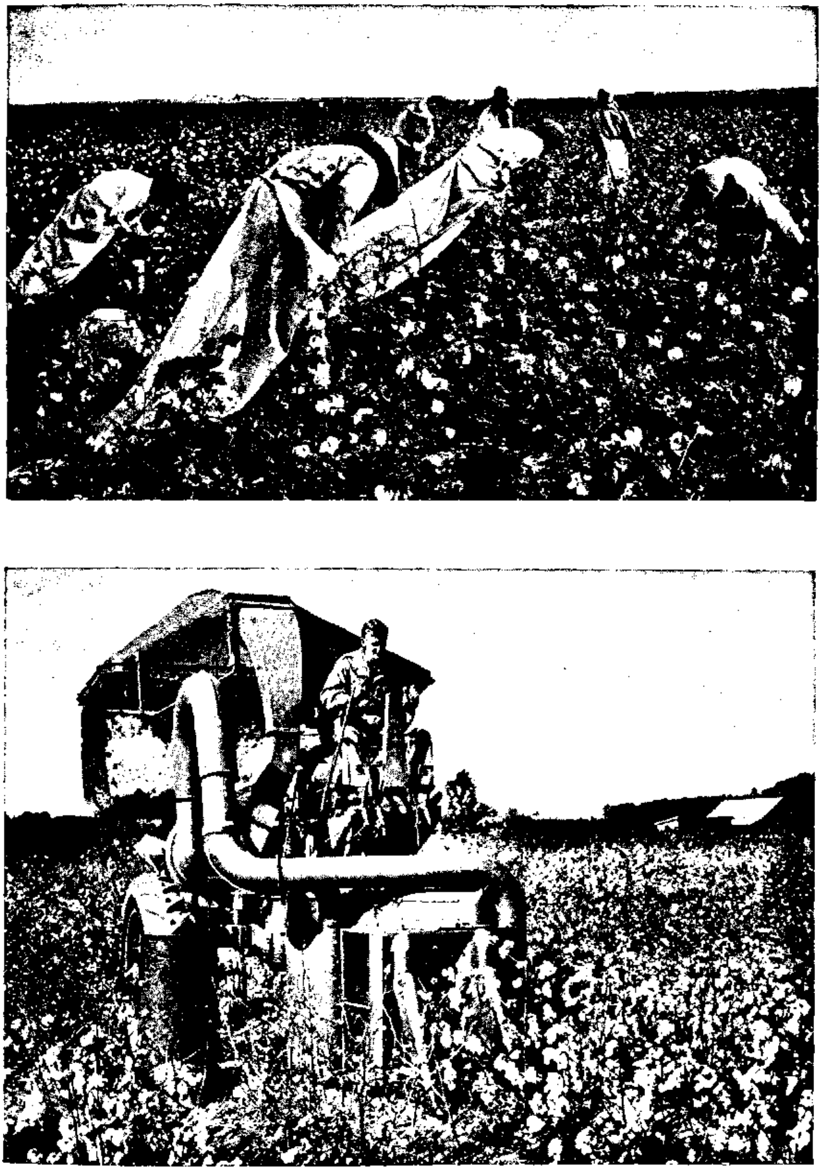


FIG. 252. (*Top*) Long sacks used by cotton pickers in large western fields. (*Bottom*) Mechanical picker. (Courtesy of the International Harvester Company.)

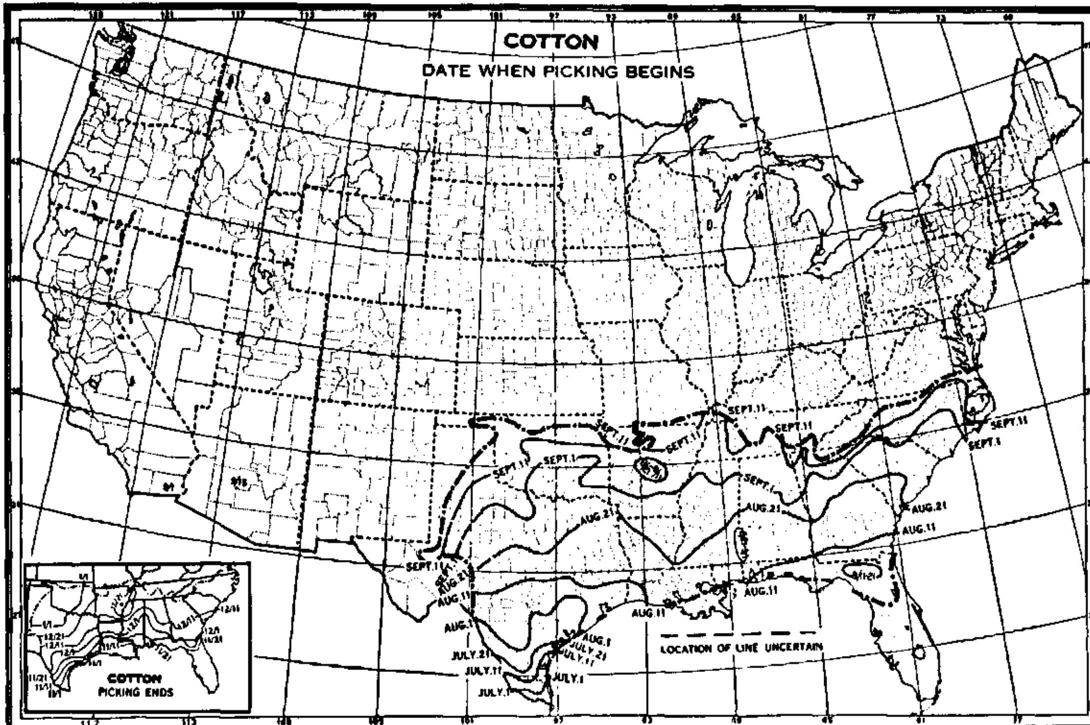


FIG. 253. Dates when cotton picking begins in the United States.

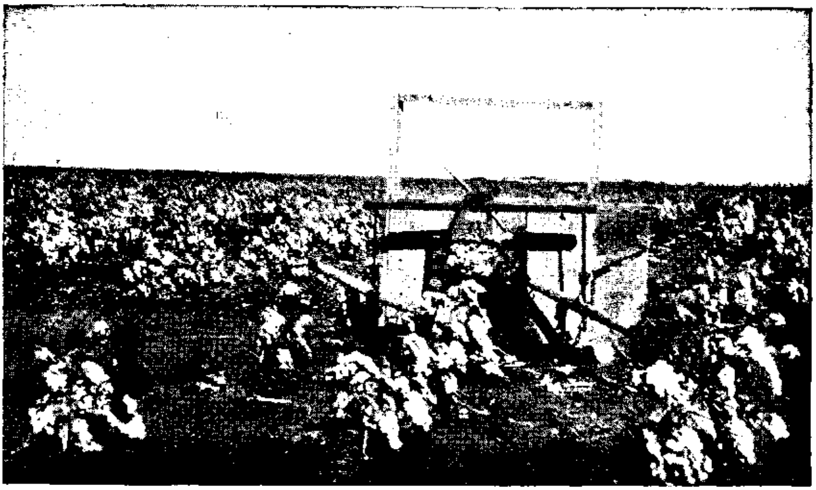


FIG. 254. Sled for stripping cotton.

plant.[11] Even then the amount of trash gathered is greater than with snapping. Despite the use of special cleaning equipment on the stripper or at the gin, the lint obtained from stripping is lower in grade than that picked or snapped.

Mechanical cotton pickers are not yet being used extensively, but recently designed machines seem to be successful (Figure 252). A mechanical harvester designed at the Texas Station removed 94 to 98 per cent of the cotton from varieties developed for mechanical harvesting.[50] Many high-yielding varieties are not adapted to mechanical picking because of plant characteristics such as widely opened bolls with poorly retained locks and irregular fruiting and maturity. However, certain so-called stormproof varieties tend to hold the lint in the locks so that it does not fall to the ground and become lost or damaged. The Macha variety [50] grown in western Texas and Oklahoma is especially adapted to mechanical stripping because of special lint attachment to the burs. When cotton is to be harvested mechanically, it is becoming a common practice in regions when the formation of nightly dew is dependable to dust the plants with 30 pounds per acre of calcium cyanamid shortly before the cotton is ready to harvest. This treatment when applied under proper conditions defoliates the plants quickly and permits earlier mechanical harvesting without having to wait for the leaves to be shed naturally. The bolls ripen and open much more rapidly after the leaves drop. The dust can be applied either from an airplane or with a field dusting machine. Hygroscopic chemicals added to the dust facilitate defoliation treatment in dry weather.

Cotton Ginning

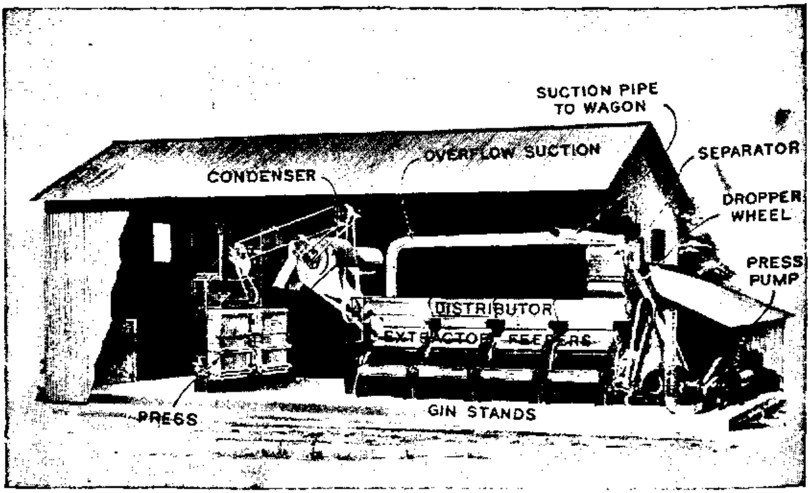
The seed cotton after picking is hauled in bulk to the gin where it is unloaded with a pneumatic metal pipe having telescoped sections at the outside end.

About 10,000 gins are in operation in the United States each year. Cotton ginning (Figure 255) involves separation of the fibers from the seed, after removal of dirt, hulls, and other trash. Damp or wet cotton may be put through a drier before ginning. Dry lint contains 8 per cent moisture or less. The essential part of a saw gin is a set of circular saws that revolve rapidly with a portion projecting through a narrow slit between parallel ribs or bars of iron.[7] The teeth of the saws catch the lint, draw it between the ribs and thus pull it from the seeds (Figure 255). The seeds are too large to pass through and are dropped into a conveyor trough or suction pipe. Brushes back of the bars remove the lint from the saws. The lint is carried to the press by suction conveyers.

American-Egyptian and Sea Island cotton are ginned on a roller gin.

At the press or baler the fluffy lint is pressed into bales of about 500 pounds (Figure 256). The bale is covered with about 6 yards of heavy (1¾ or 2 pounds per yard) jute bagging, and held by six asphalt-coated flat steel ties weighing 9 pounds. The standard bale is about 54 × 27 × 45 to 48 inches in dimensions,[1] or 38 to 40 cubic feet. A tare weight of 22 pounds of bagging and ties per 500-pound bale is acceptable without any discount from cotton prices. For more economical export, transportation, and storage, the bales often are compressed later to a size of about 15 or 22 cubic feet. About 2 per cent of the domestic cotton crop is packed into round bales weighing about 250 pounds.[3]

It usually takes about 1,200 to 1,500 pounds of picked seed cotton, 1,600 to 2,100 pounds of snapped cotton, and 1,800 to 2,600 pounds of



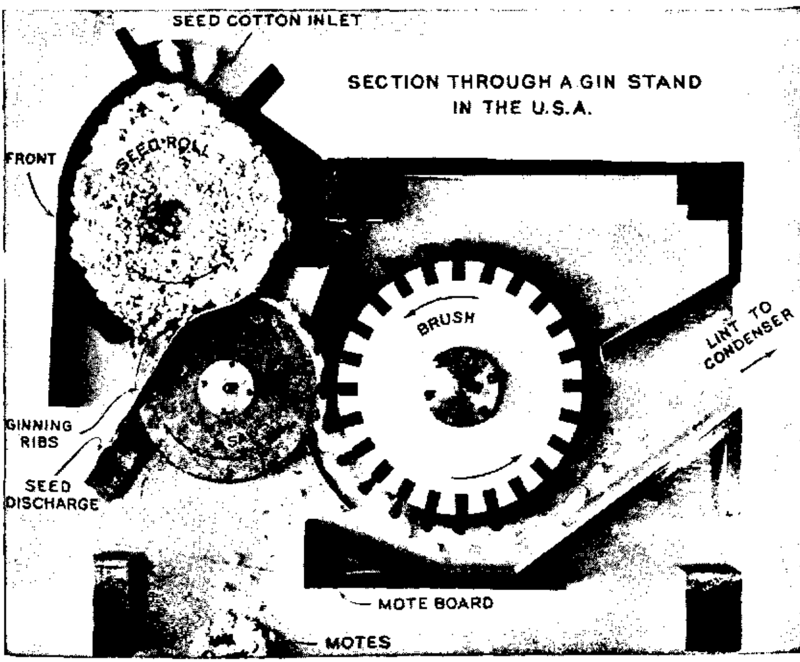


FIG. 255 (*Top*) Sectional view of a cotton gin plant. (*Bottom*) Section of a gin stand.

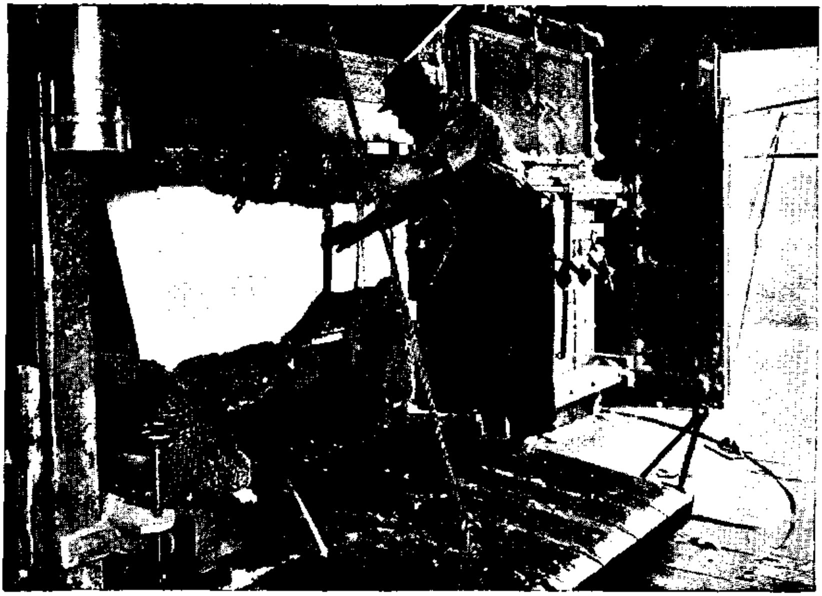


FIG. 256. Attaching the ties to a bale of cotton in a press.

stripped cotton to yield a 500-pound bale of lint. Clean seed cotton is about 32 to 45 per cent lint. Thus 750 to 1,000 pounds of seed are obtained for each bale of lint produced. So-called Half and Half cotton is high in lint percentage (usually 38 to 42 per cent) but rarely[42] the 50 per cent which the name implies. The lint percentage of American-Egyptian cotton is 27 to 28 per cent.

Utilization

Cotton lint is spun into thread to be woven into various fabrics. The finer threads are made from Sea Island and American-Egyptian cotton, while the coarser ones are made from the Upland varieties. About 60 per cent of the domestic cotton is used for clothing and household goods. The remainder is used in industry mostly for bags, belts, hose, twine, and for tires. The short lint is utilized in carpets, batting, wadding, and low-grade yarns, as well as for stuffing material for pads and cushions.[15] Linters or fuzz are used mostly for stuffing and for making rayon and other cellulose products.

About 7 per cent of the cottonseed produced is planted each year, and small quantities are used for feed. The remainder is crushed for the oil (Figure 257), the meal being a by-product. A ton of cotton seed yields about 320 pounds (or 43 gallons) of oil, 900 pounds of meal, 135 pounds of linters, and 500 pounds of hulls, leaving 145 pounds to account for trash, waste, and invisible losses. The production of linters averages more than one million 500-pound bales annually.

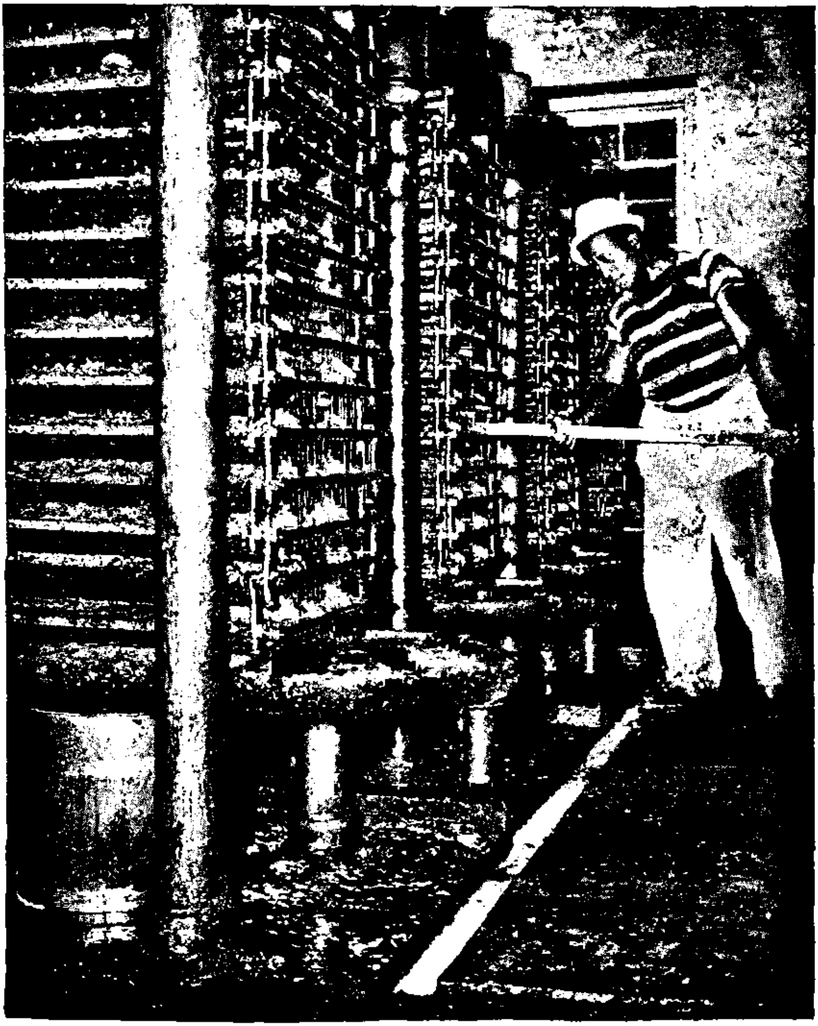


FIG. 257. Pushing a pan of cottonseed cake from an oil press.

Cotton is classed according to staple length, grade, and character. Staple length is estimated or measured from approximately a one-fourth ounce sample pulled and straightened between the fingers. For the shorter staple lengths the lint is separated into the classes: below $\frac{3}{4}$ inch, $\frac{3}{4}$ inch, $\frac{13}{16}$, and $\frac{7}{8}$. Above that length the classes differ by $\frac{1}{32}$ inch. In any sample an array of different fiber lengths is found, ranging from very short to somewhat longer than the typical length. Upland cotton having fibers $1\frac{1}{8}$ inches or longer is classed as long staple.

Quality factors determining grade include color, leaf and other foreign matter, ginning preparation, and maturity. These values are estimated by visual comparison with standard samples. Character, including strength, fineness, pliability, and uniformity of length are determined by sight and touch. Recently developed instruments for determining length, strength, fineness, and structure are now being used, but mostly in research studies of the fiber. Color classes recognized are extra white, white, blue stained, gray, spotted, yellow tinged, light stained, and yellow stained. Within these classes are 32 grades for quality. For American Upland white cotton the numerical grades are as follows:

No. 1 or Middling Fair
No. 2 or Strict Good Middling
No. 3 or Good Middling
No. 4 or Strict Middling
No. 5 or Middling
No. 6 or Strict Low Middling
No. 7 or Low Middling
No. 8 or Strict Good Ordinary
No. 9 or Good Ordinary

Grades 1 to 7 above are deliverable on future contracts.[30] Grade 5 or middling is the basic grade for commercial transactions. Premiums are allowed for higher grades, and discounts applied for grades lower than middling. Grades are established also for American-Egyptian and Sea Island cotton and for linters.

When a grower hauls his seed cotton to the gin he may sell it directly, but usually he has it custom ginned and baled, and then stores it at a warehouse, or hauls it home or to a buyer. The seed may be sold to the gin, or hauled home or to an oil mill. The identity of a grower's cotton is maintained at the gin, and when the bales are stored in a warehouse. Prices offered the grower are based upon the current future price for middling cotton, of $^{15}\!/_{16}$ staple at a terminal market, plus any premium for quality above that base (or less any discount for lower quality), less costs of handling and shipping and the buyer's margin.[13] In general, purchases tend to be on a basis of local round prices rather than reflecting the full spread in the value between individual lots.[29, 30] Bargaining is between the grower and individual buyers. Considerable cotton is stored on the ground around gins, but it is better preserved on a floor and under cover. A typical cotton warehouse is a large one-story open-sided building with the bales set on end in a single layer. Much of the cotton in recent years has not been sold immediately, but is held under loan and sold to the government later.

Diseases

ROOT ROT

Root rot, caused by the fungus *Phymatotrichum omnivorum*, is the most destructive cotton disease in this country. It is confined largely to the calcareous soils of the southwestern states, being especially serious on the heavy black waxy soil areas of Texas. Root rot usually appears in the field in May or June. The foliage of affected plants turns yellow or bronze, followed by wilting and death. The fungus attacks the roots and survives in the soil on dead roots of cotton and other tap-rooted plants or in dormant, sclerotial stages. Diseased areas on the root are bronze to dark brown in color, being separated from the healthy tissue by a reddish-brown border.[40] Diseased plants appear in irregular areas over the field.

The disease organism attacks most dicotyledonous trees, shrubs, and herbs, but does not injure plants of the grass family. Therefore, the root rot disease has been reduced in severity by a 2- or 3-year rotation with grain or grass crops combined with deep tillage after the grain crop is removed. Effective control in Arizona was obtained by liberal quantities of organic manures thrown into deep furrows and covered over in the infested areas during the winter.[33] Eradication of the plants in the diseased spots by drastic tillage treatments reduces the subsequent root rot infection.[44]

FUSARIUM WILT

Fusarium wilt, caused by the fungus *Fusarium vasinfectum,* is serious on light sandy soils from the coastal plain to New Mexico. Infected plants are stunted early in the season, and the leaves turn yellow along the margins and between the veins. The cut stem of a wilted plant shows brown or black vascular tissues inside. The disease can be controlled by the use of resistant varieties [9] and fertilizers with adequate amounts of potash. Coker 100 Wilt, Cokers 4 in 1, Stonewilt, Station 21, Dixie, Dixie-Triumph, Tri-Cook, Express 121, and Rowden 40 are among the varieties resistant to the disease.

VERTICILLIUM WILT

Verticillium wilt is a disease caused by a soil-inhabiting fungus (*Verticillium alboatrum*) that attacks the roots of the cotton plant. It causes wilting, mottling, shedding of the leaves, and vascular discoloration of the roots and stems. Recently it has been demonstrated that breeding for verticillium resistance is practicable. Acala 1517 WR developed at the New Mexico Experiment Station is being released for wilt infected areas in the irrigated southwest.

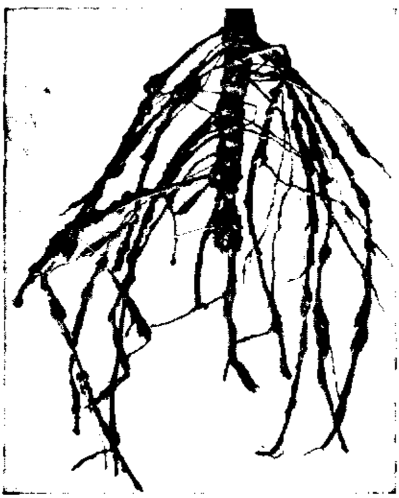


FIG. 258. Root knot of cotton.

OTHER DISEASES

Among other diseases or disease-like disturbances of cotton and their causal organisms are root knot caused by the nematode (*Heterodera marioni*) (Figure 258), anthracnose (*Glomerella gossypii*), angular leaf spot or bacterial blight (*Phytomonas malvacearum*) (Figure 259), rust, and crazy top. Root knot may be reduced by rotating the cotton with

FIG. 259. Angular leaf spot on leaf and boll.

immune crops or by soil disinfection, while bacterial blight may be controlled by use of disease-free seed, by treating seed with organic mercury compounds, or by developing resistant varieties. Rust, or potash deficiency, is reduced by addition of organic matter to the soil, plus use of potash fertilizers, and drainage of wet land. Seed rots and seedling blights are checked by treatment of seed with mercury-containing disinfectants. Crazy top, a physiological disorder occurring on certain calcareous soils, is controlled by regulating the time and amount of irrigation.[27, 31]

Insect Pests

The most serious insect pests are the boll weevil (*Anthonomus grandis*), pink bollworm (*Pectinophora gossypiella*), cotton leaf worm (*Alabama argillaceae*), bollworm (*Heliothis armigera*), cotton fleahopper (*Psallus seriatus*), cotton aphid (*Aphis gossypii*), red spider (*Tetranychus bimaculatus*), garden webworm (*Loxostege similalis*), Lygus bug or tarnished plant bug (*Lygus pratensis*), and cotton stainer (*Dysdercus suturellus*).

FIG. 260. Boll weevil puncturing cotton boll. Much enlarged.

The boll weevil is probably the most destructive but its depredations are confined to sections having an annual rainfall exceeding 25 inches. The adult female weevil punctures the squares or bolls in which it deposits its eggs (Figure 260). This destroys the squares, whereas the larvae developing within the boll destroy the lint in all or some of the locks. The bollworm and the pink bollworm also destroy the contents of the boll. The bollworm, also called the corn earworm, attacks corn, sorghum, and other crops.

The leaf worm and webworm devour the leaves and thus retard boll development. Aphids, red spiders, and flea hoppers, all sucking insects, check the development of the plants, bolls, and lint. Aphids cause curling and shedding of leaves, and they also secrete honey dew which may contaminate the lint of opened bolls. Red spiders, which may have 17 generations in a year, feed on the under side of the leaves, causing them to redden and drop from the plant. The fleahopper feeds on the juices of the terminal buds, small squares, and other young tender plant parts. The injured squares may shed while they are too small to be observed. The leaves become deformed.

The boll weevil, leaf worm, and webworm can be controlled by several applications of 4 to 6 pounds per acre each of calcium arsenate dust.[18] A heavier application, 12 to 15 pounds per acre, is desirable for bollworm control. The bollworm, thrips, tarnished plant bug, and stink bugs can be controlled with 15 to 20 pounds per acre of 5 per cent DDT. The red spider, tarnished plant bug, and flea hopper are controlled by dusting with 10 to 25 pounds per acre of fine sulfur. Two dustings with 20 pounds per acre of sulfur containing 5 per cent DDT controls the bollworm and leafhopper as well as the insects killed by the sulfur alone. Aphids are controlled with 6 to 9 pounds per acre of a mixture of 5 pints of nicotine sulfate and 100 pounds of hydrated lime. Addition of 1 to 2 per cent of nicotine to calcium arsenate or other dusts that are applied for the control of other insects prevents aphids from becoming numerous following the poisoning of natural enemies.

Benzene hexachloride (BHC, 666 or gamma hexane) controls the boll weevil, cotton aphid, cotton leafworm, cotton fleahopper, rapid plant bug, thrips, stink bugs, and loopers. When mixed with DDT the bollworm also is controlled. The addition of sulfur for red spider control to the benzene hexachloride-DDT mixture should control all important cotton pests to a large extent. The usual application is about 11 to 12 pounds per acre of the compound containing at least 5 per cent of the gamma isomer (the effective killing agent). This insecticide is discomforting to man because of its offensive, nauseating musty odor. It has caused some foliage burn, and its ultimate effects on crops and soils are not fully determined. Benzene hexachloride breaks down when mixed with calcium arsenate.

The boll weevil and some of the other insects are checked by destruction of old cotton stalks and weeds in and near the cotton fields which harbor the pests. Plowing cotton stalks under more than 6 inches deep immediately after harvest is recommended as a control measure for the pink bollworm and boll weevil. The pink bollworm overwintering in the cottonseeds can be killed with heat. The spread of pink bollworm is being held in check by severe quarantine regulations.

The cotton stainer, a serious pest in Florida, punctures the bolls and seeds, causing complete destruction or at least staining the lint. Since these insects gather in colonies attacking single plants or only a few at a time, they may be destroyed by jarring them from the plants into a pail of kerosene. They also gather on small piles of cottonseed in the spring where they can be drenched with kerosene or hot water.

Other insects attacking the cotton plant include the cotton leaf perforator (*Bucculatrix thurberiella*), controlled with a 5 per cent DDT–sulfur mixture, and cutworms, grasshoppers and the fall army worm (*Laphygma frugiperda*) which are controlled or checked with poisoned bran mash.

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35 TOBACCO*

"By Hercules! I do hold it and will affirm it, before any prince in Europe, to be the most sovereign and precious weed that ever the earth tendered to the use of man."

"By Gad's me!" rejoins Cob, "I marl what pleasure or felicity they have in taking this roguish tobacco. It is good for nothing but to choke a man and fill him full of smoke and embers."

—Ben Jonson's *Every Man in His Humour*, 1598

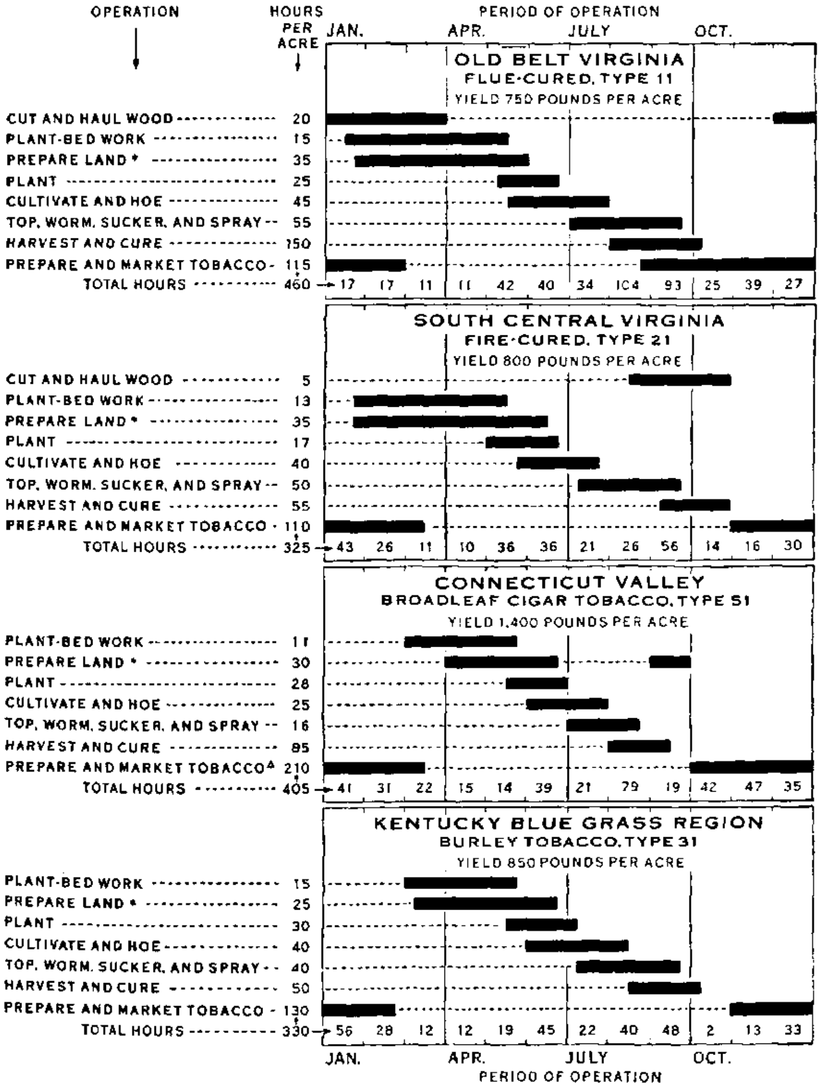
Economic Importance

The farm value of the tobacco crop of the United States ranged from about 270 million to more than a billion dollars annually in the 10 years 1937 to 1946. The average annual acreage was about 1,640,000, on which were produced 1,656,000,000 pounds, or more than 1,000 pounds of tobacco per acre. The leading states in tobacco production are North Carolina, Kentucky, Virginia, Tennessee, South Carolina, Georgia, and Pennsylvania (Figure 162, Chapter 19). In 1944 tobacco was grown on 490,000 farms in the United States, an average of only 3½ acres per farm. The extensive labor involved in tobacco production and handling (300 to 500 man-hours per 1,000 pounds) [6, 29] sharply limits the acreage that a farm family can grow (Figure 261). The leading countries in tobacco production are the United States, China, India, Russia (U.S.S.R.), Brazil, Japan, and Turkey. The United States produces more than one-fourth of the world's tobacco, and exports more than any other five countries combined.

In 1944, factories produced for each of the 139 million men, women, and children in the United States 38 cigars, 2,039 cigarettes, 1 pound of smoking tobacco, ½ pound of chewing tobacco, and

* For a complete discussion of tobacco, see W. W. Garner, *The Production of Tobacco*, The Blakiston Co., Philadelphia, 1946, pp. 1–516.

TOBACCO: ESTIMATED AMOUNT OF LABOR PER ACRE FOR GROWING, HARVESTING, CURING, PREPARING, AND MARKETING, AND APPROXIMATE DATES OF OPERATIONS IN DESIGNATED AREAS



** INCLUDES HAUL AND SPREAD MANURE, HAUL FERTILIZER, AND COVER CROP*
▲ INCLUDES ABOUT 180 HOURS FOR SORTING TOBACCO. ON MANY FARMS THE TOBACCO IS NOT SORTED WHEN SOLD.

FIG. 261. Labor involved in tobacco production.

5 ounces of snuff. Forty-four years earlier the average was 71 cigars, 35 cigarettes, 1 pound of smoking tobacco, 42 ounces of chewing tobacco, and 3 ounces of snuff. This shows why important changes have occurred in the types of tobacco grown, viz., a large increase in bright (flue-cured) tobacco used primarily for cigarettes, with decreases in dark fire-cured and air-cured chewing, smoking and export types, and also in cigar types. The aborigines of America usually smoked pipes but occasionally rolled up leaves for smoking directly. The wives of Connecticut farmers learned to roll cigars. The first cigar factory was started in Connecticut in 1810.

Origin and History

Tobacco (*Nicotiana tobacum*) is a native of the western hemisphere from Mexico southward. The Indians of Yucatan were cultivating it when the Spaniards first arrived there in 1519.[25] It was grown in France in 1556, and in England in 1565, probably 20 years before Sir Walter Raleigh popularized it. Tobacco culture was begun by John Rolfe at Jamestown, Virginia, in 1612, and 15 years later 500,000 pounds were shipped to England.

Tobacco culture began in southern Maryland in 1635 and up to the present day tobacco has continued to be the chief cash crop of that section. Indians in parts of Mexico and in the United States from the Mississippi River eastward, and northward to Canada were growing another species, *Nicotiana rustica.* The name tobacco comes from an Indian word for pipe. Three other species formerly grown by Indians in the United States[25] are *N. attenuata* in the southwest, most of the plains area, and the north Pacific coast; *N. quadrivalvis* in the northwest; and *N. trigonophylla* by the Yuma tribe of the southwest.

Adaptation

Tobacco can be grown under a wide range of climatic and soil conditions but the commercial value of the product depends largely on the environment under which it is produced. In the United States the culture of each important commercial type of tobacco is highly localized owing primarily to the influence of the climate and soil on the quality of the leaf.

Tobacco is grown from central Sweden at 60° north latitude southwest to Australia and New Zealand at 40° south latitude. The optimum temperature for germination of tobacco seed is about 88° F.[33] During the 6 to 10 weeks that tobacco seedlings are in a cold frame or hotbed, the optimum temperature for growth is about 75° to 80° F., the minimum about 50° F., and the maximum 95° F. or higher. A very heavy growth of tobacco is not desired because of its consequent poorer quality. Tobacco in the field grows most rapidly at about 80° F., and at this temperature will mature in about 70 to 80 days. In southern Wisconsin and the Connecticut Valley, tobacco regions, where the mean summer temperature is about 70° F., a frost-free period of about 100 to 120 days from transplanting to maturity is required to mature the crop. In the central tobacco regions the average temperature during the growing season is about 75° F., while in northern Florida it is about 77° F.[24] Flue-cured tobacco thrives best where the daytime temperature is 70° to 90° F.[42]

A low rainfall results in tobacco high in nitrogen, nicotine, ether extract, acids, and calcium, and low in potash and soluble carbohydrates.[17] Most of the tobacco crop in America is grown where the annual precipitation is 40 to 45 inches. An autumn humidity that permits the harvested leaves to cure at the proper rate is important, yet the humidity should be sufficiently high at times during the year to make the leaves pliable enough to be handled without breakage. High winds are damaging to tobacco leaves in the field. For this reason and because of low humidity, low summer rainfall, and alkaline soils high in nitrogen, tobacco is unsuited to semiarid regions.

The tobacco plant demands a well-drained soil. Each type of tobacco has its special soil requirements. Most of the tobacco sections have sandy loam or silt loam soils, but in the Georgia[8] and Florida sections the soils are sandy, and in the Virginia section the soil is a clay, while some of the tobacco in the Miami Valley of Ohio is grown on a clay loam. Fire-cured tobaccos are grown on heavy loam soils not adapted to other types. In some tobacco areas, e.g., Lancaster County, Pa., and the Miami Valley of Ohio, the soils are highly productive loams of limestone origin, whereas in most of the tobacco sections of the coastal plain and piedmont the soils are low in both organic matter and mineral nutrients. Heavy soils and fertile soils tend to produce tobacco high in nitrogen, nicotine, and calcium and low in potash and carbohydrates. Light sandy soils have an opposite effect.[16]

Since the high acre returns from good tobacco justify good heavy fertilization, natural fertility usually is a secondary consideration. The proper relative proportions of calcium, magnesium, and potassium, essential to good burning qualities in tobacco, especially of the cigar types,[44] usually are reached by fertilizer application. A somewhat acid soil (*p*H 5.5 to 6.5) is best for tobacco; a *p*H of 5.0 to 5.6 is optimum in Connecticut.[2] Excessive acidity (below *p*H 4.5 to 5) is often detrimental to quality or yield because it retards absorption of calcium, magnesium, and phosphorus, and leads to excessive absorption of manganese and aluminum. A soil near the neutral point favors development of the black root rot disease. Tobacco is unsuited to soils in which the water table is less than three feet from the surface.

Botanical Description

Tobacco belongs to the family *Solanaceae,* the nightshade family.

Plants of *Nicotiana tobacum*, the common cultivated tobacco, are 4 to 6 feet in height and are terminated by a cluster (raceme) of up to 150 or more funnel-shaped flowers. The terminal flowers are first to open. The petals, of which there are five, are pink, or in some varieties, white or red. The tobacco fruit is a capsule that splits into two or four valves at maturity and may contain 4,000 to 8,000 seeds. A single tobacco plant sometimes produces one million seeds. The seeds are extremely small, about five million per pound. The plants bear 12 to 25 leaves that range up to two feet in length and are covered with sticky hairs (Figures 14 and 27).

The flower of cultivated tobacco is normally self-fertilized although occasional outcrosses occur due to wind-borne or insect-borne pollen.

Of the two species of tobacco cultivated for their leaves, *Nicotiana tobacum,* which is native to Mexico or Central America, is grown in the United States and most other tobacco producing countries. The species native to the United States, *N. rustica,* is grown in India and certain other foreign countries, but in the United States it is grown only sparingly or experimentally for making insecticides because of its high content of nicotine.[13] This latter species has pale yellowish flowers and a short thick corolla tube with rounded lobes. It is characterized further by thick, broadly ovate leaves covered with sticky hairs, and with a distinct naked petiole or leaf stalk. It grows to a height of only 2 to 4 feet.

The leaves of *N. tobacum* are arranged in a spiral on the stalk.[1] A leaf of flue-cured tobacco averages about 21 inches in length, 11 inches in width, and 147 square inches in area, and the lamina (blade between veins) of the leaf is about 0.3 mm. thick. The average weight of a green leaf is about 42 grams and that of a cured leaf about 6 grams or 72 per pound. Cell division ceases when a leaf reaches about one-sixth its normal size, all subsequent growth thereafter being due to cell enlargement and thickening of cell walls, together with increases in dry weight of the cell contents. The shrinkage of a leaf during curing is about 9 per cent in length, 15 per cent in width, and 24 per cent in area.[3, 62]

The upper leaves on the plant tend to be high in nitrogen, nicotine, and acid, and low in ash, calcium, and magnesium. The potash content shows a less definite decreasing trend from top to bottom.[41, 56]

Classification

The official grades for domestic tobacco divide the product into 6 classes and 26 types. These, along with the regions in which they are grown, are shown in Figure 262.

Type 46, class 4, cigar filler, is produced in Puerto Rico and three other miscellaneous types not shown in Figure 262 are grown in the United States, viz., Perique in Louisiana, Eastern Ohio Export in Ohio, and Turkish grown in the southeast, and in California during World War II. Perique, a pungent aromatic type, is used in blends of smoking tobacco.

Flue-cured tobaccos constitute about 60 per cent of the domestic crop, fire-cured 5 to 8 per cent, air-cured 25 to 30 per cent and cigar types (which also are air-cured) about 5 to 10 per cent of the American crop.

Flue-cured tobacco is used chiefly for cigarettes, pipe, and chewing tobaccos, and for export.[20] Fire-cured tobaccos are used chiefly for export, snuff, and plug wrappers. Dark air-cured types are used for chewing plug and export. Maryland (type 32), air-cured, is used for cigarettes and export. Burley (type 31), air-cured, is used for cigarettes, pipe, and chewing tobaccos. The usual cigarette blend

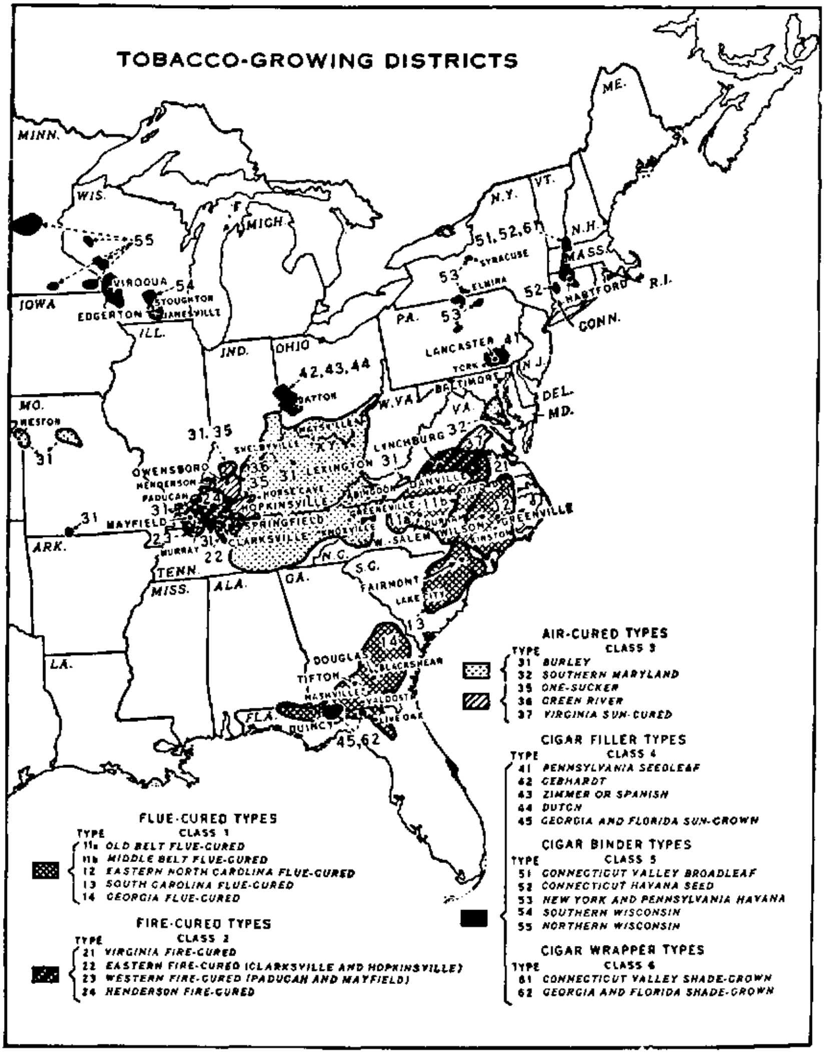


FIG. 262. Types of tobacco and the districts in which they are grown.

is about 53 per cent flue-cured tobacco, 33 per cent burley, 10 per cent Turkish, and 4 per cent Maryland.

Varieties

The leading varieties of flue-cured tobacco[22, 25] include White Stem Orinoco, Cash, Jamaica, Virginia Bright, Bonanza, and Yellow Pryor, all of which are strains of the original Orinoco variety. The Lizard Tail Orinoco, Big Orinoco, and Narrowleaf Orinoco are grown in the fire-cured and dark air-cured districts of Virginia. Other strains of Orinoco, viz., Yellow Pryor, Blue Pryor, Madole, and Yellow Mammoth are grown in the dark air-cured and fire-cured districts of Kentucky and Tennessee. The One Sucker variety, having a long, narrow, heavy leaf, is a leading dark air-cured type. The Burley type is represented by the White Burley variety which produces a very light-colored cured leaf. The Southern Maryland type is represented by the Maryland variety together with its Broadleaf and Medium Broadleaf strains. The chief cigar tobaccos are district strains of Broadleaf (or Seedleaf) called Connecticut, Pennsylvania, Ohio, and Wisconsin Broadleaf. The Havana Seed type is represented by the varieties Connecticut Havana, Zimmer Spanish, and Comstock Spanish. A narrow-leaved variety called Little Dutch is grown for cigar filler in the Miami Valley of Ohio. Strains of the Cuban variety are grown under shade in the Connecticut Valley and on both sides of the Georgia-Florida border for cigar wrappers.

Each district grows local strains of the above or other varieties. The uses of a particular strain are not wholly restricted. For example, Connecticut Havana may be used for cigar wrapper as well as binder, and occasionally for filler leaf.

Rotations

The chief considerations in determining a crop rotation system for tobacco growing are the effects of the previous crop on the quality and yield of tobacco and on the incidence of tobacco diseases.[35] Most adapted crops succeed as well or better following tobacco than following other intertilled crops such as corn, so the conditions favoring the high-priced tobacco crop obviously should govern the rotation. Since Colonial times it has been recognized that the best tobacco crops often are obtained on cleared forest land or on idle land that has gone back to weeds, grass, and brush. In southern Maryland tobacco following a natural 2-year weed fallow gives better returns than following either bare fallow or legume crops in rotations.[7] The best quality and yields are obtained following ragweed and horseweed.[7, 40] Lambsquarters has an adverse effect. In southern Maryland experiments, tobacco yielded well following red clover in a tobacco-wheat-red clover three-year rotation and also when continuously cropped, with hairy vetch as a winter cover crop, but the quality was poorer than that following ragweed and horseweed. When tobacco follows legumes, an appreciable increase in quality is obtained when nitrogen fertilization is reduced or heavy applications of potash are made to balance the deleterious effect of the excess of nitrogen. The weed-tobacco rotation is suited to low-priced lands that are not particularly productive for other crops.

Tobacco following corn, cotton, and small grain is of excellent leaf quality.[11] Following the legumes, cowpeas, crotalaria, lespedeza, peanuts, soybeans, and velvetbean, the tobacco ranges from poor to good, being better following lespedeza on poor sandy land than on richer soil. Based upon experiments in North Carolina, South Carolina, and Georgia, a 5-year rotation of cotton, corn, oats, crotalaria, and tobacco was recommended as a means of reducing damage from the diseases black shank, bacterial wilt, and root rot. Potatoes, tomatoes, peppers, or other crops of the botanical family *Solanaceae* increase the injury to tobacco from diseases when grown on the same land.

In Pennsylvania, cigar binder tobacco is grown mostly by continuous cropping, whereas the cigar filler type follows a legume in 3-year or 4-year rotations including wheat or wheat and corn. A 5-year rotation of tobacco, wheat, grass (two years), and corn also is practiced. In Kentucky, Ohio, and Virginia, tobacco usually follows a legume or grass.[4, 42, 52] In Connecticut much of the tobacco is grown in alternation with fall-sown grain, usually rye, as a cover crop, or following a grass meadow crop, because tobacco following a legume has a dark leaf.[2]

Fertilizers

A 1,000-pound crop of flue-cured tobacco leaves contains about 16 pounds of nitrogen, 4 pounds of phosphoric acid, 20 pounds of potash, 25 pounds of calcium, 31 pounds of magnesia, and 6 pounds of sulfur. A liberal amount of potash in tobacco leaves is essential to good burning quality. Nitrogen is necessary for good growth of tobacco, but abundant nitrogen results in a low-quality leaf.[26] Magnesium is essential to prevention of *sand drown*, a nutritional disorder caused by a deficiency of that element. Magnesium and calcium can be supplied in dolomitic limestone.[44] A 1,000-pound crop of tobacco leaf requires 12 to 18 pounds of water-soluble magnesium per acre, and fully five times as much available calcium in the soil.

Tobacco should be fertilized at heavier rates than those followed by many growers.[22] The most commonly used fertilizer mixture formulas for tobacco in 1938 (Table 1, Chapter 6, page 146) were 3–8–5 in Florida, Georgia, North Carolina, and South Carolina, 2–12–6 in Indiana, 4–8–12 in Maryland, 4–10–6 in Ohio, 4–8–7 in Pennsylvania, and 3–10–6 in Virginia. The quantities usually applied were 1,000 pounds per acre in Florida, Georgia, North Carolina, and Virginia; 800 pounds in Maryland; 750 pounds in Pennsylvania; 400 pounds in Ohio; and 200 pounds in Indiana. Recently the average application in South Carolina has been about 1,000 to 1,200 pounds.

For cigar binder and wrapper tobacco in the Connecticut Valley 10 to 20 tons per acre of manure may be plowed under in the fall every 2 or 3 years. Fertilizers recommended are 2,000 to 2,500 pounds of an 8–4–8 mixture containing 2 to 4 per cent magnesia. A mixture of cottonseed meal, castor pomace, and fish meal is the best source of nitrogen, although urea and potassium nitrate may supply as much as one-third of the nitrogen. For Connecticut, 200 pounds of nitrogen and 200 pounds of potash per acre with two-thirds of the nitrogen contained in natural organic carriers also have been recommended.[2] About 100 pounds per acre of P_2O_5 are recommended for new tobacco land. No phosphorus is needed on most old tobacco land in Connecticut because of the accumulation from previous applications.

In the Lancaster, Pennsylvania, cigar filler district 10 tons of manure and 500 to 1,000 pounds per acre of a 4–6–10 mixture are recommended. About 500 pounds of cottonseed meal, 300 pounds of superphosphate, and 100 to 200 pounds of potassium sulfate meet the above specifications for the fertilizer mixture. In the Miami Valley of Ohio 1,000 pounds per acre of a 4–9–8 mixture has been recommended, although often only a light application is used with or without manure.[4]

For flue-cured tobacco, 700 to 1,000 pounds per acre of fertilizer containing 3 per cent nitrogen, 10 per cent phosphoric acid, 6 to 12 per cent potash, 2 to 3 per cent chlorine, 2 per cent magnesia, and 6 per cent calcium oxide are recommended.[22, 27, 49] Only a part of the potash should be supplied as muriate (potassium chloride) because added chlorine in excess of 20 to 25 pounds per acre causes poor fireholding capacity and slow burning in the tobacco.[36] Some chlorine is necessary to prevent dessication or "dry spot" of the growing leaves.

In southern Maryland 600 to 1,000 pounds per acre of 4–8–12 fertilizer are commonly applied. The recommendation for Virginia dark tobacco is 600 to 1,000 pounds per acre of 3–10–4 or 3–10–6. In the Kentucky-Tennessee dark tobacco districts and the less productive soils of the Burley districts, 250 to 500 pounds per acre of 4–9–4 or 3–8–6 fertilizer or similar mixtures usually are applied.[52] On the good soils in the inner bluegrass region very little fertilizer is needed for Burley tobacco if proper cropping systems are followed.

In the Florida-Georgia cigar wrapper district 10 to 15 tons of manure are recommended in addition to commercial fertilizers listed above to supply 225 pounds of nitrogen, 215 pounds of phosphoric acid, and 240 pounds of potash. Very little fertilizer other than barnyard manure is used in southern Wisconsin.[58]

Seeding

Tobacco seed is planted in beds or coldframes.[22] Wooded areas, which often are cleared for seedbeds in the south, should be burned over, spaded, or plowed, and then fertilized with 1 to 2 pounds of a 4–8–4 mixture per square yard. If the bed has been used previously, it should be manured in the fall, and in the following spring should receive a 5-4-5 mixed fertilizer applied at the rate of 1 pound per square yard. Sterilization of the beds for 30 to 40 minutes, with steam from a boiler kept at 80 to 125 pounds pressure, to destroy fungi and weed seeds is desirable. After working the bed to a fine tilth, about one ounce (two tablespoons) or a somewhat smaller quantity of seed is scattered over each 200 square yards. The seeds are so small that a special seeder is required, or the seed is mixed with water, sifted ashes, or bonemeal to facilitate uniform distribution. A bed of 900 square feet in area should produce, from the 300,000 seeds sown, ample plants for 5 to 10 acres of tobacco. A spacing of about 2 to 4 plants per square inch of bed space is anticipated. The seeds are pressed into the soil with a roller or plank, and then the coldframe is covered with cloth or glass or both. Glass is used only in the northern tobacco regions. Sometimes the surface of the bed is covered with a cloth to protect the seeds until they sprout.

The beds must be kept moist. Sometimes when growth is slow the beds are fertilized at intervals with about a pound of nitrate of soda for a bed of 20 square yards, applied in solution or scattered dry, and watered immediately afterward.

Transplanting and Cultivating

Land for tobacco usually is plowed in the spring or fall, at which time the cover crop or weed growth is turned under. The land is worked down into a good tilth before transplanting the tobacco. Where rainfall is heavy the land may be thrown up into beds. Tobacco is transplanted 6 to 10 weeks after sowing the beds, when the plants have 4 to 6 leaves and are 5 or 6 inches in height. Transplanting is done in June in the northern districts, in May in the central districts and the mountainous sections of the south, in April in North Carolina and South Carolina, and from March 20 to April 15 in Florida and south Georgia. The transplanting is done by machine (Figure 263) or by hand. Distances between rows vary with local customs in each district from 32 to 54 inches, and the spacing within the row from 10 to 42 inches.[22] The space per plant in the field varies from 4 to 6 square feet in the northern tobacco districts

FIG. 263. Transplanting tobacco.

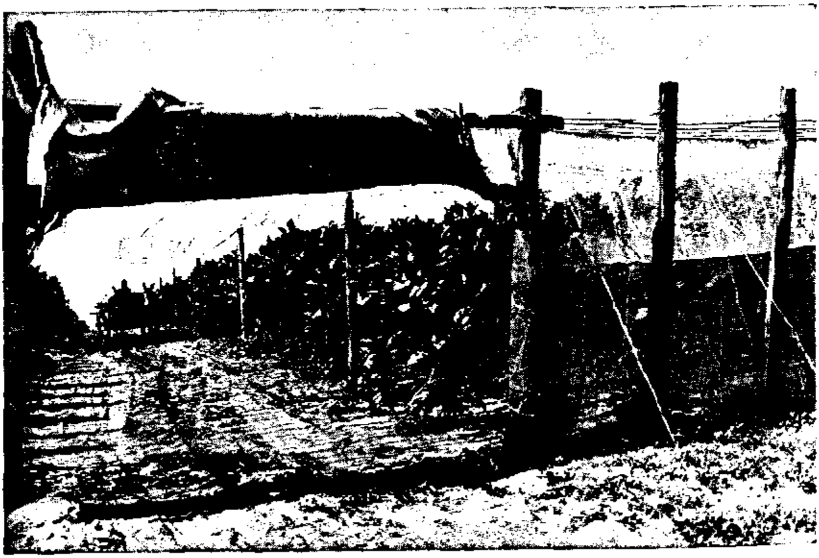


FIG. 264. Shade tobacco in Florida. Three primings of the lower leaves have been harvested.

to 8 to 12 square feet in the southern districts where the season is long and soils tend to be less fertile. Shade-grown tobacco is planted somewhat thicker, i.e., 3 to 4 square feet per plant, in order to keep shading costs per plant at a minimum.

The wide rows in the south permit use of beds and water furrows.

Tobacco is cultivated at frequent intervals, beginning a week to 10 days after transplanting. It usually is hoed soon after the first cultivation and sometimes again later in the season. The high acre value of the crop justifies intensive cultivation.

Growing cigar wrapper tobacco under artificial shade (Figure 264) costs about 800 dollars per acre. The object of shading is to produce smaller, thinner, smoother leaves with smaller veins more suitable for fine cigar wrappers.[2] The effect of the shading is to increase the humidity and reduce the air currents, thereby retarding evaporation from the plant and the soil.[28] The shading material, a loosely woven cloth (8 to 10 threads to the inch), is spread over and sewed to wires that are supported by stout posts extending eight feet above the ground. In the Connecticut Valley the posts are placed 33 feet apart. Most of the cloth is used only one year. Formerly, lath shades were used to considerable extent in Florida.

Tobacco plants seem to grow very slowly at first because the seeds and consequently the seedlings are extremely small. At transplanting, the dry weight of the seedling is less than 0.05 per cent of the final dry weight of the plant.[60] Even 26 days after transplanting, less than 2 per cent of the total growth has been produced. Growth proceeds rapidly after that stage.

Topping

Topping consists in breaking off the top or crown of the plant at about the third branch below the flower head. Tobacco plants are topped to keep them from producing seed, and thus force the synthesized carbohydrate and nitrogen materials to remain in the leaves for further growth and enrichment. The top leaves that are removed are highest in nicotine content.[41] Topping results in larger, thicker, and darker leaves that mature earlier and more uniformly than on untopped plants (Figure 265).

Topping causes a higher content of nicotine and sugars and a

FIG. 265. Flue-cured tobacco that has been topped.

lower ash content. Topping begins in cigar tobaccos when about one-half the plants show flower heads, in shade-grown wrapper and cigar-filler tobaccos before the blossoms open, in flue-cured tobaccos when the plants have 10 to 15 leaves. In the fire-cured type, the 3 or 4 bottom leaves on the plants often are removed also, leaving only 8 to 12 leaves. In flue-cured tobacco, 10 to 14 leaves remain after topping in the piedmont section, and in the coastal plain 12 to 18 leaves are left. From 14 to 18 leaves remain on Burley tobacco, 16 to 20 on Maryland tobacco and nearly all on shade-grown tobacco. A field must be gone over two or three times in order to top all plants at about the same stage of growth. After topping, it is necessary to remove the suckers at intervals of every week or 10 days. Suckers are branches that develop in the leaf axils after the tops are removed.

Harvesting

The leaves of tobacco are ripe and ready to harvest when they assume a lighter shade of green and have thickened so that when a section of the leaf is folded it creases or cracks on the line of folding. This stage is reached in the bottom leaves when the seed heads form and in the middle leaves about 2 or 3 weeks later. Flue-cured and fire-cured types are harvested when fully ripe with the leaves showing light yellow patches or flecks. Stalk cutting is done when the middle leaves are ripe.

Two general methods of harvesting are practiced, viz., *priming* and stalk cutting. Nearly all flue-cured tobacco, all of the shade-grown cigar wrapper and Georgia-Florida sun-grown cigar binder and some of the Havana Seed cigar binder tobacco is primed. The other types are stalk cut. Priming is the picking of the leaves when they are in prime condition, beginning with the lower three or four leaves of commercial size, followed by four or five successive pickings of two to four leaves each at intervals of about 5 to 10 days. The successive harvesting of the lower leaves causes gains in weight of the remaining upper leaves, which, together with the avoidance of translocation from the leaf to the stalk during curing, results in a total of 20 to 25 per cent greater weight of primed leaves as compared with leaves on cut stalks. The leaves are placed in baskets or sled-mounted bins and conveyed to the curing barn, where they are strung on sticks about 4½ feet long. A string is attached to one end of the stick and the leaves are then strung either by pushing a needle through the base of the leaf midrib or by looping the string around the base of two to five leaves. When the string is full, it is tied to the other end of the stick (Figure 266). A stick holds 60 to 80 or more leaves.

In stalk cutting, the stalks are cut off near the base with a hatchet, knife, saw, or special shears. The stalks lie on the ground until the leaves are wilted. The stalk is then hung upon a lath by piercing the stalk near the base with a removable metal spearhead placed on the end of the lath and sliding the stalks along the lath (Figure 267). A lath holds 6 to 8 stalks. Sometimes the stalks are hung on the lath with hooks or nails. Fire-cured and Burley stalks are split down toward the base, and after cutting are placed astride the laths. Splitting of cut stalks hastens the drying of the stalks and stops translocation early. The laths, bearing about six plants, are placed upon a rack and hauled to the curing barn.

FIG. 266. Tobacco leaves strung and hung on sticks.

FIG. 267. Spearing tobacco stalks and hanging them on the stick.

Curing

Curing involves the processes of drying, decomposition of chlorophyll until the green color disappears from the leaf, changes in the nitrogen compounds including release of ammonia, hydrolysis of starch into sugars, and respiration or fermentation of the sugars.[14 15, 21] Mineral salts also crystallize out producing the grain of the leaf. Practically all the sugars are used up in air-curing tobacco, but considerable quantities remain in the leaves of fire-cured and flue-cured types. Losses of nicotine during curing range from 10 to 33 per cent. Too rapid drying, like bruising the leaf, kills the tissue prematurely and prevents complete decomposition of chlorophyll, resulting in an undesirable green color. It also stops some of the other desirable chemical reactions. During curing there is a decrease in total weight of 84 to 88 per cent,[50] which includes a loss of dry matter of 12 to 20 per cent in primed leaves and an additional 10 to 12 per cent of material translocated to the stalks when the leaves are not primed. Harvested tobacco contains about 75 to 80 per cent moisture. After the leaf is cured, it is allowed to regain moisture ("order" or "case") until the leaves containing about 24 to 32 per cent moisture are pliable enough to handle without breaking. Thus, the final net loss in total weight of the leaf during curing is about 75 per cent, i.e., two tons of fresh leaves will yield 1,000 pounds of cured and cased product. Eight tons of cut stalks will yield about 1,800 pounds of cured leaf.

TOBACCO BARNS

Barns for curing tobacco usually are high enough (16 to 20 feet to the plate) to hold 3 to 5 tiers of suspended leaves or stalks. They are built in bents with poles spaced at the proper distance for hanging the sticks or laths over them. For primed tobacco on sticks 4½ feet long, the poles are spaced 50 inches apart on horizontal centers and 22 to 30 inches apart vertically. For stalk curing on 4-foot laths the pole centers are 46 inches apart horizontally and 2½ to 5 feet apart vertically. Since the tobacco should hang at least 3 feet above the ground, the lower tier of poles is 6 to 9 feet high. A space of 1½ to 2½ cubic feet per plant is required for curing tobacco. A barn 17 feet high, 32 to 36 feet wide and 140 to 160 feet long may hold the crop from about 5 acres.

AIR-CURING

Tobacco is air-cured in tight barns equipped with numerous ventilating doors on the walls that can be opened or closed to regulate the humidity and temperature. The relative humidity at the beginning should be about 85 per cent, but after the leaves begin to turn brown a lower humidity that permits rapid drying is advisable.[30] If the humidity exceeds 90 per cent for 24 to 48 hours, when the temperature is above 60° F., injured, partly-cured, and even fully-cured leaves begin to soften and decay, a condition called pole sweat or house burn. This damage is prevented by use of artificial heat to lower the relative humidity and promote drying. This may be provided by several small fires built on the earth floor inside the barn, using charcoal, which does not impart undesirable odors to the tobacco leaf. Artificial heat is required also when the temperature drops below 50° F. in order that the curing processes other than drying may continue. Air-curing may require from 4 to 8 weeks.[19]

FLUE-CURING

The objective in flue-curing is to hasten the early curing stages and then complete the drying while the leaves are still of a light yellow color. Flue-cured or bright tobacco is riper and of a lighter green than other types when curing begins. The typical temperature and humidity requirements for the yellowing, drying, killing, and ordering stages of flue-curing are illustrated in Figure 268. The yellow color of the leaf is fixed during the later period of the yellowing stage. The temperature is allowed to rise to 110° F. in about 40 hours, with the relative humidity ranging from 65 to 85 per cent in the yellowing stage. Drying is accomplished in about 30 hours while the temperature rises to about 135° F. and the humidity drops to 25 per cent. Then the leaves are killed in 25 hours by temperatures up to 165° F. and a relative humidity of less than 10 per cent. The heating is stopped after 4 or 5 days and the tobacco allowed to take up moisture. If drying is too rapid, the humidity in the barn can be increased by wetting the floor and walls, and if the

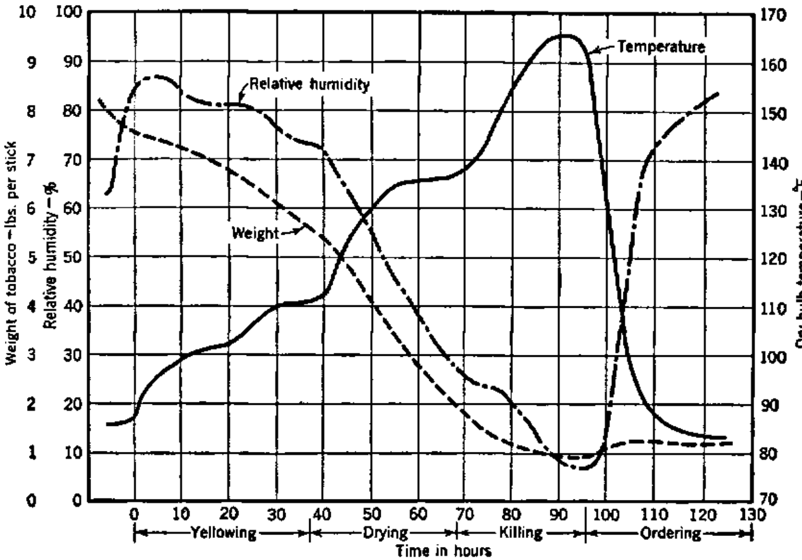


FIG. 268. Requirements for flue-cured tobacco during curing. (After Moss and Teeter, N. Car. Expt. Station.)

humidity is too high the roof ventilators are opened. Improper curing may result in discolorations of the leaf such as black splotching, green veins, green leaf, dark sponging, scalding, and black stem.

For flue-curing, a 10-inch or 12-inch sheet-iron pipe connected with the top of each furnace usually is extended to the far side of the barn, along it for a short distance, and then turned back and out through the wall on the furnace side. The outlet pipe turns up and ends in a hooded stack. Ventilation is provided for incoming air by openings near the bottom of the barn, and for the departing moist air by ventilating doors in the roof. A suggested improvement[50] is a heating jacket in which cold incoming air passes over the hot flues just inside the barn. The furnaces are fired with wood, coal stokers, or oil burners.

FIRE-CURING

The usual system of fire-curing is to allow the tobacco to yellow and wilt in the barn without fires for 3 to 5 days, then start slow fires to maintain the temperature at 90° to 95° F. until yellowing is completed, and finally raising the temperature to 125° to 130° F. until the leaves are dry. The fires are kept up for 3 to 5 days or more. The smoke from the open hardwood fires in the barn imparts the characteristic odor and taste to the tobacco.

Handling and Marketing

After the tobacco on the stalk is cured and has been cased or ordered enough to be pliable, it is ready to be stripped from the stalks by hand. In that condition, the leaf contains 24 to 32 per cent moisture. Often the tobacco is bulked without being removed from the sticks when it is first taken down after curing. The bulking prevents further drying and helps decompose any remaining chlorophyll. Both stripped and primed leaves are sorted into grades and tied into hands of 15 to 30 leaves, using a leaf as a binder. A pound of cured wrapper tobacco contains about 60 to 90 leaves.[31]

The hands of cigar types are packed in cases, or in bundles (bales) covered with paper and weighing 30 to 60 pounds. Other types are handled as loose leaf tobacco delivered on the sticks or in baskets or bundles wrapped temporarily in burlap or other cloth. The packing of tobacco on farms in hogsheads by pressure called prizing is now largely discontinued. Such hogsheads contain 500 to 800 pounds of tobacco leaf and are mostly sold by brokers on a sample basis. Fully 90 per cent of the tobacco is sold by auction in a manner familiar to all radio listeners[20] (Figure 269). An auctioneer may sell tobacco at the rate of several hundred individual baskets per hour but must alternate with another auctioneer from time to time to save his voice. Cigar tobacco is often sold at the farm soon after curing. The marketing season[20] is August to February for flue-cured types and November to April for fire-cured and air-cured types. However, Maryland tobacco is sold from May to August in the year following its production.

The tobacco as marketed is moist enough to be pliable and thus avoid severe losses from breakage, but usually is too moist for storage or export.[14] It is redried on racks, in heated chambers or containers, or recently by a high-frequency current diathermic process. The latter process has been used for drying and heat fumigation of tobacco in hogsheads destined for export. Before redrying,

FIG. 269. A tobacco auction: The leaves are tied into "hands." The auctioneer has folded his arms to indicate that a transaction has been completed.

it sometimes is sweated or fermented in bulk piles to complete processes begun during curing. Export tobacco contains about 11 per cent moisture. Fermentation consists of allowing a pile or box of slightly moist tobacco to heat at temperatures of 85° to 120° F., depending upon the type of tobacco and method of bulking. Fermentation causes losses of 5 to 12 per cent in dry matter. Decreases in starch, sugar, nicotine, amino nitrogen, and citric and malic acids occur during fermentation.

Fermented tobacco is aged for 1 to 3 years before being used in manufacture. In aging, tobacco undergoes a decrease in nitrogen, nicotine, sugars, total acids, and *p*H, and in irritating and pungent properties. The aroma is improved by aging.[18]

The leaves with the midrib (stem) removed are known as strips. Stemming may be done just before the leaf is used in manufacturing or perhaps 2 years earlier when it is shipped and stored. The stem comprises about one-fourth the weight of the leaf, but varies from 17 to 30 per cent. Tobacco used for snuff is not stemmed. Stems, along with tobacco waste, are used in manufacturing nicotine sulfate for insecticides, although the stems contain only about 0.7 per cent of nicotine as compared with the leaf, which usually contains 1 to 5 per cent. Some of the stems, which contain about 6 per cent potash, are used as fertilizer or for mulching. *Nicotiana rustica* leaves are very high (5 to 10 per cent) in nicotine content [12] and when grown are used for insecticide materials.[47] Some waste tobacco is extracted.

The shrinkage of tobacco as purchased from the grower ranges from 30 to 40 per cent, as a result of stemming, drying, sweating, and handling. A pound of tobacco, including the above-mentioned waste, will make about 40 cigars, 350 cigarettes, or 1.06 pounds of snuff. Tobacco stems, licorice, sugar, and other materials are added to unstemmed tobacco for making snuff. Chewing plug consists of about 60 per cent tobacco and the remainder of sweetening and flavoring materials. Considerable quantities (25 to 40 million pounds) of cigar filler tobacco are imported from the West Indies and somewhat larger quantities of the aromatic Turkish tobacco for cigarette blends are received from Turkey, Greece, and nearby countries.

Tobacco Quality

Tobacco varies widely in quality, depending upon the conditions of growing, curing, sorting, and handling.[61] During a typical auction observed prices for different lots of the same market type of leaf ranged from 4 cents to 36 cents per pound. The production of a good quality leaf is essential to success, since low-grade tobacco brings less than its cost of production. Color, texture, and aroma are important characteristics. Dark fire-cured tobacco is expected to be strong, dark, and gummy. Flue-cured cigarette tobaccos are usually a light lemon-yellow color, and air-cured cigarette tobaccos are light brown. Cigar wrapper leaf should be thin, uniform, and free from blemishes. The color of the wrapper, whether dark or light, is not a true measure of the mildness of a cigar, as is popularly assumed. A heavy sweating process that darkens the leaf also reduces the nicotine content. Furthermore, the color of the thin wrapper leaf does not reveal the color or mildness of the binder and filler which make up the greater part of a cigar. The highest prices are paid for shade-grown wrapper, followed by flue-cured and light air-cured types.

The composition of flue-cured and burley tobacco is shown below:

TYPICAL COMPOSITION OF TOBACCOS (PER CENT EXCEPT FOR *p*H)

	FLUE CURED	BURLEY
Total nitrogen	2.0	3.4
Nicotine	2.3	3.0
Petroleum-ether extract	5.0	5.5
Total sugars	18.75	0.5
Acids	14.0	27.0
*p*H	5.1	6.0
Ash	12.0	19.0
Potash (K_2O)	3.25	
Calcium oxide (CaO)	3.25	
Magnesia (MgO)	7.0	
Chlorine	0.70	
Sulfur	0.60	

Dark air-cured and fire-cured tobaccos contain 4 to 4.5 per cent nicotine.[47]

A high-quality tobacco usually is high in soluble carbohydrates and potash, and relatively low in crude fiber, nicotine, nitrogen, calcium, ash, and acids. An extremely low content (1 to 1.3 per cent) of nitrogen is not desired. A *p*H not lower than 5.3 is preferred.

Tobacco smoke contains carbon, carbon dioxide, carbon monoxide, oxygen, hydrogen sulfide, hydrocyanic acid, ammonia, nicotine, pyridine, methyl alcohol, resins, phenols, ethereal oils, organic acids, and other compounds.[23] The popular brands of cigarettes contain about 1.75 per cent nicotine. Cigars of all classes contain about 1.5 per cent nicotine. The nicotine contents of granulated pipe mixtures, scrap chewing tobacco, and chewing plug are about 2 per cent, 1 per cent, and 2 per cent, respectively.

A low nicotine content is desired in tobaccos grown for domestic use despite the fact that nicotine is the characteristic active stimulative principle. Nicotine content varies greatly with climate, season, soil, maturity, and general cultural practices.[57] Nicotine is an alkaloid, an oily liquid, soluble in water, and having considerable volatility at ordinary temperatures. The chemical formula is $C_{10}H_{14}N_2$. When oxidized, it yields nicotinic acid, the amide of which is the familiar vitamin called niacin. It boils at 250° C., and is extremely poisonous. Cultivated tobacco contains traces of several other alkaloids. While the amount of nicotine varies in different parts of the plant, every part has some. The nicotine content is higher in the leaf lamina (blade) than in the veins, and is higher in the veins than in the midribs or stalks.[5] The alkaloid increases as the plant grows, with the result that the greatest amount is probably present when the plant has reached fair maturity. It is believed to decrease after this time.

Diseases

The important tobacco diseases are black root rot, blackfire, wildfire, mosaic, blue mold, and frenching.[22, 32, 59]

BLACK ROOT ROT

Root rot, caused by *Thielaviopsis basicola,* is a fungus disease that produces black lesions and eventual decay of the roots. Diseased plants are small and stunted. The roots are small and begin decay at the tips. Frequently the plants become yellowish. The plants usually outgrow the disease in the field when the temperatures exceed 80° F. The fungus lives over in the soil. The most effective control measures are crop rotation, seedbed disinfection, and resistant varieties. Some strains of White Burley are resistant to root rot, e.g., Strains No. 5, 7, and 16, and Johnson Resistant Stand-up Burley. Flue-cured type "400" and Yellow Special are resistant.

MOSAIC

The mosaic disease (also called calico or walloon) is the most destructive virus disease of tobacco, and is present wherever tobacco is grown.[59] Plants infected with mosaic at transplanting time may be reduced 30 to 35 per cent in yield and 50 to 60 per cent in value.[43] The disease is characterized by a mosaic pattern of light and dark green or yellow areas. The different strains of the virus give various symptoms. Some strains cause mild mottling and no distortion of the leaves, while others cause prominent mottling, or distortion of new leaves. The virus causing the common mosaic of tobacco is a crystalline nucleoprotein of high (40,000,000) molecular weight. The crystals are rod shaped and about 270 millimicrons in length and 15 millimicrons thick. They are too small to be seen in the most powerful compound microscope, but their images shown in an electron microscope have been photographed. These virus crystals possess many characteristics of living organisms such as reproduction and mutation. The leaves and leaf juices of mosaic plants are very infectious, and the virus is spread to other plants by direct or indirect contact.

The tobacco mosaic virus remains infectious for long periods,[34] as long as 30 years, in dead plant material. It will overwinter in dry, compact, or water-logged soils. Perennial wild hosts and aphids feeding on these as well as the tobacco plants are important factors in the dissemination of the disease. The disease also is spread by workers who use tobacco.

The disease can be partly controlled by: (1) sterilizing the tobacco bed and tobacco cloths, (2) destroying nearby solanaceous weeds, (3) removing diseased seedlings from the plant bed, (4) destruction of all tobacco refuse around the bed, (5) washing the hands with strong soap after handling diseased plants, and (6) complete abstinence from use of natural leaf tobacco products during cultural operations.[39]

WILD FIRE OR BACTERIAL LEAF SPOT

This disease, caused by *Pseudomonas tabaci*, spreads rapidly through the field. The symptoms are lemon-yellow spots on the leaves, small dead spots developing in the center of the yellow spot. Use of 2-year-old seed that appears to be free of infection, or treatment of seed by soaking it 15 minutes in a 1:1000 solution of bichloride of mercury will reduce the disease. Other measures are location of the plant bed away from all tobacco trash, sterilization of the seedbeds and cloths, and drenching the plant beds with Bordeaux mixture, or dusting with copper lime when the plants are small. Injury is increased by abundant nitrogen and decreased by abundant potash.

BLACKFIRE OR ANGULAR LEAF SPOT

This is a destructive leaf-spot bacterial disease in Virginia and Kentucky, caused by *Pseudomonas angulata*. Control measures are similar to those recommended for the wild fire disease.

BACTERIAL WILT

Bacterial wilt or Granville wilt occurs in Granville County, North Carolina, and other flue-cured tobacco areas, causing losses of some 2 million dollars annually. The organism *Pseudomonas solanacearum* enters the roots and then multiplies and clogs the water-conducting vessels, causing the plants to wilt. Control methods [54] are rotations involving immune crops such as corn, cotton, sweetpotatoes, grass, clover, and small grains, in which tobacco is grown not oftener than once in 4 or 5 years. Since the wilt organism attacks other plants (tomato, pepper, peanuts, and various weeds), these must be excluded from the tobacco land. Fair control has been obtained by applying 1,000 pounds of urea per acre and growing a crop of corn before planting the tobacco the following year. Certain strains of tobacco, such as Oxford 26, T.I. 448A, and 79X, are resistant to Granville wilt.[12, 55]

BLUE MOLD

The blue mold (downy mildew) disease is caused by the fungus *Peronospora tabacina*, which attacks and destroys the leaves in the seedbed and often kills large numbers of plants. It occurs in mild form from Florida to Maryland every year and serious damage occurs sporadically, depending upon weather conditions. The best remedy is spraying or dusting with fermate to prevent the disease from starting. The spray is made with ½ to 1½ pounds of fermate in 50 gallons of water. Planting large beds will compensate for possible losses. Fumigation twice a week with paradichlorobenzene, and copper oxide-cottonseed oil spray are used after the disease starts. In the former treatment, tobacco cloth is stretched across the bed 12 to 18 inches above the soil surface, 1½ pounds of paradichlorobenzene are scattered on the cloth, and a heavy water-soaked cloth is spread over the bed and left over night to retain the gas vapors. For spraying, a mixture of one-half pound of red copper oxide, one quart of Lethane spreader, one-half gallon of cottonseed oil, and water to make 50 gallons is recommended.[10] Observations of weather conditions and of the development of the disease permit the issuance of official warnings of probable blue mold spread.

ROOT DISEASES

At least six root diseases,[11] including Granville wilt already described, damage the tobacco plant. Southern stem rot, caused by *Sclerotium rolfsii*, and sore shin, caused by *Rhizoctonia solani*, can be held in check by sterilization of the seedbed and transplanting healthy seedlings. Fusarium wilt, caused by *Fusarium oxysporum* var. *nicotianae*, can be avoided largely by using land that has not been planted previously to tobacco or sweetpotatoes. Black shank, caused by *Phytophthora parasitica* var. *nicotianae*, can be controlled by use of resistant varieties, Oxford 2 and Oxford 3, and by crop rotations[35] that do not include tomatoes, peppers, or other solanaceous plants. Root knot is caused by a nematode or eel worm (*Heterodera marioni*) that produces galls on the roots. This is controlled by planting tobacco on land that has grown resistant crops such as cotton, peanuts, oats, or crotalaria for 2 years or more. T. I. 706 is resistant.

OTHER DISEASES

Other diseases include two leaf spots, frog eye or Wisconsin leaf spot caused by the fungus *Cercospora nicotianae*, and brown root rot. Broom rape, a parasitic flowering plant, lives upon the tobacco plant in much the same manner as dodder lives on clover. Nematode root rot is caused by the *Pratylenchus* nematode or eelworm. Rotation with weed fallow checks the disease. The T. I. 706 variety is resistant.

Nutritional Disorders

FRENCHING

Frenching[37] has been confused with mosaic. Newly-frenched plants are nearly white at the growing point. The frenched leaves are narrowed and drawn, and the tips sometimes bend sharply downward so as to form a cup of the underside of the leaf. The leaves may be reduced to narrow straps in severe cases. The disease is more prevalent in seasons of abundant rainfall. It appears to be associated with slightly acid, neutral, or slightly alkaline soils. The disease may be controlled under field conditions by addition of readily decayable organic matter, drainage, and proper fertilization. Addition of sulfur to frenched soil to increase acidity has prevented frenching under some conditions.

PHYSIOLOGICAL BREAKDOWN

The physiological breakdown of maturing tobacco leaves includes leaf spots described as drought spot as well as rim fire. This type of injury occurs in Virginia on tobacco grown on soils of too low fertility and of too light texture. It is most commonly found on flue-cured and dark fire-cured tobacco.[53] Nitrogen fertilizers increase injury, while potassium, magnesium, and chloride reduce the susceptibility of the plant. Tobacco improperly fertilized is subject to physiological breakdown during either excessively wet or excessively dry growing seasons.

The occurrence of breakdown may be reduced by topping the plants higher, by harvesting the leaves before they become overripe, and, on rich soils, by using fertilizers containing only 2 per cent of nitrogen.

SAND DROWN

Sand drown (magnesia hunger) is caused by deficiency of available magnesium. It occurs most frequently after heavy rains on sandy soils subject to leaching of soluble minerals, hence its name. The leaves turn nearly white at the tips and along the margins, especially of the lower leaves. Sand drown is prevented when a fertilizer containing 10 to 20 pounds available magnesia has been applied. This can be supplied by the use of sulfate of potash-magnesia as the potash fertilizer. Dolomitic limestone high in magnesia applied in the drill at the rate of 500 pounds per acre or broadcast at the rate of 1,000 pounds per acre likewise prevents sand drown. Manure and other organic fertilizers such as cottonseed meal and tobacco stems also tend to prevent the disease.

DETECTION OF MINERAL DEFICIENCIES

Tobacco serves as an excellent test plant for determination of mineral deficiencies in soils or culture solutions, because the disorders produce symptoms that can be recognized readily.[45] A key to these symptoms adapted from McMurtrey,[46] and McMurtrey and Robinson [48] is given below.

FIELD KEY TO PLANT-FOOD DEFICIENCY SYMPTOMS ON TOBACCO

A. Causal parasites or viruses present (not included in present discussions). Parasitic and virus diseases.

A. Causal parasites or viruses absent. More or less localized effects and decreased growth. Commonly classed with nonparasitic diseases.

B. Effects localized on older or lower leaves or more or less general on whole plant. (Group 1)

C. Local, occurring as mottling or chlorosis with or with necrotic spotting of lower leaves, little or no drying up of lower leaves.

D. Lower leaves curved or cupped under with yellowish mottling at tips and margins. Necrotic spots at tips and margins. *Potassium*

D. Lower leaves chlorotic between the principal veins at tips and margins of a light green to white color. Typically there are no necrotic spots. *Magnesium*

C. General; also yellowing and drying or firing of lower leaves.

D. Plant light green, lower leaves yellow, drying to light brown color. *Nitrogen*

D. Plants dark green, leaves narrow in proportion to length; plants immature. *Phosphorus*

D. Lower leaves faintly chlorotic, followed by necrotic spots on lower leaves and leaf tips at first surrounded by halo and later turning brown, and finally suffering complete breakdown of the leaves. *Zinc*

B. Effects localized on terminal growth, consisting of upper and bud leaves. (Group 2)

C. Dieback involving the terminal bud, which is preceded by peculiar distortions and necrosis at the tips or base of young leaves making up the terminal growth.

D. Young leaves making up the terminal bud first light green followed by a typical hooking downward at tips, followed by necrosis, so that if later growth takes place tips and margins of the upper leaves are missing. *Calcium*

D. Young leaves constricted and light green at base, followed by more or less decomposition at leaf base; if later growth takes place, leaves show a twisted or distorted development; broken leaves show blackening of vascular tissue. *Boron*

C. Terminal bud remains alive, chlorosis of upper or bud leaves, with or without necrotic spots, veins light or dark green.

D. Young leaves with necrotic spots scattered over chlorotic leaf, smallest veins tend to remain green, producing a checkered effect. *Manganese*

D. Young leaves without necrotic spots, chlorosis does or does not involve veins so as to make them dark or light green in color.

E. Young leaves with veins of a light green color of same shade as intervein tissue. Color light green, never white or yellow. Lower leaves do not dry up. *Sulfur*

E. Young leaves chlorotic, principal veins characteristically darker green than tissue between the veins. When veins lose their color, all the leaf tissue is white or yellow. *Iron*

C. Upper leaves permanently wilted, growth reduced, poor seed set and seedstalk sometimes unable to stand erect. *Copper*

Insects

The most serious pests of tobacco in the United States[9, 38] are the hornworms or greenworms of which there are two important species, the tomato hornworm (*Protoparce quinquemaculata*) and tobacco worm or southern tobacco worm (*P. sexta*) (Figure 270). Other serious insect pests are the tobacco fleabeetle (*Epitrix hirtipennis*) and the tobacco budworm (*Chloridea virescens*). The hornworms devour entire leaf blades, whereas the fleabeetle riddles the leaves with small holes. The fleabeetle is most damaging to young plants. The budworm feeds in the top of the plants and cuts holes in the young leaves. By chewing into the bud it may puncture several unfolded leaves at once. This insect is prevalent in the southern tobacco-growing areas. Hornworms can be controlled with lead arsenate sprays, fleabeetles with DDT, and budworms by applying a 1:75 mixture of lead arsenate and cornmeal into the buds of the plants. Cutworms, which attack the plants in the beds, can be controlled with poisoned baits. Destruction of tobacco plant residues, unused plants in the beds, and weeds near the beds and fields helps in keeping down the insect populations.

The tobacco or cigarette beetle (*Lasioderma serricorne*) damages stored and manufactured tobacco. The discovery of beetle borings in a half-smoked cigar is extremely disconcerting. The tobacco moth (*Ephestia elutella*) attacks flue-cured and imported Turkish cigarette tobacco in storage.[51] The larvae devour the entire leaves

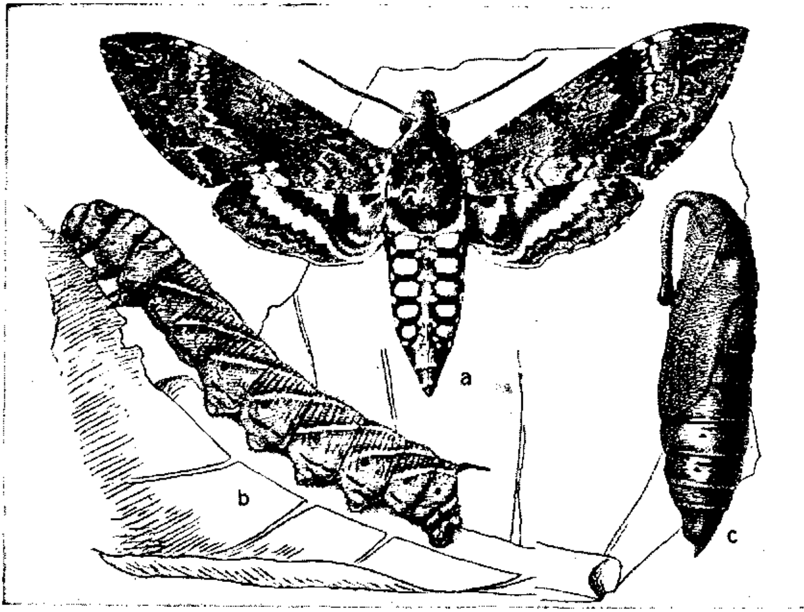


FIG. 270. Southern tobacco hornworm, (a) adult; (b) larva, (c) pupa.

except for the larger veins, and in addition foul other leaves with webs and excreta. They infest tobacco stored in cases, hogsheads, or piles in warehouses or storage sheds. This pest is kept under control by periodic fumigation with hydrocyanic acid gas in closed storages.[48] In open storages pyrethrum sprays and dust are effective.

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36 SUGAR BEETS

Economic Importance

The farm value of sugar beets in the United States ranged from 46 to 85 million dollars annually from 1937 to 1946. Government payments raised the returns to growers to 54 to 106 million dollars annually. During this period, the average acreage of sugar beets was about 787,000, the production 9,800,000 tons and the acre yield 12.4 tons. About 10,000 additional acres are devoted annually to production of sugar beet seed. The beet tops, a by-product, provided some 7½ million tons of green feed. The processing of the beets produced an annual average of 1,400,000 tons of sugar, 150,000 tons of molasses pulp, 95,000 tons of dried pulp, and 1,500,000 tons of moist pulp. Colorado, California, Michigan, Montana, and Nebraska are the leading sugar beet producing states (Figure 271). The leading countries in sugar beet production are U.S.S.R., Germany, United States, France, and Czechoslovakia (Figure 116, Chapter 14). The sugar beet is the only feasible sugar crop for cool climates.

Sugar beets have been one of the most uniformly profitable cash crops in many irrigated valleys in the western United States. Sugar beets facilitate diversification and provide an intertilled crop that helps to control weeds in rotations with hay and grain crops on more than 80,000 farms. Feeding the by-products of beet culture and manufacture forms the basis of an extensive sheep and cattle fattening industry around each factory.

History

The sugar beet dates back 200 years.[13, 29] In 1747 a German chemist named Marggraf found that the kind of sugar in two cultivated

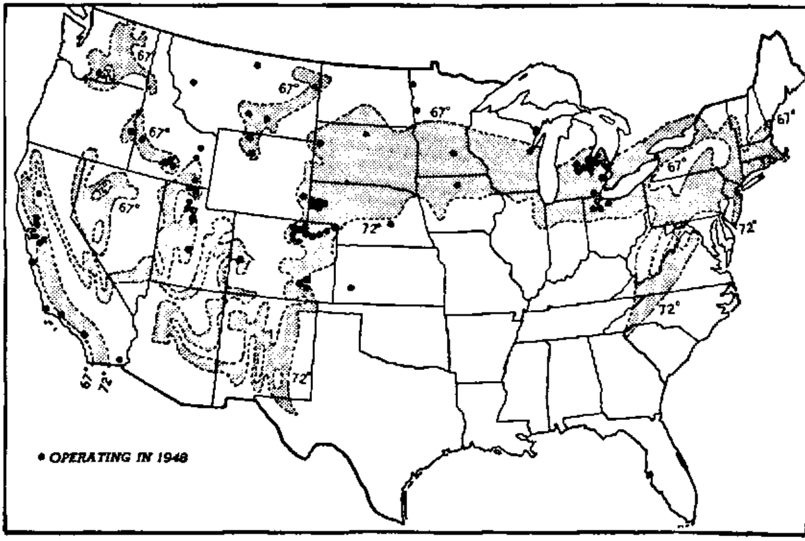

FIG. 271. Sugar beets are produced in the vicinity of sugar factories, mostly within the shaded zone in which the mean summer temperature is from 67° to 72° F. The dots show the location of the 73 beet sugar factories operating in the United States in 1948.

species of beets was identical with that in cane. The first factory, built in 1799–1801 in Silesia, was a failure. The percentage of sucrose in the sugar beets used then was very low. Louis Vilmorin in France selected beets by progeny test methods and raised the sugar content from 7.5 per cent up to 16 or 17 per cent. By 1880 sugar beets had practically as high a sugar percentage as the varieties of today. The first successful commercial factory in America was erected at Alvarado, California, in 1870. General success of the industry in the United States dates from 1890. In 1948, 73 beet sugar factories were operating in this country, and some 1,200 formerly operated in Europe. About 35 per cent of the world sugar supply is furnished by the sugar beet. A popular prejudice against beet sugar, now forgotten, continued for many years despite the fact that it could not be distinguished from cane sugar. The pure sugar (sucrose) from the beet and from the cane are identical. The chemist can determine whether a sugar is from sugarcane or sugar beets only by analyzing for small traces of certain impurities that are different.

Adaptation

Sugar beets are grown in favorable localized sections within a feasible shipping radius of sugar beet factories. Since a factory represents an investment of $500,000 to $2,000,000 and usually has a capacity of 1,000 to 3,500 tons of beets daily, it is essential that several thousand (usually 10,000 or more) acres of beets be grown in order to keep the factory in operation during the season of 65 to 100 days in the fall and early winter.

Successful sugar beet production is found only on fertile soils. A good percentage of soil organic matter, supplied naturally, by manuring, or by legume residues, favors beet yields. Loam or sandy loam soils predominate in most of the sugar beet areas, but heavy clay soils are used to some extent. These stickier soils usually are less favorable for high yields, and they increase the difficulties of lifting the beets and freeing them from adhering soil. The sugar content of beets is highest on soils that also produce the best tonnages.[35] However, nitrogen fertilizers applied late in the season lower the sugar content. Sugar beets can endure large quantities (1 to 1.5 per cent) of saline salts (alkali) after they become established.[15,16]

Irrigation water is necessary for successful commercial sugar beet production where the rainfall is less than about 24 inches in the northern boundary states of the United States. The commercial sugar beet production west of the hundredth meridian is on irrigated land. Those grown in eastern North Dakota, Minnesota, north central Iowa, and states to the east are not irrigated.

Sugar beet seed germinates well when the soil temperature is about 60° F. The sugar beet root has the highest sugar content in sections where the summer temperature averages about 67° to 72° F.[5] (Figure 271). The plant is uninjured by cool nights. Cool autumn weather favors sugar storage in the roots. Temperatures of 86° F. or above retard sugar accumulation. Sugar beets make a good vegetative growth in the south, but the roots are low in sugar content.[5] On the other hand, sugar beets planted in the winter in California and harvested during very hot July weather have a high sugar content. The newly emerged seedling may be killed by a temperature of 25° F. Later the plants become more resistant to cold. The mature plant is able to withstand fall frosts, but a temperature as low as 26° F. usually causes foliage injury. Following such injury, a period of warm weather may bring about a growth of new leaves and a sharp decline in the sugar content of the roots.[26]

Sunlight has a sanitary effect in disease control. The intensity of light is associated more closely with the utilization of nutrient elements than with their absorption. The relative sugar content is not influenced by light until growth is inhibited[35] by high or low intensities.

Initiation of seedstalks and flowers of sugar beets (a long-day plant) is brought about mainly by the cumulative effect of low-temperature exposure followed or accompanied by the effects of long photoperiods. This combined effect of light and temperature has been termed photothermal induction.[27] Seedstalks are produced most abundantly and seed yields are highest when the weather is cool (less than 69° F. maximum temperature), wet and cloudy (with less than 10.6 hours sunshine per day) for a period of about 6 weeks, and then followed by 2 weeks of cool dry weather to stimulate seed production.[18] Early beets are able to flower at cooler temperatures than are those planted late.[30]

Botanical Characteristics

The sugar beet (*Beta vulgaris*) is a herbaceous dicotyledon, a member of the family *Chenopodiaceae*, characterized by small, greenish, bracteolate flowers. The flowers are perfect, regular, and without petals. A large fleshy root develops. The species includes four groups: (1) sugar beets, (2) mangelwurzels or mangels, (3) garden beets, and (4) leaf beets such as chard and ornamental beets. The sugar beet sometimes is classed as a separate species, *B. saccharifera*, but there appears to be little justification for such a separation.

It is believed that a wild type of *Beta vulgaris*, often referred to as *Beta maritima*, is the progenitor of the sugar beet. Several wild species of *Beta* native to Europe[9] have been crossed with *B. vulgaris*.

VEGETATIVE DEVELOPMENT

The sugar beet, a biennial, normally completes its vegetative cycle in 2 years. It develops a large succulent root during the first year, in which much reserve food is stored. During the second year it produces flowers and seeds. Prolonged cool periods cause a seedstalk to be sent up the first year, a behavior known as bolting. Some strains of beets bolt more readily than others.

FIG. 272. Sugar beet top, and root showing characteristic groove.

The mature beet (Figure 272) is an elongated pear-shaped body composed of three regions—the crown, the neck, and the root.[1] The crown is the broadened, somewhat cone-shaped apex, that bears a tuft of large succulent leaves and leaf bases. Just below it is the neck, a smooth thin zone, which is the broadest part of the beet. The root is cone-shaped and terminates in a slender taproot. It is flattened on two sides, and often is more or less grooved. The two depressions extend vertically downward or form a shallow spiral and contain the lateral rootlets indistinctly arranged in two double rows. The surface of the beet is covered by a thin cork layer that is yellowish-white except on the aerial parts at places of injury.[4]

In cross section the beet is made up of a number of rings or zones of growth. The center of the beet is occupied by a more or less star-shaped core. Most cultivated beets have ivory-white flesh, but in poor strains the flesh is of a watery-greenish or yellowish hue.

The beet root is richest in sugar slightly above the middle with decreases towards both ends. The tip of the root is lower in sugar than any other part except the center of the crown. There is little consistent relation between the internal structure, size, or shape of the root, and the sugar content.[3]

The beets grown in one season may have a higher average sugar percentage than those grown in another. Individual beets vary widely in sugar content, ranging from 10 to 20 per cent.

The leaves are arranged on the crown in a close spiral.[1] The beet, being a cross-fertilized plant, shows a striking lack of uniformity in foliage characters.

FLOWER AND SEED DEVELOPMENT

The sugar beet normally sets seed as a result of wind or insect pollination. Either the bagging of branches or plant isolation is necessary for the production of pure strains.[6, 11]

During their second year the beets first produce a rosette of leaves like those of the first year, but after about 6 weeks of growth the newly-formed leaves become progressively smaller and then the flower stalk develops.[2] The flower stalk grows rapidly and branches considerably. The mature inflorescence or *seed bush* is composed of large, paniculate, more or less open spikes bearing the flowers and later the seeds (Figure 273). The calyx and stigma adhere to the mature fruit.

The fruit is an aggregate, formed by the cohesion of 2 or more flowers grown together at their bases and forming a hard and irregular dry body, the so-called seed ball, which usually contains 2 to 5 seeds. The mature seed is a shiny, lentil-like structure about 3 mm. long and 1.5 mm. thick (Figure 274). The mature outer reddish-brown seed coat is very brittle and separates easily from the seed.[2] Attempts begun many years ago [29] to produce a suitable beet with a single-germ seed ball have been unsuccessful thus far.

Varieties

A type of sugar beet called Kleinwanzleben, developed near the town of Kleinwanzleben in Germany, was most widely grown in the United States before seed of improved varieties was produced in this country.

In order to combat the curly top disease that was threatening the beet sugar industry of the western United States, U.S. No. 1, the first resistant variety, was introduced.[7] It was quickly followed by other mass-selected resistant varieties, U.S. No. 33 and U.S. No. 34,[9, 27] a decided improvement in curly-top resistance over U.S. No. 1. Under conditions of severe exposure, comparative yields in one test were as follows: U.S. No. 34, 10 tons; U.S. No. 1, about 7 tons; and commercial brands, 2 to 3 tons per acre. More recently, these have been replaced by U.S. No. 22, a strain with still greater

FIG. 273. Sugar beet plant producing seed.

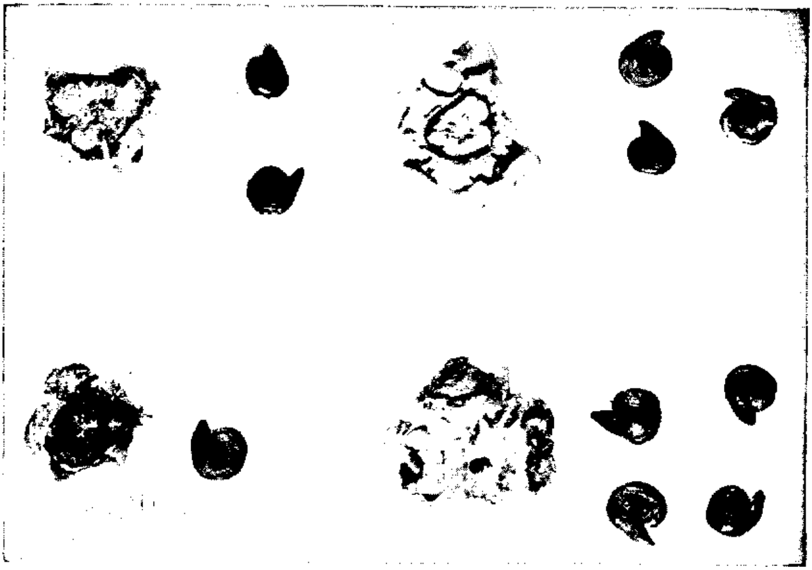

FIG. 274. Seed balls containing 1 to 4 seeds each, and detached seeds of the sugar beet.

resistance. U.S. No. 15 is a nonbolting type grown from fall and winter planting in southern California.

Many of the beet sugar companies in the United States have developed improved varieties adapted to their particular areas. Some of these are resistant to curly top or leaf spot.

Practically all sugar beets are grown under contract with a sugar company which furnishes technical assistance and usually produces or procures the seed and sells it to the grower.

Rotations

Sugar beets are grown almost exclusively in rotations involving the legumes (alfalfa, red clover, and sweetclover), small grains, and frequently potatoes, corn, or beans. The growing of sugar beets in continuous culture soon results in depressed yields,[25] and often encourages infestation of the land by the sugar beet nematode or by disease-producing fungi and bacteria. Planting sugar beets immediately following a legume usually is inadvisable. The early spring preparation essential to early planting of sugar beets destroys the legume crop before it can make enough spring growth to provide much green manure. Consequently, such land is best left for later plowing in preparation for corn or potatoes. Furthermore, the frequent failure to kill all alfalfa and sweetclover plants by tillage is detrimental to sugar beet yields. The growing of an intertilled crop, such as potatoes or corn, after a legume crop facilitates disease and weed control and is favorable to beet stands and yields. Certain legume crops and weeds promote the occurrence of soil-borne organisms causing damping off and black root of sugar beets. Better stands of beets are obtained following corn, potatoes, small grain, or soybeans than following alfalfa, sweetclover, or red clover. Thus sugar beets usually follow the crop that follows the legume.

Fertilizer Practices

Barnyard manure applied at the rate of 6 to 12 tons per acre is the chief fertilizer used in sugar beet production. Pasturing of legumes preceding beets adds some manure to the land. Applications of manure produce substantial increases (often 5 tons or more per acre) in yields of beets on irrigated land.[14] Most of the sugar beets are grown on soils well supplied with potash. However, muck soils often require potash. Turning under legume residues and application of barnyard manure supply most of the nitrogen required for beet production. Lime is abundant in most western soils. Consequently, phosphorus is the dominant element in commercial fertilizer applied for beets. In the humid area, an application of some 200 pounds of superphosphate per acre usually suffices. Heavier applications are advisable in the irrigated sections of the Great Plains states on heavy highly calcareous soils from which much of the available phosphorus has been removed by long cropping to alfalfa. There, 150 pounds of treble superphosphate (equivalent to 400 pounds of ordinary superphosphate) have given profitable returns.[26] On the more porous sandy soils of the Great Plains and intermountain region, from which calcium has been leached by irrigation water, the application of phosphorus has not been particularly beneficial.

Small applications of borax, not exceeding 15 pounds per acre, are beneficial on soils which are deficient in boron. On some muck soils the beets respond to applications of 25 to 50 pounds of copper sulfate.

Cultural Methods

Fall plowing in preparation for sugar beets usually is advisable except for very friable soils. Deep plowing (8 to 12 inches) usually is recommended,[20, 24, 26] although experimental evidence justifying plowing deeper than 8 inches is inadequate. Sugar beet roots penetrate below any plowing depth, the feeding roots going down 5 or 6 feet.[33] Tillage subsequent to plowing should provide a mellow seedbed for the small beet seedlings. Planting usually is done with a special four-row (Figure 42) or six-row beet planter with rows 18 to 22 inches apart.

Planting rates in the United States range from 12 to 25 pounds per acre and average about 15 pounds of unsheared seed. A rate of 20 pounds of seed per acre for irrigated land has been recommended.[26] The most recent method of beet production is the planting of processed (decorticated) and treated seed at the rate of 6 to 8 pounds per acre, or 10 to 12 balls per foot of row. The processed ball contains 1 or 2 seeds and is about 1/7 inch in diameter. Sheared or segmented seed, i.e., portions of balls most of which contain only a single seed, eliminates much of the subsequent thinning. Roughly, 50 to 60 per cent of the domestic acreage was planted with sheared seed in 1945. Only about 4 to 6 pounds per acre of sheared seed is required.[33] Frequent irregular stands from injured sheared seed caused a shift to the use of processed seed.

Since each seed ball of unsheared beet seed usually produces more than one plant, it is necessary to thin the plants for good root development. In the past much of the thinning and blocking has been done by hand, this operation requiring 20 to 40 hours of labor per acre. The rows are first blocked out with a hoe to leave a clump of plants at the desired spacing between centers, usually about 10 to 12 inches. Then each clump is thinned by hand to a single plant. The blocking and thinning may be done together or as separate operations. Thinning is often done when the plants have six to eight leaves, but usually begins about 3 weeks after planting when the seedlings have about four leaves. Thinning should be completed by the time the plants have 8 to 10 leaves. Mechanical blocking is practicable only where a good initial stand prevails[33] but it is now a common procedure. Beet yields often are 10 per cent higher after hand blocking and thinning than after mechanical blocking without thinning. Both across-the-row machines equipped with knives and down-the-row cotton choppers are used for blocking beets. In mechanical blocking [23, 31] the size of blocks to be left for hand thinning depends on the initial stand. Where 50 inches of every 100 inches of row contain beets, an 85 per cent stand is obtained when the knives are set so as to leave 4-inch blocks and 8-inch spaces.

It is customary to hoe sugar beets twice after they are thinned, and then to rely upon cultivation for the remaining weed control. Special four-row or six-row beet cultivators are in common use. Those equipped with both knife-type and small sweep-type shovels are most satisfactory. In fully mechanized production the hoeing is omitted and weeds in the row are suppressed while small by cultivation with a harrow or flexible-shank weeder before the beets are up and shortly thereafter.

In the west, beets are irrigated by the furrow method about every 10 days or 2 weeks, or when water is available, or whenever the plants evidence the need of water by their dark green color and the continuation of leaf wilting after sunset. Better yields result when the field is irrigated before the plants show signs of water need. The highest acre yields are obtained when the soil moisture at the one-foot depth is maintained at not less than 50 per cent of the total available water-holding capacity of the soil. The usual irrigation is 2 to 6 acre-inches at each application, or 12 to 36 inches for the season. The final irrigation should provide sufficient moisture for the sugar beets to complete their growth and, in addition, should leave the soil moist enough for the roots to be dug. In some sections it is necessary to irrigate in the spring before or after planting or both in order to germinate the seed.

Harvesting

Sugar beets should be left in the field until they reach a maximum sucrose content. Maturity is indicated by browning in the lower leaves and a yellowing of the remaining foliage.[13] Usually the contracting sugar company makes sugar analyses and instructs the growers when harvesting should begin. The beets are first loosened and partly raised out of the ground with a special implement, called a lifter or puller, which has two sloping prongs that run along the row underground on each side of the roots. The beets are then pulled by hand and knocked together to remove dirt, and then thrown into windrows or piles, either before or after topping. The beets are topped with special knives by cutting off the crown at the base of the lowest leaf sear (Figure 275). The crown contains little sugar and is high in mineral salts. Mechanical loaders are in common use. Recently mechanical pulling, topping, and loading machines have been put into use (Figure 276).

The topped beets are hauled in trucks or wagons, usually to a beet dump located at a railroad siding. The beet dump, which has a long inclined driveway and a tilting platform, unloads mechanically, screening out the loose soil as the roots slide down a slatted chute into gondola freight cars. The beets are shipped to a factory where they are either processed immediately or piled for future processing within a few weeks.

Sugar Manufacture

In the manufacture of sugar the topped beets are first washed in a flume of rapidly flowing water. They are then sliced mechanically with V-shaped knives into thin angular strips called cosettes, which are about the diameter of a lead pencil. The sugar is extracted from the slices by the diffusion process in large drums containing warm juice followed by warm water at a temperature of 80° to 84° C. After separation of the juice from the pulp, milk of lime is added to the juice in large tanks to precipitate impurities and to neutralize oxalic and other organic acids. The acids combine with the calcium to form less soluble salts which settle out of solution. Excess calcium is precipitated as calcium carbonate by carbonation of the limed juice. The juice is filtered and then further clarified, decolorized with sulfur dioxide, and again filtered. The juice is then concentrated to a sirup by boiling under reduced pressure in steam-heated vacuum pans or evaporators called effects. The sirup is treated with sulfur dioxide, again filtered, and evaporation is continued until the sugar crystallizes. The mixture of sugar crystals and molasses is separated in centrifuges with perforated inner walls. The washed sugar crystals are then separated and dried in a granulator. The molasses or mother liquor is reworked several times to recover additional sugar, leaving a residue of final-discard molasses.

The average yield of sugar obtained in the United States is about 295 pounds per ton of beets, or more than 3,600 pounds of sugar per acre. The average sugar content of the beets exceeds 15 per cent,

FIG. 275. Topping sugar beets.

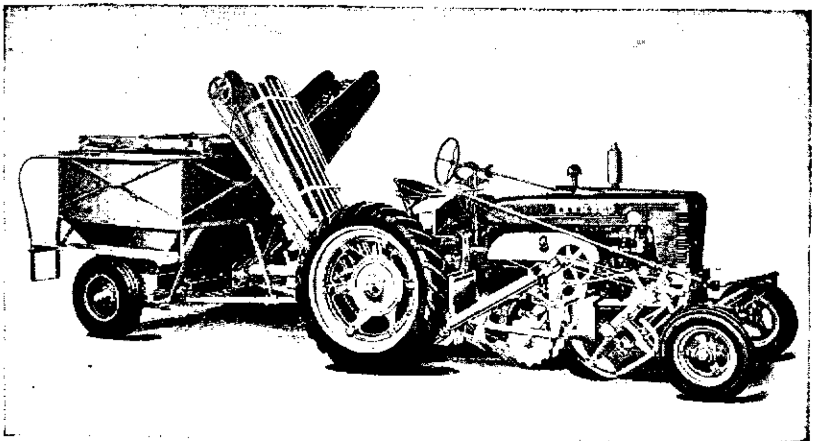

FIG. 276. This beet harvester pulls, tops, screens, and loads sugar beets. (Courtesy of International Harvester Company.)

but some of the sugar (usually 5 to 15 per cent of the total) is left in the molasses and pulp.

By-products of beet sugar manufacture are pulp and molasses, and lime cake or waste lime from the filter presses. The beet pulp is the wet fibrous material left after the sugar is extracted from the sliced beets. The yield of wet pulp containing 90 to 95 per cent water is about 1,600 pounds per ton of beets. The final yield of wet pulp after removing part of the excess water by pressing or partial drying is 400 to 600 pounds per ton of sliced roots. The pulp is used for stock feed either fresh, ensiled, or dried. Usually 2 to 3 gallons or more of final discard molasses are obtained from each ton of beets. This molasses contains about 20 per cent water, 60 per cent carbohydrates (mostly sucrose, arabinose, and raffinose) and about 10 per cent of ash or mineral matter in which potassium compounds predominate. The molasses often is added to the pulp and used as dried molasses pulp. Considerable quantities are fed in mixture with other feeds. The remainder is used mostly in the manufacture of alcohol.

The dry matter in the lime cake contains the equivalent of more than 80 per cent calcium carbonate, 10 per cent of organic matter and traces of potash, phosphorus, and nitrogen. It is suitable for liming soils, but, unfortunately from the standpoint of utilizing the lime cake, most soils in the western sugar beet areas are not in need of lime. About 100 pounds of burned limestone is used after adding water to form milk of lime, for each ton of sliced beets.[32]

Beet tops consist of about one-third crown and two-thirds leaves by weight. The green weight of tops ranges from 75 to 80 per cent of the weight of topped beets. Beet tops are fed mostly to sheep and cattle, either fresh, ensiled, or in dry form as cured in small piles in the field. Often the stock are turned into the field to eat the piled tops, but this is a wasteful practice. Beet tops are palatable and nutritious, but are dangerous when fed in large quantities to horses and pigs because of their abundance of cathartic salts and oxalic acid. Ruminants are able to utilize large quantities without injury. Beet tops contain about two-thirds of the digestible nutrients found in corn silage.

Seed Production

Production of sugar beet seed formerly was largely a European enterprise, and nearly all of the seed planted in America was imported, except during World War I, because of the labor involved in beet seed production. By the old methods, the beets for seed were planted in the usual manner but were left closer together in the row at thinning time in order to obtain more but smaller beets, usually called stecklings. These were dug in the fall, and siloed, i.e., stored in a pit or pile and covered with straw or earth or both. In the spring the stecklings were set out in the field for seed production.

The discovery that beets were able to overwinter in the field in the mild climates of the southwest and Pacific coast in about 1925 started the American seed industry.[9, 12] The beet seed is planted in rows in September. The beets are left unthinned and given sufficient irrigation to keep them alive over winter. The next summer seed is produced on the overwintered plants. The seed crop may be cut by a mower or by hand. The seedstalks are cured in cocks. The seed is threshed from the field or from stacks with standard threshing equipment adapted for that crop. The average seed yield in recent tests has been 2,200 pounds per acre. From a small beginning in commercial seed production about 1932, the entire domestic seed requirements were produced in this country for the 1942 crop.

Selection is generally practiced on foundation stocks of mother beets planted for seed production.[28] They are tested for sucrose, purity, and other characters, and the poor individuals are discarded. The commercial lots of beet seed thus are maintained or improved.

Diseases

CERCOSPORA LEAF SPOT

This leaf spot, caused by the fungus *Cercospora beticola,* is one of the most prevalent of sugar beet diseases.[19] The attack begins as very small sunken, water-soaked spots scattered over the leaf, which spots later develop into circular sunken spots about 1–2 mm. in diameter. The center of a spot is ashy-gray, and frequently the spot has a reddish-purple margin. When the spots are numerous, they coalesce, causing the leaf blades to become brown and dry. The outer leaves of the plant often show the blighting which is a result of infection that took place when these leaves were unfolding. Under severe attack the affected leaves die, become brown or black, and the field looks brown or scorched.

The principal control measure for leaf spot is use of resistant varieties such as U.S. 216 × 225. Since the fungus lives over winter on the debris from a previous beet crop, crop rotation reduces infection from this source, but at least 3 years without sugar beets are required to clean up an old field. Deep fall plowing may facilitate decay of the sugar beet residues. Three applications of copper dusts or of Bordeaux mixture, given at about 10-day intervals beginning about the middle of July, have proved to be a relatively effective direct protective measure against leaf spot.

CURLY TOP

Curly top is a virus disease that formerly caused such heavy losses to sugar beet growers in the intermountain region and in California that production declined and several beet sugar factories were abandoned. The insect vector of curly top is the beet leafhopper (*Eutettix tenellus*), the so-called white fly.[17] This leafhopper breeds and feeds upon numerous plant species, principally weeds of the goosefoot and mustard families. Russian thistles and other weeds which spread over overgrazed range and abandoned fields caused the beet leafhopper and curly top disease to increase. Epidemic years occur when large numbers of beet leafhoppers overwinter and move to the sugar beet fields after the range plants dry up in the spring. A portion of the leafhoppers carry the curly top virus after feeding upon weeds that are subject to curly top. Others pick up the virus from sugar beet plants diseased with curly top. The beet leafhoppers introduce and spread the virus throughout a sugar beet field.

The typical curling is upward and is usually accompanied by more or less roughening and distortion of the leaf veins. These symptoms are accompanied by a shortening of the petiole and a general retardation in the growth of the entire plant. The stunted beets commonly develop large numbers of tiny rootlets. The most satisfactory control is the planting of resistant varieties. The variety, U.S. 22, is sufficiently resistant to avoid losses of more than 20 per cent. Little loss occurs under light to medium exposures. U.S. 15, which is used in California for winter plantings, is only moderately resistant.

SEEDLING DISEASES

A general complex of damping-off diseases which leads to the death of the sugar beet plant at the time that sprouting takes place or as the seedling is emerging from the soil, and to those later phases of attack which occur on plants that have partly recovered from damping-off has been called black root by growers.

A number of fungus pathogens are responsible for sugar beet black root. Death of the plant may occur at the time of sprouting or when the plants emerge from the soil. Some plants persist in spite of fungus attack, but these may remain stunted or eventually die. Soil-inhabiting organisms such as species of *Pythium* and *Rhizoctonia* cause the death of sugar beet plants. A seed borne fungus, *Phoma betae*, also is serious. The most serious loss apparently is caused by *Aphanomyces cochlioides*, a water mold. This fungus does not kill the plant outright but dwarfs it because of a persistent attack on the lateral or feeding roots.

The control of seedling diseases or black root involves long rotations and crop sequences that keep soil infestation at a minimum, proper drainage and fertilization so that the plants make vigorous growth, and seed treatment with fungicides. Certain inbred strains of sugar beet are resistant to *Aphanomyces*, and breeding for resistance has been started.

ROOT ROTS INCLUDING RHIZOCTONIA CROWN ROT

Sugar beet roots may rot in midseason because of the attack of a number of fungus pathogens. *Rhizoctonia* crown rot is probably the most serious of these rots. In many cases the rotting of the mature root is a carryover from an attack of the fungus in the seedling stage which was followed by partial recovery and then a renewed spread of the fungus on the half-grown plants. Such plants usually show a cleft top, and sometimes the entire crown breaks away. The fungus tends to spread down the row, it being common to find a number of contiguous plants affected with crown rot. The control of seedling diseases, crop rotation, and good culture serve to check the losses from root rots to a considerable extent. No varieties resistant to *Rhizoctonia* have been introduced.

STORAGE DISEASE

Sugar beets must be harvested before freezing weather sets in. Consequently, deliveries are greatly in excess of processing capacity, and the roots are piled at the factory where they may be stored for a month or more. The roots keep well as long as they are alive, reasonably cool, and adequately aerated. Frozen roots, wounded roots, roots topped excessively low, and those roots whose tails die because of excessive drying out are subject to attack not only by such parasites as *Phoma betae*, *Rhizoctonia*, and *Phycomycetes* but also by saprophytes such as *Fusarium*, *Penicillium*, *Aspergillus*, and the *Mucors*. Prevention of storage losses requires careful handling of the beets and avoiding excessive drying.[34] Blowing cold night air in the beet piles lowers the temperature, reduces respiration, and checks storage rots.

Deficiency Disorders

Sugar beets show typical deficiency symptoms when the supply of any of the essential mineral elements is inadequate. Nitrogen starvation produces typical yellowing effects, as also does sulfur deficiency. Potash hunger manifests itself by a reddish coloration or bronzing. When phosphorus is deficient the plants show stunting and unbalanced proportions of roots and tops as well as characteristic necrotic blotches on the blades of the older leaves. In severe cases the leaves dry and shrivel, the leaf rolling in on the midrib from the tip to give a fiddle neck effect. The severe aspects of phosphate deficiency have been called black heart,[22] a name that indicates the symptoms very poorly.

Boron deficiency causes blackening and death of the heart leaves, blackening or black markings on the inner faces of the petioles, and cankers on the roots. The flesh beneath the dried necrotic spot or canker is brown or lead-colored. The sugar beet requires a relatively large amount of boron to avoid the deficiency symptoms. Applications of about 10 pounds of boron per acre are adequate where this element has merely been leached out. In soils in which boron is bound much heavier applications are necessary.[10]

Nematodes

The sugar beet nematode (*Heterodera schachtii*), a minute whitish eelworm, attacks the roots of sugar beets and kills or stunts the plants.[21] Stunted roots may be covered with short hairy rootlets. Infestation is spread through soil (dump dirt) that is transferred at the beet dumps and then returned to the fields. The pest is controlled by long rotations with immune crops such as alfalfa, beans, potatoes, small grains, and corn, with sugar beets grown at intervals not less than every 4 or 5 years. Fumigation of the soil with D–D,* and E.D.B., and similar chemicals is restoring to sugar beet culture fields now abandoned because of nematode infestation. The cost of such fumigation in 1947 ranged from 20 dollars to 40 dollars per acre. The land also must be kept free from susceptible weeds such as mustard, lambsquarters, knotweed, ladysthumb, purslane, curly dock, and black nightshade, as well as from susceptible crops such as mangels and turnips.

* D–D = 1–2 dichloropropane-dichloro-1–3-propylene. E.D.B. = ethylene dibromide.

Insects

The beet leafhopper (*Eutettix tenellus*)[8] causes some damage by feeding on the leaf sap, but the chief injury from this insect is the spread of the curly-top virus. Losses are minimized by growing varieties resistant to curly top. Good cultural treatments to promote rapid growth of the beet plants is helpful in reducing losses. Dusting with insecticides such as DDT also may prove to be helpful.

The beet webworm (*Loxostege sticticalis*) and the beet armyworm (*Laphrygme exigua*) devour the leaves, and the latter insect also may attack the crowns and roots of the plants. These pests can be controlled with a spray containing 8 pounds of Paris green in 100 gallons of water.[33]

Fleabeetles, which puncture the sugar beet leaves, can be controlled with cryolite or rotenone dusts or with spray consisting of 1 pound of derris or cubé (containing 2 per cent rotenone) in 50 gallons of water.

Grasshoppers, which attack sugar beets frequently, are controlled with poisoned baits or chlordane dust.

Wireworms are destroyed by fumigating the soil with D–D or E.D.B. Wireworm losses are reduced by delaying thinning of the sugar beets until the wireworms have ceased their heaviest destruction. Planting in late April or early May when the wireworms are near the surface of the soil should be avoided.

Other insects attacking sugar beets include leaf miners, white grubs, the sugar beet maggot (*Eurycephalomyia myopaeformis*), and the sugar beet root aphid (*Pemphigus betae*). Direct control methods for these pests have not been developed fully.

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37 POTATOES

Economic Importance

In 1939, 2,644,098 acres of potatoes were grown on 2,631,331 farms, which is about three-eighths of all the farms in United States. The average area was slightly more than one acre per farm, and only 3.2 per cent of the growers produced 5 acres or more. Potatoes were harvested from an average of about 2,900,000 acres yearly from 1937 to 1946, yielding 138 bushels per acre with an average production of 390 million bushels. The annual value of the potato crop ranged from 200 million to nearly 700 million dollars. The leading states in potato production are Maine, Idaho, California, New York, Minnesota, North Dakota, Pennsylvania, and Colorado (Figure 277). In 1945 about one-ninth of the nation's entire potato crop was produced in Aroostook County, Maine.

The world potato crop amounts to nearly 8 billion bushels. Except for the cereals, it is the most important food crop. The leading countries in potato production are Germany, Russia (U.S.S.R.), Poland, France, United States, and Czechoslovakia. Acre yields in the British Isles and the countries of northwestern Europe have been approximately double the average yields in the United States, but about the same as the yields in Maine where climatic conditions and intensive cultural methods are comparable.

Origin and History

The potato is a native of the western hemisphere and is believed to have originated somewhere between Mexico and Chile, possibly in the Andes highlands of Bolivia or Peru, where several wild potato species are still present. The most likely place of origin appears to be

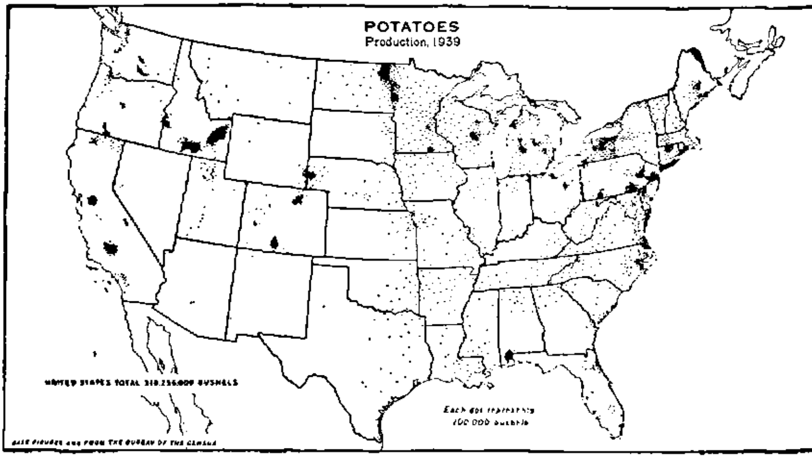

FIG. 277. Distribution of potatoes in 1939.

a valley near Cuzco, Peru. Spanish explorers found the potato under cultivation in western South America but not in Mexico, and took it to Europe some time after the conquest of Peru in 1531 to 1535. It reached England and Ireland by 1586, but did not become generally grown in any European country until after 1750. Although potatoes probably were brought to the American colonies by Spanish traders during the seventeenth century, the first authentic record of their culture in the United States was at Londonderry, N. H., in 1719. The planting stock had been received from Ireland, hence the name Irish potato.[41]

Adaptation

Potatoes are grown for sale in every state in the Union, and some potatoes for home or local use are produced in nearly all communities. Despite this fact, a large part of the commercial crop is highly localized. These concentrated areas either are especially suited to potato production or are probably favorably situated to supply certain seasonal or regional markets. The south, of necessity, specializes on potatoes for the early market. Southern Idaho, although handicapped by a long distance from markets, succeeds by producing high-quality baking potatoes.

The potato is a cool-weather plant, making its best growth where the mean July temperature is about 70° F. or lower.[38] Main-crop potatoes are produced chiefly in cool climates such as are found in northern Europe and northern United States. The young sprouts develop best at soil temperatures of about 75° F. but later growth is best at a soil temperature of 64° F.[33] Tuber production is retarded at soil temperatures above 68° F., and completely inhibited at 84° F., above which point the carbohydrates consumed by respiration exceed those produced by photosynthesis.[9] Potatoes grown in the south are planted in early spring or in the fall or winter so that growth takes place while the weather is cool. Where temperatures of 77° F. or higher prevail, the symptoms of mosaic are indistinct.[7] The potato plant withstands light frosts, but frequently is injured by freezing in the fall, winter, or early spring. The freezing point of the tubers is 28.5° to 29.5° F., and when completely frozen the tissues disintegrate soon after thawing.

Long days, high temperature, and high nitrogen favor a heavy growth of plants.[7] Short days, cool temperatures or a deficiency of nitrogen favor early tuberization. Days of intermediate length, cool temperatures and abundant nitrogen favor maximum tuberization. Although flower primordia (rudimentary flowers) can be formed in either long or short days and even in darkness,[23] flowering and seed formation are favored by long days and cool temperatures. Thus potato plants commonly produce seeds in the more northern states but not in the middle latitudes or the south. However, varieties differ in their fertility.[30] Unfruitfulness may be caused by abnormal chromosome behavior at the time of pollen formation. Considerable shedding of buds may occur even before pollen formation.

A uniform supply of soil moisture is essential to the production of good well-formed tubers. Interrupted growth followed by later favorable growing conditions may result in knobby, pear-shaped tubers. Potatoes are commercially successful in northern semiarid sections such as western Nebraska which produce the crop chiefly for the seed market.

Cool moist conditions favor development of the late blight disease. Warm weather favors reproduction of insects that transmit the mosaic viruses, which in turn accelerates the spread of mosaic diseases.

Commercial potato production is found on a wide range of soil types ranging through sandy loams, silt loams, loams, and peat.[31] Good yields of potatoes may be obtained in fertile clay soils, but sticky soil adhering to the tubers interfere with digging and marketing. Well-drained soils are desirable. Either fertile soil or heavy fertilization is essential to high yields of potatoes. In the northeast, where scab-sensitive varieties are grown, an acid soil (*p*H 4.8 to 5.4), which retards scab, is considered best. However, the soils in the irrigated intermountain and Great Plains potato regions are alkaline in reaction. The highest recorded potato yields in the United States, exceeding 1,100 bushels per acre, have been secured on the subirrigated peat soils of the San Joaquin delta in California.

Botanical Description

The cultivated potato (*Solanum tuberosum*) belongs to the family *Solanaceae*. The plant is an annual having stout erect branched stems 1 to 2 feet long and slightly hairy, and distinctly winged on the angles.[22] The slightly hairy leaves are 1 to 2 feet long, and comprised of one terminal leaflet, 2 to 4 pairs of oblong acute leaflets, and 2 or more short leaflets (Figure 278). Flowers are borne in compound, terminal cymes, with long peduncles. The five petals are white, rose, lilac, or purple in color. The flower has five anthers, and one pistil with a long style. The fruit or potato ball is a smooth globose, green or brown berry (Figure 279) less than an inch in diameter. The stolons, which are 2 to 4 inches long, enlarge at the outer end to form a tuber. The tuber is a modified stem with lateral branches forming what are known as potato eyes.[6] Each eye contains at least three buds protected by scales. The eyes are arranged around the tuber in the form of a spiral.

The interior of the tuber shows a pithy central core with branches leading to each of the eyes. Surrounding the pith is the parenchyma, in which most of the starch is deposited. Toward the outer part of the tuber are the vascular ring containing the cambium, and a cortex that contains the pink, red, or purple pigment of colored-skinned varieties. The potato skin (periderm) is a layer 6 to 10 cells deep, composed largely of cork (or suberin) having a basic composition similar to that of fatty substances. Scales form on the outer surface of periderm. Openings in the periderm called lenticels become enlarged under moist conditions (Figure 280).

When a potato is cut and left in a suitable environment, the surface of the cut suberizes (corks over) to form a new skin—a wound periderm, which serves to protect the tuber from decay. When a

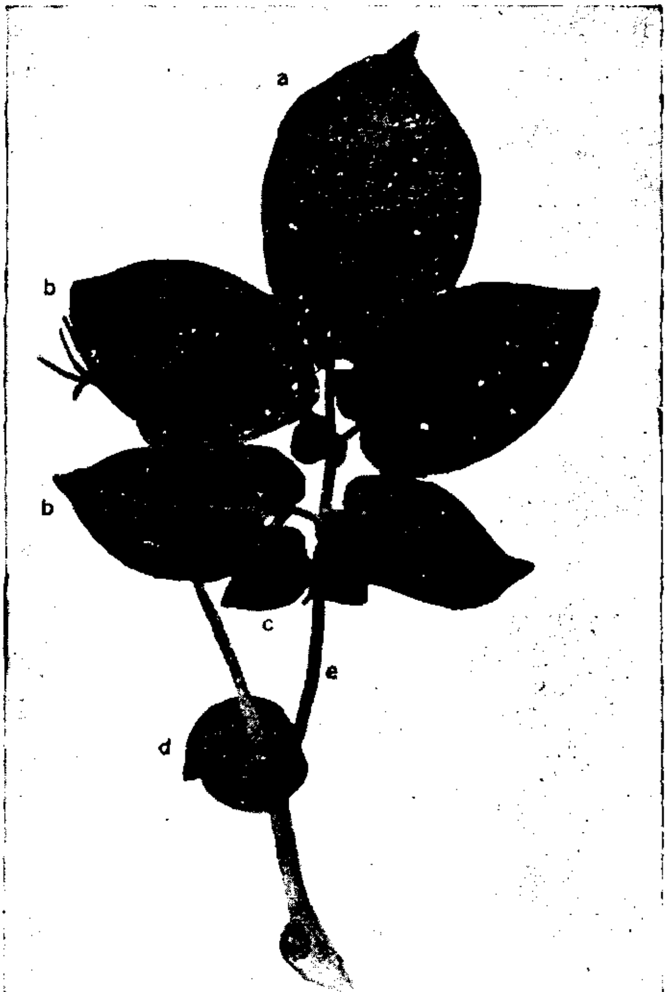

FIG. 278. A potato leaf: showing the terminal leaflet (a); 2 pairs of acute leaflets (b); four short leaflets (c); and the stipules (d); at the base of the petiole (e).

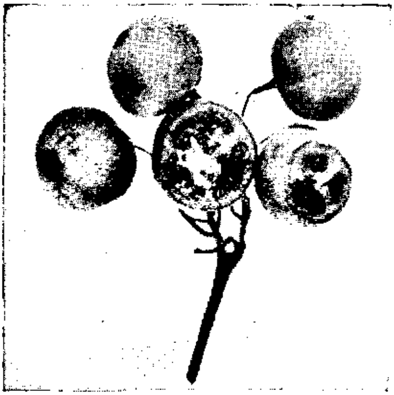

FIG. 279. Potato "balls" containing seeds.

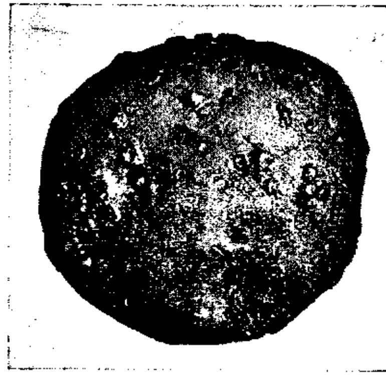

FIG. 280. Enlarged lenticels on the potato periderm.

tuber is exposed to sunlight for several days, either before or after digging, the skin of most varieties turns green as the result of development of chlorophyll. Some varieties, such as Pawnee and Dakota Red, turn purple. Along with this change, increased quantities of solanin are formed in the cortex. Solanin is an alkaloidal glucoside, bitter in taste, and poisonous when taken in sufficient quantities. The poisonous alkaloid in solution is called solanidine. The quantity of solanin in sunburned tubers may be more than 20 times that in normal tubers. Most of the solanin is discarded with the peelings.

Varieties

Many varieties of potatoes have been grown in the United States but only 20 are important at the present time.[12, 21, 40, 42, 44] In 1945, the 4 leading varieties, Cobbler (Irish Cobbler), Triumph (Bliss Triumph), Katahdin, and Green Mountain accounted for 75 per cent of the acreage and, together with four others, Sebago, White Rose (Wisconsin Pride or American Giant), Russet Burbank (Netted Gem), and Chippewa, constituted more than 90 per cent of the acreage (Figure 281). Many of the older varieties are being replaced. Newer varieties, some of which are disease resistant, include Katahdin, Chippewa, Houma, Sebago, Earliane, Earliane 2, Warba,

FIG. 281(A). Potato varieties: Triumph (a); Warba (b); Pontiac (c); Sebago (d); Katahdin (e); Sequoia (f).

Sequoia, Mesaba, Pontiac, Mohawk, Erie, Kasota, Pawnee, Potomac, Red Warba, and Kennebec.[39]

Two yellow-fleshed varieties have been distributed, viz., Marygold in Maryland, and Calrose in California. This characteristic should be popular because of its assumed high vitamin A value and its illusion of having already been buttered, although American consumers, except some of foreign extraction, have not yet demanded a potato having such a color. Some of the potatoes of South America have purple flesh.

Some of the distinctive characteristics of the important varieties include the oblong tubers of Green Mountain (Figure 281), the red skin and short rounded shape of Triumph, and the long cylindrical tuber of Burbank and Russet Burbank, with the russeted skin of the latter.[12, 21, 40, 42, 44] The ideal tuber seems to be short, wide, and flat

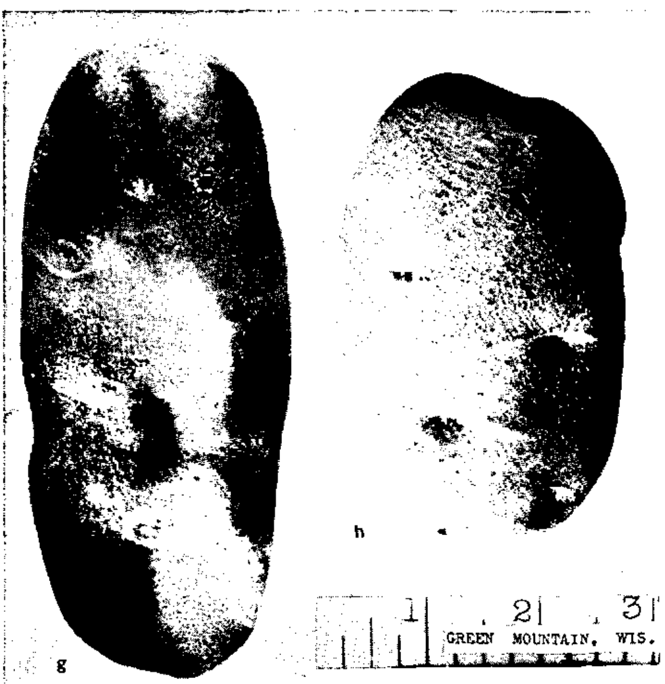

FIG. 281 (B). Potato varieties: Russet Burbank (Netted Gem) (g); Green Mountain (h).

with shallow eyes, and many of the newly-developed varieties are of that type.

Cobbler and Triumph are widely grown for early potatoes in many diverse regions of the country. Green Mountain, a late variety, is grown mostly in the northeastern states and, to some extent, in the mountainous sections of the south. Katahdin, the leading late variety, is becoming generally grown in all parts of the country where a late potato is desired. Chippewa is grown in the north central, northeastern and some of the southern states. Sebago is grown mostly in the northeastern fourth of the country but also in Florida and Alabama. Russet Burbank (Netted Gem) is the predominant variety in southern Idaho, Washington, Oregon, and Montana. To the eastern consumer it is the *Idaho baking potato*. This variety also is grown to some extent in the other western states, extending as far east as Minnesota. Rural New Yorker and Russet Rural are grown mostly in the central and eastern states and also in Colorado.[20] Houma is grown in New England and in the south.[24, 29]

Development of new improved varieties and elimination of inferior or unadapted varieties have been important factors in improving potato yields. Along with this have been the use of better planting stocks, increased fertilizer usage, better control of insects and diseases, better cultural methods, and concentration of the crop in the more favorable localities. All of these factors together are responsible for the consistent increases in potato yields from an average of 80 bushels around 1890 to more than 200 bushels per acre in 1948.

Rotations

Potatoes usually succeed best following a legume crop, such as clover, alfalfa, sweetclover, vetch, or peas, with the residues turned under in the fall. In the northeastern states, the rotation usually is potatoes, small grain, clover. In the corn belt, the rotation may be corn, potatoes, small grains, clover. The potato field leaves a good seedbed for small grains without plowing. Sometimes two consecutive crops of potatoes are grown. In the irrigated regions, potatoes often follow alfalfa that has been *crowned* in the fall and replowed in the spring. Beets follow the potato crop advantageously, and the beet field makes a good seedbed for sowing small grain and alfalfa

In the south, potatoes planted in early spring often follow an early fall-sown green-manure crop such as crimson clover, vetch, winter peas, or lupines. Those planted in the fall or winter can follow a summer legume such as the velvetbean, lespedeza, cowpea, soybean, or crotalaria.

In the dryland regions, potatoes usually are planted on fallowed land. The potato crop is likely to fail on dry land unless the soil is moist to a depth of 3 feet or more at planting time. A spring grain crop usually follows the potatoes, the land being worked but not plowed before sowing the grain.

Fertilizers

Potatoes respond well to applications of barnyard manure. Light applications of 6 to 8 tons per acre of manure that is well rotted or else turned under considerably in advance of planting time are recommended in order to avoid excessive scab injury. Also the addition of 50 to 75 pounds of superphosphate to each ton of manure is advised in order to provide a better fertility balance.[24] Manure is used more generally for potatoes than for any other field crop except sugar beets. Fully one-half the potato acreage of the United States is manured each year. In New Jersey, Florida, South Carolina, Virginia, North Carolina, and the New England states, the average application of commercial fertilizer to all potato land ranged from 1,100 to 1,900 pounds per acre in 1938. Other states used smaller quantities. Not more than one-sixth of the potato acreage in any of the states of Idaho, Colorado, Wyoming, Nebraska, Kansas, and North Dakota received any commercial fertilizer in 1938.

The most popular fertilizer formulas for potatoes in 1938 (Chapter 6, page 146) were 0–10–10 on the muck lands in Indiana, 2–8–10 in Pennsylvania, and 4–8–10 in Maine, where soil nitrogen either was fairly abundant or was supplied largely by manure or legume residues. The other states used mostly more completely-balanced mixtures such as 6–6–5 or 4–8–8. Recently, higher-analysis mixtures such as 5–10–10 and 8–16–20 have come into common use. Except for Louisiana and Indiana, the most common rate of application in the east and south was 1,000 or 2,000 pounds per acre. Maximum rates exceed 3,000 pounds per acre. Use of high-analysis fertilizers results in a saving of labor when such large quantities are applied. A good supply of potash is essential to heavy starch production, and thus is an important constituent in potato fertilizers. A 300-bushel potato crop contains about 90 pounds of potash, and twice that quantity often is supplied by fertilization. On peat and muck soils that are rich in nitrogen, abundant potash applications, and often some phosphorus also, are needed to balance the soil nutrients. In Minnesota, where potatoes do not respond to fertilizer on all soils,[35] an equivalent of 200 pounds per acre of 0–20–10 for the heavier soils and 275 pounds of 0–12–12 for lighter soils is recommended. Consistently higher yields are secured when the fertilizer bands are at the side and slightly below the potato seed piece rather than directly under the piece, or when mixed in the soil around the seed piece.[8] The side placement of fertilizer bands is accomplished with a planter having a fertilizer attachment.

Magnesium deficiency symptoms, which have appeared in potatoes grown on acid soils along the Atlantic seaboard, are corrected by including magnesium in the fertilizer mixture. Some potato soils are deficient in calcium or are excessively acid, but heavy applications of lime increase the incidence of the scab disease. In general, liming of potato land where the soils have a reaction above *p*H 5.2 is not recommended. On more acid soils, finely ground limestone or hydrated lime may be applied at rates not exceeding 1,000 pounds per acre for the clover that precedes the potato crop.

Seed Potatoes

The planting of certified nearly disease-free seed has been rather generally adopted by successful commercial growers. This eliminates the problems of place effect and running out that are the result of increasing infection of viruses causing mosaic, leaf roll, spindle tuber, and other diseases.[36] The common belief that potatoes grown on dry land are better for planting purposes than those grown under irrigation seems to be without foundation.[17]

Tubers left in the air or in dry soil will produce sprouts but no roots. In moist soil or some other wet medium, both sprouts and roots are formed. Large vigorous sprouts are an indication of quick emergence and relatively early maturity. In darkness or subdued light, the sprouts are long and lack green color. In the sunlight, the sprouts are short and soon turn green, and the tuber also becomes green. Occasionally, the tubers are prepared for planting by exposing them to light, a process called greening.

Since each eye usually contains several buds, sprouts will be produced even after some of them are removed or damaged. The removal of one crop of sprouts is only slightly detrimental to the tuber, although growth and removal of sprouts reduce the vigor of subsequent sprouts.[4] However, all eyes do not sprout at once unless the tubers are cut up because of a phenomenon called apical dominance, i.e., the eyes nearest the blossom (outer) end of the tuber sprout first. Long storage destroys apical dominance.[4]

Sprouting of potato tubers in storage occurs at temperatures of 40° F. or higher, but only after completion of a rest period, which is caused by restricted oxidation.[3] The rest period may range from 4 to 16 weeks when the potatoes are stored at 70° F., or longer at cooler storage temperatures. Immature tubers may have a longer rest period than do those that are fully mature.

SIZE OF SEED PIECE

The planting of certified nearly disease-free seed and the prevalent closer planting has altered the situation as compared with that 30 to 40 years ago when planting small tubers was considered hazardous.[43] Small-sized graded tubers from certified seed fields called No. 1 B (1½ to 2 inches in diameter) often are used for seed. Specialized seed potato growers often plant thickly so the seed-crop tubers will not be too large. The usual procedure, however, is to plant larger tubers cut into pieces of 1¼ to 2 ounces in size. When cut by hand, it is desired that each piece have one to three eyes. Blocky pieces 1½ to 2 inches in diameter are preferred. Tubers 5 to 8 ounces in weight can be cut into quarters of suitable planting size, and smaller tubers can be cut in half. Whole seed may be superior to cut pieces of the same size for seed purposes.[25, 26]

PREPARATION OF SEED TUBERS

Where conditions permit, potatoes are cut immediately before planting, but often labor is more readily available when fields are too wet for tillage operations, making it advisable to cut the seed before planting time. In the latter case, it is usually recommended that the tubers be suberized before planting. This consists in handling the tubers so as to promote development of cork tissue on the cut surface. The tubers are held in crates or sacks for a day or two after cutting and then emptied out to separate any pieces that have stuck together. Throughout the 10-day period of suberization, the temperature should be kept at about 60° F., with a high humidity (about 85 per cent) maintained by wetting the storage room or keeping wet sacks over the pile of cut seed.[46] Suberized potatoes usually can be stored up to 30 days after cutting without a reduction in stand or yield in the resultant crop. Shrinkage of the suberized tubers should not exceed 2 or 3 per cent in 30 days under good storage conditions.[28] Cutting may be done by hand or by special machines.

Seed potatoes usually are treated with disinfectants for the control of common scab, rhizoctonia, canker, and black scurf. The five most common materials used for the liquid dip treatments are listed below.[15, 20]

(1) Mercuric chloride (4 ounces in 30 gallons water) for 1½ hours.
(2) Acidulated mercuric chloride (6 ounces mercuric chloride and 1 quart commercial hydrochloric acid in 25 gallons of water) for 5 minutes.
(3) Formaldehyde, 1:120 solution, at 124° F. for 4 minutes.
(4) Various organic mercury commercial seed disinfectants.
(5) Yellow oxide of mercury (1 pound per 30 gallons of water) long enough to wet all of the surface of the tubers. This treatment is suitable only for whole tubers to be planted within 10 days.

Clean seed needs no treatment. Clean seed, or even treated seed, planted in scabby soil or in soil heavily infested with the rhizoctonia organism will produce diseased tubers.

CERTIFIED SEED POTATOES

Planting certified seed has resulted in yields of 31 to 219 bushels per acre higher than those secured from uncertified seed supplies.[43] In 1948 more than 48 million bushels of potatoes of known varieties were certified for seed in the United States, which was sufficient for planting the total commercial domestic acreage in 1949. The leading states in certified seed production are Maine, North Dakota, Minnesota, and California. Cool seasonal conditions in these states are very suitable for producing certified seed potatoes because mosaic disease symptoms come to full expression in the field, and the diseased plants can be rogued or removed easily. Also the cool temperature conditions in the north are suited to the growing of well-developed tubers. Both field and bin inspections are required for certification. The growing of certified seed potatoes has become an important specialized industry.

Formerly hill testing of selected tubers was generally recommended to growers as a means of improving their seed stocks. Now, however, new varieties of potatoes are being developed rapidly by professional breeders, and seed supplies come largely from inspected certified fields, practically free from off-type and diseased plants. Consequently, only the seed growers need consider tuber selection, and then only as a means of eliminating undesirable or diseased plants from the foundation seed stocks. Undesirable types among the initial foundation stocks can be detected if a piece of each tuber is planted early to observe its behavior while keeping a record of and storing the remaining portion. Only those that pass the preliminary inspection are planted later for increase. This procedure called tuber index is required of the producer of foundation stocks in the potato certification rules of certain organizations. Other seed potato growers test selected stock by the tuber unit method. This consists in quartering the tubers and planting the four pieces in adjacent hills. The four progeny plants of any defective tubers can then be located and eliminated.

Seedbed preparation

Plowing for potatoes often is done in the fall to turn under legume residues, but spring plowing is satisfactory if it can be completed 2 to 4 weeks in advance of planting so that any vegetation has time to decompose. Deep plowing for potatoes usually is recommended. It is essential that the seedbed be prepared at least 2 inches deeper than the 3 to 5 inch depth at which potatoes are planted. Most of the potato roots are found within the surface foot of soil but since they may penetrate to a depth of 5½ feet, there is no object in plowing deep to faciliate root growth. Subsoiling in preparation for potatoes is of no advantage even in heavy Fargo clay underlaid by a clay subsoil.[37] However, heavy soils in California frequently are tilled with a "chisel" at a depth of 12 to 16 inches in preparation for potatoes. A very compact and fine seedbed such as is desired for small-seeded crops is not essential for potatoes. In the south, the land often is bedded-up with a lister so that the potato rows on the beds will be well drained.

Planting

Most of the commercial potato crop of the north is planted with machines. The picker-type planter requiring only one operator is used most generally. This machine selects the seed piece by jabbing it with a pointed spike, which may spread diseases to healthy seed pieces. Cup-type planters requiring one or two operators are most suitable for planting whole tubers. The assisted-feed planter, which requires one or two men to help distribute the seed pieces in the compartments so that one piece is dropped each time, gives the most uniform stands. Planters for 1, 2, 3, or 4 rows are available. Small-scale planting can be done by opening the furrows with a lister, shovel plow, or moldboard plow, dropping the seed by hand and covering with a plow, cultivator, or harrow. Planting usually is deeper in sandy soil than in heavier soils, and for late planting than for early planting while the soil is cold, and for dry soil than for wet soil.

The average rate of planting potatoes in the United States is about 15 bushels per acre, the rates ranging from about 8 bushels in New Mexico to 20 or 21 bushels in Maine, California, Idaho, and Colorado. Formerly, a common rate of planting potatoes was 8 to 16 bushels per acre, a rate equivalent to a 1½-ounce seed piece every 15 to 30 inches apart in 42-inch rows. Six to eight bushels per acre is still considered to be a satisfactory rate in certain dryland sections. However, under irrigated or humid conditions where the soil is fertile or heavily fertilized, close planting results in better yields and fewer oversized tubers. About 23 bushels per acre are required for planting 1½-ounce seed pieces 12 inches apart in 36-inch rows.

Varieties such as Katahdin which produce few tubers per hill require thick planting so the tubers will not be too large for the best market demand.

Under irrigation in Colorado, planting 14 inches apart in 36-inch rows resulted in lower yields than was obtained from planting 8, 10, or 12 inches apart.[19] In general the best yield and quality of tuber is obtained from relatively close spacing.[19] Thick planting and large seed pieces reduce the incidence of oversized tubers, hollow heart and growth-cracked tubers.

In the northern part of the United States the planting of potatoes often begins as early as the soil can be fitted after the land has thawed and become sufficiently dry for seedbed tillage. The minimum temperature for any sprout growth in the potato is 40° F. Planting in the late winter and spring is general when the mean air temperature has risen to about 50° to 55° F. In the spring the soil temperature at a 4-inch depth where potatoes usually are planted is about the same as the mean air temperature. In the northern portion of the country, this temperature is reached about 10 to 14 days before the average last killing frost. In the central latitudes of the United States, planting is general about 4 weeks before, and in the southern latitudes about 6 weeks before the average last killing frost in the spring. The milder cold spring periods in the south that do not freeze the ground as deep as the potatoes are planted permit relatively earlier planting with reference to spring frosts. Potatoes are planted during the winter in the Gulf region (Figure 282). Spring planting begins about January 20 to February 1 in southern Georgia at 31° latitude, and about May 10 to 20 in Aroostook County, Maine, at about 46° north latitude. Thus, in the low altitude, Atlantic coastal region, the planting date differs by one day for about every 8 miles, or one-eighth of a degree difference in latitude. For higher elevations at a given latitude, planting is delayed about one day for each additional 100 feet in altitude.

The period between planting and digging is about 3½ to 4 months for the early crop in all sections and for the main crop in the northern border states, and 3 to 3½ months for the late or fall crop where early growth is not retarded by cold weather. The late crop usually is planted sufficiently early for the tubers to be fully mature at or

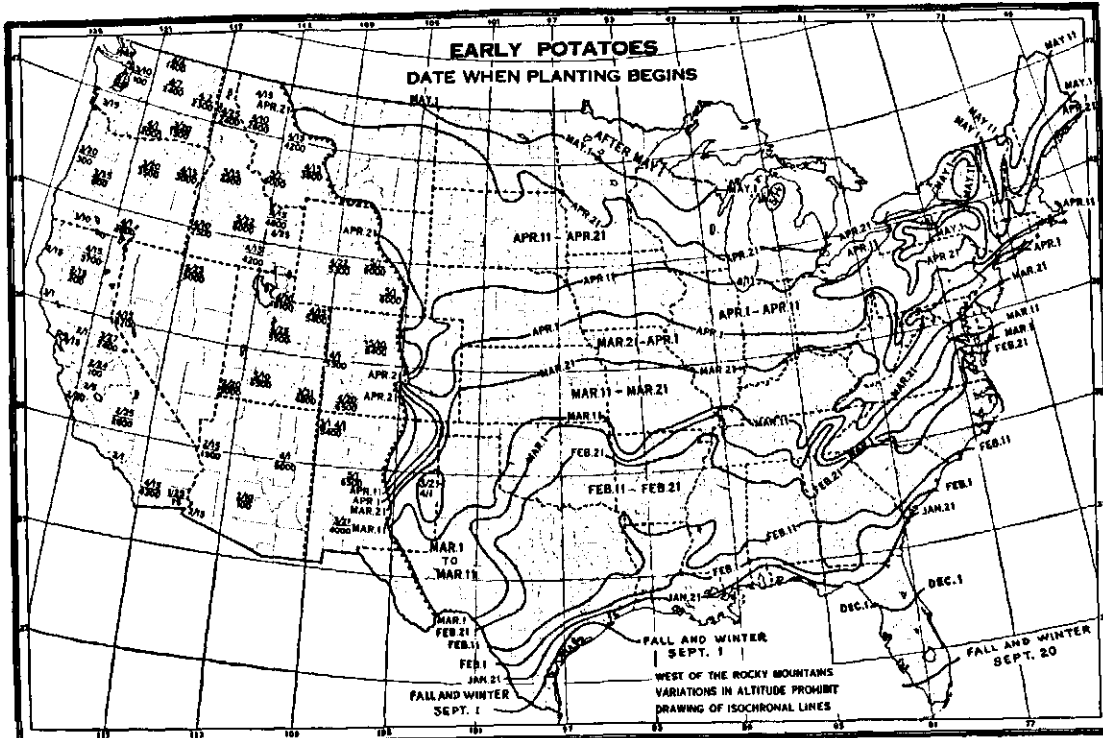

FIG. 282. Date when potato planting begins.

before the date of the average first killing frost. Thus, quick-maturing varieties such as Triumph, Cobbler, and Warba can be planted safely at a later date (2 to 4 weeks later) than can late, i.e., long-season, varieties such as Green Mountain, Katahdin, Sebago, or Rural New Yorker. A late variety tends to produce the highest yields when planting is early and when the tubers are able to reach maturity before frost, whereas an early variety usually gives the highest yields when planting is late.[18]

Two crops of potatoes a year often are grown, sometimes in the same field, in the area from Maryland and Kentucky southward. The fall or late crop is planted from July to September in time for the tubers to mature before freezing weather. The seed for the late crop is obtained either from stored tubers, usually from the north, or from the early southern crop. Certain varieties of these early-crop tubers do not sprout promptly because the rest period has not been broken. Freshly-harvested tubers of certain varieties such as Marygold and Warba will sprout promptly after chemical treatment. A fairly successful treatment is to dip freshly cut seed for an instant in a solution of ammonium thiocyanate (3 pounds in 50 gallons of water), drain, and plant the next day.[45] Other treatments also are successful.

Cultivation

Extra tillage beyond that necessary to kill weeds is of no benefit.[27] It merely injures the roots and dries out the soil. Pre-emergence tillage (or blind cultivation) to destroy small weeds is an accepted practice, a spike-tooth harrow or a light flexible-shank weeder being used once or twice before the potato plants are up. This usually is followed by a deep cultivation close to the row as soon as the plants are clearly visible, which loosens the soil for tuber development. Later, in some sections, the rows often are ridged to prevent the shallower tubers from being exposed to sunburn, or to protect them from freezing. Ridging, except to a slight degree incident to ordinary cultivation, is not practiced in many sections, particularly on dry land where evaporation of moisture from the soil is increased by ridging.

The growing of potatoes under a straw mulch lowers the soil temperature several degrees and increases the yields appreciably under hot conditions[10] when 8 to 10 tons of straw per acre are applied, which leaves a mulch 4 inches deep after settling. In the cooler northern border states, mulching has resulted in lower yields than was obtained from ordinary cultivation. Mulches should be applied after the soil begins to get warm. Weeds are able to penetrate the straw mulch when the rate of application is less than 8 tons per acre, i.e., 8 to 10 inches deep when applied.

Irrigation

Under irrigated conditions water should be applied often enough to keep the crop well supplied with moisture and always before the plants show the need of moisture by a dark green color in the leaves. The field should not be flooded. A seasonal total of 12 to 24 acre-inches of water in about 6 applications usually is ample for potatoes in the intermountain and Great Plain regions. On sandy soils in warmer regions, heavier irrigation may be necessary. The largest use of water is after the potatoes bloom but while the tubers are making rapid growth. Potato roots may absorb 57 per cent of the water used by the crop from the surface foot, 23 per cent from the second foot, 13 per cent from the third foot, and 7 per cent from the fourth foot of soil. The roots feed below the second foot only in the latter part of the season.

Top Killing

Various chemical dusts and sprays, including dinitro ortho secondary butyl phenol, sodium pentachlorphenate, and a proprietary compound, Sinox 15, have been used to kill the potato vines before harvest. Killing the vines hastens maturity, checks formation of oversize and hollow heart tubers, and reduces spread of late blight infection from the vines to the tubers. Hastening maturity may permit digging before freezing weather begins. The tubers ripen quickly, the skins thicken, and digging is easier after the vines are killed. Trials in Idaho show that dusting with an airplane can cover 10 acres in 6 minutes, applying 30 to 40 pounds of dust per acre.

The vines also are killed with mechanical beaters and by flaming. A second flaming a few days later burns the dead vines.

Harvesting

Early potatoes ordinarily are dug as soon as they are large enough for the market. Such new potatoes, in addition to being small, have thin, poorly-suberized skin that is easily damaged or rubbed off in handling, and they are watery and somewhat low in starch content. High seasonal prices justify such premature harvest. The number of tubers per hill and the percentage of starch, protein, and ash continue to increase until most of the leaves are dead, and the total weight may increase fivefold between blossoming and the stage at which all the leaves are dead.[5] In this same period, the sugar content may decrease from 1.0 down to 0.2 per cent, and the moisture content drops from 84 down to 80 per cent, but the crude fiber content remains almost constant. The starch content of Cobbler tubers may increase from 11.5 per cent up to 15 per cent during the three weeks between the time when all of the blooms have fallen and when 80 per cent of the leaves are dead. About 54 per cent or more of the total weight of tubers may be produced in the last month of the growing period.[14]

Most commercial potatoes are dug with a mechanical digger except in the south, where a shovel plow or some other implement or hand tool often is used. Most diggers shake and screen out the soil through round bars and deposit the tubers on top of the rows. Some new digging machines elevate and bag the tubers (Figure 283). The tubers are picked up by hand into baskets, crates, or bags, and passed over sorting machines to screen out small tubers, either at a warehouse or shed, or sorted by machine or by hand in the field before they are hauled. Number One potatoes are 1⅞ inches or more in diameter. Careful handling in all operations will avoid bruises or other damage to the tubers. In hot bright weather the tubers must be picked up within a few hours after digging in order to avoid sun scald. Many of the potatoes are washed mechanically after digging.

Potatoes are now marketed mostly in burlap bags of 100 pounds each.[32] A carload of potatoes averages 500 to 700 bushels.

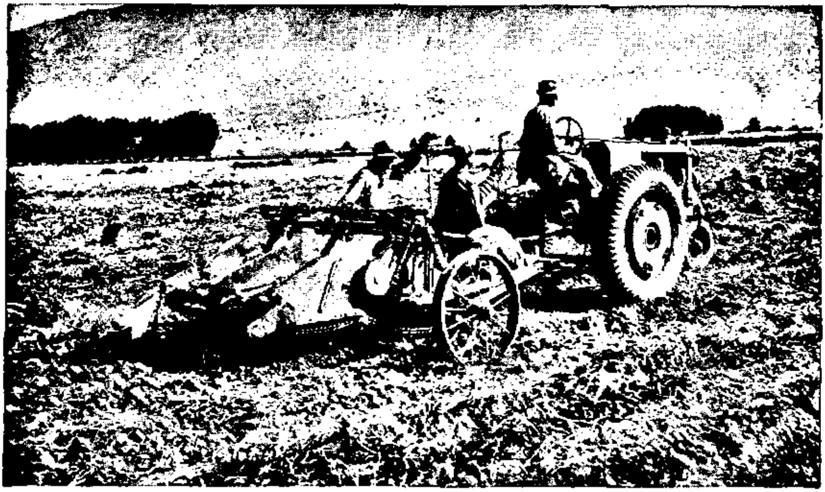

FIG. 283. A two-row potato digger. (Courtesy of International Harvester Company.)

The earliest potatoes on the market usually command the highest prices, and the seasonal prices of early potatoes drop as the crop from successive northern areas comes into the market.

Storage

For best keeping quality, potatoes going into storage should be held at about 60° F. with a humidity of 85 per cent for 2 weeks to permit injured tubers to heal. Thereafter, the temperature should be lowered to 36° to 38° F.[34] if it is desired to keep them from sprouting for an indefinite period. At 40° F., potatoes will remain dormant for 3 to 5 months after harvest. Potatoes stored at 32° F. do not freeze, but they do not keep so well as when stored at 36° F. to 38° F. Potatoes are stored occasionally in cold storage chambers, but usually in pits, cellars, or warehouses, the latter often being mostly or partly under ground. At low temperatures, the potatoes can be stored in large bins without danger of heating. At milder temperatures, they should be stored in sacks.[16] Ventilation of the storage place is necessary to prevent spoilage, because the tubers are living organisms that continue respiration with evolution of heat, water, and carbon dioxide. Warm air admitted to cold potatoes causes condensation of moisture, which in turn encourages decay, so the ventilators should be closed when the outside temperature is higher than that in the cellar. The relative humidity should be kept at 85 to 90 per cent to prevent shrinkage of the tubers.

Potatoes stored at temperatures below 50° F. undergo conversion of starch into sugar. At 36° F., 25 to 30 per cent of the starch is converted into sugar within 6 weeks,[47] and the tubers are sweet, soggy instead of mealy, and of poor cooking quality. When slices of such potatoes are French fried or cooked into chips, they are of an unattractive dark brown color because of caramelization of the sugar. Starch conversion is much less at 40° F. and scarcely perceptible at 50° F. The sugar reverts largely to starch when the storage temperature is raised to 50° or 60° F. for a few weeks or sometimes for only a few days. For immediate or early use, potatoes should be stored at 50° to 70° F. At 60° to 70° F. nearly all the initial sugar present is eventually used up in respiration, and the tubers become more mealy. For home storage at moderate temperatures, sprouting can be checked by storing apples in the same compartment. The apples give off substances (probably ethylene) that check sprouting. When it is necessary to hold potatoes for some time at the higher storage temperatures or to ship them southward, the sprouting of tubers can be retarded by dusting or spraying them with hormonelike chemicals such as MENA (methyl ester of alphanaphthalene-acetic acid). About ⅔ gram to 1½ grams of this chemical is required for each bushel of potatoes. It is diluted with a dust before application to the tubers. The treatment is too new for safe recommendation for seed potatoes, although it does not prevent eventual sprouting.

Uses

In the United States, fully one-eighth of the average potato crop is used for planting, and nearly 80 per cent is held or sold for food purposes. The remaining 7 per cent is fed to livestock on the farms where they are grown, or is lost by decay and shrinkage on the farm. Starch is manufactured from cull potatoes. Dehydrated potatoes are used for food and in whisky manufacture. In Germany, considerable quantities of potatoes are processed into starch and alcohol, or are fed to livestock. Russians make vodka from potatoes.

The average whole potato consists of about 79 per cent water, 1 per cent ash, 2 per cent protein, 0.1 per cent fat, 0.6 per cent crude fiber, and 17 to 18 per cent of nitrogen-free extract. About 20 per cent of a large sound tuber consists of peeling, i.e., periderm (or skin) plus some of the layers of the cortex.[11] The remaining edible portion is composed of about 78 per cent water, 2.2 per cent protein, 1 per cent ash, 0.1 per cent fat, 0.4 per cent crude fiber, and 18 per cent starch, sugar, and other carbohydrates. A good mealy potato is about 25 per cent dry matter.[2] The dry matter consists of about 70 per cent starch, 15 per cent other carbohydrates, 10 per cent protein, 4.4 per cent ash, and 0.3 per cent fat. High starch content is associated with mealiness and good cooking quality. Since starch predominates in the potato solids, the starch content is closely associated with the specific gravity of the whole tuber. The value of a given lot of potatoes for drying, starch manufacture, or cooking can be measured by a simple density test consisting of immersion in a series of common salt solutions of different concentration in which the tubers either float or sink, depending upon their own specific gravity.[13]

Most of the present leading varieties of potatoes grown and matured under good conditions in four states contain 14 to 19 per cent starch. Several European varieties are higher in starch content, but they tend to produce low acre yields of tubers.[1]

Diseases

DISEASES CAUSED BY VIRUSES

The virus diseases include mild mosaic, rugose mosaic, leaf roll, spindle tuber, and yellow dwarf. Tubers from infected plants carry the virus, and when planted, produce diseased plants. Such affected plants should be removed from fields producing seed stock, but it is not necessary to remove them from plantings for table use. The virus is spread considerably by insects, especially aphids. Use of certified seed reduces losses from virus diseases.

Mild Mosaic. Mild mosaic is characterized by a definite mottling in which yellowish or light-colored areas alternate with similar areas of normal green in the leaf (Figure 284). A slight crinkling is usually present; under conditions favorable for the disease, the margins of the leaves may be wavy or ruffled. Usually affected plants will not produce more than three-fourths of the normal yield. Katahdin, Chippewa, Earlaine, Sebago, and Houma varieties are all resistant to this disease.

FIG. 284. Potato leaflet affected by mild mosaic.

Rugose Mosaic. Rugose mosaic is more destructive than mild mosaic. Plants from diseased tubers are dwarfed and the leaves are mottled, the mottled areas being smaller and more numerous than in mild mosaic. A distinct crinkling is always present. The under sides of lower leaves generally show more or less blackening and death of veins. Tubers from plants with current-season infection will produce plants with rugose mosaic the following season.

No varieties resistant to rugose mosaic are known, but Katahdin contracts the disease less rapidly than do other varieties.

Leaf Roll. The symptoms of leaf roll are leathery leaflets that roll upward at the edge. These rolled leaves become yellow green instead of dark green, and the plants are considerably dwarfed. Affected leaves are brittle to the touch. The yield of affected plants may be reduced to one-third or one-half normal.

Only certified seed stock known to have come from plantings that were free from leaf roll should be used for planting.

Resistant varieties are being tested, and one or more of them will probably be increased for distribution.

Spindle Tuber. In most varieties, spindle tuber is well characterized by a pronounced elongation of the tubers. The tubers are small and may become pointed at one or both ends.

The plants are more erect and somewhat spindling in growth, and there are narrowness of shoots, dwarfing, and a decidedly darker green color of the foliage.

The disease may cause a marked reduction in yield, and the tubers are often so poorly shaped as to be of low commercial grade. Certain insects, such as grasshoppers, flea beetles, the tarnished plant bug, and the Colorado potato beetle, spread the disease. Cutting knives and picker planters also spread it. It can be controlled by use of good certified seed.

COMMON SCAB

Common scab[15] is caused by a soil-inhabiting fungus (*Actinomyces scabies*) that also is carried on the tubers. The disease is characterized by round, corky pits on the skin of the potato (Figure 285).

Development of common scab is favored by an alkaline soil reaction, but it occurs in slightly acid soils. Increasing soil acidity will check development of the fungus. Addition of lime or barnyard manure to any soil, except a very acid one, tends to increase scab. The fungus develops best when the soil moisture is slightly below the optimum for development of the potato plant. In loose, well-aerated soils, it may develop readily even under very wet conditions. Application of 300 to 600 pounds of sulfur an acre on lighter types of soils to make the soil more acid usually reduces the severity of the attack somewhat.

Common scab can be practically eliminated on moderately infected tubers by treatment with hot formaldehyde or with acidulated mercuric chloride, if the field is clean.

A number of varieties, Menominee, Ontario, Cayuga, and Seneca, are highly resistant to scab even under conditions most favorable for the disease.

RHIZOCTONIA CANKER (BLACK SCURF)

Rhizoctonia canker, or black scurf, is caused by a widespread soil inhabiting fungus, *Rhizoctonia solani*, that sometimes causes considerable reduction in stand and yield.

The most common symptom of the disease, irregular small black crusts on the skin, does little harm except to the appearance of the mature tubers (Figure 285). When infested tubers are planted, the fungus may attack and destroy the young sprouts. In this stage, brown decayed areas on the white underground stems often girdle the stems. Plants attacked in this manner may turn yellowish, the leaves may roll, and small greenish tubers may appear on the stems

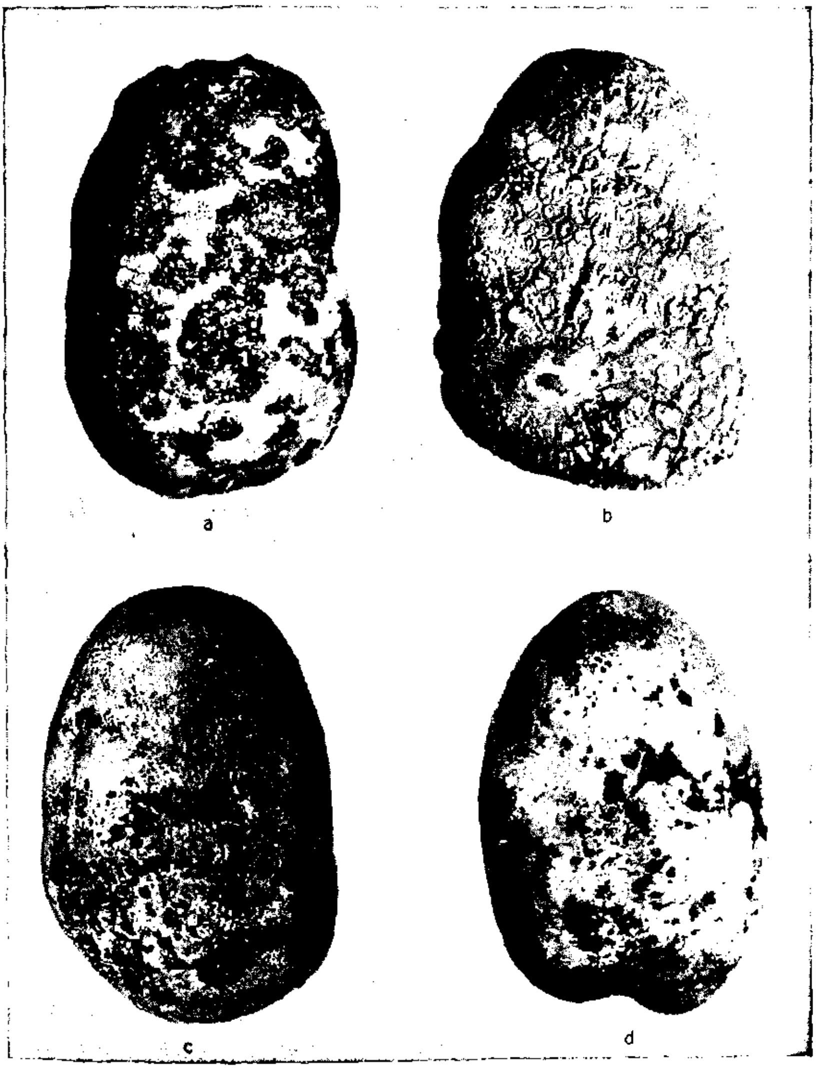

FIG. 285. Scab (a), russet scab (b), black scurf (c), and rhizoctonia (d).

above ground. The fungus thrives under moist low-temperature conditions, and is most likely to attack potatoes planted in the cooler part of the year.

Rhizoctonia canker can be controlled in clean fields by treatment of infected seed stock with either hot formaldehyde or acidulated mercuric chloride. Planting on a ridge tends to reduce the seriousness of this disease, since the soil warms up more rapidly than on flat land, thus making conditions unfavorable for the fungus.

RING ROT

Ring rot, or bacterial ring rot, caused by *Corynebacterium sepedonica* is a very destructive seed-borne disease. The first symptom of the disease in the foliage is a wilting of the tips of leaves and branches. Later, the leaves become slightly rolled and mottled and fade to a pale green followed by a pale yellow color. Dead areas develop on the leaves, and the affected plants gradually die.

When dug, diseased hills usually contain tubers ranging from those that are apparently sound to those that are completely decayed. Decay of the tuber begins in a region immediately below the skin, thus causing a ring rot appearance.

Infected seed should not be planted, and only dependable certified seed should be used, to avoid possible loss from ring rot. One variety, Teton, is highly resistant, but not immune, to ring rot.

LATE BLIGHT

Late blight, caused by *Phytophthora infestans,* is usually seen first on the margins of the lower leaves, and works inward until entire leaves may be affected and killed. Irregular water-soaked spots develop at the margins of the leaves. Under conditions of high moisture with warm day temperatures and cool nights, the spots enlarge rapidly and the infection spreads to other leaves. All the plants in a field may be killed in a few days. A noticeable odor is given off from the dead foliage in fields that are severely attacked. Late blight was the chief cause of the potato famine in Ireland in 1845–46.

The organism may also attack the tubers and produce in them slightly sunken brownish or purplish spots that enlarge until the entire tuber is affected. When such tubers are cut, the interior shows granular brick-red blotches, a distinctive characteristic of late blight. Infected tubers may rot in the field or in storage.

An 8–8–100 Bordeaux mixture spray will control late blight and should be applied as soon as symptoms of the disease appear. The spraying should be repeated at weekly intervals so as to keep the foliage well covered.

The use of resistant varieties is the best means of controlling late blight. The Sebago variety is moderately resistant to this disease in foliage and tubers.

EARLY BLIGHT

Early blight, caused by the fungus *Alternaria solani*, is a very common disease of potatoes and causes noticeable damage in some years. It usually becomes serious several weeks before harvest. Small, scattered, dark, circular spots are first produced on the lower leaves, which often become yellow. These spots enlarge, and the affected tissue dies. The enlarged spots develop a series of concentric rings and produce a target-board effect.

Spraying with 8–8–100 Bordeaux mixture, as recommended for late blight, gives control of early blight.

Insects

COLORADO POTATO BEETLE

The Colorado potato beetle (*Leptinotarsa decemlineata*) is one of the most widespread, and formerly was one of the most destructive, insect pests of potatoes in this country. The adult, which appears in the spring, is a hard-shell beetle about two-fifths of an inch long, stout and roundish, and of a light yellowish color, with 10 black stripes down its back (Figure 286). The female beetles lay orange-red eggs on the under sides of the potato leaves. The eggs hatch into small larvae, or soft-bodied slugs, ranging in color from lemon to reddish brown and marked with two rows of black spots on each side. The head and legs are black. The slugs feed greedily and grow rapidly for a period of approximately 2 weeks, during which they devour large quantities of potato foliage. There may be one to two generations of this insect each year, depending upon climatic conditions.

The Colorado potato beetle can be controlled with insecticides containing arsenicals, rotenone, or DDT. For sprays other than DDT use 1 pound of Paris green and 4 pounds of hydrated lime, or 4 pounds of calcium arsenate, or 4 pounds of lead arsenate, or 4 pounds of derris or cubé root containing from 4 to 5 per cent rotenone, to each 100 gallons of water. If a Bordeaux spray is to be applied for control of diseases, add the arsenicals in the quantities men-

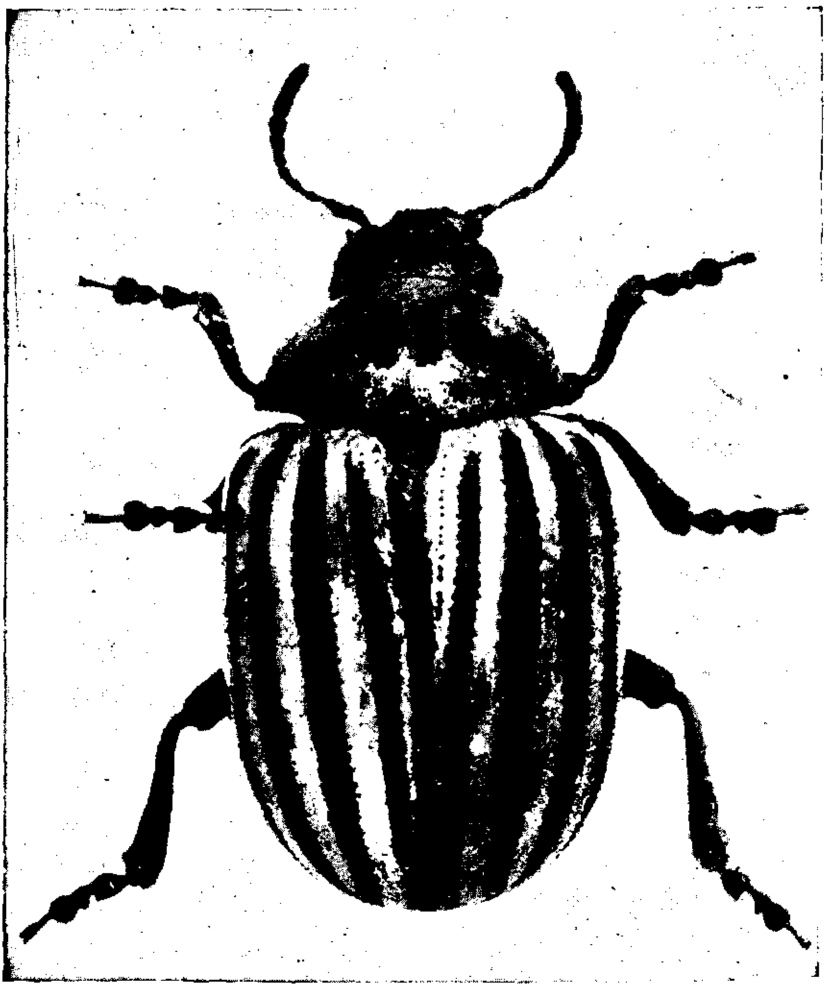

FIG. 286. Colorado potato beetle adult (much enlarged).

tioned, to each 100 gallons of the Bordeaux mixture. For dusts, use them at the rate of 1 pound of Paris green or lead arsenate to 12 pounds of hydrated lime or equal parts of calcium arsenate and hydrated lime, or use a dust mixture containing 0.75 per cent rotenone.

POTATO FLEA BEETLE

The potato flea beetle adult (*Epitrix cucumeris*) reduces potato yields by eating the foliage, and the larvae may attack the tubers.[24] The adult beetle is about one-sixteenth inch long, black in general appearance, with yellow legs. When disturbed, it jumps quickly and may readily disappear from sight. It eats holes in the leaves, causing some leaves to dry and fall. The slender, white, wormlike larva, approximately one-fifth inch long, feeds on the roots and tubers. On the tubers its feeding results in tiny tunnels near the surface of the tubers and pimplelike scars on the surface. The potato flea beetle on the foliage may be controlled by spraying at 7- to 10-day intervals with 4 pounds of calcium arsenate to 100 gallons of Bordeaux mixture, or by dusting with a calcium arsenate-monohydrated copper sulfate-hydrated lime mixture (25–20–55). Dusting is less effective than spraying. Some varieties such as Sequoia are resistant to flea beetle injury.

POTATO AND TOMATO PSYLLID

The potato and tomato psyllid (*Paratrioza cockerelli*) greatly reduces the yields of potatoes in Colorado, Nebraska, Wyoming, and New Mexico. The adult psyllids often migrate long distances from their winter hibernation quarters. The young psyllids or nymphs, which are flat, scalelike, and light yellow or green, feed on the under side of the leaves. The feeding causes a curling and yellowing of the leaves known as psyllid yellows, and the production of many small tubers in the hill. Several generations of the psyllid develop within a year. They are controlled by dusting with sulfur or by use of a lime-sulfur spray.

POTATO TUBER WORM

The potato tuber worm (*Gnorimoschema operculella*) is the immature stage of a small gray moth that deposits its eggs on the foliage of potatoes and related plants. In stored potatoes the moth lays eggs near the eyes of the tubers or in other depressions. The eggs soon hatch into small white tuber worms that develop a pinkish cast along the back as they mature. In the field the young tuber worms are *leaf* or *stem miners*. When the infested foliage dries, they find their way to the tubers through cracks in the soil. The tuber worms tunnel throughout the tubers and render them unmarketable.

The tuber worm is best controlled by cultural practices, careful clean-up measures, and fumigation of storages. All culls and infested tubers should be destroyed or fed to stock immediately after harvest. All volunteer potato plants should be destroyed. Tuber worms within the tubers may be killed by fumigating for 3 hours with methyl bromide at the rate of 2.4 pounds per 1,000 cubic feet of space, including that occupied by the tubers.

POTATO APHIDS

Several species of soft-bodied plant lice, or aphids, attack potato foliage and transmit leafroll, mosaic, and other diseases. When abundant, these aphids reduce the yield of tubers by sucking the juices from the foliage. Potato aphids are controlled with DDT dusts and sprays which also control flea beetles and the Colorado potato beetle. Dust mixtures containing 0.75 per cent rotenone are also effective against the aphids. Some varieties of potatoes are less subject to injury from aphids than others.

SEED-CORN MAGGOT

The seed-corn maggot (*Hylemya cilicrura*) is the immature, or maggot, stage of a small fly that lays its eggs on soil and decaying vegetable matter. Seed-corn maggots' food preferences appear to be the sprouting seed and the seedlings or decaying parts of such plants as beans, corn, peas, and potatoes. Their feeding on potato seed pieces in the soil is accompanied by decay, and the young potato plants are either killed or become so weakened as to reduce their growth and yield. The best control for the seed-corn maggot is to allow the potato seed pieces to heal, or suberize, before they are planted.

POTATO LEAFHOPPER

The potato leafhopper (*Empoasca fabae*) causes a very destructive diseaselike condition known as hopperburn. This condition begins with a yellowing of the leaf around the margin and tip, followed by a curling upward and rolling inward. The leaf changes in appearance from yellow to brown and then becomes dry and brittle. When the leafhopper infestation is heavy the entire plant may die prematurely.

The potato leafhopper is a small green wedge-shaped insect, about one-eighth inch in length. Both young and adults feed on the underside of the leaves and suck the juices from the plants.

Leafhoppers and the resultant hopperburn can be controlled by spraying or dusting with DDT, or dusting with a pyrethrum-sulfur mixture. Care should be taken to cover the underside of the leaves. Some varieties, including Sequoia, show a high degree of resistance to hopperburn.

WIREWORMS

Potato tubers are often rendered unmarketable by small holes caused by the feeding of wireworms. Wireworms bore clean tunnels that are usually perpendicular to the surface of the tuber and are lined with a new growth of plant tissue. Lands known to be infested with wireworms should be avoided for potato culture. Soil fumigation with D–D or E.D.B. will kill wireworms as well as nematodes (Figure 287). The expense of fumigation, (often 20 dollars to 40 dollars per acre), is fully justified in productive potato areas, because one treatment may protect the soil for several seasons.

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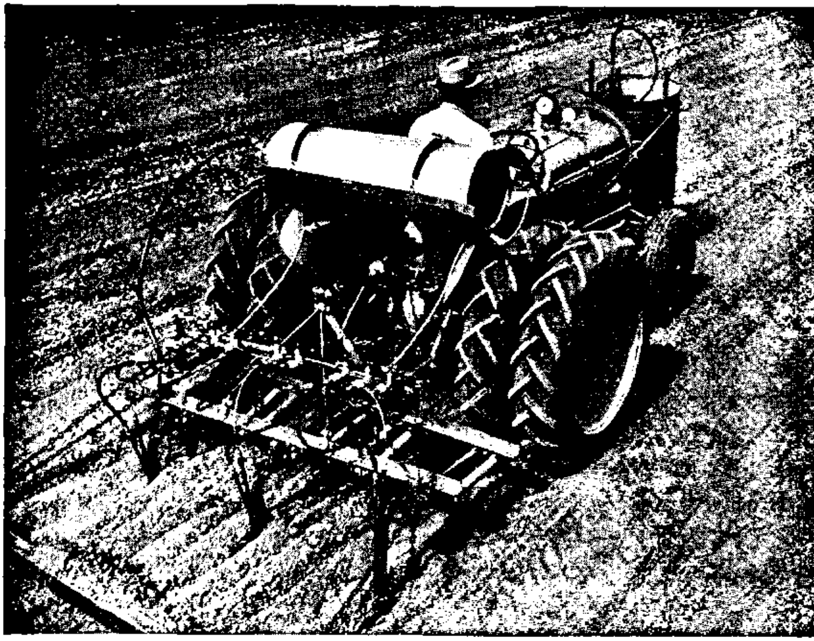

FIG. 287. Applying D–D to the soil to control the rootknot nematode, and also liquid ammonia for nitrogen fertilization in the same operation. (Courtesy Shell Chemical Corporation.)

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38 MISCELLANEOUS INDUSTRIAL CROPS *

Hops

ECONOMIC IMPORTANCE

The hop is an intensive crop requiring a heavy initial investment and a large expenditure of labor and materials for maintenance and operation on more than 800 farms. Including interest and depreciation, the annual costs often exceed $200 per acre.[25]

Production in the United States from 1937 to 1946 averaged about 43 million pounds on 35 thousand acres, or more than 1,200 pounds of cured hops per acre. Oregon, Washington, and California, now produce nearly all the domestic commercial hops, although a few are still grown in New York (Figure 100). Hops were introduced into America as early as 1629. The first commercial hopyard was established in New York in 1808. Cultivation of hops later extended into Wisconsin, and before 1869 had become established in the Pacific coast states.

The leading countries in hop production are United States, England (including Wales), Czechoslovakia, Germany, and Yugoslavia. Czechoslovakia is the chief exporting country. The hop is thought to be indigenous to the British Isles,[31] but cultivated hops were grown in Germany in 768 A.D., and were introduced into England late in the fifteenth century.[46]

* In the preparation of this chapter, liberal use has been made of mimeographed circulars on the different crops issued by the Bureau of Plant Industry, Soils, and Agricultural Engineering, U. S. Department of Agriculture, Beltsville, Md.

ADAPTATION

Hops are grown under a wide range of climatic conditions, but mostly in mild regions having abundant early rainfall, or irrigation, followed by dry warm weather. Such conditions are found in the Pacific northwest, the valleys of the northern half of California accessible to cool ocean breezes, western New York, and northern and central Europe.

BOTANICAL DESCRIPTION

Hops belong to the tribe or subfamily *Cannabineae* of the family *Urticaceae*, the nettle family. The hop plant (*Humulus lupulus*) is a long-lived perennial. The stems are herbaceous, roughened, angular, and hollow. Their color among different varieties is purplish-red, pale green, or green streaked with red. The stems above ground bear thin opposite lateral branches. The slender trailing or twining vines may grow to a length of 25 to 30 feet. The stems, as well as the leaf petioles, have several lines of strong hooked hairs which help them cling to their supports. After being cut back each year new stems arise each spring from buds on the underground rootstalks.

Inflorescences. The hop is a dioecious plant with sterile flowers in racemes or panicles, and fertile (pistillate) flowers in clusters or catkins. Occasional plants are monoecious. The commercial hops borne on the female plants are the spikelike pistillate inflorescences,[36] somewhat resembling fir cones in shape (Figure 288). The cones, botanically, are called strobiles, and colloquially are referred to as beer blossoms. The strobiles are borne on lateral branches of the main stem. The strobiles are 1 to 2½ inches in length.

The staminate flowers are about 6 mm. in diameter. Since the male vines produce no hops, large numbers of them are undesirable. One or two per cent of male plants uniformly distributed throughout the hopyard provide sufficient pollen for fertilizing the pistillate plants.[21]

Fruit and Seed. The fruit of the hop is purple, oval, and about the size of a mustard seed. The seed possesses a curved embryo and a very small amount of endosperm.[47] The crop is seldom reproduced from seed because of the great variability in the progeny. Seedless (unfertilized) hops weigh about 30 per cent less than those that develop seed. Their quality is better than that of seeded hops but the yield is smaller. Hop seeds contain a bitter unpalatable oil.[25]

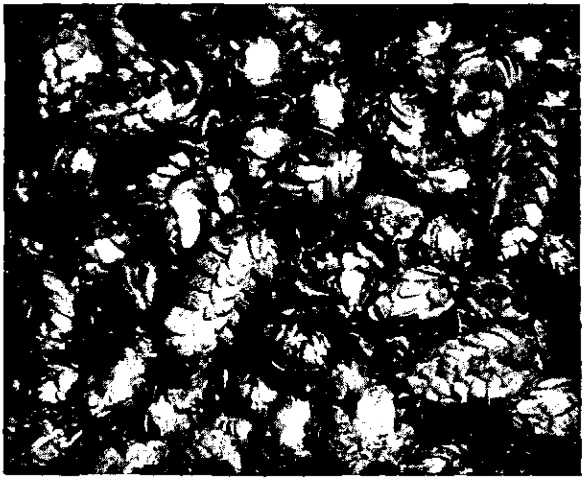

FIG. 288. These machine-picked hops are freer from leaves than are the hand-picked product. (Courtesy of E. Clemens Horst Co.)

The outer surface of the bracteoles, perianth, and bases of the bractlike stipules are covered with yellow pollenlike resinous grains. These latter are the lupulin or hop meal. The commercial value of well-cured hops is based upon the amount and quality of the lupulin.

The principal active ingredients in the lupulin glands are:

(1) Hop oil. A volatile essential oil having a characteristic aroma, constituting about 0.2 to 0.8 per cent.
(2) Nonresinous bitter principle.
(3) Resins. Of these the hard resin is practically tasteless and is devoid of brewing value. The soft alpha and beta resins are bitter and they impart this taste to the beer wort, and also have a preservative effect. Hops contains 10 to 18 per cent or more of total resins.
(4) Tannin, which constitutes 4 to 5 per cent of the hop.

VARIETIES

The leading varieties are English or Late Cluster, Early Cluster, and Fuggles, and Red Vine which is grown as a mixture with the others.[18, 50] The Late Cluster is high in yield and lupulin content, and is about two weeks later than Early Cluster or Fuggles. Fuggles is resistant to downy mildew.

CULTURAL METHODS

Hops are propagated by cuttings from the numerous runners sent out by the plant just below the surface of the ground. The excess shoots from the rootstalk are pruned once a year, usually in the spring. These are cut into pieces 6 to 8 inches long that bear at least two sets of buds, and planted promptly thereafter.[21]

The hops are set in hills 4 to 8 feet apart, with three or four cuttings in each hill. Hills 8 feet apart permit tractor cultivation. Very few strobiles are produced the first year, and the vines do not reach full bearing until the second or third year.

Hopyards, once established, often are maintained for many years, missing hills being replaced at pruning time each spring. Winter cover crops such as vetch are grown, or weeds are allowed to grow throughout the mild rainy winter season to be plowed under in the spring. Fertilizers often are applied, usually consisting of 300 to 500 pounds of superphosphate (and occasionally 100 to 200 pounds of muriate of potash), applied in the fall, and 150 to 400 pounds of 20 per cent nitrogen fertilizer applied in the spring.

Training. Hop plants are trained on trellises or poles, chiefly the former at present. Trellised hops are healthier, more successfully sprayed, mature earlier, are usually richer and brighter, and can be picked cleaner.

The high trellis or high wire system consists of posts at every sixth or seventh hill throughout the yard. At the tops of these posts heavy wires are stretched across the yard at right angles to the rows, 12 to 20 feet above the ground. Posts also are set at the ends of each row or at alternate rows, and wires stretched over each row are hung on the cross wires with S-shaped wire hooks. Strings tied to small stakes at each hill and to the wire above the row permit the vines to climb up to the wire which they are trained to follow.

In the low form of trellis poles about 8 feet long are set at each hill or every third hill and wires or string are strung along the tops of the poles in both directions.

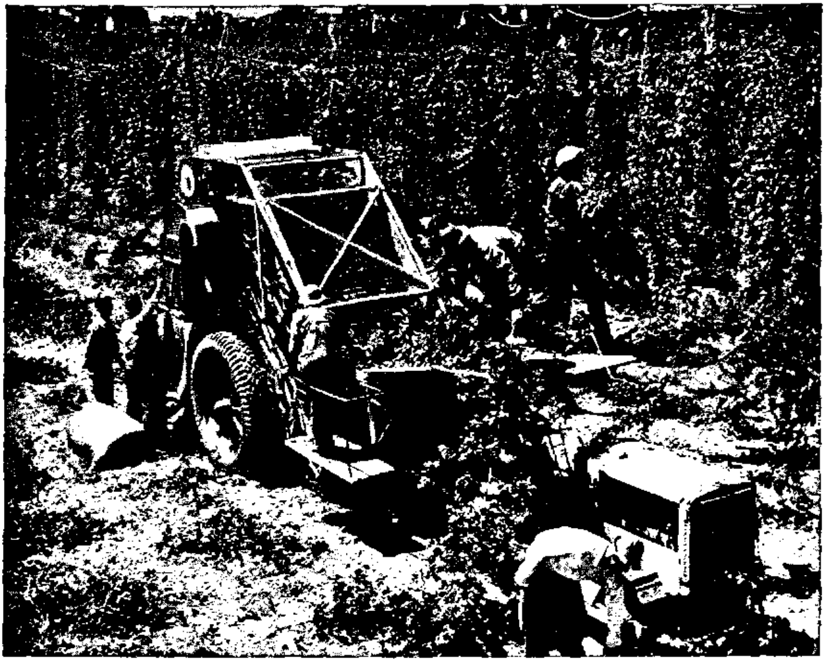

FIG. 289. Mobile hop-picking machine operating in the field. The vines are cut by hand and fed into the moving machine. (Courtesy of E. Clemens Horst Co.)

HARVEST

Ripe hops have the best quality. The strobiles or cones change from a bright green to a bright yellowish-green, and become more resilient, sticky, crisp, and papery, the pericarp on the hop fruits takes on a dark purple color, and the characteristic lupulin odor becomes very marked as hops approach ripeness. In harvesting, a section of the wire is unhooked from the crosswires with a long wire-down pole to lower the vines to a convenient height for picking. Then the light fluffy hops are stripped or plucked from the vines by hand into baskets holding about 4½ bushels or 25 pounds. The vines are cut from the wire immediately after the hops are picked and the wires are hooked up again to permit the crop to be hauled from the field. The picking and handling of hops requires about two itinerant workers per acre for a two-or-three week period. Machines devised to pick hops mechanically have been widely used since 1944, particularly in Washington (Figure 289).

CURING

The sacked hops are hauled to the drier the day they are picked. Unless dried soon after picking, the hops undergo oxidation, which seriously injures their appearance as well as their aroma and other valuable qualities. The moisture content of 65 to 80 per cent in the field is reduced to 10 to 14 per cent. Hops usually are kiln dried for about 20 hours in a layer about 20 to 24 inches deep. The elevated slatted floor of the kiln is covered with one thickness of burlap. Beneath this floor are the furnaces and hot-air pipes (Figure 290). The drying temperature is kept below about 110° F., until the cells are killed, when the temperature is raised to about 140° to 150° F. to complete the drying. Proper curing brings about the death of the cells through the gradual withdrawal of water.[49] Unsulfured hops are now in greater demand, but formerly the burning of 1 to 4 pounds of sulfur per 100 pounds of undried hops under the curing floor was a common practice. Sulfuring bleaches the hops, checks microorganisms present, and retards the deterioration of the desir-

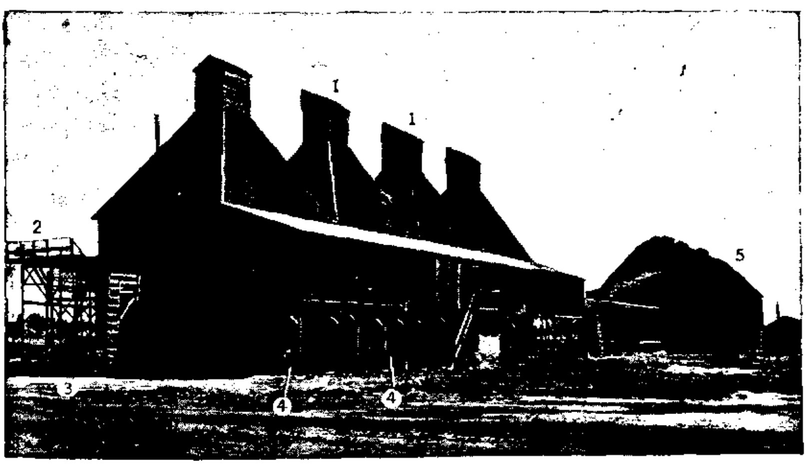

FIG. 290. A typical hop dryer showing ventilating cupolas (1), unloading platform (2), portable derrick platform used in training the vines in the field (3), furnaces (4); and (5) cooling house.

able chemical constituents. The dried hops are moved to the cooler bin, allowed to cure for 10 to 14 days, and then pressed into burlap-covered bales weighing about 200 pounds.

USES

The principal use of hops is in the manufacture of beer. The sweet beer wort is boiled with the hops. The flavor of the wort is improved by the extraction of the active ingredients of the hops. The essential oil of the lupulin glands imparts an aroma to the beer, and the resins give to the hopped wort a slightly bitter taste, and the tannin probably serves to precipitate albuminous substances. The malic and citric acids in the hops tend to increase the acidity of the wort. About 8 to 13 ounces of hops are used for each barrel of beer.[46]

DISEASES

Downy mildew is the most serious disease of hops in the world. This disease is caused by a fungus (*Pseudoperonospora humuli*). The disease, which attacks the shoots,[20] stems, and flower parts, is spread in damp weather by wind, and from cuttings. Downy mildew may be controlled by destroying the cut vines, escaped plants, and affected shoots, and by spraying or dusting. Stripping all leaves from the stems from the bottom up to within 4 feet of the trellis wire reduces the spread of downy mildew as well as of the red spider and the hop aphid. Sprays should be applied (1) when the vines are first trained, (2) when the vines get to the cross wires, (3) just before the female flower buds open, and (4) at other times if weather conditions are favorable to spread of the disease. The recommended spray is zinc sulfate-hydrated lime 4–4–50 plus a rosin soap spreader.[21] For dusting, 1 to 10 proportions of monohydrate copper sulfate and hydrated lime are used.

Sooty mold (*Fumago vagans*) blackens the cones and the infection is carried into the cones by aphids. Control of aphids largely prevents the trouble. Powdery mildew (*Sphaerotheca humuli*) which occurs in New York is controlled by sulfur dusting. Plants affected by virus diseases, crown gall, and rots should be removed from the field and be replaced by healthy cuttings.

INSECTS

The chief insect attacking hops is the hop aphid (*Phorodon humuli*) which is controlled by stripping the lower leaves from the vines and by insecticidal sprays and dusts. Recommended sprays are: (1) 1 part of nicotine sulfate and 4 to 5 parts of whale oil soap, or (2) 3 to 5 parts of quassia chips and 5 parts of whale oil soap, in water. For dusting, a 10–50–40 mixture of nicotine sulfate, hydrated lime, and a filler is used. Other insects attacking hops include cucumber beetles, thrips, leaf tier, hop-plant borer, hop butterfly, hop flea beetle, and webworm.

The red spider is controlled by stripping the lower leaves and by dusting with a 5–50–45 mixture of nicotine sulfate (40 per cent), hydrated lime, and dusting sulfur.

Mint

ECONOMIC IMPORTANCE

Peppermint and spearmint were harvested on about 46,000 acres annually in the United States from 1938 to 1947. About four-fifths of this was peppermint. The average production of extracted mint oil was 1,400,000 pounds. The average acre yield of oil was about 30 pounds valued at 2 dollars to 6 dollars per pound. The census of 1940 reported 1,970 growers of mint, harvesting an average of 16.5 acres each. The leading states in mint production are Indiana, Michigan, California, Ohio, Oregon, and Washington. Spearmint is grown commercially only in Michigan and Indiana.

The distilling of mint oil for use in medicines was practiced in Egypt as early as 410 A.D. The Japanese were distilling mint oil for an eyewash as early as 984 A.D. Production began in England about 1696, and in the United States, at Ashfield, Mass., in 1812. Production extended to Michigan in 1835, to Indiana about 1855, and to the Pacific coast states over a half-century later.

ADAPTATION

Mint is grown mostly in humid sections of the northern states where summer temperatures are not too high. It succeeds, however, under warmer conditions in California. Deep, rich, well-drained soils, especially muck, or other soils that are high in organic matter, are peculiarly suited to mint production. The muck soils usually are somewhat acid. The Houghton muck of northern Indiana has a reaction of *p*H 5.2 or less.[14] Mint is grown, however, in the alkaline sandy loam irrigated soils of the Yakima Valley of Washington. The preferred *p*H range is 6.0 to 7.5.

BOTANICAL RELATIONSHIPS

Mint belongs to the family *Labiatea,* the mint family, the plants of which have a four-sided or square stem. The two perennial species grown commercially are peppermint (*Mentha piperita*) and spearmint (*M. spicata* or *M. viridis*). The inconspicuous flowers, which are borne in whorls on a spike about two inches long, produce very few seeds. The plants produce numerous stolons which are used for propagation and field planting. Peppermint (Figure 291) plants usually are 3 feet or less in height.

The three varieties of peppermint are: (1) black peppermint (black mint, English peppermint, or Mitcham mint), which has dark green to purple stems and deep green, broadly lanced, slightly toothed leaves, and usually light purple flowers; (2) American peppermint (American mint or State mint) which has green stems and lighter-green leaves, and is similar to black mint otherwise but not very satisfactory commercially; and (3) white peppermint (also known as white mint, Mitcham mint, and White Mitcham) which is smaller than black peppermint, has green stems and light green, slightly pointed, deeply toothed leaves. The latter is not cultivated commercially in the United States, but is still grown in England.

Spearmint has light green pointed spear-shaped leaves and pointed flower spikes that are longer than those of peppermint. Spearmint is the common home-garden plant grown for its leaves which give the mint flavor and the green decoration to drinks and foods (Figure 291).

Native species of mint, including *M. canadensis,* contain oil of an inferior quality, and should be eradicated where they occur as weeds in commercial mint fields.

FIG. 291. Flowers and leaves of peppermint (*left*); flowers, leaves and stolons of spearmint (*right*).

Japanese mint (*M. arvensis* var. *piperascens*) is grown to a limited extent in the United States.

CULTURE

Lands planted to mint should be comparatively free from weeds,[45] since many species of weeds affect the color or odor of the distilled oil. Ragweed is the most objectionable weed because it contains a light volatile oil that distills over and contaminates the mint oils with a disagreeable flavor. A mixture of one per cent ragweed in spearmint discolors the oil and renders chewing gum unsalable.[14]

Other weeds such as smartweed, pigweed, horseweed, nettles, hemp, purslane, lambsquarter, buttermold, and Canada thistle impart disagreeable odors, but their oils are heavier than water and thus separate from mint oils after distillation. Clean land is best attained by planting the mint after fallow or after an intertilled crop such as potatoes or onions, which also are adapted to muck soils. Perennial grasses in mint fields are difficult to eradicate by cultivation after the mint plants spread between the rows.

Fertilizer application on muck soils usually consists of 100 to 400 pounds per acre of sulfate of potash or muriate of potash, or about 300 pounds per acre of a 0–10–20 or 0–20–20 mixed fertilizer. Where a preceding crop of potatoes or onions has been manured or otherwise heavily fertilized, further applications for the mint crop may not be necessary. Mint fields used to supply stolons (seed runners) should be fertilized heavily.

The fields for mint should be prepared in time for early spring planting of the stolons. Sometimes strips of rye or other tall crops or permanent willow windbreaks are planted at intervals across the field to prevent drifting sand particles from damaging the young mint plants. For hand planting, the field is marked off with furrows about 3 feet apart and 4 inches deep.

The fields that supply the stolons should have been cut early the previous year so the runners have time to build up adequate food reserves. The stolons are dug or plowed out and then forked free from soil, thrown into piles, and the piles covered lightly to prevent excessive drying. One acre produces enough stolons to plant 10 acres or more.

The runners are dropped into the furrows by hand, lengthwise and end to end. Much of the planting is now done with special machines. About 40 bushels of loosely packed roots are required for planting an acre. Mint often is propagated by pulling up young rooted plants that arise from the stolons in established mint fields in the spring. These are set out with vegetable or tobacco transplanting machines.

A rotary hoe, or a light weeder or harrow is used for cultivation until the mint plants are 5 to 6 inches high. Row cultivation, after the first year, is precluded by the spreading of the plants between the rows. Spring-tooth or other harrows or the rotary hoe may be used early in the spring, followed by hand weeding later in the season. After harvest the fields are left until late fall or early spring when they are plowed. Fall plowing covers the stolons deep enough to protect them from winter cold. The plants come up from stolons each year. Fall plowing is not recommended in the coastal districts where the land is subject to overflow during the winter or early spring.

HARVESTING

The maximum oil yield of both peppermint and spearmint occurs about when the plants are in bloom.[45] In Indiana the oil and menthol yield continue to increase up to the stage of 50 per cent bloom.[14] The crop must be cut before leaf shedding occurs since the leaves contain much of the oil. The crop usually is harvested after the plants are well in bloom except sometimes in Oregon and Washington, where cutting in early bloom permits the cutting of two crops in a season. Cutting is done in July in California and in August and September in the Pacific northwest and corn belt states.

New mint often is cut with a scythe to save as much of the crop as possible from the short plants, especially as the rows often are somewhat ridged. The old fields and many of the new fields are cut with a mower equipped with lifter guards. The mint is raked a day or two later after it is partly dried, and if the weather continues cloudy it is placed in cocks. It is dry enough for distilling when the moisture content is down to 40 to 50 per cent, and must be gathered and hauled to the still before the leaves are dry enough to shatter. It usually is gathered from the swath with a hay loader and unloaded into the distilling tub with slings.

DISTILLATION OF THE OIL

The oil is distilled from the mint with steam (Figure 292). Distillation is completed in 45 to 60 minutes. The vapors are condensed in water-cooled coils and pass into a tank receiver. About 6 gallons of water boil over with each gallon of oil. The oil, which is in the top layer, is drawn off into metal cans or drums of 5 to 6 gallons capacity. One 5-gallon can will easily hold the crop from an average acre of mint.

USES

Peppermint oil should contain 50 per cent or more of menthol and 4 to 9 per cent of esters. Peppermint oil is used in ointments, salves, and other medicines, as a flavoring, and is used also as a remedy for digestive disturbances. It has an important use in confections, toothpastes, tooth powders, and perfumes. Spearmint oil contains at least

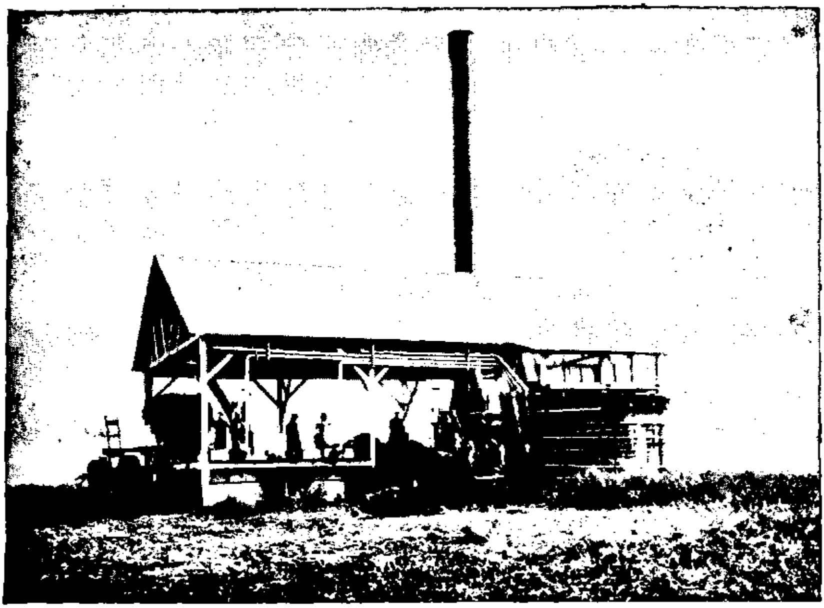

FIG. 292. Unloading mint into a distillation vat.

50 per cent carvone or carvol. The chief use of spearmint oil is in chewing gum, mint sauces, and mint flavors.

DISEASES AND INSECTS

The chief diseases of mint are anthracnose (leopard spot), caused by the fungus *Sphaceloma menthae*, and Verticillium wilt. Mint rust caused by the fungus *Puccinia menthae* is important at times, especially on spearmint.

The chief insect pests of mint are a leaf-chewing insect, the mint flea beetle, controlled by calcium arsenate and Paris green dusts,[17] and grasshoppers and cutworms, controlled with poisoned bran mash. The suitability of insecticides less toxic to humans than the above-mentioned arsenicals has not been established.

Dill

According to the United States census, dill was grown as a field crop by 14 farmers in 1939. The total production was 13,429 pounds valued at $15,621. Most of this was produced in Ohio, Idaho, Oregon, and Michigan. Production increased to 18,000 pounds on 28 acres in 1940 and 43,500 pounds on 66 acres in 1941. Imports of dill seed chiefly from British India are reported to have been as much as 35,000 pounds in a year. Dill is grown commercially chiefly for the fruits or seeds that are used to flavor foods, chiefly pickles, or for the volatile oil distilled from the harvested plants, that is used for similar purposes, and in perfumes and medicines. The leaves and seed heads, often grown in herb gardens, also are used to season prepared foods.[6]

Dill (*Anethum graveolens*) belongs to the family *Umbelliferae*, the parsnip family. The dill plant is a perennial that develops flowers and seeds the year of seeding if the time of sowing is early enough so that the cold temperature requirements are satisfied. The plants reach a height of 3 to 4 feet.

Dill, although a native of the Mediterranean region, is adapted to the relatively cool climate of the northern states, where it grows well on fertile soils. Dill is sown in cultivated rows 1½ to 3 feet apart either in early spring or so late in the fall that the plants do not emerge until early spring. The plants are later thinned to a spacing of 6 to 15 inches apart in the row. The seed crop is cut with a mower when the first seeds are ripe, while the plants are damp enough to avoid excessive losses from shattering. The crop is partly cured in small cocks and then threshed, using all possible precautions to prevent shattering of the seed. The seed is then spread out in shallow piles, with occasional stirring, until dry.

In harvesting for oil production, the dill is mowed when the most nearly ripe seed is turning brown. After partial field curing, the crop is hauled to the still where it is handled about as described for the distillation of mint oil. The yield of seed under good cultural conditions is reported to average about 500 to 700 pounds per acre. Oil yields are approximately 20 pounds per acre.

Wormseed

The culture of wormseed constitutes a unique localized industry that has persisted for many years in the vicinity of Westminster in Carroll County in north-central Maryland. The census of 1940 reported 240 producers of wormseed oil. These farmers grew 927 acres of wormseed which yielded a total of 38,281 pounds of wormseed oil, or as it is often called, Baltimore oil. Formerly about 60,000 pounds of the oil were produced annually. It has been grown also in Illinois.

Wormseed (*Chenopodium ambrosioides anthelminticum*) belongs to the *Chenopodiacea* or goosefoot family. The genus *Chenopodium* includes such plants as *C. album*, the ordinary lambsquarters weed, and *C. quinoa*. The latter is a crop grown for its edible seeds, utilized in place of a cereal by the natives of the Andes highlands. There it is called quinua (pronounced Keen'-Wah) but in the United States, where it is not adapted, often has been called quinoa (Kwin-o'-uh).

Wormseed is known also as Chenopodium, American wormseed, and Jerusalem oak. The plant, a native of Europe, has become naturalized in waste places from New England to Florida and westward to California. It is a much-branched annual herb, 2 to 4 feet in height. The entire plant, including the fruit and seed, contains a volatile oil of disagreeable odor that is used in worm remedies for man and beast. The seeds also are used in vermifuges.[42] The oil contains more than 65 per cent of ascaridole, the active principle that kills several internal parasites.

Wormseed is grown mostly in rotation with corn, wheat, potatoes, and hay. It is sown in beds in the spring and transplanted to the field when the plants are about 4 inches high. Usually a transplanting machine is used to place the plants about 18 inches apart in rows about 3 feet apart. The crop is harvested about the middle of September, usually with a modified binder. The rather loose bundles are shocked and then hauled to the still when partly dried. The oil is distilled out in 2 hours or less, a long trough-type of condenser being used. The spent material is used for fertilizer. Distillation is much like that described for mint. Yields of oil range from 30 to 90 pounds per acre.[41] A federal permit must be obtained to operate any still.

Wormwood

Wormwood, absinth, or madderwort, (*Artemisia absinthium*) is produced in Michigan and Oregon, mostly by mint growers. The plant is a hardy long-lived perennial, 2 to 4 feet in height, related botanically to sagebrush. The hairy silvery shoots bear grayish-green leaflets and small yellow flower clusters. The seed is planted in a bed or directly in the field. The plants also can be propagated by division. It is harvested once a year with a mower or self-rake reaper.[42] The oil distilled from the leaves and tops is used in tonics and external proprietary medicines. Although formerly considered as anthelmintic it is not used as a worm remedy because of its toxic properties when taken internally.

Mustard

ECONOMIC IMPORTANCE

An average of nearly 27 million pounds of mustard seed was produced in the United States from 1936 to 1945. The states growing important commercial quantities include Montana, California, Oregon, Washington, and California. About four-fifths of the crop is produced in Montana. Some 6 to 19 million pounds of cultivated mustard seed and its products were imported annually before World War II. Increases in domestic production fully offset the greatly reduced supplies from other countries as a result of war conditions. About 20,000 acres annually are required to produce normal domestic requirements. Most of the seed imported in peace times has been received from China, Netherlands, the United Kingdom, and Rumania.

ADAPTATION

Mustard seed is best adapted to sections having relatively cool summer temperatures, a fair supply of soil moisture during the growing season, and a dry harvest period. Such conditions are found in the "triangle" section of north-central Montana and the low-rainfall but foggy coastal valley sections of southern California. It can be grown with fair success in other western areas where the rainfall is somewhat limited. In Montana, the soils where mustard is grown chiefly are medium loams that are slightly alkaline. In California, the brown mustard is grown mostly on sandy loam, and the yellow mustard on either a heavy type of sandy loam or a light adobe soil.

BOTANICAL RELATIONSHIPS

Mustard belongs to the family (*Cruciferae*, or *Brassicaceae*) genus *Brassica*, described in Chapter 31. The species grown for their seeds are all annual herbaceous plants about 2 to 3 feet in height. They include (1) *Brassica alba*, the yellow or white mustard (Figure 293);

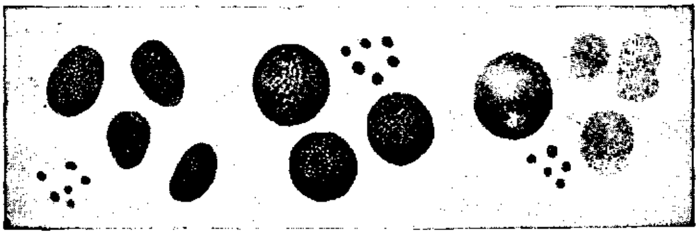

FIG. 293. Seeds of black mustard (*left*), yellow mustard (*center*) and wild mustard or charlock (*right*).

(2) *B. juncea*, the brown mustard; and (3) *B. nigra*, the black mustard. In California, the brown mustard yields 500 to 1,500 pounds and the yellow mustard 250 to 1,000 pounds per acre. The mustards occurring as weeds, the seeds of which are sometimes processed, include the white mustard and black mustard as well as the charlock or wild mustard, *B. arvensis* and ball mustard, *Neslia paniculata*; and sometimes other species.

CULTURE

The cropping system, seedbed preparation, and seeding date for mustard seed are all very similar to those for small grains in any particular region. Thus in Montana, most of the mustard is sown in the spring on fallow land or as a catch crop where winter wheat has winterkilled. In California, the mustard is sown from January to March on fall-plowed land. The seed is sown with a grain drill about one inch deep at a rate of 3 to 4 pounds per acre.

Mustard is harvested just before the pods open in order to avoid heavy losses from shattering of seed. It is cut with a grain binder, shocked, and threshed, or cut with a swather and then threshed with a combine having a pickup attachment.

USES

As a condiment the chief use of mustard is the ground seed or paste spread on cooked meats and other foods. The counter-irritant properties of the nondrying mustard oil are the basis for the familiar mustard plaster and other medicinal applications. The brown mustard is best for medicinal uses. Whole seeds of yellow mustard are used for seasoning pickles.

Charlock and other species of mustard are common constituents of the screenings from flax and small grains received from the northern spring-wheat states. Flaxseed often contains 5 to 10 per cent of mustard seed when grown on weedy fields, and oats, barley, and wheat frequently contain as much as one or two per cent. Thus, large quantities of mustard seed are available at terminal grain markets, that can be salvaged when there is a demand for it. Mustard is separated from other weed seeds of similar size in a spiral separator that allows the round mustard seeds to roll over the edge of inclined chutes while odd-shaped seeds merely slide to the bottom.

Sesame

Sesame seed (or benne) has been grown sporadically in the United States in Nebraska, Arizona, California, and other states. About 460 bushels were produced in South Carolina in 1939. It is well adapted to the irrigated valleys of the southwest, and also to other southern and south central states, but the labor involved in current methods of production and harvesting the crop has precluded its profitable culture in competition with imported supplies. Imports of sesame seed before World War II ranged from 7 to 118 million pounds yearly. The world production is about 1½ million tons annually. Sesame is grown extensively in China, India, Japan, Africa, Burma, Turkey, and Mexico. The crop has been under cultivation for many centuries.

Sesame (*Sesamum indicum*) belongs to the plant family, *Pedaliaceae,* having bell-shaped flowers and opposite leaves. It is an erect annual herb reaching a height of 3 to 5 feet. The tubular, two-lipped flowers are about ¾ inch long, with a pink or yellow corolla. The lower flowers begin blooming 2 or 3 months after seeding, and blooming continues for some time until the upper flowers open.

The upright pods split open at the top at maturity (Figure 294), and the seeds drop out if the plant is inverted. Varieties with indehiscent pods are being developed. The seeds of different varieties are creamy white, dark red, brown, or black. The seeds somewhat resemble flaxseed in size and shape and sometimes also in color.

FIG. 294. Spike and capsules of sesame.

Sesame requires a warm climate, a long growing season, and a sandy loam or loam soil for successful culture. Yields, under suitable conditions, range from 500 to 2,000 pounds per acre.

CULTURE

Sesame should be planted in cultivated rows about 3 feet apart, in late spring after the danger of frost is over, at the rate of about 5 pounds per acre. A stand of plants about 2 to 4 inches apart in the row is desired. The crop can be harvested with a corn binder just before most of the pods are open and shocked immediately for curing. At threshing time the bundles must be handled with extreme care to avoid excessive shattering of the seed. The bundles may be hauled to the thresher in tight or canvas-covered wagon or truck beds. A nonshattering type would permit combine harvesting and probably make production feasible in the United States.

USES

The chief use of sesame is for the fixed (nonvolatile) oil the seed contains that is utilized mostly for edible purposes. It is suitable for a salad oil when combined with equal or larger proportions of other palatable oils. The oil has been used for lighting purposes in Asia. Decorticated seeds of sesame are sprinkled on the surface of certain types of bread, rolls, cookies, and cakes just before baking. This is the usage most familiar to Americans.

Safflower

ECONOMIC IMPORTANCE

Safflower, an oil crop plant, has been tested extensively in the western half of the United States during the past 20 years.[28] Small acreages have been grown in Montana, Nebraska, Texas, and other states. Probably 1,500 acres were grown in 1946 and 15,000 acres in 1948. Yields of seed range from nothing to 3,300 pounds per acre. In the northern Great Plains, safflower yields about twice as many pounds of seed per acre as does flaxseed but the safflower seed consists of 40 to 55 per cent hulls. The safflower meats yield more oil than flaxseed. This difference may not offset the somewhat lower value of the oil and the necessity of handling and shipping a weight of hulls nearly equal to that of the useful product. Also, flax straw has a considerable value for feed and industrial purposes, whereas safflower straw is worthless.

Safflower is cultivated extensively in India, some 500,000 acres or more being grown annually in the semiarid Deccan region of the Bombay Presidency. It also is grown in Egypt, China, Japan, Turkestan, and parts of Europe. It was cultivated in Egypt 3,500 years ago.

ADAPTATION

In the United States safflower appears to be best adapted to semiarid and irrigated sections in the northern Great Plains. It is adapted to areas in Nebraska in which the altitude exceeds 3,000 feet.[7] In some years it has produced good yields in north Texas, but has been subject to severe disease injury when wet weather prevailed during the blooming period. The best yields are obtained when the weather is hot and dry during the blooming period but with ample soil moisture present. It has survived temperatures as low as 10° F. in the early stages of growth but is not frost resistant in the blooming stage. The growing period is about 4 to 5 months. The best yields have been obtained on loam soils.

BOTANICAL RELATIONSHIPS

Safflower (*Carthamus tinctorius*) is a member of the family *Compositeae.* It is an annual, erect, glabrous herb, 1 to 3 feet high, and

FIG. 295. Safflower plant and seeds. (Courtesy of Allis-Chalmers Mfg. Co.)

branched at the top, with white or yellowish smooth pithy stems and branches. The flower heads are globular, ½ to 1½ inches in diameter, with white, yellow, orange, or red florets (Figure 295). The seed is smooth, obovoid, four-angled, white or cream-colored, and resembles a small sunflower seed. The leaves and outer floral bracts of the best adapted varieties bear short spines, making the plant a typical thistle in appearance. Varieties without spines are being tested.

CULTURE

Since safflower does not thrive on weedy land, it should be sown following an intertilled crop or legume sod crop. Planting in cultivated rows is recommended for weedy land.[7] Seedbed preparation, drilling, and irrigation requirements are about the same as for small grains.[34] A seeding rate of 60 pounds per acre usually results in the desired stand of plants about 4 or 5 inches apart in the drill row under irrigated or favorable moisture conditions. A rate of 30 to 45 pounds is recommended for dryland conditions, and about 20 pounds when sown in cultivated rows. The best seeding time in the northern Great Plains is in April or early May, or immediately after seeding spring grains. The seed germinates at temperatures of 40° F. or higher. Varieties giving the highest yields in Nebraska tests include N–852 and N–805, which originated in India. These varieties have a higher oil content than the Russian and Indian varieties previously grown.

HARVESTING

The crop is ready to harvest when the seeds are hard and dry. Since the crop does not lodge, and the seeds seldom shatter and are not eaten by birds, the crop may be allowed to stand until the stems also are dry enough for combine harvest. The crop is thus well adapted to harvesting with a combine. It also can be cut with a binder, shocked, and then threshed, but the spines often damage both the binder canvasses and the clothing and skins of the harvest crew. The combine or thresher cylinder and concaves should be operated as for threshing oats or barley.

USES

Safflower seed weighs from 30 to 48 pounds per bushel, good plump seed weighing about 45 pounds. The whole seed contains 22 to 34 per cent oil, and the meats about 45 to 55 per cent. A bushel of seed containing 30 to 33 per cent oil yields 11 to 13 pounds of oil and 32 to 34 pounds of meal. The meal contains about 18 to 24 pounds of crushed fibrous hulls and 10 to 18 pounds of kernel meal comparable to cottonseed meal in feeding value and in composition. The oil can be extracted in a cottonseed seed oil mill with some adaptations. Safflower oil is a drying oil having an iodine number of about 140 to 155. The oil is used for edible purposes and soaps, and in paints, varnishes, and enamels. Although of lower drying value, it is superior to linseed oil for white inside paints because the painted surface remains white instead of turning yellow, as does white linseed oil paint when not exposed to sunlight.

The flower heads of safflower yield a red dye, carthamin, formerly extracted commercially in India.

DISEASES AND INSECT PESTS

Safflower is comparatively free from diseases in dry seasons, but may be damaged seriously by anthracnose, leaf spot, rust, and wilt when continued moist weather occurs during the blooming season.[13] Cutworms, grasshoppers, and other insects occasionally attack the crop.

Castorbean

ECONOMIC IMPORTANCE

The castorbean is grown on a much more limited scale in the United States than formerly. The acreage for 1939 was 105 acres on 19 farms, of which 17 were in Texas. Production increased to 5,000 or 6,000 acres in 1942 and 1943. The plant is widely used as an ornamental in the southern two-thirds of the United States. Imports of castorbeans for oil extraction chiefly from Brazil but also from India and the Far East, were 135 million to 300 million pounds annually from 1935 to 1941. Castor oil also is imported. About 100,000 to 200,000 acres would be required to produce our domestic requirements.[12]

The world production of castorbeans is about 480,000 tons annually. The leading producing countries are Brazil and India. Other producing countries include Russia, Manchuria, Mexico, Argentina, the Netherlands Indies, and parts of Africa.

HISTORY

The castorbean is generally believed to be a native of Africa. It may have originated in India, because wild forms occur in that country.

The castorbean was grown in Kentucky and New York as early as 1803, and by 1850 some 23 oil extraction mills were operating in the east and south and in the Mississippi Valley. Between 1865 and 1900 the chief area of production shifted from Missouri to Kansas and then to Oklahoma. A total of 766,000 bushels was produced in Kansas in 1879, but thereafter the domestic crop declined to a total of less than 100,000 bushels after 1892, and to negligible quantities after 1900. During World War I, a demand for castor oil as a lubricant for airplane motors stimulated an army-sponsored production of 250,000 bushels in 1918, in the south and in California. Competition with more profitable crops and with foreign countries having cheaper labor to hand-pick the crop apparently prevents the United States from producing its domestic requirements for castor oil from existing varieties under present conditions.

ADAPTATION

The castorbean is adapted to sections having a frost-free period of 180 days or more, an average warm season (April to September) precipitation between 15 to 25 inches, an average July temperature above 76° F., and an average relative humidity at noon during July of less than 60 per cent.[12] The region of best adaptation includes southeastern Kansas, Missouri, southern Illinois, southern Indiana, the southern tip of Ohio, western and central Kentucky and Tennessee, Arkansas, Oklahoma (except the Panhandle), and parts of northern Texas. The crop also is well adapted to irrigated regions of the southwest. The gray-mold disease makes the castorbean a risky crop in the humid high-rainfall areas comprising the Atlantic and Gulf coastal plains sections. Summer temperatures are too low in parts of the southern Appalachian region. One small section of the Gulf coast region, a limited area around Corpus Christi, Texas, appears to be well adapted to castorbean production.

The castorbean requires a well-drained soil, preferably loam, silt loam, sandy loam or loamy sand. High soil productivity has proved to be less important than a good physical condition of the soil, in the securing of satisfactory yields.[12]

BOTANICAL CHARACTERISTICS

The castorbean belongs to the family Euphorbiacea, the spurge family. The castorbean (*Ricinus communis*) is a short-lived perennial that in the tropics grows into a tree 30 to 40 feet in height. In the United States it is an annual, 4 to 12 feet in height, except in Florida and parts of Texas and California, where it can survive the winters.

The leaves are large, usually 4 to 12 inches wide or wider, alternate, and palmately divided into 5 to 11 lobes (Figure 296). The leaves of different varieties, including numerous ornamental forms, may be green, purple, or red, and the stems also may be green or red. The greenish-yellow flowers without petals are borne in racemes. The plant has an indeterminate blooming habit, and is monoecious, with the pistillate flowers in the upper part of the raceme and the staminate flowers below. Consequently, it is frequently cross-pollinated. The fruit is a spiny or smooth, dehiscent or indehiscent, three-celled capsule, each cell containing a hard-shelled seed that usually is mottled.

The pods of many varieties forcibly eject the seeds at maturity. Improved varieties for seed production retain most of the seeds for a time after maturity.

The general appearance of the seed is somewhat similar to that of a mottled bean, except that it is obovoid instead of kidney-shaped, and it has a prominent hilum or caruncle at the end instead of a depressed hilum on the edge of the seed as in a bean.

Since the castorbean is not a legume, the seed truly is not a bean, and, furthermore, the oil is not used to lubricate castors. The name castor apparently was coined by English traders who confused the oil with that from *Vitex agnus-castus* which the Spanish and Portuguese in Jamaica called agno-casto.

The castorbean also is called the castor oil plant, Palma Christi, and mole bean.

FIG. 296. Castorbean plant showing spike (*left*). Castorbean seeds (*right*). The protuberance at the end of the seed is the strophiole or caruncle.

VARIETIES

Three varieties, Conner, Doughty 11, and Kentucky 38, give consistently good yields of hulled beans, are of suitable plant type, and have low shattering tendencies. These varieties produce 3½ to 7 spikes per plant and have hulling percentages of about 67 to 70 per cent. Average yields of these three varieties ranged between 700 and 900 pounds of shelled beans per acre. The plants of the Conner and Doughty 11 varieties exceed 6 feet in height, whereas those of Kentucky 38 are about 5 feet. Conner, the highest yielding of the three varieties, has red stems. Kentucky 38 is the earliest of the three varieties and probably is best adapted for the more northern latitudes. Doughty 11 has yielded best in the vicinity of Corpus Christi, Texas, where it originated. Numerous ornamental types are too tall, too late, or otherwise unsuitable for satisfactory seed production. Improved varieties are now being developed.

CULTURE

The proper fertilization for castorbeans has not been determined.

"Eight fertilizer tests in Kansas, Kentucky, Mississippi, Missouri and Oklahoma failed to show any marked yield increase from nitrogen, phosphorus, or potassium, either alone or in combination, on the Conner variety of castor beans." [12]

A seedbed preparation such as that required for corn has been recommended for castorbeans. The seed is best planted with a corn planter or lister, equipped with special planting plates. Surface planting has given higher yields than planting in lister furrows, but it requires three extra cultivations to control weeds.[12] The optimum spacing recommended is one plant every 2 to 3 feet apart in rows 40 to 42 inches apart, or 5,000 plants per acre. Such stands may be expected from planting about 10,000 seeds per acre, which would require 10, 8, and 7 pounds, respectively, of the Conner, Doughty 11, and Kentucky 38 varieties. Larger racemes are obtained from this spacing than when planting is thicker.

Planting after the danger of heavy frost is past and the soil has become warm is a safe procedure for castorbeans. Planting a few days earlier than the normal corn-planting time for any locality is recommended. Progressively lower yields were obtained from successively later plantings after that season.[12] Lower yields from later planting probably result from the shorter period in which to bloom and set seeds, since the plants continue blooming until killed by frost.

Heading back the plants to stimulate branching and to encourage more uniform maturity merely decreases the yields.

HARVESTING

Castorbeans must be harvested before the ripe dry seeds have shattered appreciably. This usually necessitates stripping all ripe racemes at least twice in a season. A satisfactory machine for harvesting castorbeans has not yet been devised, although the combine, after some modifications, might be used if special varieties can be developed. The most satisfactory method of harvesting is to hand-strip all the pods from each fully ripe raceme and drop the seeds in a cotton-picking or fruit-picking sack dragged or carried through the field. Strong gloves must be worn to protect the hands while stripping off the spiny pods. By this method about 600 to 1,000 pounds of beans in the hull are gathered in a day by an experienced adult picker.

The pods must be dried by occasional stirring of shallow piles in the open or under shelter whenever they are harvested before they are fully ripe and dry. Special hulling machines for castorbeans have been constructed recently.[2, 16, 35]

USES

The hulled castorbean contains 35 to 55 per cent oil, averaging about 50 per cent in well-developed seed. The oil usually is extracted by pressure without grinding or decorticating, and usually without heating the beans. The oil is used chiefly in the manufacture of soap, linoleum, oil cloth, and printer's ink, and in the treatment of leather and the dyeing of textiles.[40] Its use as a laxative for ailing youths is all too well known to those of a generation ago. Castor oil is used frequently in hydraulic cylinders. Formerly castor oil was the preferred lubricant for airplane motors and certain types of marine engines, but improved petroleum lubricants have replaced castor oil for that purpose. Castor oil is a nondrying oil with an iodine number ranging from 82 to 90. Recent processes of dehydrating castor oil give it drying-oil properties, so that it is now widely used in paints and varnishes. The oil also is used as a solvent and plasticizer in the manufacture of certain types of nitrocellulose plastics.

The castorbean, and the press cake after extracting the oil, are poisonous to humans, livestock, and poultry. The toxic principles are ricin, an albumin, and ricinine, an alkaloid. The press cake is used largely in mixed fertilizers, under the name of castor pomace. The oil is not poisonous, but the leaves and stems of the plant contain a sufficient quantity of ricinine to be toxic. Eating one castorbean seed is said to produce nausea, and ingestion of appreciable numbers often proves fatal.

DISEASES AND INSECTS

The most common disease of the castorbean, the gray mold, caused by *Sclerotinia ricini*, attacks and destroys the racemes. It occurs in warm humid regions. The only known remedy is to plant mold-free seed in drier areas where the climate does not favor the disease.[15] Another, but unnamed disease caused by the fungus, *Alternaria ricini* destroys the young inflorescences. No control for this disease is known, but fortunately it usually causes little damage in the area where the castorbean is well adapted. The castorbean is highly susceptible to the Texas root rot disease caused by the fungus *Phymatotrichum omnivorum*, and the crop should not be planted in fields infested with that organism.

Insects attacking the castorbean include army worms, corn earworm, stinkbugs, leaf hoppers, leaf miners, caterpillars, grasshoppers, and Japanese beetles, but usually the damage is not great. Nematodes also attack the castorbean to some extent.

Perilla

Perilla is grown for its seeds, which contain a drying oil of excellent quality that in the United States is used in paints, varnishes, and linoleum manufacture. It has not been grown in this country except in preliminary field trials and experimental plots. The commercial possibilities for this crop have not yet been determined. Imports of perilla oil ranged from 21 million to 114 million pounds annually between 1932 and 1939, but declined thereafter because most of the production was in the warring countries, Manchuria, China, Korea, and Japan. India also is a heavy producer. The world production formerly was about 200,000 tons annually.

Perilla requires a warm growing season of 5 to 6 months with an ample supply of moisture. It can be grown successfully in the United States only in the humid southeast and in the irrigated southwestern region. The plants can withstand light frosts. Sandy loam soils of average fertility are suitable for perilla.

Perilla (*Perilla frutescens*, or *P. ocymoides*) belongs to the Labiatae, the mint family. A subspecies, *P. frutescens nankinensis*, also is grown. Perilla is a coarse annual plant indigenous to India, Japan, and China, where it is cultivated. The plants are 3 to 6 feet in height, much branched unless crowded, and having coarse-toothed leaves and small inconspicuous white flowers borne in racemes 3 to 8 inches long. The seeds are round, brownish, and resemble mustard seeds. A bushel of good seed weighs about 37 pounds.

Preliminary experiments indicate that in this country perilla should be sown in the spring after the soil has warmed somewhat, or about March or early April in the south, at a depth of one-half inch in cultivated rows at the rate of 4 or 5 pounds per acre. Germination is slow, about 3 weeks usually elapsing before the plants emerge. Blooming begins about 4½ months after seeding, and most of the seeds are ripe about 6 weeks later. The crop is ready to harvest as soon as the seeds are brown and the calyxes still slightly green, at which stage little shattering has occurred. The most satisfactory harvesting method has not been determined. It can be threshed with an ordinary grain separator adjusted for small light seeds. The average yield in Japan is about 560 pounds per acre.

The oil content of the seed ranges from 35 to 45 per cent and averages about 38 per cent. The extracted oil is yellow or greenish. It is similar to linseed oil in odor and taste, but is higher in drying quality (iodine number about 200), and therefore suitable for quick-drying paints and varnishes. In Japan the oil is used in the manufacture of paper umbrellas, oil papers, artificial leather, printer's ink, paint, varnish, and lacquer. During the present shortage of imported perilla oil, its place has been taken largely by processed oil from other plants.

Guayule

ECONOMIC IMPORTANCE

Guayule (pronounced y-oo′-leh or gwy-oo′-leh) is the Indian name for an American rubber crop. A total of 550 acres of cultivated guayule was harvested in California in 1943, yielding 440 tons (or 1,600 pounds per acre) of underesinified rubber. In addition, about 250 tons of rubber were obtained between 1942 and 1944 from wild guayule shrubs gathered in the Big Bend region of western Texas. Imports of guayule rubber from Mexico ranged from none up to

6,000 tons annually previous to World War II, and large quantities were obtained during the war period. More than 33,000 acres of guayule were planted in California, Arizona, and Texas from 1942 to 1944. Experiments with guayule, a wholly undomesticated plant before 1907, may yet evolve techniques [19] that will enable the cultivated crop to compete successfully with other sources of natural and synthetic rubber. For certain purposes such as friction stock, it is superior to either the *Hevea* or synthetic product. It has been estimated that 100,000 tons of guayule rubber could be used advantageously for special purposes in the United States each year. A total planted area of 500,000 acres, one-fourth being harvested each year, would be required to produce the above quantity.

ADAPTATION

Guayule is distributed naturally over an area of 130,000 square miles, extending southward from the vicinity of Fort Stockton, Texas, into Mexico.[26] This area has an annual rainfall of 10 to 15 inches with altitudes of 3,000 to 7,000 feet. It might be cultivated in the United States in a belt about 150 miles wide, north of the Mexican border, extending from the mouth of the Rio Grande River to southern California and along the coast of California up to San Francisco Bay, and also through the interior valleys of California northward to Red Bluff, or even a larger area. In a dormant condition the plants may withstand temperatures of 5° F. to 10° F., but while growing actively are injured somewhat by temperatures of 20° F. Guayule thrives under hot conditions. It may be grown either on irrigated or nonirrigated land. The soil conditions best for guayule have not been fully determined.

ORIGIN AND HISTORY

Guayule is a native of northern Mexico or southwestern Texas. The plant was first collected for identification in 1852.[26] Indians long ago learned to extract the rubber by chewing the wood. The first experiments on the commercial extraction of rubber from guayule were begun about 1888. Several factories were established in Mexico in 1904 and shortly thereafter, and one at Marathon, Texas, in 1909. Attempts to cultivate guayule were begun in Mexico about

FIG. 297. Cultivating guayule.

1907. A total of 8,000 acres was planted in California, Arizona, and elsewhere in United States between 1912 and 1942.

BOTANICAL DESCRIPTION

Guayule (*Parthenium argentatum*) is a slow-growing, widely branching, woody, long-lived perennial shrub belonging to the family Compositae. Plants in the wild may live 40 or 50 years. It is seldom more than 30 inches tall at maturity. The plant develops a strong tap root, and a number of long shallow lateral roots from which new shoots may arise. The leaves are silvery-gray, as a result of a covering of thick short white hairs, and are 1 to 2 inches in length (Figure 297).

The inconspicuous flower heads, about ⅕ inch in diameter, and borne on the tip of branches, have about 5 ray flowers. The fruit is an achene with ray and disk flowers attached after maturity. A pound consists of about 600,000 achenes, of which about 90 per cent contain no seeds because of sterility resulting from irregular chromosome numbers and other factors. Many seeds are produced without fertilization by a process called apomixis. Fresh seed of guayule germinates very poorly, but afterripening is completed in about a year, so that year-old seed can be planted without treatment. Fresh seeds are treated in a solution of calcium hypochlorite and then sown immediately or after drying. One pound of seed is soaked for 2 hours in 2½ gallons of sodium or calcium hypochlorite containing 1½ per cent of available chlorine, after a pre-soak of 18 hours in water.

The rubber is stored largely in the outer living portions of the stems, branches, and roots. The leaves contain little or no rubber. Very little rubber is deposited while the plant is growing actively, but rubber storage begins when growth is restricted in late fall or during dry periods.[3] The acre yields of rubber increase rapidly until the plants are 4 or 5 years old, with relatively slow increases thereafter.

CULTURE

Selected strains that grow rapidly in the early stages may be sown directly in the field. Such a procedure would shorten the total growing period and reduce the expense of nursery maintenance and transplanting. Another possible improvement in cultural practices is the mowing instead of digging of the crop. This would recover only 67 to 75 per cent of the total rubber, but would leave the roots to start a quick new growth and save the expense and delay incident to establishment and growing of new plantings.

The cultural methods up to the present time[27] include planting treated presprouted seed in beds with the seeds covered by a ¹⁄₁₆-inch depth of sand by the planting machine. After 8 months the seedlings are topped and then undercut by special machines.

The seedlings are then lifted from the beds, and are transplanted 30 inches apart in each direction with a tractor-drawn 6-row machine, at the rate of 14,000 per hour. Weeds are controlled largely by use of oil sprays.

The plants normally are suitable for harvest after 4 years growth on irrigated land and 5 years on nonirrigated land. A special machine digs two rows at a time and leaves the plants in a single windrow. A special pickup machine gathers, chops, and binds the material and conveys the bundles or bales into an accompanying truck.

A special rotary cylinder machine with vacuum suction equipment is used to gather seed from mature plants in the field.

RUBBER EXTRACTION

The present commercial method of extracting rubber from guayule involves the crushing of the material in corrugated rolls, then mascerating it in water in a series of pebble mills to release the rubber.[1] The particles of rubber aggregate into *worms* that float and can be skimmed off. The worms then are separated from adhering bark, scrubbed, dried, and pressed into blocks.

USES

Good strains of guayule yield about 20 per cent rubber or about 1,600 pounds of rubber per acre every fourth or fifth year.[32]

Guayule rubber as recovered ordinarily contains 15 to 20 per cent of resins. Removal of these resins (deresinating) leaves a product very similar to *Hevea* rubber, except that it does not make a satisfactory rubber cement. For many purposes, however, such as the fabric of tires, the presence of resins is beneficial in reducing friction. Some use may be found for the resins. Guayule plants make a hot fire when burned, and formerly were used for smelting in Mexico. The native shrub is browsed by burros and goats.

DISEASES AND INSECTS

The principal diseases attacking guayule are Verticillium wilt caused by the fungus *Verticillium albo-atrum*, and Texas root rot, caused by *Phymatotrichum omnivorum*. There is no control for the former disease. The latter, which is not serious, can be evaded only by avoiding infested fields when planting. Several other root rot diseases attack guayule.

Insects attacking guayule include grasshoppers, Lygus bugs, lacebugs, harvester ant, leaf-cutting ants, and termites.

The dodder weed sometimes parasitizes guayule plants.

OTHER RUBBER SOURCES

The commercial success of guayule hinges upon recent and probably further improvements in varieties, culture, and rubber extraction, combined with public policies regarding this and other sources of natural rubber and the synthetic product. Up to the present time, the price of *Hevea* rubber from the tropics has been lower most of the time than the cost of producing guayule rubber. Experiments with goldenrod (*Solidago leavenworthii*) show that low yields of low-grade rubber are obtained by double solvent extraction of the leaves that contain 4 to 7 per cent rubber. The roots of Russian dandelion or kok-saghyz (*Taraxacum koksaghyz*) yield an excellent quality of rubber, but yields of existing strains cannot be expected to exceed 50 to 60 pounds of rubber per acre per year under average conditions.

A vinelike rubber-bearing shrub, *Cryptostegia grandiflora*, grown in India and Madagascar, has been planted extensively in Haiti, and experimentally in Florida and California. Yields of 100 pounds per acre per year are obtained by excessive expenditure for hand labor

Rabbitbrush (*Chrysothamus nauseosus*), a native shrub distributed over the drier sections of western United States, yield a good quality of rubber but the percentage is too small for commercial success.

Hemp

ECONOMIC IMPORTANCE

Hemp is grown chiefly for the bast fiber in the stalks that is used for making rope and twine. The average acre yields in the United States have been about 900 pounds of fiber or 400 pounds of seed. It formerly was grown rather extensively in the United States, chiefly in Kentucky, but declined to less than 200 acres in 1933. This was increased to 7,400 acres in 1941. Then the Japanese invaded the Philippine Islands, the chief source of abaca or Manila hemp, which is used for marine ropes. Thereafter, production of hemp in the United States expanded until about 146,000 acres were harvested for fiber and 40,000 acres for seed in 1943. Most of the fiber was produced in Minnesota, Iowa, Illinois, Wisconsin, Indiana, and Kentucky. The seed was grown chiefly in Kentucky. Production declined to 4,600 acres for fiber in Wisconsin and 400 acres for seed in Kentucky in 1946.

Hemp escaped from cultivation many years ago and now occupies large areas chiefly in the bottom lands along the lower Missouri River and its lower tributaries. Because of scattered and irregular stands and growth and of mixtures with other types of vegetation, harvesting of the wild growth has not been feasible.

Hemp probably is native to central Asia. It has been grown in China for many centuries. It was grown by the ancient Greeks and is still grown in central Europe. Hemp has been grown in the United States since early Colonial days.

In addition to the true hemp (*Cannabis sativa*), grown in the United States and in various parts of both hemispheres, several fiber plants sometimes called hemp are grown in other countries.[10] These include abaca or Manila hemp (*Musa textilis*), a relative of the banana plant grown in the Philippines and other Pacific Islands; Sunn hemp (*Crotalaria juncea*), a legume cover crop also harvested for fiber in India and other parts of Asia; Mauritius hemp, the green aloe, or piteira (*Furcraea gigantea*) of Africa; New Zealand hemp (*Phormium tenax*); jute or India hemp (*Corchorus capsularis*); and sisal hemp. The latter type includes sisal (*Agave sisalana*) grown in Africa and the West Indies, and henequen or Mexican or Cuban sisal (*Agave fourcroydes*). Henequen, sisal, and abaca are the chief fibers used in binder twine. Jute is used in making burlap. All the above fibers are used in making rope or twine. *Sansevieria* or bowstring hemp, is being tested in Florida as a possible substitute for Manila hemp.

ADAPTATION

Hemp is adapted to sections that produce a good crop of corn. It requires a frost-free season of about 4 months for fiber production and 5 months for seed production.[38] It will withstand light frosts. For good uniform growth, the rainfall or soil moisture should be ample throughout the season. A higher quality of fiber usually is obtained in the more humid climate east of the 95° longitude because of better conditions for dew retting than commonly occur west of that meridian.

Well-drained, deep, fertile medium-heavy loams have produced the best hemp. Barnyard manure, commercial fertilizers, or lime should be applied to soils where other crops respond to these supplements.

BOTANICAL DESCRIPTION

Hemp (*Cannabis sativa*) belongs to the family *Urticaceae,* tribe *Cannabineae.* It is a stout, erect annual that grows to a height of 5 to 15 feet. It is dioecious; the male plants, which comprise one-half the crop, produce no seed.

Hemp is of considerable historical interest because it first revealed sex in plants to Camerarius in 1694, and it has served as the subject for determining the nature of sex in plants. Hemp under normal field conditions is strictly dimorphic (two forms) as to flowers and vegetation parts, the carpellate and staminate plants showing almost no sex reversal. However, individual bisexual plants occur under unfavorable conditions,[29] such as old pollen,[5] mutilation,[33] and reduced light.[39]

The main stem is hollow and produces a few branches near the top. The bast fibers are not so fine as those of flax, even when the plants are grown close together. The staminate inflorescences are in axillary, narrow, and loose panicles.[31] The pistillate flowers are in erect leafy spikes (Figure 298).

The hemp ovary matures into an ovoid hard achene.[36] The seeds mature on the lower part of the spikes first and on the upper part last.

TYPES AND VARIETIES

The common fiber hemp has larger stalks than the drug-plant type, which is grown in the hot climates of India, Syria, and elsewhere, and often classified as a separate species, *Cannabis indica.* The variety now generally grown commercially in this country, known as Kentucky or domestic hemp, is of Chinese origin.[11]

CULTURAL METHODS

Hemp should be planted on fall-plowed land just before planting corn.[14] Hemp responds to fertilizers on some of the less fertile soils of the corn belt states, but heavy nitrogen fertilization reduces the strength of the fibers.[23]

For seed production in Kentucky, the hemp usually is planted in hills 5 by 5 feet, with 6 to 10 seeds per hill or about 1½ pounds of seed per acre. Later the hills are thinned to 2 or 5 plants per hill. Harvesting for seed occurs when the seeds in the middle branches are ripe, and usually is done by hand. Harvesting and shocking when the plants are damp save much seed that otherwise would be shat-

FIG. 298. Pistillate (seed-bearing) hemp plant (*left*); staminate plant (*right*).

tered. The seed is flailed out by hand, and the stalks can thus be saved for fiber extractions if so desired. Fiber obtained from mature hemp is not of the best quality.

For fiber production, hemp should be sown with a grain drill ½ to 1 inch deep at the rate of 5 pecks (55 pounds) of seed per acre to produce fine uniform stems suitable for machine processing. For hand breaking, large stalks are desired, so the seeding should be at a rate of about 3 pecks per acre. Hemp is harvested for fiber when the male plants are in full flower and shedding pollen.[36] Earlier harvesting yields weak fiber. Harvesting is done with a modified 8-foot rice binder that delivers the stalks in an even swath on the ground. A self-rake reaper may be used if the stalks are too tall for the binder. The stalks are left in this position for retting. After retting is complete, the stalks are gathered up and bound, either by a machine pickup binder (Figure 299) or by hand. The bundles are shocked, and are hauled to the processing plant any time after drying. In Kentucky, it often is necessary to shock the hemp im-

FIG. 299. Binding retted hemp. (Courtesy of International Harvester Company.)

mediately after harvest in August or September and postpone retting until the cooler days of November in order to avoid sun-scald of the fiber.

PREPARATION OF HEMP FOR MARKET

Retting is a process of partial rotting in which the cementing substances surrounding the bast fibers are broken down or dissolved, freeing the fibers from the wood and thinner outer bark, and from each other. This separation is due to the decomposing action of certain bacteria and fungi. Hemp in this country is dew-retted. The stalks are spread out on the ground where they are exposed to cool moist weather or sometimes to alternate freezing and thawing. The process is complete when the bark separates easily from the woody portion of the stem. Water-retting is practiced in Europe, i.e., the stalks are immersed in streams, ponds, or artificial tanks. During dew retting, the stalks are turned once or twice to provide for uniform exposure. Turning is done by machine, or by hand using a 10-foot pole to upend and turn over each swath a small section at a time.

In the breaking process, the inner cylinder of brittle woody tissue is broken into short pieces called hurd, while the long flexible fibers are left largely intact. This permits the wood to be separated from the fibers. Many hemp-breaking machines have been unsatisfactory because the fiber was injured in the process.[22] Scutching is the beating or scraping off of the broken pieces of wood.

The rough fiber is combed out by drawing it over coarse hackles. Hemp tow consists of short and more or less tangled strands. A ton of dry retted hemp stalks processed by modern machine methods yields about 340 to 360 pounds of fiber, of which slightly more than half is line (long) fiber and the remainder is tow.

The uses of hemp are: commercial twine, small cordage, thread, hemp carpet twines, oakum, and marline.[22] It ranks next to Manila hemp for marine ropes.

HEMP SEED AND LEAVES

Hemp seed is often fed to cage birds after the germination of the seed has been killed in accordance with federal regulations. The seed contains 20 to 25 per cent of an oil that sometimes is extracted and used in making soft soaps and as a substitute for linseed or other oils. A drug is derived from the stems and leaves of common hemp. The glandular hairs secrete both a volatile oil and the strong narcotic resin (cannabin). The drug called marijuana in North America and hashish or bhang in Asia is obtained from the flowers and leaves of both *Cannabis sativa* and *C. indica.* Hemp is the source of the so-called reefer cigarettes sometimes sold illegally in this country. Hemp can be grown only under a license issued by the Commissioner of Narcotics.

Ramie

Ramie, also called China grass and rhea, was introduced into the United States in 1855. Since then this intriguing fiber crop has been tested in many states, and small acreages are grown occasionally. The census of 1940 reported one farm in the United States growing 10 acres in 1939. Several hundred acres were planted in the Florida Everglades section in 1945 and 1946. Interest in the crop is stimulated by the lustrous appearance of ramie cloth woven from the strongest of vegetable fibers. It is grown in China, Japan, India, and Russia. China produces about 100,000 tons annually, 15,000 to 20,000 tons of which are exported. It has been grown in the Orient since the earliest records of agriculture.

ADAPTATION

Ramie is a semitropical plant. Experiments and field trials have shown that the ramie crop is adapted to sections of the southeast where the annual rainfall exceeds 40 inches, and to interior irrigated valleys of California, where frost does not penetrate into the soil more than an average of 3 inches. The capacity of the plants to make a heavy vegetative growth necessitates a rich alluvial soil for a satisfactory crop. Excellent results have been obtained on the Florida Everglades.[20] Sandy soils often have proved unsatisfactory.

BOTANICAL RELATIONSHIPS

Ramie (*Boehmeria nivea*) belongs to the family *Urticacae.* The plant is a perennial that sends up new stalks from the rootstocks and often reaches a height of 8 feet. The stems are one-half inch or less

FIG. 300. Leaves and inflorescences of ramie.

in diameter and covered with inconspicuous hairs (Figure 300). The flowers are small and monoecious, with the staminate flowers in the lower part of the cluster. Established plantings live 10 or more years.

CULTURE

About 500 pounds per acre of 2–4–36 commercial fertilizer containing the essential minor elements (manganese, copper, and zinc) are recommended for the peat and muck soils of the Florida Everglades.[30] Ramie is propagated by dropping pieces of rootstocks about 6 inches long in an upright or slanting position in furrows and then filling the furrows so the upper ends are covered by about 2 inches of soil. The rootstock pieces are spaced 18 to 24 inches apart in rows 3 to 6 feet apart. The fields are cultivated to control weeds and to prevent the stand from becoming too thick. Young plants require 3 or 4 cultivations before the plants are large enough (2 feet high) to shade the ground.

Ramie is best cut with a hemp harvester or self-rake reaper when the growth of the stems has ceased and the staminate flowers begin to open. The harvesting period extends from May to November in the Florida Everglades. Two to four crops, cut at intervals of 2 months or more, are obtained each season under favorable conditions. The crop must be removed from the field promptly, as new growth is very rapid, sometimes 2 inches or more per day. Under very humid conditions it must be processed within a day or two in order to avoid decay.

FIBER PREPARATION

In China the bark is peeled from the stems by hand, and while keeping the peelings wet, the bark and cortical tissues are scraped free from the bast fibers with crude hand scrapers of bone or bamboo.[37] The separated fibers are then dried and are ready for the market. Before spinning, the fibers must be degummed, after which they are soft and silky. Many machines have been invented to decorticate ramie fiber but until recently none has been sufficiently perfected to meet the requirements for an established economical production of ramie in the United States.

In China, ramie yields 400 to 700 pounds of fiber per acre, extracted from 10 to 18 tons of fresh stalks. About one-half the green weight of fresh stalks consists of leaves. The dried fiber loses about 35 per cent of its weight when degummed, so the final yield of so-called degummed filasse is 260 to 455 pounds per acre. Higher yields are obtained under favorable conditions. Ramie fiber is similar to linen in appearance and use. The fabrics are called Swatow grass cloth, grass linen, Chinese linen, and Canton linen. The commercial fiber strands are 3 to 5 feet long and 0.002 to 0.003 inch in diameter. The ultimate fiber cells average 6 to 8 inches long.

Teasel

In 1939 teasels were harvested from 70 acres on five farms, four of which were in New York. The yield of teasels was about 620 pounds per acre valued at nearly 20 cents per pound. The commercial product is the dried ovoid, dense flower head, bearing numerous pointed bracts which end in hooked spines, and are used to raise the nap on woolen cloth (Figure 301). The heads of the fuller's teasel or clothier's teasel are attached to revolving cylinders that engage fibers of a passing bolt of cloth and raise the nap to make the goods feel softer and warmer.[4]

The teasel was introduced from Europe about 1840, and since that time its culture has been concentrated largely on the shores of Skaneateles Lake in New York. It also has been grown in the Willamette Valley of Oregon.

FIG. 301. Teasel head.

The teasel, a native of southern Europe and belonging to the Dipsaceae family, has escaped from cultivation in England, New York, and Oregon. The fuller's teasel (*Dipsacus fullonum*) plant is an erect herbaceous, branched, monoecious biennial, 2 to 6 feet in height, with opposite or whorled leaves, with the upper pairs of leaves united to form a cup around the stem that holds water. The blue or lilac flowers are in heads or whorls, surrounded by a many-leaved involucre. A low leafy plant is produced in the first season, but flower stalks shoot up the second year. The crop is propagated by seeds planted in cultivated rows in the spring. It is ready for harvest in the summer of the second year. In harvesting the stems are cut a few inches below the heads with a knife as soon as the blossoms have fallen. The cut heads are dropped into a wagon box, bag, or basket, and then hauled to a drying yard.

Chicory

Chicory roots were harvested on 785 farms in 1939. The production was 22,062 tons valued at $198,755 on 3,331 acres, all but 2 acres of which were in Michigan. The average yield was about 6.6 tons per acre. Chicory culture began in Michigan about 1890. Formerly the dried roots were imported from Europe. The roots are grown chiefly for drying and grinding to be mixed with coffee or used as a coffee substitute. The chicory imparts a special flavor and bitterness to the beverage brewed from the coffee mixture familiar to those who have tasted the French drip coffee of the deep south. Before the passage of pure food laws, chicory often was used to adulterate coffee.

The chicory plant, a native of Europe, was introduced into United States many years ago, and is now naturalized over a large part of the north, where it is a common weed pest in meadows and waste places.

It is a member of the family *Compositae*. Chicory (*Cichorum intybus*), also called succory, blue sailors, blue daisy, coffee weed, and bunk, is a perennial, erect herb 1½ to 6 feet in height, with long, slender, fleshy roots resembling parsnips. The ray flowers are bright blue and fertile.[24]

Chicory thrives best where the average growing-season temperature does not exceed 70° F.[8] It will stand considerable drought. It thrives on fertile, well-drained loam or clay loam soils. It requires a clean seedbed, and succeeds best when following a legume hay crop or an intertilled crop. Fertilizers recommended in Michigan are 8 to 10 tons of barnyard manure and 150 to 500 pounds of superphosphate, or a 2–16–2 or 0–14–4 mixed fertilizer. Chicory is planted from early May to early June with a sugar beet planter or garden drill, about ¼ inch deep in cultivated rows 18 to 24 inches apart, at the rate of 1½ to 2 pounds per acre. The plants are later blocked out and thinned to a spacing 8 to 10 inches in the row. Cultivation and digging are about the same as for sugar beets. They are dug in the fall before the ground freezes. The roots are topped with a knife above the crown. Yields of fresh roots range from 5 to 10 tons per acre.

The roots are shipped to a drying plant where they are cut up into one-inch cubes and then dried. The dried product is shipped to factories where it is ground and roasted as needed.

Pyrethrum

Pyrethrum is grown for its flowers, which contain two active principles, pyrethrin I and pyrethrin II, that have insecticidal properties.

Pyrethrum is now grown on a limited scale in Colorado. Its culture was begun in California many years ago and then discontinued. More recently, it was grown in Pennsylvania for a few years, but again production stopped because of the expense involved in harvesting the flowers by hand. The crop has been tested in many states, and efforts to reduce picking costs by development of a mechanical harvester have met with some success.[44]

For several years prior to World War II, imports of pyrethrum into the United States ranged from 10 to 20 million pounds annually. It has been grown extensively in Yugoslavia, Japan, East Africa, and Brazil. Recently pyrethrins have been synthesized in the laboratory.

ADAPTATION

The pyrethrum plant is adapted to many sections of the United States that are free from late spring and summer frosts and extreme winter cold, and that supply sufficient soil moisture or rainfall to support crop growth. The seedlings require a soil that is slightly acid, neutral, or slightly alkaline. The plants are best suited to well-drained sandy loam soils and clean fields free from perennial grasses or other weed plants that are difficult to control. Ample moisture at flowering time is essential to good yields.

BOTANICAL CHARACTERISTICS

Pyrethrum (*Chrysanthemum cinerariaefolium*) is a herbaceous perennial belonging to the family *Compositae*, the flower being a typical white daisy in appearance. The plant forms a clump 6 to 12 inches in diameter at the base from which the stems flare upward and outward (Figure 302). The height ranges from 15 to 40 inches. The plants do not flower during their first year. Thereafter they bloom each season. When grown in the southern states, it often lives only as an annual or biennial.[9]

CULTURE

The methods of establishing pyrethrum fields are very similar to the early phases of tobacco culture (Chapter 35). About 9 ounces of good seed planted in 300 square feet of bed space should produce 15,000 to 30,000 plants. The plants from spring sowing reach

FIG. 302. Pyrethrum plant in bloom (*left*). Leaves and pods of pyrethrum (*right*).

a height of 3 to 5 inches and are ready for transplanting about 3 months after sowing. The transplanting usually is done from early June to early August in central and northern latitudes. It also can be planted in July or August and transplanted the next spring. In the south the seed can be sown in the fall about 6 to 8 weeks before freezing weather begins, the seedlings mulched to protect them over winter, and the plants set out the next spring. Methods of transplanting are the same as for tobacco. The plants are set in rows at a rate of about 10,000 plants per acre. About 300 to 500 pounds per acre of a 4–12–4 fertilizer applied between the rows and worked into the soil either in early spring or after the crop is harvested, has been recommended.[9]

HARVEST

The flowers are ready for gathering when one-half to three-fourths of the florets on most of the disks are opened. A higher content of pyrethrins and higher total yields are obtained when harvesting is early than when delayed until the plants are in three-fourths bloom.[9] An efficient hand worker can gather only about 100 pounds of fresh flowers, equivalent to 25 pounds of dried flowers in a day. A machine designed by the United States Department of Agriculture harvests about 4 acres a day with a two-man crew, but some stems, leaves, and trash that require subsequent removal are gathered along with the flowers.[44] Stripping scoops similar to those used to gather bluegrass seed and cranberries have been devised for gathering the flowers. Another method tried has been to cut off the stems with a hand sickle and strip off the flowers from the stem drawn through a comb or held against a revolving spiked cylinder. Trashy material would be unsuitable for pyrethrum powder but would not be objectionable for chemical extraction of the pyrethrins.

The flowers must be dried soon after picking, on trays in the sun, on floors of large drying sheds, or in artificial driers.

USES

Yields of dried flowers average about 700 to 800 pounds per acre where the crop is adapted. No crop is obtained in the year the plants are set out. Fair yields are obtained in the second year, and better yields in the third and fourth years, but thereafter yields tend to decline. Dried flowers contain about 1 per cent of total pyrethrins, the stems about 0.1 per cent and the leaves practically none. The pyrethrin content is affected only slightly by soil type and fertilization. The powdered dried flowers of pyrethrum constitute the well-known insect powder used by our grandparents to destroy household insects, fleas, and other domestic vermin. Pyrethrins dissolved in kerosene or other petroleum derivatives, when supplemented by mint oil or other aromatic perfumes, constitute the common fly sprays used either alone, or more recently, in combination with DDT. This combination when sprayed on the housefly has a double action. The pyrethrins knock the flies down and the DDT prevents them from getting up. An important use of pyrethrum for some years has been for dusting vegetables, particularly when nearly ready for harvest, when use of arsenic and fluorine compounds would leave a residue of poisons on edible portions of the plants. Commercial success of pyrethrum culture in the United States awaits development of economical means of production and harvesting.

DISEASES AND INSECTS

Several diseases attack pyrethrum causing the death of plants which then require annual replacements. These diseases are caused by the fungi, *Septoria chrysanthemella, Diplodia chrysanthemella, Sclerotium rolfsii, S. delphinii, Rhizoctonia,* and various species of *Fusarium, Sclerotinia, Alternaria,* and *Phytophthora.* Insects have not been especially damaging to pyrethrum, but the fact that the plant contains an insecticide is no assurance that certain insects might not attack pyrethrum severely.

Belladonna

Belladonna was grown as an emergency crop on 275 acres in 1918 and again on about 700 acres in 1942 when imports of this essential drug plant were cut off by war. Annual imports of the herb and root, mostly from Yugoslavia, Italy, and U.S.S.R., average 190,000 pounds. Belladonna is best adapted to the northeastern, north central, and Pacific coast states.[43, 45] The name belladonna means beautiful lady. The sowing, transplanting, culture, harvest, and curing are very similar to the methods used for tobacco. The 1942 crop was produced by tobacco growers in Kentucky, Tennessee, Virginia, Ohio, Pennsylvania, and Wisconsin. It can be cut two to four or more times in a season. The belladonna plant (*Atropa belladonna*) is a poisonous perennial herb of the *Solanaceae* (nightshade) family, 2 to 6 feet in height, with ovate, entire leaves and purple bell-shaped flowers. The leaves, stems, and roots contain an alkaloid, atropine, used to dilate the pupils of the eyes. Extracts of the plant are used internally and externally as a sedative. Belladonna plants are attacked by the Rhizoctonia disease and by the same insects that attack potatoes and other solanaceous crops, including the Colorado potato beetle, cutworms, fleabeetles, and tobacco worms.

Henbane

The leaves, flowers, and stems of henbane (*Hyoscyamus niger*) contain several poisonous alkaloids that are used in the preparation of medicines. Extracts of henbane are used as sedatives for the relief of coughs, spasmodic asthma, spasms, and other ailments. Henbane was grown on a small acreage in Montana, Michigan, and other states during World War II, and in Michigan and California 25 years earlier. The crop from about 200 acres will supply our ordinary domestic requirements. Supplies usually are imported from Russia and Hungary. Henbane was introduced from Europe but it escaped from cultivation.

The plant is an annual or biennial belonging to the family *Solanaceae*. The biennial type, which usually is grown, produces a crop the first year and may not live over winter. It can be harvested the second year when it survives. The plant has a nauseous odor and is covered with hairs. The flowers have a five-toothed calyx and an irregular funnel-shaped corolla. The seeds are borne in a capsule.

Henbane is adapted to the relatively cool conditions of the northern border and Pacific coast states. It usually is sown in pots under glass in midwinter, the seedlings being transplanted to 3-inch pots and then transplanted to the field in May. The plants are set about 15 inches apart in rows 30 inches or more apart. The leaves and stems are harvested by hand when the plants are in full bloom which usually is in August. The drying process and facilities required are about the same as for tobacco.

The plant is extremely susceptible to tobacco mosaic virus and often is destroyed by the disease.

Ginseng

Ginseng was grown on 112 farms in the United States in 1939, the total production of roots being 25,508 pounds, valued at $77,270 on 138 acres. This production was chiefly in Wisconsin, Washington, Michigan, Oregon, New York, and Iowa. Ginseng (*Panax quinquefolium*), also called American ginseng, sang, red berry, and five-fingers, occurs sparingly in sloping shady locations in rich, moist soil in the hardwood forests from Maine to Minnesota and southward to the mountains of northern Georgia and Arkansas. The gathering of wild ginseng for export began about 1800, and the culture of the plant began about 1886, as natural supplies began to become depleted. Ginseng might truly be regarded as a glamour crop. In the United States, it has been the subject for visions of great wealth, because of the high price per pound, although the profits indicated by its promotors seldom have been realized. In China, Japan, and Korea, it is regarded as a medicine possessing extraordinary virtues, and as a cure-all, but particularly as a remedy for exhaustion of body and mind. Older branched roots that resemble the human form are especially prized.[42] The chief market for ginseng is in exports to the Orient.

Ginseng can be produced by dividing the roots of old plants, but this entails a risk of transmitting diseases.[52] Ginseng usually is propagated by seeds which are stratified in moist sand or sawdust, and kept in a cool damp place until they are ready to germinate, which usually is in the second spring after they are gathered.[48] The seeds are then planted under dense natural or artificial shade in a bed of deep leaf mold or compost. The plants are spaced about 6 or 8 inches apart. The roots are ready to dig and dry for the market not earlier than the sixth year from seeding, when they have reached a length of about 4 inches.

Goldenseal

Goldenseal (*Hydrastis canadensis*) was harvested on 51 farms in the United States in 1939. The total production of rootstocks was 15,144 pounds, valued at $40,464, on 50 acres. It was grown chiefly in Washington, Oregon, and Wisconsin. Goldenseal is native to the United States, being found in patches in high, open woods, and usually on hillsides or bluffs, from western New England to Minnesota and south to Georgia and Missouri. The plant is an erect perennial with a hairy stem, about 1 foot in height, with two branches at the top, one bearing a leaf and the other a leaf and a flower. The greenish-white flower is followed by a fleshy, berrylike head containing 10 to 20 small shining hard black seeds. The rootstock is about 2 inches long, ¾ inch thick, and bright yellow when fresh, with yellow flesh, and it bears numerous fibrous rootlets.

Goldenseal, which belongs to the Ranunculaceae or crowfoot family, also is called yellowroot, yellow puccoon, orange-root, yellow Indian paint, turmeric root, Indian turmeric, Ohio curcuma, ground raspberry, eyeroot, eyebalm, yelloweye, jaundice root, and Indian dye.

Goldenseal was used by Indians and early settlers of eastern North America as an external remedy for sore mouth and inflamed eyes and internally as a bitter tonic for stomach and liver troubles.[51] Commercial demand began about 1860 and collection from the wild for domestic and export use had so largely exhausted the supply by 1904 that its cultivation was begun by ginseng growers.

Goldenseal is propagated from seeds, rootstock division, or from buds or sprouts on the fibrous roots, rootstock division being most popular. The seeds are partly separated from the pulp of the fresh fruit and stratified in moist sand until October, and then planted in beds. They are transplanted a year or two later.

The soil and shade conditions for goldenseal are about the same as for ginseng except that about 600 pounds per acre of sulfate of potash or an equivalent quantity of potash from some other source should be applied. The rootstocks are ready for digging after 3 or 4 years from rootstock or bud planting or 5 years after planting seed. They are dug in the autumn after the tops are dead, and then sorted, washed, and then dried in trays. Yields of 2,000 pounds or less of dried roots may be obtained. Goldenseal is subject to certain diseases which preclude its culture in the southeastern piedmont states.

Poppy

Seed of the opium poppy (*Papaver somniferum*) is imported from the Netherlands, Poland, and Hungary, chiefly for use in the bakery trade, about 8 million pounds being imported annually. The seeds are sprinkled on certain types of bread and rolls before baking. The seeds produce an edible oil having an iodine number of about 135. White-seeded types are fed to birds under the name *maw* seed. Considerable quantities of opium for medicinal purposes are imported from Asia Minor, India, and China. Federal narcotic laws prohibit the growing of the opium poppy in the United States except under permit, and there is no commercial production here at the present time because of the risk of facilitating illicit drug traffic. The opium poppy is adapted to sections where certain other species of the

Oriental poppy are known to be adapted as ornamentals. *P. somniferum* is an annual plant belonging to the family Papaveraceae. It is a native of Greece and the Orient. The plants grow to a height of 4 feet, and have large white, purple, reddish-purple, or red flowers.

Opium is the dried milky juice obtained by lancing the fertile but unripe seed capsules. Opium contains about 19 distinct alkaloids including morphine and codeine. Paregoric and laudanum are manufactured from opium. Morphine can be extracted from the dried plant.

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39 SWEETPOTATOES

Economic Importance

Sweetpotatoes * were harvested on about 740,000 acres annually on one million farms from 1937 to 1946. The average production was 65 million bushels, and the average yield 88 bushels per acre. The leading states in sweetpotato production are North Carolina, Georgia, Louisiana, Alabama, and Mississippi (Figure 303). Sweetpotatoes are grown in most tropical and subtropical regions, including Mexico, Central America, South America, the Mediterranean

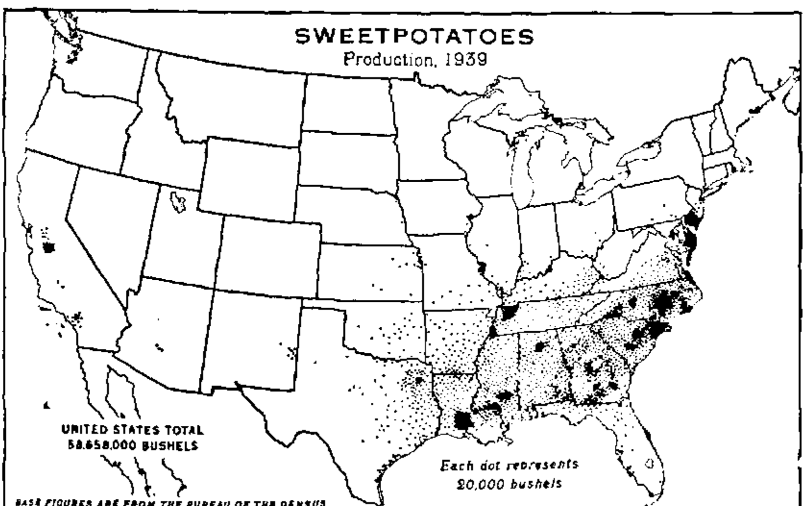

FIG. 303. Distribution of sweetpotato production in 1939.

* For more complete information on the sweetpotato, see the following books: H. C. Thompson, *Sweetpotato Production and Handling*, Orange Judd Publishing Co., Inc., New York, 1929. J. J. Taubenhaus, *The Culture and Diseases of the Sweet Potato*, E. P. Dutton & Co., New York, 1923.

region of Europe, Africa, India, China, Japan, southeast Asia, the East Indies, and the Pacific islands.

The original home of the sweetpotato is unknown but has been variously suggested as Mexico,[31] South America, Central America, and even Asia. The plant appears to have been introduced into the Pacific islands in early times, and possibly its culture also may have spread to China and other Asiatic countries before 1492. Columbus found sweetpotatoes growing in the West Indies. Sweetpotatoes were grown in Virginia as early as 1648.

In the United States, the sweetpotato is the second most important vegetable, being exceeded only by the potato. Although, like the potato, the sweetpotato usually is regarded as a truck crop, they are "sometimes classed as field crops." The growing of sweetpotatoes for starch manufacture necessitates economical production and harvesting, and also harvesting schedules that will permit the starch factory to operate at a uniformly high capacity. This has resulted in improved mechanized methods of planting and harvesting comparable to the production of other field crops.

Adaptation

The sweetpotato thrives only in moderately warm climates. It requires a growing period of at least four months of warm weather. A slight frost kills the foliage, and prolonged exposure of the plant or roots to temperatures much below 50° F. is damaging,[11] but no part of the United States is too hot or too moist for the sweetpotato to thrive. Maximum yields of roots are obtained where the mean temperature for July and August exceeds 80° F. Where sweetpotatoes are grown commercially, the mean temperature for summer months (June, July, and August) is above 70° F. It is higher than 75° F. in all sections except Maryland, Delaware, and New Jersey, and the less-important growing areas of Iowa, southern Illinois, and southern Indiana.

Differences in day length at different latitudes in the United States do not greatly modify root production. Long days promote heavy vegetative growth and the plants make their growth during the long days of the summer. Relatively short days, high temperatures, and a long growing season are required for the sweetpotato to produce an abundance of seed or flowers. Consequently, the plant does not bloom profusely or seed heavily in the United States except under greenhouse culture. An 11-hour day is favorable for flowering.[24] Sweetpotatoes produce seed readily in the West Indies and other tropical regions. Seed is produced in Louisiana by growing the young plants in the greenhouse in winter, transplanting them to the field in the spring, providing a trellis for the vines to climb, and partly girdling the stems.[27]

The sweetpotato, although rather lenient in its soil requirements, is grown mostly on sandy loam soils of the Norfolk and Sassafras series.[28] A sandy soil with a clay subsoil is desirable but good yields are obtained in very sandy soil types that are heavily fertilized.[26] Very fertile soils tend to be detrimental to root growth but favorable to a heavy growth of vines.[26] However, the crop succeeds well on fertile soils in the southwest. A well-drained soil is desirable, but bedding or ridging the field helps to overcome the effects of inadequate surface drainage. Sweetpotatoes thrive under subirrigated conditions in California where the water table is only 4 or 5 feet below the surface.

Nearly all of the nonirrigated commercial crop is grown where the average rainfall exceeds 35 inches, but sweetpotatoes are grown to some extent where the annual rainfall is as low as 25 inches.

The states producing the highest average yields of sweetpotatoes are Maryland, New Jersey, Delaware, California, and Virginia. In these states, however, the crop is confined largely to intensive specialized truck-crop sections where considerable attention is given to maintaining optimum fertilization and cultural conditions.

Botanical Description

The sweetpotato is a member of the *Convolvulaceae*, or morning-glory family. The sweetpotato (*Ipomoea batatas*) has funnel-shaped flowers ¾ to 1½ inches wide and 1 to 1½ inches long, with usually rose-violet or bluish petals and a darker color in the throat, five stamens, and an undivided style (Figure 304). One to four small, black, flattened seeds are borne in each fertile capsule.

The plant is a perennial that, in the United States, is killed by cold weather each winter and thus is grown only as an annual. The

FIG. 304. Flowers and leaves of the sweetpotato.

vines usually are 4 to 16 feet long, green or red to purple or both, and often somewhat hairy, especially at the nodes. The leaves are tinged with purple in some varieties. The characteristic leaves in many varieties are somewhat heart-shaped in outline, with the margins entire or toothed in the more popular varieties or deeply lobed in others. The roots have white, yellow, salmon, red, or purplish-red skin while the flesh is white or various shades of yellow, orange, or salmon.[36] Roots with purple or partly purple flesh are encountered occasionally.

The root does not have eyes or buds as in the potato tuber, but shoots arise from adventitious buds.[5] Starch is stored in the parenchyma cells of both the central core and the cortex.

Varieties

Sweetpotatoes are often considered as falling into two culinary classes, viz., the dry-fleshed or Jersey type and the moist-fleshed type or yam. The starch and feed varieties represent still other classes.

The Jersey type in general is favored in the northern markets, and the moist-fleshed varieties such as Nancy Hall and Porto Rico are favored in the south. The difference between the two types refers to the structure and appearance of the flesh, because the Jersey group is higher in moisture content.[13] The name yam as applied to either types or varieties of sweetpotatoes is a misnomer. The true yam, a tropical plant that produces tubers instead of fleshy roots, belongs to the genus *Dioscorea*, family *Dioscoreaceae*, and is not grown in the United States except to a limited extent in gardens in southern Florida.

Most present day sweetpotato varieties have originated from root selection. New types arise from bud mutations[18] or from controlled breeding methods.

Of the 40 or more varieties grown in the United States, Big-Stem Jersey, Yellow Jersey, Gold Skin, and Red Jersey have dry flesh and a low starch content. Maryland Golden and Orange Little Stem have a semidry flesh. The Triumph is a productive southern variety of high starch content and medium moist flesh grown chiefly for feed and starch production.[10] Yellow Strasburg is preferred for stock feeding. Yellow Jersey, Big-Stem Jersey, Maryland Golden, and Orange Little Stem are leading varieties in New Jersey, Delaware, and Maryland. Porto Rico is the principal variety in Georgia, South Carolina, Florida, Mississippi, and Texas. The Louisiana Unit 1 selection of Porto Rico leads in Louisiana, Nancy Hall leads in Tennessee, Arkansas, and Oklahoma. Nancy Hall, Porto Rico, Triumph, and Southern Queen are popular market moist-fleshed varieties in North Carolina, Alabama, and Mississippi. Both the Jersey types and the moist-fleshed varieties are grown in Virginia.[16] A new improved selected strain, Pelican Processor, has been released for starch production.[85]

Rotations

Rotation with other crops such as corn, cotton, potatoes, small grains, and legume hays is helpful in sweetpotato production, by reducing the infestation of soil-borne organisms causing diseases of sweetpotatoes, such as black rot, foot rot, and scurf.[21] Sweetpotatoes follow legume winter cover crops advantageously because there usually is time to plow under the cover crop before the sweetpotato plants are set in the field.[26] Legume crops sown in the fall either before or after the previous crop is harvested save about one-half to two-thirds of the quantity of nitrogen fertilizer that would otherwise need to be applied.[2]

Fertilizers

In Mississippi sweetpotatoes respond favorably to applications of 50 pounds each of nitrogen, phosphorus (P_2O_5), and potash (K_2O), or only 25 pounds of nitrogen when a good legume growth is turned under.[2] Heavier fertilization may be required for soils of very low fertility. Other fertilization plans suggested are 400 to 600 pounds per acre of 2–8–10 or 3–8–10 mixed fertilizer for the south, along with barnyard manure or a legume green manure turned under, and 800 to 1,200 pounds of 2–6–10 to 2–8–15 mixture for the Atlantic coastal plain region producing the Jersey type of sweetpotatoes.[26] About 1,200 pounds of 3–8–8 mixture were recommended for New Jersey.[33] Experiments in New Jersey, Virginia, Maryland, Georgia, and Florida indicate that sweetpotatoes respond to quantities of potash in excess of 40 to 50 pounds per acre, whereas other experiments in North Carolina, South Carolina, Mississippi, and Louisiana show that quantity to be sufficient.[9] Ample potash sometimes produces thick roots,[33] but in other cases has little influence on root shape.[9] Moderate liming may be helpful where the soil is below *p*H 5.0,[26] but a slightly acid soil prevents injury from scurf. Deep placement of fertilizer and lime may tend to develop long roots.

Cultural Methods

The seedbed preparation for sweetpotatoes is about the same as for other row crops in a particular region. Throwing up ridges or beds about 10 inches high in the field is believed to encourage growth of long roots.

PLANTING

Sweetpotato roots are bedded in warmed soil, and about a month to 6 weeks later, when the danger of frost is past, the rooted sprouts (called slips or draws) are pulled and planted in moist warm soil in ridged cultivated rows. In the north, the roots are bedded in a greenhouse, an artificially heated bed, or a hotbed heated by an underlying layer of fresh fermenting horse manure. In the south where the season is longer, a coldframe or an outdoor bed may be used, although heated beds are common there also.

Sound small to medium-sized roots are first treated with Semesan Bel, bichloride of mercury (1:1,000) solution, or some other recommended fungicide. Then they are laid in the bed, close together but not touching, and pressed into the surface of a 4- or 5-inch layer of sand. As the sprouts elongate, additional sand (2 or 3 inches) is added gradually to provide for root development along 2 or 3 inches at the base of the stem. Sometimes the beds are mulched to retain the heat until the sprouts emerge. Usually small roots are selected for bedding because more slips per bushel of roots are obtained.[1] A bushel of roots in 24 square feet of bed space should produce 1,000 plants in one pulling, so that 10 to 12 bushels of roots provide sufficient slips for planting an acre, while 6 to 8 bushels or less are sufficient when 2 or 3 pullings are made. The plants are pulled or drawn by hand when they reach the desired size. The yields from plants 6 to 7 inches high (Figure 305) are equal to those from 9- to 10-inch plants, whereas 12-inch plants are too long to handle conveniently.[8] A new crop of sprouts develops in 2 to 3 weeks after the first sprouts are pulled. The lower yields usually obtained from the second and third pullings are merely a consequence of later planting.[8] Prompt planting of the pulled sprouts is essential to the highest yields.[14]

The sprouts or draws may be planted with a transplanting machine or by hand. Growing and pulling plants for an acre requires about 25 man-hours. Machine planting, together with watering, requires about 13 man-hours per acre.[4]

Sweetpotatoes often are grown from vine cuttings in the south, and for a late seed crop farther north. Cuttings are taken from plants as soon as the vines start to run, and 8- to 12-inch sections of vine are pushed into the soil at desired intervals. Vine cuttings are cheaper than sprouts and less likely to spread diseases, but their use

FIG. 305. Sweetpotato sprouts or slips ready for planting.

delays planting. One acre of plants will supply cuttings for 8 acres of crop.

The plant spacing within the row may range from 10 to 24 inches without much effect upon total yield, yield of marketable roots, or starch content of the roots.[3] On very productive soils where high yields of market potatoes are expected, a closer spacing of 6 to 8 inches may be advantageous. The thinner spacings tend to produce fewer small roots and more large (Jumbo) roots.[7] Uniformly medium-sized roots are desired for the food market, but root size is of little importance when the crop is grown for starch manufacture.

The plants usually are set in ridges or beds 28 to 48 inches apart, wide rows being more common on infertile soils. Level planting is common in the drier sections of the United States. Sometimes the *hills* are set in checkrows to permit cultivation in both directions.

Any delay beyond the earliest practicable frost-free planting date results in marked decreases in yield.[3, 14] Late planting also produces slender roots of low starch and carotene content.[3]

CULTIVATION

The field is cultivated or hoed to control weeds until the vines spread between the rows. Early cultivation may be done with a modified rotary hoe.[32] For other cultivations the prevailing local implements such as sweep cultivators are satisfactory. Deep cultivation injures the roots. In laying-by the crop, the rows are ridged up well by using a disk cultivator, a middlebuster, or other convenient device.

HARVESTING

The maximum yield of sweetpotatoes is reached at the end of the growing season. Consequently, the roots often are not dug until immediately after the first light frost. The number, and often the size of roots, continue to increase for a month after the maximum starch content is reached.[20] Since the sweetpotato vines interfere with the operation of digging machines, they usually are cut either during or before digging. The vines can be cut with a mower, with shallow-running vertical knives attached to sled runners, or with rolling coulters attached to a plow or to a digging machine.[4] Cutting vines prematurely decreases yields materially. Even pruning vines to obtain cuttings for planting reduces yields decidedly if more than one-half the runners are removed.[14]

For food use, the most important factor in digging is to avoid cutting or bruising the roots, which would promote rapid decay.[32] A wide-bottom (16-inch) plow is recommended for digging sweetpotatoes that are to be stored. Such a plow run at the side of the row turns a furrow leaving the roots on top. The most commonly used type of implements, the middlebuster and the wide-shovel plow, operate satisfactorily if rod wings are attached to the shovel.

Usually the roots are allowed to dry for a few hours before they are picked up. The dug roots are picked up by hand into crates, hampers, or baskets. For food purposes, the roots usually are sorted by picking up the marketable roots first and the culls later. Great care in handling the roots will prevent future storage losses. For starch manufacture, the roots may be thrown or forked as into trucks because they are ground up promptly before decay begins.

Curing and Storage

Uncured roots decay quickly at temperatures of 50° F. or lower.[23] About 40 per cent of the harvested sweetpotato crop may spoil before the roots are used.[19] The conditions for curing are a temperature of 80° to 85° F. and a relative humidity of 85 to 90 per cent maintained for 10 to 14 days.[23] Such conditions promote the healing of wounds in the roots and thus check future fungus infection.[6] Ventilation during curing does not appear to be essential.[22]

After curing, the roots should be stored at 50° to 55° F. and a relative humidity of 80 to 85 per cent.[22] Slightly higher storage temperatures may be desirable for certain Jersey type varieties such as Maryland Golden. Storage of cured roots at 40° F. for 2 weeks or more tends to promote decay.[23] Ventilation occasionally is necessary to regulate the temperature and to prevent condensation of moisture in the storage room or on the roots. The storage room should provide for artificial heat to keep the temperature from falling much below 50° F.[38] Storage in baskets or crates causes less bruising and consequent shrinkage and decay than occurs when the roots are stored in slatted bins. New containers, or bins and containers that have been disinfected, reduce the initiation of decay.

Curing causes a shrinkage of 5 per cent or more, due to moisture evaporation and loss of dry matter resulting from respiratory oxidation of sugars. Subsequent shrinkage during a 5-month storage period may be fully as much,[37] but total shrinkage and spoilage under good conditions should not exceed 15 per cent. In storage, some of the starch and dextrin is converted to sugar, and under proper conditions the flesh softens somewhat, and the cooking quality, color, and flavor improve.[22]

Uses

Sweet potatoes are used primarily for food, being prepared mostly from the fresh state, but large quantities are canned, and some are dehydrated. A frozen sweetpotato puree and other products are now available to consumers. Large quantities of sweetpotatoes were dehydrated for food during World War II. Considerable quantities are dehydrated for animal feeding. Sweetpotatoes may be shredded in the home and then sun-dried,[20] or dehydrated in commercial plants. The culls are used mostly for stock feed and are suitable also for starch manufacture where processing facilities are available. Sweetpotato vines make a satisfactory roughage or silage. Sweetpotatoes contain about 70 per cent water, 1 per cent ash, 1.5 per cent protein, 0.5 per cent fat, 1 per cent crude fiber, 25 per cent nitrogen free-extract (of which about 3 to 4.5 per cent is sugars and the remainder mostly starch), 0.2 per cent calcium, and 0.05 per cent phosphorus. The sweetpotato contains about 100 micrograms per gram of carotene, and also fair quantities of ascorbic acid and B vitamins. Compared with the Irish potato tuber, the sweetpotato root is higher in dry matter, starch, sugar, crude fiber, and fat, but lower in protein.

Roots preferred by consumers are about 4 to 6 inches long and 1¾ to 3½ inches in diameter, and weigh not more than 1 to 1½ pounds.[18] Thick roots longer than 10 inches, called Jumbos, usually are not shipped. A standard bushel of sweetpotatoes varies in weight among different states from 50 to 60 pounds.

Extraction of starch from sweetpotatoes [11, 17, 25, 29] was carried on in southern United States from 1934 to 1948. The starch is used chiefly for textile sizing and in laundering. The average yield has been 10 to 11 pounds of starch per bushel of roots. Roots of high starch content (23 per cent) should yield 20 per cent starch or 12 pounds per bushel (60 pounds) with efficient operation.

Diseases

The diseases of sweetpotatoes [19] are of two main types: (1) those attacking the plants or roots in the field, and (2) storage diseases attacking the mature harvested roots. Some organisms attack the roots both in the field and in storage.

STEM ROT OR WILT

The stem rot or wilt disease is caused by two species of fungi, *Fusarium batatatis* and *F. hyperoxysporium*. The fungus is carried over in infected roots and also in the soil, where it remains for several years. It causes a wilt in the sprouts in the bed and in the vines in the field, and also a rotting of the vines. It forms a blackened ring inside the root. Control measures consist in bedding disease-free roots, disinfected for 5 to 10 minutes in 1:1000 bichloride of mercury, in clean or sterilized beds and then transplanting to noninfested fields. Selection of bedding roots from hills in which the stems, when split at harvest time, show no evidence of stem rot blackening is a good method of getting clean seed. Crop rotation is helpful but does not offer complete protection where the disease has occurred previously. The Southern Queen, Yellow Strasburg and Triumph varieties are somewhat resistant and the Pelican Processor (L-5) is highly resistant.

BLACK ROT

Black rot, caused by the fungus *Ceratosomella fimbriata,* causes widespread, heavy losses in the field and in storage. It often destroys sprouts, and yellows, wilts, and dries the foliage, and then black cankers develop in the underground parts of the stem. The infected roots show dark brown or black spots that enlarge until most of the root is affected. Control measures are similar to those for stem rot. Precautionary sanitary measures in and around the plant beds help prevent the spread of black rot.

SOIL ROT OR POX

The soil rot or pox disease, caused by the bacterialike fungus, *Actinomyces ipomoea,* that infests the soil, is widespread and very serious in certain important sweetpotato sections. Affected plants are stunted, have decayed roots, and often succumb to the disease. The surface of diseased mature roots shows pits or cavities with irregular jagged or roughened margins. These pits are filled with dead tissue at first but this later sloughs off. Soil rot does not develop on soils in Louisiana having a *p*H below 5.2.[30] The disease was largely checked there by applying sufficient sulfur to acidify the soil down below *p*H 5.

FOOTROT OR DIE-OFF

This disease, caused by the fungus *Plenodomus destruens,* occurs in Virginia, Ohio, Iowa, Missouri, and other states. It stunts or kills the sprouts, rots or girdles the base of the stem, and spreads to the roots, where it develops brown spots. The black fruiting bodies of the fungus are visible on diseased stems. Infection usually spreads in the plant bed. Sanitary measures recommended for stem rot aid in control of footrot.

TEXAS ROOTROT

This disease caused by the fungus *Phymatotrichum omnivorum* occurs in irregular areas in many fields and uncultivated areas chiefly in Texas, Oklahoma, New Mexico, Arizona, and California. On the sweetpotato it causes a brown rot of the roots and a browning of the stems. Control for sweetpotatoes consists of avoiding areas in the field known to be heavily infested.

SCURF

Scurf (called also soil-stain, rust, and Jersey mark) is caused by the fungus *Monilochaetes infuscans*. It produces brown or blackish spots on the surface of the roots that affect their appearance. It is not a decaying organism but causes excessive shrinkage in storage. Control consists in treating roots with Semesan Bel, bichloride of mercury (1:1,000), or other fungicides before bedding, avoiding heavy liming of the soil, and occasionally the application of 300 to 400 pounds of sulfur to the soil.

MOSAIC

The sweetpotato, like many other crops, is attacked by mosaic, a virus disease, and control consists in the use for bedding of roots from mosaic-free fields.

SOFT ROT

Soft rot, caused by the ever-present, ordinary bread-mold fungus, *Rhizopus nigricans*, is perhaps the most destructive storage disease of the sweetpotato. The mold enters the root through wounds or at the attachment end and spreads quickly over the root, causing complete decay. Control consists in proper curing of the roots to heal wounds, and good storage.

OTHER STORAGE ROTS

Dry rot caused by the fungus *Diaporthe batatatis* produces a firm brown rot. Java black-rot caused by *Diplodia tubericola* makes the roots dry and hard, and charcoal rot caused by *Macrophomina phaseoli* (*Sclerotium bataticola*) breaks down the interior of the root, leaving black spore bodies. The latter widespread disease is carried in the soil.

Insects

The sweetpotato weevil (*Cylas formicarius*)[15] deposits its eggs in small punctures in the stems or roots. The newly-hatched larvae bore through the stems and roots, leaving a frass that is so unpalatable that hogs will not eat badly damaged roots. A complete generation develops every few weeks throughout the year. It is most damaging in the Gulf coast region. Control measures are chiefly sanitation practices such as feeding or destruction of all plant residues, including small roots in the field and plant beds, destruction of related wild hosts belonging to the genus *Ipomoea,* and purchase of vine cuttings or slips from weevil-free areas. Omission of sweetpotato growing for a year is effective if all volunteer plants and weed hosts in the immediate vicinity are destroyed.[34]

The adults of the sweetpotato leaf beetle (*Typophorus viridicyaneus*), a pest of much less importance, emerge in late May and feed on sweetpotato leaves, and the larvae feed on the leaves and roots, enter the soil, and pupate in the fall. Some of the larvae are still in the roots at digging time and are thus transported to other fields. Control consists in dusting the plants with calcium arsenate or a 3:2 mixture of synthetic cryolite and talc, or a 1:2 mixture of 80 per cent barium fluosilicate and infusorial earth to poison the adult beetles.[12]

Other insects attacking the sweetpotato include the grasshopper, flea beetles, and termites.

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PART V APPENDIX

TABLE 1. SEEDING; SEED AND PLANT CHARACTERISTICS

Temperature type: C = cool weather growth; W = warm weather growth.
Growth habit: A = annual; W.A. = winter annual; B = biennial; P = perennial; P(A) = perennial but grown as annual.
Chromosome number: reduced number (N).
Photoperiodic reaction: L = long day; S = short day; N = day neutral or indeterminate; I = intermediate.

CROP	BOTANICAL NAME	SEEDING RATE PER ACRE: CLOSE DRILLS	SEEDING RATE PER ACRE: ROWS	SEEDS PER: POUND	SEEDS PER: GRAM	WEIGHT PER BUSHEL	GERMINATION TIME	TEMPERATURE TYPE	GROWTH HABIT	CHROMOSOME NUMBER	PHOTOPERIODIC REACTION
		(lbs.)	*(lbs.)*	*(thousands)*	*(no.)*	*(lbs.)*	*(days)*				
Alfalfa	*Medicago sativa* L.			220	500	60	7	C	P	16	L
Humid areas		10–20									
Irrigation		10–15									
Semiarid		8–10									
Alyceclover	*Alysicarpus vaginalis* DC.	10–20		275	660	60	21	W	A		
Bahia grass	*Paspalum notatum* Flügge	10–12		150	336		21	W	P	20	
Barley	*Hordeum vulgare* L.	72–96		13	30	48	7	C	A; WA	7	L
Bean											
Adzuki	*Phaseolus angularis* Wight		20–25	5	11	60	10	W	A	11	
Field	*Phaseolus vulgaris* L.		40–75	1–2	4	60	8	W	A	11	S; N
(dryland)			5–20								
Lima	*Phaseolus limensis* Macf.		120	0.4	2	56	9	W	P(A)	11	S
Lima (baby)	*Phaseolus lunatus* L.		60	0.5				W	A	11	S; N
Mung	*Phaseolus aureus* Roxb.		10–15	11	24		7	W	A	11	S
Tepary	*Phaseolus acutifolius latifolius* Freem		10–12	2	5			W	A	11	S
Beet (see mangel and sugar beet)											

TABLE I. SEEDING; SEED AND PLANT CHARACTERISTICS (continued)

CROP	BOTANICAL NAME	SEEDING RATE PER ACRE: CLOSE DRILLS (lbs.)	SEEDING RATE PER ACRE: ROWS (lbs.)	SEEDS PER: POUND (thousands)	SEEDS PER: GRAM (no.)	WEIGHT PER BUSHEL (lbs.)	GERMINATION TIME (days)	TEMPERATURE TYPE	GROWTH HABIT	CHROMOSOME NUMBER	PHOTOPERIODIC REACTION
Beggarweed (Florida)	*Desmodium purpureum*	10		194		60		W	P(A)	11	S
unhulled	DC.	30–40									
Bentgrass											
Astoria	*Agrostis tenuis* Sibth.	40–60		5,500	12,000		21	C	P	14	
Colonial	*Agrostis tenuis*	40–60		8,000	19,000	20–40		C	P	14	
Creeping	*Agrostis palustris* Huds.	40–60		7,700	17,000		28	C	P	14	L
Highland	*Agrostis tenuis*	40–60		9,100	20,000		28	C	P	14	
Velvet	*Agrostis canina* L.	40–60		11,000	24,000			C	P	7; 14	
Belladonna	*Atropa belladonna* L.			480					P	36	
Bermuda grass	*Cynodon dactylon* (L)	6–8		1,800	3,900	40(14)	21	W	P	15; 18	
(unhulled)	Pers.	10–15		1,300							
Berseem (see clover, Egyptian)											
Big trefoil	*Lotus uliginosus* Schkuhr.	4–6		1,000	1,900	60	7	C	P	7	
Birdsfoot trefoil	*Lotus corniculatus* L.	8–12		375	800	60	7	C	P	6	
Black medic	*Medicago lupulina* L.	10–15		300	600	60(hulled)	7	C	A	8	
Bluegrass											
Annual	*Poa annua* L.	15–25		1,200	2,600		21	C	A	7; 14	
Bulbous	*Poa bulbosa* L.	20–25		450	1,000		35	C	P	14	L
Canada	*Poa compressa* L.	15–25		2,500	5,500	14	28	C	P	21; 28	L
Kentucky	*Poa pratensis* L.	15–25		2,200	4,800	14	28	C	P	14; 28; 35	N
Nevada	*Poa nevadensis* Vasey	6–10		1,000	2,300		21	C	P	31; 32; 33	
Rough	*Poa trivialis* L.	15–25		2,500	5,600		21	C	P	7	
Texas	*Poa arachnifera* Torr.	6–10		1,100	2,500		28	C	P	21	
Wood	*Poa nemoralis* L.			3,200	7,000		28	C	P	14; 21	

Bluestem											
Big	Andropogon furcatus										
	Muhl.	15-20		150	340		28	W	P	35; 20	S
Little	Andropogon scoparius										
	Michx.	12-20		260	560		28	W	P	20	
Sand	Andropogon hallii Hack.	10-15		100	230		28	W	P	30; 35	
Bonavist	Dolichos lablab L.		20-25	1		60			P(A)	11; 12	N
Bromegrass											
Awnless	Bromus inermis Leyss.	15-20		137	300	14	14	C	P	21; 28; 35	L
Mountain	Bromus marginatus Nees.	10-20		64	140			C	P	21; 28; 35	
Broomcorn	Sorghum vulgare Pers.		2-4	25	60	(44-50)	10	W	A	10	S
Buckwheat (common)	Fagopyrum esculentum										
	Gaertn. (sagittatum)	36-60		20	45	48	6	W	A	8	L; N
Buckwheat (tartary)	Fagopyrum tataricum										
	Gaertn.	24		26		48			A	8	
Buffalo grass (burs)	Buchloe dactyloides										
	Engelm.	15-20		50	110		28	W	P	28; 30	
Buffalo grass (caryopses)		2		330	738						
Burclover											
California (out of bur)	Medicago hispida Gaertn.	15-20		209	303	50	14	C	WA	7	
Spotted (in bur)	Medicago arabica Huds.	50-75		22	40	8-12	14	C	WA	8	
Burnet	Sanguisorba minor Scop.							W	P	14	
Canary grass	Phalaris canariensis L.	20-25		68		50			A	6	
Carpet grass	Axonopus compressus										
	(Swartz) Beauv.	8-12		1,350	2,500	18-36	21	W	A	6	
Carrot (stock)	Daucus carota L.		2	405	800	50	28	C	B	9	L
Cassava (roots)	Manihot utilissima										
	(esculenta) Pohl.		900					W	P	18 +	
Castorbean	Ricinus communis L.		7-10	1		50		W	P(A)	10	
Cheat	Bromus secalinus L.	30-50		71				C	WA	7; 14	
Chicory	Cichorium intybus L.		1-2	420	940		14	C	P	Cu 9	
Chickpea	Cicer arietinum L.	60		1	2		7	C	A	7; 8	N; L
Chufa	Cyperus esculentus L.		15-40			44		W	P	54(?)	

TABLE 1. SEEDING; SEED AND PLANT CHARACTERISTICS (*continued*)

CROP	BOTANICAL NAME	SEEDING RATE PER ACRE: CLOSE DRILLS	SEEDING RATE PER ACRE: ROWS	SEEDS PER: POUND	SEEDS PER: GRAM	WEIGHT PER BUSHEL	GERMINATION TIME	TEMPERATURE TYPE	GROWTH HABIT	CHROMOSOME NUMBER	PHOTOPERIODIC REACTION
		(*lbs.*)	(*lbs.*)	(*thousands*)	(*no.*)	(*lbs.*)	(*days*)				
Clover											
Alsike (alone)	*Trifolium hybridum* L.	6–8		680	1,500	60	7	C	P	8	L
(with timothy)		2–4									
Alyce (see alyceclover)											
Bur (see burclover)											
Cluster	*Trifolium glomeratum* L.	3–4		1,300	2,900	60	10	C	WA	7; 8	L
Crimson	*Trifolium incarnatum* L.	15–25		150	330	60	7	C	WA	7; 8	L
(unhulled)		40–60									
Egyptian (berseem)	*Trifolium alexandrinum* L.	15–20		210	460	60	7	C	WA	8	L
Hop	*Trifolium agrarium* L.	8–12		830		60			WA	7	L
Ladino	*Trifolium repens* L.	5–7		860	1,900	60	10	C	P		
Lappa	*Trifolium lappaceum* L.	4–5		680	1,500	60	7	C	WA	8	L
Large Hop	*Trifolium procumbens* L.	3–4		2,500	5,400	60	14	C	WA	7	L
Low Hop	*Trifolium dubium* (minus) L.	4–5		860	1,900	60	14	C	WA	14; 16	L
Persian	*Trifolium resupinatum* L.	4–8		640	1,400	60	7	C	WA	8	L
Red	*Trifolium pratense* L.	8–12		260	600	60	7	C	P	7; 14	L
(with timothy)		4–6									
Sour (see sourclover)											
Strawberry	*Trifolium fragiferum* L.	4–6		290	640	60	7	C	P	8	L
Sub (subterranean)	*Trifolium subterraneum* L.	20–25		55	120	60	14	C	WA	8	
Sweet (see sweetclover)											
White	*Trifolium repens* L.	5–7		700	1,500	60	10	C	P	8; 12; 14; 16	L
Zigzag	*Trifolium medium* L.								P	40; 48; 49	L

Corn											
Field—for grain	*Zea mays* L.		6–10	1.2	3	56	7	W	A	10	S
—for silage			8–18								
Pop	*Zea mays* L.		3–6	3		56	7	W	A	10	S
Sweet	*Zea mays* L.		12–18	2		50	7	W	A	10	S
Cotton						32					
Upland	*Gossypium hirustum* L.			4	8	28–33	12	W	P(A)	26	N
Eastern humid			24–40								
Mississippi Valley			24–48								
Drier areas			16–32								
Irrigated			25–30								
Egyptian (S.W. irrigated)	*Gossypium barbadense* L.		35–40	4			12	W	P(A)	26	N
Cowpea	*Vigna sinensis* Endl.	75–120	30–45	2–6	8	60	8	W	A	12	S
Crested dogtail	*Cynosurus cristatus* L.	15–25		860	1,900		21	C	P	7	
Crested wheatgrass (see wheatgrass)											
Crotalaria											
Showy	*Crotalaria spectabilis* Roth.	15–25	4–6	30	80	60	10	W	A		
Striped	*Crotalaria mucronata* Desv. (*striata* DC.)	10–20	3–4	75	215	60	10	W	A	8	
"Intermedia"	*Crotalaria intermedia* Kotschy.	10–15	2–4	96	210	60	10	W	A		
"Juncea"	*Crotalaria juncea* L.	20–40	5–7	16	35	60	10	W	A	8	
"Lanceolata"	*Crotalaria lanceolata*	8–12	2–3	170	375	60	10	W	A	8	
Dallis grass	*Paspalum dilatatum* Poir.	8–25		340	485	12–15	21	W	P	20; 25	
Digitalis (foxglove	*Digitalis purpurea* L.								B	28	
Dill	*Anethum graveolens* L.		5	410					A; P	11	
Fenugreek	*Trigonella foenumgraecum* L.	15–30				60			A	8	
Dropseed, Sand	*Sporobolus cryptandrus* (Torr.) A. Gray	3–5		5,450	12,000		42	W	P	9	

TABLE 1. SEEDING; SEED AND PLANT CHARACTERISTICS *(continued)*

CROP	BOTANICAL NAME	SEEDING RATE PER ACRE: CLOSE DRILLS (*lbs.*)	SEEDING RATE PER ACRE: ROWS (*lbs.*)	SEEDS PER: POUND (*thou-sands*)	SEEDS PER: GRAM (*no.*)	WEIGHT PER BUSHEL (*lbs.*)	GERMINATION TIME (*days*)	TEMPERATURE TYPE	GROWTH HABIT	CHROMOSOME NUMBER	PHOTOPERIODIC REACTION
Fescue											
Chewings	*Festuca rubra* var. *commutata* Gaud.	15–40		615		14–30	21	C	P	21	
Hair	*Festuca capillata* Lam.			1,500	3,200		28	C	P	7	
Meadow	*Festuca elatior* L.	10–25		230	500	14–24	14	C	P	7; 14; 21; 35	
Red	*Festuca rubra* L.	15–40		400			21	C	P	7; 21; 28; 35	
Sheeps	*Festuca ovina* L.	25				10–30	21	C	P	7; 14; 21; 35	
Feterita (see sorghum)											
Field pea (large seeded)	*Pisum arvense* L.	120–180		4	8	60	8	C	A	7	L
(small seeded)		90–120									
Austrian Winter	*Pisum arvense* L.	30–90		5			8	C	WA		
Flax (for seed)	*Linum usitatissimum* L.	28–42		135	180	56	7	C	A	15	L
(for fiber)		84		113							
Gamagrass	*Tripsacum dactyloides* L.	Veg.		7				W	P	35; 18; 36	S
Giant panic grass	*Panicum antidotale*	2–6		610	1,450		28		A	9	
Goldenseal	*Hydrastis canadensis* L.								P	13	
Grama grass											
Black	*Bouteloua eripoda* Torr.	7–9		560				W	P	21	
Blue	*Bouteloua gracilis* (H.B.K.) Lag.	8–12		900	1,980		28	W	P	20; 21; 14	N; S
Hairy	*Bouteloua hirsuta* Lag.	10–15		980						21	
Side oats	*Bouteloua curtipendula*							W	P		
	Torr.	15–20		200	442		28	W	P	21; 28; 35	
(caryopses)				730	1,600						
Grasspea	*Lathyrus sativus* L.	70–80		5			60		A	7	

Guar	*Cyamopsis psoralides* DC.	10–60	10	2		60		W	A	7	
Guayule	*Parthenium argentatum* Gray			600					P	36	
Guinea grass	*Panicum maximum* Jacq.	Veg.		1,000	2,200		28	W	P	18	
Hairy indigo	*Indigofera hirsuta*	3–10		200		55		W	A		
Harding grass	*Phalaris tuberosa* var. *stenoptera* Hitchc.	25–30		340	750		28		P	14	
Hegari (see sorghum)											
Hemp	*Cannabis sativa* L.	44		27	45	44	7	C	A	10	S
Henbane	*Hyoscyamus niger* L.								A; B	17	L
Hop	*Humulus lupulus* L.		Veg.						P	10	
Horsebean	*Vicia faba* L.	120–200		1–2		47	10	C	A	6; 7	L
Hungarian grass (see millet-foxtail)											
Indian grass	*Sorghastrum nutans* (L.) Nash			170	365		21	W	P	20	I
Jerusalem artichoke (tubers)	*Helianthus tuberosus* L.	300–800						C	P	Ca 51	S; N
Job's tears	*Coix lachyryma-jobi* L.								A	10	N
Johnson grass	*Sorghum halepense* (L.) Pers.	20–30		130	290	28	35	W	P	20	S
Kafir (see sorghum)											
Kale (Thousand-headed)	*Brassica oleraceae* DC.	½–¾		140	315		10	C	B	9	N; L
Kidney vetch	*Anthyllis vulneraria* L.	20		150		60				6	
Kudzu	*Pueraria thunbergiana* Benth.	Veg.	6–10	37	81	54	14	W	P		
Lentil	*Lentilla lens*		5–8	9		60		W	A	7	L
Lespedeza											
Chinese (Sericea)	*Lespedeza cuneata* (Dum. de Cours) G. Don.	30–40				35	28	W	P	9	
(scarified)		15–20		335	820	60					
Common and Tenn. 76	*Lespedeza striata* Hook & Arn	25–30		343	750	25	14	W	A	10	L
Kobe	*Lespedeza striata*	30–35		185	750	30	14	W	A	10	L
Korean	*Lespedeza stipulaceae* Maxim	20–25		240	525	45	14	W	A	10	L
Siberian	*Lespedeza hedysaroides*	10–15		370	820	60	21	W			

TABLE 1. SEEDING; SEED AND PLANT CHARACTERISTICS (*continued*)

CROP	BOTANICAL NAME	SEEDING RATE PER ACRE: CLOSE DRILLS (*lbs.*)	SEEDING RATE PER ACRE: ROWS (*lbs.*)	SEEDS PER: POUND (*thousands*)	SEEDS PER: GRAM (*no.*)	WEIGHT PER BUSHEL (*lbs.*)	GERMINATION TIME (*days.*)	TEMPERATURE TYPE	GROWTH HABIT	CHROMOSOME NUMBER	PHOTOPERIODIC REACTION
Lovegrass, Weeping	*Eragrostis curvula* (Schrad.) Nees.	¼		1,500	3,300		14	W	P	20	
Lehmann	*Eragrostis lehmanniana* Nees.	1–3		4,245				W	P		
Sand	*Eragrostis trichoides* (Nutt.) Nash	1–2		1,800				W	P		
Lupine											
Blue	*Lupinus angustifolius* L.	70–90		3	7	60	10	C	A	20; 24	N; S
White	*Lupinus albus* L.	120–160		3	7	60	7	C	A	Ca 20	N
Yellow	*Lupinus luteus* L.	45–60		4	9	60	21	C	A	Ca 23	N; L
Mangel	*Beta vulgaris* L.		6–8	22				C	B	9	L
Meadow fescue (see fescue)											
Meadow foxtail	*Alopecurus pratensis* L.	15–25		540	1,200	6–12	14	C	P	14	
Melilotus indica (see sourclover)											
Millet											
Browntop	*Panicum fasiculatum* Swartz.			140	300		14	W	A	18	
Foxtail	*Setaria italica*(L.) Beauv.	20–30		220	470	50	10	W	A	9	S
Japanese (barnyard)	*Echinochloa crusgalli frumentacea* W. F. Wight	20–25		155	320	35	10	W	A	18; 24; 28	
Pearl (cattail)	*Pennisetum glaucum* L.	16–20	4–6	85	190		7	W	A	7	S
Proso	*Panicum miliaceum* L.	15–35		80	180	56	7	W	A	18; 21; 36	S
Ragi (finger)	*Eleusine coracana* (L.) Gaertn.							W	A	18	S
Milo (see sorghum)											

Mint											
Peppermint	*Mentha piperita* L.	Veg.							P	18	
Spearmint	*Mentha spicata* L.	Veg.							P	18	
Molasses grass	*Melinis minutiflora* Beauv.			6,800	15,000		21	W	P	18	
Mustard			3–4			58					
Black	*Brassica nigra* Koch			570	1,250		7	C	A	8	L
Brown	*Brassica juncea* Coss.	3						C	A	18	
White	*Brassica alba* Rabenh.	4		73	160		5	C	A	12	
Napier grass	*Pennisetum purpureum* Schumach.	Veg.		1,402			10	C	P	14	
Oats											
Common	*Avena sativa* L.	48–128		14	30	32	10	C	A; WA	21	L
Red	*Avena byzantina* C. Koch	48–128		14	30	32	10	C	A; WA	21	L
Oatgrass, tall meadow	*Arrhenatherum elatius* (L.) Mert & Koch	30–40		150	330	11–14	14	C	P	14	
Orchard grass	*Dactylis glomerata* L.	20–25		590	1,440	14	18	C	P	14	N; L
Para grass	*Panicum purpurescens* (var. *barbinode*) Raddi	Veg.						W	P	18	
Pea (see field pea)											
Peanut	*Arachis hypogeae* L.		20–40	1	1–3	20–30	10	W	A	20	S
Pepper	*Capsicum frutescens* L.		½	75	165		14	W	A	12	
Perilla	*Perilla frutescens* Britt. (*ocymoides*)		4–5			37			A		S
Pigeon pea	*Cajanus cajan* (*indicus* Spreng)		8–10	8		60			P	11	
Popcorn (see corn)											
Poppy (opium)	*Papaver somniferum* L.					46			A	11	L
Potato (tubers)	*Solanum tuberosum* L.		1,000			60		C	P(A)	12; 24	L; N
Pumpkin (hills)	*Cucurbita pepo* L.		3–4	2	4		7	W	A	12	
Cushaw	*Cucurbita moshata* Duchesne		3–4						A	12; 20; 24	

TABLE 1. SEEDING; SEED AND PLANT CHARACTERISTICS *(continued)*

CROP	BOTANICAL NAME	SEEDING RATE PER ACRE: CLOSE DRILLS *(lbs.)*	SEEDING RATE PER ACRE: ROWS *(lbs.)*	SEEDS PER: POUND *(thousands)*	SEEDS PER: GRAM *(no.)*	WEIGHT PER BUSHEL *(lbs.)*	GERMINATION TIME *(days)*	TEMPERATURE TYPE	GROWTH HABIT	CHROMOSOME NUMBER	PHOTOPERIODIC REACTION
Pyrethrum	*Chrysanthemum cineriaefolium* Vis.		½						P	9	
Ramie (China grass)	*Boehmeria nivea* Gaud.	Veg.							P	14	
Rape						50					
Oilseed (summer)	*Brassica napus* var. *annua* Koch	3–4		160	345		7	C	A	19	L
Biennial turnip	*Brassica campestris* var. *autummalis* DC.		2	240	535		7	C	B	10	
Bird Annual turnip	*Brassica campestris* L.	3–4		190	425		10	C	B	10	
Winter (broadcast	*Brassica napus* var. *biennis* (Schubl. and Mart.) Reichb.	2–3 4–6		104	230	50	7	C	B	19	L
Redtop	*Agrostis alba* L.	10–12		5,100	11,000	14	10	C	P	14; 21	
Reed canary grass	*Phalaris arundinacea* L.	8–12		550	1,200	44–48	21	C	P	14	L
Rescue grass	*Bromus catharticus* Vahl.	25–30		1,700	145	8–12	35	W		14; 21	
Rhodes grass	*Chloris gayana* Kunth	10–12		1,700	4,700	8–12	14	W	P	10; 20	
Rice	*Oryza sativa* L.	67–160		15	65	45	14	W	A	12	S
Ricegrass, Indian	*Oryzopsis hymenoides*	8–10		140	310		42	C	P	24	
Roughpea	*Lathyrus hirsutus* L.	20		14	40	55	14	C	WA	7	
Rough-stalked meadow grass (see bluegrass, rough)											
Rutabaga	*Brassica napobrassica* Mill.		1–2	200	430	60	14	C	B	18	
Rye	*Secale cereale* L.	28–112		18	40	56	7	C	A; WA	7	L
Ryegrass											
Italian	*Lolium multiflorum* Lam.	25–30		227	500	24	14	C	WA	7	
Perennial	*Lolium perenne* L.	25–30		330	500	24	14	C	P	7	L

Sacaline	*Polygonum sachalinense* F. Schmidt								P	22	
Safflower	*Carthamus tinctorius* L.	20–100		8–13		45			A	12	
Sainfoin	*Onobrychis viciaefolia* Scop.	30–35		23	50	55	10		P	11	
Sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray	½		3–5	5,000			W	P	9	
Serradella	*Ornithopus sativus* Brot.	15–20				36			A	8	
Sesame (benné)	*Sesamum indicum* L.		5	100		46	10	W	A	13; 26	
Sesbania	*Sesbania macrocarpa* Muhl. (*exaltata*)	25–30		40	105	60	7	W	A		
Smilograss	*Oryzopsis miliacea* (L.) Benth. and Hook.			990	2,000		42		P	12	
Sorghum	*Sorghum vulgare* Pers.						10	W	A	10	S
feterita			3–6	13		56	10	W			
hegari			3–6	20		56	10	W			
kafir		15–45	3–6	20	55	56	10	W			
milo			2–5	15		56	10	W			
sorgo		15–75	4–8	28	50	50	10	W			
sorgo (Sumac)		15–75	3–6	40		50	10	W			
Sourclover	*Melilotus indica* All.	15–20		300	660	60	14	C	WA	8	
Soybean (small-seeded)	*Glycine max* Merrill (*Soja max* Piper)	60	15–20	8		60	8	W		20	S; N
(medium-seeded)		90	20–30	2–3	6–13	60					
(large-seeded)		120	30–45	1		60					
Spelt (see wheat)											
Squash	*Cucurbita maxima* Duchesne		2	6	14		7	W	A	20; 24	
Sudan grass	*Sorghum vulgare sudanense* (Piper) Hitchc.	20–35	4–6	55	120	40	10	W	A	10	S
Sugar beet	*Beta vulgaris* (*saccharifera*) L.			22		15		C	B	9	L
Sugarcane	*Saccharum officinarum* L.	Veg.						W	P	40	S

TABLE 1. SEEDING; SEED AND PLANT CHARACTERISTICS (*continued*)

CROP	BOTANICAL NAME	SEEDING RATE PER ACRE: CLOSE DRILLS	SEEDING RATE PER ACRE: ROWS	SEEDS PER: POUND	SEEDS PER: GRAM	WEIGHT PER BUSHEL	GERMINATION TIME	TEMPERATURE TYPE	GROWTH HABIT	CHROMOSOME NUMBER	PHOTOPERIODIC REACTION
		(*lbs.*)	(*lbs.*)	(*thousands*)	(*no.*)	(*lbs.*)	(*days*)				
Sulla (sweet vetch)	*Hedysarium coronarium* L.	20–25		100		60			P(A)	45?	S
Sunflower (seed)	*Helianthus annuus* L.		3–7	3–9		24	7		A	17 +	N
(silage)			5–10								
Sweetclover											
White	*Melilotus alba* Med.										
	(hulled)	12–15		250	570	60	7	C	B; A	8	
Yellow	*Melilotus officinalis* Lam.										
	(unhulled)	30–45		250	570	60	7	C	B	8	
Sweetpotato	*Ipomoea batatas* Lam.		Veg.			55–60		W	P(A)	45	S
Sweet vernalgrass	*Anthoxanthum odoratum* L.	15–25		730	1,600		14	C	P	5	
Switchgrass	*Panicum virgatum* L.			370	815		28	W	P	18; 36; 35; 28	S
Tall meadow oatgrass (see oatgrass)											
Teasel	*Dipsacus fullonum* L.								B	10	
Teosinte (annual)	*Euchlaena mexicana* Schrad.	3–5		7					A	10	
(perennial)	*Euchlaena perennis* Hitchc.								P	20	S
Timothy (alone, spring)	*Phleum pratense* L.	8–12		1,230	2,500	45	10	C	P	7; 21	L
(alone, fall)		3–4									
(with clover)		4–6									
Tobacco	*Nicotiana tobacum* L.		1/250	5,000			14	W	A	24	N
Trefoil (see big trefoil and birdsfoot trefoil)											
Turnip	*Brassica rapa* L.		1–2	154	535	55	7	C	B	10	N
(broadcast)		4–5									

Vasey grass	*Paspalum urvillei* Steud.	8–15		440	970		21	W	P	20; 30	
Velvetbean (with corn)	*Stizolobium utile* (*deeringianum* Bort)		30–45	1	2	60	14	W	A		
Velvetgrass	*Holcus lanatus* L.	10–25		1,200			14	C	P	7	
Vetch											
Common (alone)	*Vicia sativa* L.	40–80		7	19	60	10	C	A; WA	6; 7	L
Hairy (alone)	*Vicia villosa* Roth	20–40		21	36	60	14	C	WA; B	7	L
(with grain)		20									
Hungarian	*Vicia pannonica* Crantz	40–80		11	24	60	10	C	A; WA	6; 7	
Monantha	*Vicia monantha* Desf.	30–70		10		60	10	C	A; WA	7	
Narrowleaf (wild)	*Vicia angustifolia* L.	20–30		27	60	60	14	C	A	6	
Purple	*Vicia atropurpurea* Desf.	40–70		9	20	60	10	C	WA; A	7	
Woolypod	*Vicia dasycarpa* Ten.	25–50		11	25	60	14	C			
Wheat											
Club	*Triticum compactum* Host	60–90		20–24		60	7	C	A; WA	21	L
Common	*Triticum vulgare* Vill. (*aestivum* L.)	30–120		12–20		60	7	C	A; WA	21	L
Durum	*Triticum durum* Desf.	60–90		8–16		60	10	C	A	14	L
Emmer	*Triticum dicoccum* Schrank	60–90				40	7	C	A; WA	14	L
Spelt	*Triticum spelta* L.	60–90				40	7	C	A; WA	21	L
Wheatgrass											
Crested (Fairway)	*Agropyron cristatum* (L.) Gaertn.	12–20	4–6	320	714		14	C	P	7	
Crested (Standard)	*Agropyron desertorum* Fisch.	12–20	4–6	190	425	20–24	14	C	P	14	
Slender	*Agropyron trachycaulum* Malte (*pauciflorum*)	12–20		150	320		14	C	P	14	
Western	*Agropyron smithii* Rydb.	12–20		110	235		35	C	P	21; 28	L
Wild rice	*Zizania aquatica* L.	50–100							A	15	S
Wild rye, Canada	*Elymus canadensis* L.	10–12		120	261		21	C	P	14; 21	
Wormseed	*Chenopodium ambrosioides anthelminticum* Gray								A	16 +	
Wormwood	*Artemisia absinthium* L.								P	9	

TABLE 1. SEEDING; SEED AND PLANT CHARACTERISTICS (*continued*)

Average rates of seeding in the United States in 1945 were: corn 7.8 lb., winter wheat 1.18 bu., durum wheat 1.39 bu., other spring wheat 1.16 bu., oats 2.38 bu., barley 1.62 bu., rye 1.28 bu., buckwheat 1 bu., flaxseed 0.62 bu., sorghum 8 lb., rice 110 lb., dry beans 43 lb., field peas 140 lb., soybeans 1.39 bu., cowpeas 1.03 bu., potatoes 15.6 bu., peanuts 48.8 lb.

Seeding rates and seeds per pound were taken mostly from compilation by the late Dr. A. J. Pieters; but also from other sources.

Seeds per gram, calculated seeds per pound and germination time are from Federal Seed Act Regulations, dated August 4, 1945.

Weights per bushel listed are legal U. S. weights (if established), state legal weight most widely adopted, or customary weight when no legal weight has been established. Federal legal weights have been established for barley, beans, castorbean, buckwheat, corn, flaxseed, potatoes, rye, and wheat.

Chromosome number and photoperiodic reaction are compiled from various sources, chiefly summary papers on chromosome number and photoperiodic reaction. See references below:

H. A. Allard and W. J. Zaumeyer, "Responses of beans (*Phaseolus*) and other legumes to length of day," *U. S. Dept. Agr. Tech. Bull. 867*, pp. 1–24 (1944).

H. A. Allard and W. W. Garner, "Further observations on the response of various species of plants to length of day," *U. S. Dept. Agr. Tech. Bull. 727*, pp. 1–64 (1940).

L. O. Gaiser, "Chromosome Numbers in Angiosperms," II *Bibliotheca Genetica*, 6: 171–466 (1930).

W. M. Myers, "Cytology and genetics of forage grasses," *Botanical Review*, 13 (*6 and 7*): 319–421.

R. von Schick, "Photoperiodismus," *Der Zuchter*, 4 (5): 122–135 (1932).

Yearbooks of Agriculture, 1936 and 1937.

The most complete recent compilation of chromosome numbers is that of C. D. Darlington, and E. K. Janaki Ammal. *Chromosome Atlas of Cultivated Plants*, George Allen and Unwin Ltd., London, 1945, pp. 1–397.

TABLE 2. THE PERCENTAGE COMPOSITION OF CROP PRODUCTS

GRAINS, SEEDS, AND MILL CONCENTRATES

PRODUCT	MOISTURE	ASH	CRUDE PROTEIN	ETHER EXTRACT [a]	CRUDE FIBER	NITROGEN-FREE EXTRACT [b]	CALCIUM	PHOSPHORUS
	%	%	%	%	%	%	%	%
Barley	9.6	2.9	12.8	2.3	5.5	66.9	0.07	0.32
Barley feed	7.9	4.9	15.0	4.0	13.7	54.5	0.03	0.41
Bread, kiln dried	10.5	2.1	12.5	1.6	0.4	72.9	0.03	0.12
Brewers' dried grains:								
18–23-per cent protein	7.9	4.1	20.7	7.2	17.6	42.5	0.16	0.47
23–28-per cent protein	7.7	4.3	25.4	6.3	16.0	40.3	0.16	0.47
Brewers' rice	11.6	.7	7.0	0.8	0.6	79.3	0.03	0.25
Buckwheat	12.6	2.0	10.0	2.2	8.7	64.5		
Buckwheat middlings	12.4	4.6	28.0	6.6	5.3	43.1		
Corn, shelled	12.9	1.3	9.3	4.3	1.9	70.3	0.01	0.26
Corn bran	10.0	2.1	10.0	6.6	8.8	62.5	0.03	0.14
Corn chop	11.3	1.4	9.8	4.1	2.1	71.3	0.01	0.26
Corn (ear) chop	10.7	2.0	8.2	3.4	9.2	66.5		
Corn-feed meal	10.8	1.9	10.5	5.3	2.9	68.6	0.04	0.38
Corn-germ meal	7.0	3.8	20.8	9.6	7.3	51.5	0.05	0.59
Corn-gluten feed	9.5	6.0	27.6	3.0	7.5	46.4	0.11	0.78
Corn-gluten meal	8.0	2.2	43.0	2.7	3.7	40.4	0.10	0.47
Corn-oil meal	8.7	2.2	22.1	6.8	10.8	49.4	0.06	0.62
Cottonseed, whole pressed	6.5	4.3	29.6	5.8	25.1	28.7		
Cottonseed cake	7.5	5.9	44.1	6.4	10.3	25.8		
Cottonseed feed, 32 per cent protein	8.3	4.8	32.1	6.4	15.3	33.1	0.20	0.73
Cottonseed hulls	8.7	2.6	3.5	1.0	46.2	38.0		

[a] Fat.
[b] Carbohydrates except fiber.

TABLE 2. THE PERCENTAGE COMPOSITION OF CROP PRODUCTS (*continued*)

GRAINS, SEEDS, AND MILL CONCENTRATES (*Continued*)

PRODUCT	MOISTURE	ASH	CRUDE PROTEIN	ETHER EXTRACT	CRUDE FIBER	NITROGEN-FREE EXTRACT	CALCIUM	PHOSPHORUS
	%	%	%	%	%	%	%	%
Cottonseed meal:								
33–38 per cent protein	7.4	5.2	36.6	5.6	15.3	29.9	0.28	1.30
38–43 per cent protein	7.3	6.1	41.0	6.5	11.9	27.2	0.19	1.11
Over 43 per cent protein	7.2	5.8	43.7	6.5	11.1	25.7	0.18	1.15
Distillers' (corn) dried grain	7.0	2.4	28.3	9.4	14.6	38.3	0.04	0.29
Distillers' (rye) dried grain	6.1	2.4	17.9	6.3	15.9	51.4	0.13	0.43
Feterita	9.1	1.7	14.2	2.9	1.4	70.7		
Hemp cake	10.8	18.0	30.8	10.2	22.6	7.6		
Hempseed, European	8.8	18.8	21.5	30.4	15.9	4.6		
Hominy feed	9.5	2.9	11.2	8.3	6.3	61.8	0.03	0.44
Kafir	11.9	1.7	11.1	3.0	2.3	70.0	0.01	0.25
Kafir-head chops	10.4	3.9	10.9	2.5	6.0	66.3	0.09	0.20
Linseed meal:								
33–38 per cent protein	8.5	5.6	35.3	5.4	8.3	36.9	0.36	0.84
38–43 per cent protein	8.5	5.3	40.4	5.8	7.5	32.5	0.33	0.74
Malt	7.7	2.9	12.4	2.1	6.0	68.9		
Malt sprouts	7.3	6.1	28.1	1.8	13.3	43.4	0.26	0.68
Mesquite beans and pods	6.6	4.5	13.0	2.7	22.8	50.4		
Millet, foxtail	10.1	3.3	12.6	4.3	8.4	61.3		
Millet, proso or hog millet	9.8	3.4	12.0	3.4	7.9	63.5		
Milo	9.3	1.6	12.5	3.2	1.5	71.9		
Milo-head chops	10.4	4.3	10.7	2.6	7.1	64.9		
Molasses, cane	24.0	6.8	3.1			66.1	0.35	0.06
Oats, grain	7.7	3.5	12.5	4.4	11.2	60.7	0.10	0.40
Oat chops	8.9	3.9	12.8	5.0	11.8	57.6	0.10	0.36
Oat clips	[illegible]	9.3	11.8	4.5	22.7	42.7		

Oat groats, ground rolled	10.4	2.6	17.3	6.6	1.8	61.3	0.08	0.43
Oat hulls	5.8	6.5	4.3	1.9	30.8	50.7	0.09	0.12
Oatmeal	8.9	2.3	16.5	4.8	3.6	63.9	0.08	0.43
Oat millfeed	6.9	6.0	6.3	2.2	27.9	50.7	0.20	0.22
Peanuts, kernels	5.5	2.3	30.2	47.6	2.8	11.6	0.06	0.38
Peanuts, shells on	6.0	2.8	24.7	33.1	18.0	15.4		
Peanut meal:								
38–43 per cent protein	6.4	4.4	41.6	7.2	16.0	24.4	0.10	0.50
43–48 per cent protein	6.7	4.6	45.1	7.2	14.2	22.2	0.17	0.55
Over 48 per cent protein	7.0	5.0	51.4	4.8	9.2	22.6		
Rapeseed, brown Indian	5.7	6.4	21.0	41.2	12.5	13.2		
Rapeseed, common	7.3	4.2	19.5	45.0	6.0	18.0		
Rice, rough	9.7	5.4	7.3	2.0	8.6	67.0	0.10	0.10
Rice, bran	9.8	12.2	12.8	13.8	12.2	40.2	0.10	1.84
Rice hulls	6.5	21.9	2.1	0.4	44.8	24.3	0.08	0.06
Rice polish	10.0	7.6	12.4	13.2	2.8	54.0	0.03	1.52
Rice-stone bran	8.4	11.9	12.5	13.0	11.1	43.1		
Rye	9.5	1.9	11.1	1.7	2.1	73.7	0.04	0.37
Rye feed	10.2	4.0	15.6	3.2	4.3	62.7		0.59
Rye middlings	9.5	4.4	16.7	3.7	5.5	60.2		
Sesame seed	5.5	6.5	20.3	45.6	7.1	15.0		
Sesame-seed cake	9.8	10.7	37.5	14.0	6.3	21.7		
Sorgo	12.8	2.1	9.1	3.6	2.6	69.8		
Soybeans	8.0	4.8	38.9	18.0	4.8	25.5	0.22	0.67
Soybean meal:								
38–43 per cent protein	7.8	5.8	41.7	5.8	6.2	32.7	0.29	0.67
43–48 per cent protein	8.2	6.0	44.7	4.6	5.8	30.7	0.34	0.71
Sunflower seed	6.9	3.2	15.2	28.8	28.5	17.4		
Sunflower hulls	10.5	2.6	4.4	3.1	57.0	22.1		
Sunflower kernels	6.9	4.2	29.4	43.9	2.6	13.0		
Velvetbeans	9.8	3.1	26.2	4.8	6.0	50.1		
Wheat	10.6	1.8	12.0	2.0	2.0	71.6	0.05	0.38

TABLE 2. THE PERCENTAGE COMPOSITION OF CROP PRODUCTS (*continued*)

GRAINS, SEEDS, AND MILL CONCENTRATES (*Continued*)

PRODUCT	MOISTURE	ASH	CRUDE PROTEIN	ETHER EXTRACT	CRUDE FIBER	NITROGEN FREE EXTRACT	CALCIUM	PHOSPHORUS
	%	%	%	%	%	%	%	%
Wheat bran	9.4	6.4	16.4	4.4	9.9	53.5	0.10	1.14
Wheat, brown shorts	10.8	4.0	17.8	4.8	5.8	56.8		
Wheat-flour middlings	10.4	3.3	18.8	4.0	4.2	59.3	0.09	0.80
Wheat, gray shorts	11.0	4.1	17.5	4.4	5.4	57.6	0.08	0.86
Wheat, mixed feed	9.9	4.4	18.2	4.4	6.9	56.1	0.11	0.96
Wheat, red dog	11.1	2.2	18.3	3.4	2.3	62.7	0.12	0.83
Wheat, standard middlings	10.4	3.9	17.0	4.3	5.4	59.0	0.09	0.90
Wheat, white shorts	10.9	2.2	15.6	3.7	2.4	65.2		
Wheat waste, shredded	8.0	1.6	12.4	1.6	2.6	73.8		
DRIED FORAGES								
Alfalfa hay	7.2	8.0	15.4	1.6	30.3	37.5	1.51	0.21
Alfalfa-leaf meal	8.5	14.4	20.9	2.6	15.7	37.9	1.42	0.25
Alfalfa meal	8.2	10.0	15.2	2.2	27.5	36.9	1.56	0.22
Alfalfa meal, dehydrated	6.6	10.0	16.9	2.6	25.4	38.5		
Alfalfa-stem meal	9.1	7.7	11.4	1.3	36.1	34.4		
Alsike clover hay	10.5	8.8	14.4	2.5	24.7	39.1	0.78	0.20
Australian saltbush hay	6.7	16.9	16.1	1.8	21.5	37.0		
Barley hay	15.0	6.4	6.7	1.6	21.4	48.9	0.17	0.25
Barley straw	14.2	5.7	3.5	1.5	36.0	39.1		
Bermuda grass hay	8.9	7.9	7.2	1.7	24.9	49.4	0.60	0.16
Black grama hay	5.5	7.0	4.3	1.3	31.4	50.5	0.22	0.09
Blue grama hay	10.9	8.5	6.7	1.8	27.9	44.2		
Bluegrass hay, immature	7.3	7.9	15.2	3.0	23.7	42.9	0.45	0.35
Bluegrass hay, bloom	11.9	7.0	9.3	3.4	27.9	40.5	0.30	0.21
Bluejoint grass hay	7.5	6.9	6.7	3.0	34.2	41.7		

Bromegrass hay	14.0	9.7	9.3	1.8	26.6	38.6		
Buckwheat straw	9.9	5.5	5.2	1.3	43.0	35.1		
Buffalo grass hay	6.2	10.8	5.6	1.7	26.1	49.6		
Burclover hay	8.7	12.3	15.7	3.0	25.5	34.8	1.11	0.15
Corncobs	10.7	1.4	2.4	0.5	30.1	54.9		
Corn fodder	11.8	5.8	7.4	2.4	23.0	49.6		
Corn husks	9.8	2.9	2.9	0.7	30.7	53.0		
Corn leaves	11.8	8.5	8.1	2.2	24.4	45.0		
Cornstalks	11.7	4.6	4.8	1.8	32.7	44.4		
Corn stover	10.7	6.1	5.7	1.5	30.3	45.7	0.45	0.10
Cowpea hay	9.7	12.9	17.5	2.8	20.5	36.6	1.84	0.25
Cowpea straw	9.7	5.3	7.4	1.3	41.5	34.8		
Crabgrass hay	9.0	7.9	6.5	2.2	32.1	42.3	0.33	0.17
Crimson clover hay	9.6	8.6	15.2	2.8	27.2	36.6	1.18	0.13
Feterita fodder	13.3	6.4	8.7	1.9	21.5	48.2	0.27	0.19
Field-pea hay	10.6	8.3	16.1	2.7	24.8	37.5		
Flax straw	6.2	3.8	7.8	2.1	46.9	33.2		
Hegari fodder	13.5	8.2	6.2	1.7	16.7	53.7	0.17	0.18
Hegari stover	15.1	9.7	4.5	1.9	26.6	42.2	0.38	0.09
Johnson grass hay	7.2	7.2	8.1	2.8	30.4	44.3	0.55	0.40
Kafir fodder	9.1	7.8	6.6	2.1	28.4	46.0	0.31	0.05
Kafir stover	12.6	9.0	5.8	1.7	27.5	43.4		
Lespedeza hay	7.9	6.2	11.9	2.8	28.5	42.7	0.80	0.25
Little bluestem hay	8.6	4.9	4.0	1.6	35.4	45.5		
Meadow fescue hay	11.6	7.0	6.6	2.0	31.6	41.2		
Millet hay, foxtail	7.0	8.2	9.2	2.8	28.0	44.8		
Millet hay, pearl or cattail	10.1	9.7	9.0	1.8	32.3	37.1		
Natal grass hay	7.5	4.8	3.7	1.4	39.5	43.1	0.49	0.32
Oatgrass, tall, hay	8.1	6.4	9.4	2.7	29.8	43.6		
Oat hay	11.8	5.7	6.1	2.4	27.1	46.9	0.27	0.22
Oat straw	8.1	7.6	4.4	2.5	36.2	41.2	0.23	0.20
Orchard grass hay, immatur	9.9	6.0	8.1	2.6	32.4	41.0	0.31	0.18
Orchard grass hay, mature	9.9	7.0	6.9	3.0	32.7	40.5		

TABLE 2. THE PERCENTAGE COMPOSITION OF CROP PRODUCTS (*continued*)

DRIED FORAGES (*Continued*)

PRODUCT	MOISTURE	ASH	CRUDE PROTEIN	ETHER EXTRACT	CRUDE FIBER	NITROGEN-FREE EXTRACT	CALCIUM	PHOSPHORUS
	%	%	%	%	%	%	%	%
Prairie hay (Colorado, Wyoming)	5.5	7.2	7.0	2.4	31.3	46.6		
Prairie hay (Kansas, Oklahoma)	9.5	7.5	4.4	2.3	30.4	45.9	0.55	0.07
Prairie hay (Minnesota, South Dakota)	11.6	7.2	6.0	2.4	30.3	42.5	0.44	0.11
Red clover hay	7.0	10.0	16.1	2.6	23.6	40.7	1.01	0.14
Red clover, mammoth, hay	12.2	7.5	12.8	3.3	27.1	37.1		
Redtop hay	8.9	5.2	7.9	1.9	28.6	47.5	0.35	0.18
Rhodes grass hay	8.6	8.4	5.3	1.2	33.4	43.1		
Rice straw	8.9	13.5	4.5	1.6	34.0	37.5	0.18	0.05
Rye hay	6.4	4.7	5.9	2.0	37.4	43.6	0.27	0.22
Rye straw	7.1	3.2	3.0	1.2	38.9	46.6		
Rye grass, perennial, hay	10.2	8.6	8.6	4.1	24.5	44.0	0.17	0.11
Rye grass, Italian, hay	8.5	6.9	7.5	1.7	30.5	44.9		
Rye grass hay	8.3	8.5	6.3	2.0	33.0	41.9		
Sedge, western species	5.4	6.7	11.6	2.4	27.4	46.5		
Slender wheatgrass	7.5	6.6	7.8	2.1	30.8	45.2		
Sorgo fodder	11.6	6.0	5.3	2.4	26.0	48.7	0.27	0.15
Sorgo hay	5.8	9.5	9.5	1.9	26.8	46.5	0.31	0.09
Soybean hay	8.4	8.9	15.8	3.8	24.3	38.8	1.26	0.22
Soybean straw	8.7	7.4	5.7	2.5	34.6	41.1		
Sudan grass hay	5.3	8.1	9.7	1.7	27.9	47.3	0.47	0.24
Sweetclover hay	8.1	7.5	16.2	2.8	25.9	39.5	0.74	0.08
Sweetclover straw	5.1	3.4	6.7	1.2	49.6	34.0		
Timothy hay	7.1	5.8	7.5	2.9	30.2	46.5	0.31	0.13
Vetch, hairy, hay	13.1	8.4	20.9	2.7	24.2	30.7	0.25	0.30
Western needlegrass hay	9.9	6.2	5.5	2.7	33.2	42.5		
Western wheatgrass hay	8.6	8.7	8.4	2.3	31.9	40.1		

Wheat hay	9.6	4.2	3.4	1.3	38.1	43.4	0.14	0.15
Wheat straw	6.8	5.4	4.3	3.4	36.8	43.3		
White clover hay	7.2	9.4	15.6	2.2	22.7	42.9	1.31	0.28
Wire grass hay	8.5	7.3	6.6	1.3	34.6	41.7		
GREEN FORAGES								
Alfalfa, immature	79.4	2.9	5.2	0.7	3.8	8.0	0.28	0.09
Alfalfa, in bloom	77.2	1.8	3.2	0.6	7.8	9.4	0.39	0.07
Alsike clover, immature	81.2	2.4	4.9	0.6	3.1	7.8	0.26	0.09
Alsike clover, in bloom	74.8	2.0	3.9	0.9	7.4	11.0	0.21	0.06
Barley, immature	83.4	1.5	2.8	0.7	3.6	8.0	0.06	0.07
Barley, mature	77.1	1.6	2.2	0.5	6.4	12.2	0.05	0.07
Bluegrass, Kentucky, immature	70.5	2.5	5.0	1.2	7.5	13.3	0.15	0.13
Bromegrass, immature	77.5	2.9	4.3	0.9	5.2	9.2	0.14	0.10
Cabbage	90.5	0.9	2.4	0.3	1.2	4.7	0.06	0.02
Canada bluegrass, immature	74.1	2.5	4.3	1.3	6.8	11.0	0.11	0.12
Corn fodder:								
Dent, immature	79.0	1.2	1.7	0.5	5.6	12.0		
Dent, mature	73.4	1.5	2.0	0.9	6.7	15.5		
Flint, immature	79.8	1.1	2.0	0.7	4.3	12.1		
Flint, mature	77.1	1.1	2.1	0.8	4.3	14.6		
Cowpeas	82.5	2.5	3.4	0.5	4.0	7.1	0.18	0.05
Crimson clover	80.9	1.7	3.1	0.7	5.2	8.4	0.28	0.04
Kafir	73.0	2.0	2.3	0.7	6.9	15.1		
Lespedeza, Korean, immature	74.1	2.4	4.6	0.8	5.8	12.3	0.34	0.11
Meadow fescue, immature	78.8	2.6	4.0	0.9	4.7	9.0	0.15	0.11
Meadow foxtail, immature	73.9	2.8	4.5	1.2	5.6	12.0	0.15	0.12
Millet, foxtail	71.1	1.7	3.1	0.7	9.2	14.2	0.09	0.05
Oatgrass, tall, immature	78.4	3.0	4.3	1.0	4.6	8.7	0.11	0.13
Oats, immature	82.6	1.7	2.9	0.7	3.3	8.8	0.07	0.07
Oats, mature	72.0	2.1	2.7	0.9	7.4	14.9	0.08	0.08
Orchard grass, immature	78.3	2.8	3.4	1.0	5.3	9.2	0.14	0.13

TABLE 2. THE PERCENTAGE COMPOSITION OF CROP PRODUCTS (*continued*)

GREEN FORAGES (*Continued*)

PRODUCT	MOISTURE	ASH	CRUDE PROTEIN	ETHER EXTRACT	CRUDE FIBER	NITROGEN-FREE EXTRACT	CALCIUM	PHOSPHORUS
	%	%	%	%	%	%	%	%
Orchard grass, in bloom	73.0	2.0	2.6	0.9	8.2	13.3		
Pricklypear	78.9	4.3	.7	0.4	2.6	13.1		
Rape	85.7	2.0	2.4	0.6	2.2	7.1		
Red clover, immature	81.2	2.7	5.0	0.8	3.0	7.3	0.27	0.10
Red clover, in bloom	70.8	2.1	4.4	1.1	8.1	13.5	0.44	0.07
Red fescue, immature	70.5	2.8	4.1	0.9	8.2	13.5	0.16	0.13
Redtop, immature	76.8	2.8	4.1	0.9	5.4	10.0	0.15	0.10
Reed canary grass, immature	80.7	2.4	3.5	0.7	4.3	8.4	0.13	0.10
Rye, immature	80.8	2.3	4.5	1.1	3.4	7.9	0.10	0.10
Rye, mature	76.6	1.8	2.6	0.6	11.6	6.8	0.08	0.06
Rye grass, Italian, immature	77.3	2.5	3.5	1.0	5.2	10.5	0.13	0.12
Rye grass, perennial, immature	75.9	3.0	3.8	0.9	5.4	11.0	0.15	0.12
Sorgo	77.3	1.3	1.5	1.0	6.2	12.7		
Soybeans	73.9	2.9	4.0	1.1	7.6	10.5	0.28	0.05
Sweetclover, immature	75.3	2.2	5.3	0.7	6.7	9.8	0.26	0.07
Sweet corn	79.1	1.3	1.9	0.5	4.4	12.8		
Timothy, immature	74.9	2.3	4.1	0.9	5.4	12.4	0.12	0.11
Timothy, in bloom	61.6	2.1	3.1	1.2	11.8	20.2	0.13	0.05
Wheat, immature	82.3	2.1	3.8	0.9	3.0	7.9	0.07	0.10
Wheat, mature	68.7	2.6	2.4	0.7	8.6	17.0	0.06	0.08
White clover, immature	82.0	2.1	4.9	0.6	3.1	7.3	0.23	0.09
White clover, wild, immature	81.2	2.2	5.2	0.6	2.9	7.9	0.25	0.10

SILAGES, ROOTS, TUBERS, AND BY-PRODUCTS

Alfalfa silage	68.9	2.7	5.7	1.0	8.8	12.9		
Alfalfa-molasses silage	68.6	3.4	5.8	1.0	8.4	12.8		
Beet pulp, dried	9.2	3.2	9.3	0.8	20.0	57.5	0.66	0.06
Beet pulp, molasses, dried	8.0	5.2	11.6	0.7	16.4	58.1	0.59	0.09
Carrots	88.6	1.0	1.1	0.4	1.3	7.6		
Cassava	63.8	1.4	1.0	0.3	0.8	32.7		
Corn silage	73.8	1.7	2.1	0.8	6.3	15.3	0.08	0.08
Corn silage, immature	79.1	1.4	1.7	0.8	6.0	11.0		
Corn silage, mature	70.9	1.4	2.4	0.9	6.9	17.5		
Corn stover silage	80.7	1.8	1.8	0.6	5.6	9.5		
Cowpea silage	77.8	2.1	3.2	0.9	6.5	9.5		
Hegari silage	66.3	3.4	2.3	0.8	6.7	20.5		
Jerusalem artichokes	78.7	1.1	2.5	0.2	0.8	16.7		
Mangel-wurzel	90.8	1.0	1.4	0.2	0.9	5.7	0.02	0.02
Napier grass silage	67.5	1.8	1.2	0.7	14.4	14.4	0.10	0.10
Parsnips	80.0	1.3	2.2	0.4	1.3	14.8		
Pea-vine silage	75.1	1.7	3.0	0.9	8.1	11.2		
Potatoes	78.9	1.0	2.1	0.1	0.6	17.3	0.01	0.06
Red clover silage	72.0	2.6	4.2	1.2	8.4	11.6		
Rutabagas	88.6	1.2	1.2	0.2	1.3	7.5	0.05	0.04
Sorgo silage	74.7	1.4	1.6	1.0	6.9	14.4	0.09	0.04
Soybean silage	75.6	2.6	2.4	0.8	9.6	9.0	0.29	0.10
Sugar beets	78.0	1.0	1.5	0.1	2.9	16.5	0.05	0.06
Sugar-beet pulp	90.5	0.4	.9	0.2	2.2	5.8		
Sunflower silage	77.9	2.1	1.8	1.6	6.5	10.1		
Sweetclover silage	70.2	2.9	6.1	1.0	9.7	10.1		
Sweetpotatoes	71.1	1.0	1.5	0.4	1.3	21.7	0.02	0.05
Turnips	90.6	0.8	1.3	0.2	1.2	5.9	0.05	0.05

From *U. S. Dept. Agr. Ybk.*, 1939.

TABLE 3. CONVERSION TABLES

MASS

1 microgram (μgm.) = 0.000001 gm.
1 milligram (mgm.) = 0.001 gm.
1 centigram (cgm.) = 10 mg. = 0.01 gm.
1 decigram (dgm.) = 100 mg. = 0.1 gm.
1 gram (gm.) = 1,000 mg. = 15.432356 grains
1 dekagram = (dkgm.) = 10 gm.
1 hectogram (hgm.) = 100 gm.
1 kilogram (kgm.) = 1,000 gm. = 2.204622341 lb.
1 metric quintal = 100 kg. = 220.46 lb.
1 metric ton = 1,000 kg. = 2,204.62 lb.

AVOIRDUPOIS WEIGHTS

1 grain (gr.) = 64.798918 mgm.
1 ounce (oz.) = 437.5 gr. = 28.349527 gm.
1 pound (lb.) = 16 oz. = 7,000 gr. = 453.5924 gm.
1 short hundredweight = 100 lb.
1 long hundredweight = 112 lb.
1 short ton = 2,000 lb.
1 long ton = 2,240 lb.

LENGTH

1 kilometer (km.) = 1,000 m. = 0.62137 mile
1 hectometer (hm.) = 100 m. = 328 ft. 1 in.
1 dekameter (dkm.) = 10 m. = 393.7 in.
1 meter (m.) = 1 m. = 39.37 in. = 3.28 ft.
1 decimeter (dm.) = $\frac{1}{10}$ m. = 3.937 in.
1 centimeter (cm.) = $\frac{1}{100}$ m. = 0.3937 in.
1 millimeter (mm.) = $\frac{1}{1000}$ m. = 0.03937 in.
1 micron (μ) = $\frac{1}{1000}$ mm.
1 millimicron (mμ) = $\frac{1}{1000}$ μ
1 Ångström (Å) = $\frac{1}{10}$ mμ

1 mile = 5,280 ft. = 1,760 yd. = 320 rd. = 80 chains
1 chain = 66 ft. = 22 yd. = 4 rd. = 100 links
1 rod = 16½ ft. = 5½ yd. = 25 links
1 yard = 3 ft. = 36 in. = 0.9144 m.
1 foot = 12 in. = 30.48006 cm.
1 link = 7.92 in.
1 inch = 2.540005 cm. = 25.4 mm.

AREA

1 centare (ca.) = 1 square meter
1 are (a.) = 100 sq. m.
1 hectare (ha.) = 10,000 sq. m. = 2.47104 A.
1 labor (lah-bore′) = 177$\frac{1}{7}$ A.
1 square league = 25 labors = 4,409 A.
1 Old Spanish league = 2.63 miles
(Parts of Texas are surveyed in leagues and labors)

TABLE 3. CONVERSION TABLES (*continued*)

AREA

1 sq. in. = 6.451626 sq. cm.
1 sq. ft. = 144 sq. in.
1 sq. yd. = 9 sq. ft.
1 sq. rd. = 1 perch = 30¼ sq. yd. = 272¼ sq. ft.
1 acre = 160 sq. rd. = 4,839 sq. yd. = 43,560 sq. ft. = 0.404687 ha.
1 sq. mi. = 1 section = 640 A.
1 township = 36 sections = 23,040 A.

VOLUME

1 cubic centimeter (cc.) = 0.06102338 cu. in.
1 cubic decimeter = 1,000 cc. = 61.02338 cu. in.
1 cubic meter = 1,000,000 cc. = 35.31445 cu. ft.
1 cu. in. = 16.387162 cc.
1 cu. ft. = 1,728 cu. in. = 28,317.016 cc.
1 cu. yd. = 27 cu. ft. = 46,656 cu. in.

CAPACITY (liquid measure)

1 gill = 118.292 ml.
1 pt. = 4 gi. = 473.167 ml. = 0.473167 l.
1 qt. = 2 pt. = 8 gi. = 0.946333 l.
1 gal. = 4 qt. = 8 pt. = 3.785332 l. = 231 cu. in.
1 liter (l.) = 1,000 milliliters (ml. or cc.) = 2.11342 pt. = 1.05671 qt.
1 teaspoon = 4.93 ml.
3 teaspoons = 1 tablespoon = 14.79 ml.
2 tablespoons = 1 fluid oz. = 29.578 ml.
16 tablespoons = 8 fluid oz. = 1 cup = 236.583 ml.
2 cups = 16 fluid oz. = 1 pt. = 473.167 ml.

CAPACITY (dry measure)

1 liter = 61.025 cu. in. = 0.908102 dry qt.
1 dekaliter (dkl.) = 10 l. = 0.28378 bu.
1 hecktoliter (hl.) = 100 l. = 2.8378 bu.
1 U. S. bu. per A. = 0.8708 hl. per ha.
1 hl. per ha. = 1.1483 bu. per A.
1 dry pt. = 33.6003125 cu. in. = 0.550599 l.
1 dry qt. = 2 dry pt. = 1.101198 l.
1 peck = 8 dry qt. = 8.80958 l.
1 bushel = 4 pk. = 32 dry qt. = 35.2383 l.
1 Winchester (U. S.) bu. = 1.244 cu. ft. = 2,150.42 cu. in.
1 Imperial (British) bu. = 2219.36 cu. in. = 1.0305 Winchester bu.

CONVERSION CENTIGRADE TO FAHRENHEIT TEMPERATURE

1° C. = 1.8° F. 1° F. = 5/9° C.
° C. = (° F. − 32) × 5/9 ° F. = 9/5° C. + 32

° C.	° F.	° C.	° F.	° C.	° F.
100	212	50	122	0	32
90	194	40	104	− 10	14
80	176	30	86	− 20	− 4
70	158	20	68	− 30	− 22
60	140	10	50	− 40	− 40

TABLE 3. CONVERSION TABLES (*continued*)

WATER

1 gal. = 8.355 lb.
1 cu. ft. = 7.48 gal. = 62.42 lb.
1 acre-inch = 113 tons (approximately)
1 acre-foot = 43,560 cu. ft. = 323,136 gal.
1 second foot = 1 cu. ft. per sec. flow past a given point
1 second foot = 7½ gal. per sec. = 450 gal. per min.
1 second foot in 24 hours = 1.983 acre-feet
1 second foot in 1 hour = 1 acre-inch (approximately)
1 second foot = 40 miner's inches (in some states by statute)
1 second foot = 50 miner's inches (in other states)

DRY SOIL

1 cu. ft. muck = 25 to 30 lb.
1 cu. ft. clay and silt = 68 to 80 lb.
1 cu. ft. sand = 100 to 110 lb.
1 cu. ft. loam = 80 to 95 lb.
1 cu. ft. average soil = 80 to 90 lb.
1 acre foot (43,560 cu. ft.) = 3,500,000 to 4,000,000 lb. (2,000 tons)
The soil surface plow depth (6⅔ in.) is usually calculated as 2 million lb. (1,000 tons) per acre.
The volume of compact soil increases about 20 per cent when it is excavated or tilled.

GRAIN STORAGE

To compute the approximate capacity of a grain bin in bushels from the measurements of the bin in feet:
Rectangular bins—Length × width × height × 0.8 = bu.
Round bins—Diameter squared × height × ⅝ = bu.
Ear corn in crib:
Length × average width × average depth in feet × 0.4 = bu.

WEIGHTS, MEASURES AND CONVERSION FACTORS USED BY THE UNITED STATES DEPARTMENT OF AGRICULTURE

Barley
Flour 1 bbl. (196 lb.) ≈ 9 bu. barley
Malt 1.1 bu. (34 lb.) ≈ 1 bu. (48 lb.) barley
Beans, dry 1 sack = 100 lb.
Beer 1 bbl. = 31 gal.
Broomcorn 1 bale = 333 lb.; 6 bales = 1 ton
Buckwheat flour 1 bbl. (196 lb.) ≈ 7 bu. buckwheat
Corn
Meal (degermed) 1 bbl. (196 lb.) ≈ 6 bu. corn
Meal (nondegermed) 1 bbl. (196 lb.) ≈ 4 bu. corn
Ear corn (dry) 2 level bu. or 3 heaping half-bushels weighing 70 lb. ≈ 1 bu. (56 lb.) shelled corn
Cotton 1 lb. ginned ≈ 2.86 lb. unginned
Lint 1 bale (gross) = 500 lb.
1 bale (net) = 478 lb.

TABLE 3. CONVERSION TABLES (*continued*)

Flour 1 bbl. = 196 lb. 1 sack = 100 lb.
Hops 1 gross bale = 200 lb.
Jerusalem artichoke 1 bu. = 50 lb.
Linseed oil 2½ gal. (19 lb.) ≈ 1 bu. flaxseed
Oatmeal 1 bbl. (196 lb.) ≈ 10⅝ bu. oats
Oil (corn, cottonseed, soybean, peanut, linseed, etc.) 1 gal. = 7.7 lb. (in trade), castor oil 1 gal. = 8 lb.
Potatoes 1 bu. = 60 lb.; 1 bbl. = 165 lb.; 1 sack = 100 lb.
Rice
  Rough 1 bag = 100 lb.; 1 bbl. = 162 lb.
  Milled 1 pocket (100 lb.) ≈ 154 lb. (3.42 bu.) rough (unhulled)
Rye flour 1 bbl. (196 lb.) ≈ 6 bu. rye
Sorgo sirup 1 gal. = 11.55 lb.
Sugar 1 ton domestic 96° raw sugar ≈ 0.9346 tons refined sugar
Sugarcane sirup 1 gal. = 11.35 lb.
Sweetpotatoes 1 bu. = 55 lb.
Tobacco 1 lb. stemmed ≈ 1.33 lb. unstemmed
  Maryland (hogshead) = 600–800 lb.
  Flue-cured (hogshead) = 900–1,100 lb.
  Burley (hogshead) = 1,000–1,200 lb.
  Dark air-cured (hogshead) = 1,000–1,250 lb.
  Virginia fire-cured (hogshead) = 1,050–1,350 lb.
  Kentucky and Tennessee fire-cured (hogshead) = 1,350–1,650 lb.
  Cigar leaf (case) = 250–365 lb.
  (bale) = 150–175 lb.
Turnips (without tops) 1 bu. = 54 lb.
Vegetables and other dry commodities 1 bbl. = 7,056 cu. in. = 105 dry qt.
Wheat flour 1 bbl. (196 lb.) ≈ 4.7 bu. wheat
  100 lb. ≈ 2.33 bu. wheat
(Bushel weights of grains and seeds are shown in Appendix Table 1.)

TABLE 4. TRADE NAMES OF SEED TREATMENT CHEMICALS

Arasan (50 per cent tetramethyl thiouramdisulfide)
Ceresan (2 per cent ethyl mercury chloride)
Ceresan M (7.7 per cent ethyl mercury p-toluene sulfonanilide)
New Improved Ceresan (5 per cent ethyl mercury phosphate)
Panogen (2.1 per cent methyl mercury dicyan diamide)
Phygon X L (50 per cent dichloronaphthaquinone)
Semesan (30 per cent hydroxymercurichlorophenol)
Semesan Bel (12 per cent hydroxymercurichlorophenol)
Semesan Jr. (1 per cent ethyl mercuric phosphate)
Spergon (98 per cent tetrachloro-para-benzquinone)

GLOSSARY OF AGRONOMIC TERMS

[Adapted from, (1) reports of the Committee on Terminology of the American Society of Agronomy, (2) "A Glossary of Special Terms," *U. S. Dept. Agr. Ybk.*, 1938, (3) "A Glossary of Genetic Terms," *U. S. Dept. Agr. Ybk.*, 1936, (4) "Manual of the Grasses of the United States," *U. S. Dept. Agr. Misc. Pub. No. 200*, and (5) several botanical glossaries.]

A HORIZON The surface and subsurface soil which contains most of the soil organic matter and is subject to leaching.

ABORTIVE Imperfectly developed.

ACHENE (AKENE) A dry, hard 1-celled, 1-seeded, indehiscent fruit to which the testa and pericarp are not firmly attached.

ACID SOIL A soil with a *p*H reaction of less than 7.0 (usually less than *p*H 6.6). It has a preponderance of hydrogen ions over hydroxyl ions. Litmus paper turns red in contact with moist acid soil.

ACUMINATE Gradually tapering to a sharp point as in a grass leaf.

ACUTE Sharp pointed but less tapering than acuminate.

AERIAL ROOTS Roots arising from the stem above the ground.

AFTERMATH (ROWEN) The second or shorter growth of meadow plants the same season after cutting a hay or seed crop.

AGGREGATE A mass or cluster of soil particles or other small objects.

AGEOTROPIC Lacking a geotropic response as in stolons, rhizones and lateral roots which grow neither erect nor downward.

AGROBIOLOGY A phase of the study of agronomy dealing with the relation of yield to the quantity of a fertilizer element added or available.

AGROECOLOGY A term used to describe the study of the relation of crop varietal characteristics to their adaptation to environmental conditions.

AGROLOGY Study of applied phases of soil science and soil management.

AGRONOMY The science of crop production and soil management. The name is derived from the Greek words agros (field) and nomos (to manage).

ALEURONE The outer layer of the

cells of the endosperm of the seed. It sometimes contains pigment.

ALKALI SOIL A soil, usually above *p*H 8.5, containing alkali salts in quantities that usually are deleterious to crop production.

ALKALINE SOIL A soil with a *p*H above 7.0, usually above 7.3.

ALTERNATE One leaf at a node, not opposite. Flower parts of one whorl opposite to intervals of the next.

AMMONIFICATION Formation of ammonium compounds, or ammonia in soils.

ANGIOSPERMS The higher seed plants.

ANNUAL A plant that completes its life cycle from seed in one year.

ANNULAR Forming a ring, or circular.

ANTHER The part of the stamen that contains the pollen.

ANTHESIS The period during which the flower is open and in grasses when the anthers are extended from the glumes.

APETALOUS Without petals.

APICULATE Having a minute pointed tip.

APOGEOTROPIC Turning upward in response to a stimulus opposed to the force of gravity, e.g., seedling stems grow erect.

APOMIXIS A type of asexual production of seeds as in Kentucky bluegrass.

APPRESSED Pressed close to the stem.

AQUATIC A plant inhabiting water.

ARGENTATE Silvery.

ARID CLIMATE A dry climate with an annual precipitation usually less than 10 inches and not suitable for crop production without irrigation.

ARISTATE Awned.

ARTICULATE Jointed.

ARVICULTURE Crop science.

ASEXUAL Reproduction without involving the germ or sexual cells.

ASH The nonvolatile residue resulting from complete burning of organic matter.

ASSOCIATION A biologically balanced group of plants.

ATTENUATE Gradually narrowed to a slender apex or base.

AURICLES Ear-shaped appendages as at the base of barley and wheat leaves.

AWN The beard or bristle extending from the tip or back of the lemma of a grass flower.

AXIL The angle between the leaf and stem or between a branch or pedicel and its main stem.

AXILLARY In the axil.

AXIS The main stem of a flower or panicle.

B HORIZON The subsoil layer in which certain leached substances (i.e., iron) are deposited.

BACKCROSS Cross of a hybrid with one of the parental types.

BANGBOARD (BUMPBOARD) A high side on a wagon bed against which ears of corn are thrown when husking from the standing stalk.

BANNER The upper or posterior, usually broad petal of a papilionaceous legume flower; the standard.

BARBED Furnished with rigid points or hooks.

BASIN LISTING The formation of basins in lister furrows by attachments to the lister, or with a special damming lister, which build dams at intervals.

BEAK A point or projection as on the glume of the wheat flower.

BEARD Awn of grasses.

BED (1) A narrow flat-topped ridge on which crops are grown with a furrow on each side for drainage of excess water. (2) An area in which seedlings or sprouts are grown before transplanting.

BED-UP To build up beds or ridges with a tillage implement.

BIENNIAL Of two years' duration. A plant germinating one season and producing seed the next.

BINDER A machine for cutting a crop and tying it into bundles with twine. A grain binder is used usually for a drilled or broadcast crop, and a corn binder (row binder) for corn, sorghum, and other crops in rows.

BINE A twining vine stem as in the hop.

BINOMIAL The two Latin names for a plant species.

BIOMETRY Application of statistical methods to biological problems.

BLADE The part of the leaf above the sheath.

BLIND CULTIVATION Cultivating with a harrow, weeder, rotary hoe, or other implement to kill weeds before a seeded or planted crop has come up.

BOLL The subspherical or ovoid fruit of flax or cotton.

BOOT (1) The upper leaf sheath of a grass. (2) The stage at which the inflorescence expands the boot.

BRACE-ROOT An aerial root that functions to brace the plant as in corn.

BRACT A modified leaf subtending a flower or flower branch.

BRAN The coat of a caryopsis of a cereal removed in milling, consisting of the pericarp, testa, and usually the aleurone layer.

BRANCH A lateral stem.

BRISTLE A short stiff hair.

BROADCAST To sow or scatter seed on the surface of the land by hand or by machinery.

BROWN HAY Hay stacked when half cured and allowed to ferment, the resultant product being brown.

BROWN SOILS A group of soils formed in semiarid climates, having a brown surface soil and a zone of carbonate accumulation at a depth of usually 1 to 2 feet.

BROWSE (1) Leaves and twigs of woody plants eaten by animals. (2) To bite off and eat leaves and twigs of woody plants.

BUCK-RAKE A sweeprake or bullrake.

BUD An unexpanded flower or a rudimentary leaf, stem, or branch.

BULB A leaf bud with fleshy scales, usually subterranean.

BUR A prickly or spiny fruit envelope.

BUSH-AND-BOG A heavy cut-away disk tillage implement used on rough or brushy pasture land.

C HORIZON The layer of weathered parent rock material below the B horizon of the soil but above the unweathered rock.

calcareous soil An alkaline soil containing sufficient calcium and magnesium carbonate to cause visible effervescence when treated with hydrochloric acid.

caliche A more or less cemented deposit of calcium carbonate often mixed with magnesium carbonate at various depths, characteristic of many of the semiarid and arid soils of the southwest.

callus A hard protuberance at the base of the lemma in certain grasses.

calyx The outer part of the perianth, composed of sepals.

cambium The growing layer of the stem.

caniculate Longitudinally channeled.

capillary Hairlike, or a very small tube.

capitate With a globose head.

capsule (pod) Any dry dehiscent fruit composed of more than one carpel.

carbohydrates The chief constituents of plants, including sugars, starches, and cellulose, in which the ratio of molecules of hydrogen to molecules of oxygen is 2:1.

carbonate accumulation zone A visible zone of accumulated calcium and magnesium carbonate at the depth to which moisture usually penetrated in semiarid soils before they were brought under cultivation.

carinate Keeled.

carotene A yellow pigment in green leaves and other plant parts (the precursor of vitamin A). Beta carotene has the formula $C_{40}H_{56}$.

carpel A simple pistil or one element of a compound pistil.

caruncle A strophiole.

caryopsis The grain or fruit of grasses including the cereals.

catkin A spike with scalelike bracts.

cell The unit of structure in plants. A living cell contains protoplasm, which includes a nucleus and cytoplasm within the cell walls.

cellulose Primary cell wall substance. A carbohydrate having the general formula $(C_6H_{10}O_5)n$.

cereal A grass cultivated for its edible seeds or grains.

chaff (1) A thin scale, bract or glume. (2) The glumes and light plant-tissue fragments broken in threshing.

chalaza That part of the ovule where all parts grow together.

chartaceous Having the texture of paper.

checkrow A row of seeds or plants spaced equally in both directions.

chernozem soil A dark to nearly black grassland soil high in organic matter developed in a subhumid climate.

chestnut soil A soil having a dark brown surface developed under mixed tall and short grasses in a subhumid to semiarid climate.

chisel A tillage implement with points about a foot apart that stir the soil to a depth of 10 to 18 inches.

CHLOROPHYLL The green coloring matter of plants which takes part in the process of photosynthesis. It occurs in the chloroplasts of the plant cell.

CHLOROSIS Yellowing or blanching of leaves and other chlorophyll-bearing plant parts.

CHROMOSOME Dark-staining bodies visible under the microscope in the nucleus of the cell at the time of cell division. The chromosomes carry genes (or factors), the units of heredity.

CILIATE Fringed with hairs on the margin.

CLAVATE Club-shaped.

CLAY Small mineral soil particles less than 0.002 mm. in diameter (formerly less than 0.005 mm.).

CLEISTOGAMOUS Fertilized without opening of the flowers.

CLIMATE The total long-time characteristic weather of any region.

CLON A group of organisms composed of individuals propagated vegetatively from a single original individual.

COCK (1) A small round conical pile of hay. (2) To put into cocks.

COLEOPTILE The sheath covering the first leaf of a grass seedling as it emerges from the soil.

COLEORHIZA A sheath covering the tip of the first root from a seed.

COLLAR The area on the outer side of the leaf at the junction of the sheath and blade.

COLLOID A fine particle usually 10^{-6} to 10^{-4} mm. in diameter, which carries an electric charge. A wet mass of colloidal particles is gluelike in consistency.

COLUMELLA The axis of a capsule which persists after dehiscence.

COMBINATION STACKER (1) A combined sweeprake and overshot hay stacker. (2) A jayhawker.

COMBINE A machine for harvesting and threshing in one operation.

CONTINENTAL CLIMATE Climate typical of the interior of large land masses having wide extremes of temperature.

CONTOUR FURROWS Furrows plowed at right angles to the slope, at the same level or grade, to intercept and retain runoff water.

CONVOLUTE Rolled longitudinally.

CORDATE Heart-shaped with point upward.

CORIACEOUS Leathery.

CORM The hard swollen base of the stem.

COROLLA Inner part of the perianth, composed of petals.

CORRELATION A relation between two variable quantities such that an increase or decrease of one is associated (in general) with an increase or decrease in the other.

CORRELATION COEFFICIENT (r) The degree of correlation ranges from + 1 to − 1. A correlation coefficient of zero means that the two variables are not interrelated. An r value of + 1 or − 1 indicates complete association. A positive (plus) correlation means that high values of one variable are associated with high values of the other. A negative (minus) correlation means that as one variable increases the other tends to decrease.

CORYMB A flat-topped or convex flower cluster in which the pedicels are unequal and the outer flowers blossom earliest.

COTYLEDONS The first leaves of a plant as found in the embryo. The major portion of the two halves of a pea or bean (legume) seed.

COVER CROP A crop grown between orchard trees or on fields between cropping seasons to protect the land from leaching and erosion.

CRENATE Dentate (toothed) with rounded teeth.

CROSS (1) A hybrid. (2) To produce a hybrid.

CROSS-DRILL To drill seed in two directions, usually at right angles to each other.

CROSS-FERTILIZATION OR CROSS-POLLINATION. Fertilization secured by pollen from another plant.

CROWN The base of the stems where roots arise.

CULM The jointed stem of grasses.

CURE To prepare for preservation by drying or other processes.

CURLER A disk implement for cultivating crops planted in lister furrows.

CUTICLE The outer corky or waxy covering of the plant.

CUTTING A part of a plant to be rooted for vegetative propagation.

CYME A somewhat flat-topped determinate inflorescence.

CYTOLOGY The study of the structure, function, and life history of the cell.

DECIDUOUS Falling away (shedding) of leaves or awns.

DECUMBENT Curved upward from a horizontal or inclined position.

DEFLOCCULATE To separate or break down soil aggregates of clay into their individual particles.

DEHISCENCE Opening of valves or anthers, or separation of parts of plants.

DENITRIFICATION The reduction of nitrates to nitrites, ammonia, and free nitrogen in the soil.

DENTATE Toothed.

DETASSEL To remove the tassel.

DETERMINATE INFLORESCENCE Flowers arise from the terminal bud and check growth of axis.

DIADELPHOUS (STAMENS) Collected in two sets.

DICOTYLEDONOUS Plants producing two cotyledons in each fruit.

DIFFERENTIATION The process whereby cells and tissues become structurally unlike during the process of growth and development.

DIFFUSE Spreading loosely and irregularly.

DIGITATE Fingered. Compound with parts radiating from apex of support.

DIOECIOUS Having stamens and pistils in separate flowers upon different plants.

DIPLOID Having two sets of chromosomes. Body tissues of plants are ordinarily diploid.

DISARTICULATING Separating at maturity.

DOMINANT A character possessed by one of the parents of a hybrid which is manifested in the hybrid to the apparent exclusion of the contrasted character from the other (the recessive) parent.

DORSAL Relating to the back or outer surface.

DRILL (1) A machine for sowing seeds in furrows. (2) To sow in furrows.

DRILLROW A row of seeds or plants sown with a drill.

DUCKFOOT CULTIVATOR A field cultivator equipped with small sweep shovels.

ECHINATE Armed with prickles.

ECOLOGY The study of the mutual relations between organisms and their environment.

ECOTYPE A variety or strain adapted to a particular environment.

EDAPHOLOGY Soil science, particularly the influence of soil upon vegetation.

EGG The female reproductive cell.

ELLIPTICAL Oblong and rounded at the ends.

ELLUVIATION Removal of material by solution or suspension.

EMARGINATE Notched at end.

EMBRYO Rudimentary plantlet within seed. Germ.

EMBRYO SAC The sac in the embryo containing the egg cell.

ENDEMIC Indigenous or native in a restricted locality.

ENDOCARP Inner layer of pericarp.

ENDOSPERM The starchy interior of a grain.

ENSILAGE Silage.

ENSILE To make into silage.

EPICARP (EXOCARP) Outer layer of pericarp formed from ovary wall.

EPICOTYL The stem of the embryo or young seedling above the cotyledons.

EPIDERMIS External layer of cells.

EPIGYNOUS Corolla seems to rise from top of ovary.

EROSION Wearing away of the land surface by running water, wind, or other processes.

ETHER EXTRACT Fats, oils, waxes, and similar products extracted with warm ether in chemical analysis.

EXOTIC PLANT An introduced plant not fully naturalized or acclimated.

EXSERTED Protruding beyond covering.

F_1 The first filial generation. The first generation offspring of a given mating.

F_2 The second filial generation. The first hybrid generation in which segregation occurs.

FACTOR (GENETIC OR HEREDITARY) The gene or unit of heredity.

FASICLE A compact bundle or cluster of flowers or leaves.

FERTILE (PLANT) Capable of producing fruit.

FERTILITY (PLANT) The ability to reproduce sexually.

FERTILITY (SOIL) The ability of the soil to provide the proper compounds in the proper amounts and in the proper balance for the growth of specified plants under the suitable environment.

FERTILIZATION (PLANT) The union of the male (pollen) nucleus with the female (egg) cell.

FERTILIZATION (SOIL) The application to the soil of elements or compounds that aid in the nutrition of plants.

FIBROUS ROOT A slender threadlike root as in grasses.

FIELD CULTIVATOR A wheeled machine equipped with small shovels, or narrow sweeps usually on spring-mounted shanks, used to stir the soil for weed control or seedbed preparation.

FILAMENT The stalk of the stamen which bears the anther.

FILIFORM Thread-shaped.

FLAT-BREAK To plow with a moldboard plow as contrasted with the corrugated surface of a field after listing it.

FLESHY ROOT A thickened root containing abundant food reserves, e.g., carrot, sweetpotato, and sugar beet.

FLOAT (1) A land leveller. (2) A plank clod masher.

FLOCCULATE To aggregate individual particles into small groups or granules.

FLORET Lemma and palea with included flower (stamens, pistil, and lodicules).

FODDER Maize, sorghum, or other coarse grasses harvested whole and cured in an erect position. Pulled fodder is the leaves of corn or sorghum stripped by hand from the standing stalk and then cured. Topped fodder is the top of the maize stalk above the ear cut off and cured.

FOLIATE Leaved.

FORAGE Vegetable matter, fresh or preserved, gathered and fed to animals.

FRIABLE Easily crumbled in the fingers; nonplastic.

FRUIT The ripened pistil.

FUNGICIDE A chemical substance used as a spray, dust, or disinfectant to kill fungi infesting plants or seeds.

FUNGUS A group of the lower plants that causes most plant diseases. The group includes the molds and belongs to the Phylum Thallophyta. Fungi reproduce by spores instead of seeds, contain no chlorophyll, and thus live on dead or living organic matter.

FUSIFORM Feather-shaped. Enlarged in the middle and tapering at both ends.

GEE-WHIZ An adjustable-width walking cultivator equipped with a number of spike or spring teeth used for seedbed preparation, and for cultivating row crops.

GENE The unit of inheritance, which is transmitted in the germ cells.

GENETICS The science of heredity, variation, sex determination, and related phenomena.

GENICULATE Bent abruptly or kneelike, as the awn of wild oats.

GEOTROPIC Turning downward in response to a stimulus caused by the force of gravity, e.g., the roots of a seedling grow downward.

GERM CELL A cell capable of reproduction, or of sharing in reproduction.

GLABROUS Smooth.

GLANDULAR Beset with glands.

GLAUCOUS Covered with whitish waxy bloom as on the sorghum stem.

GLUMES The pair of bracts at the base of a spikelet.

GLUTEN The protein in wheat flour which enables the dough to rise.

GLUTINOUS Gluelike.

GOPHER (1) A crop-damaging burrowing rodent. (2) A type of plcw.

GO-DEVIL A row-crop cultivator on runners equipped with knives and gangs of small disks. (The name is sometimes applied to a sweeprake and other implements.)

GRAIN (1) A caryopsis. (2) A collective term for the cereals. (3) Cereal seeds in bulk.

GRASS A plant of the family *Gramineae*.

GREEN MANURE Any crop or plant grown and plowed under to improve the soil, especially by addition of organic matter.

GULLY EROSION Erosion which produces channels in the soil.

GYNOPHORE A pedicel bearing the ovary, e.g., the "peg" which penetrates the soil and bears the peanut pod.

HABIT Aspect or manner of growth.

HALOPHYTE A plant tolerant of soils high in soluble salts.

HAPLOID Single; referring to the reduced number of chromosomes in the mature germ cells of bisexual organisms.

HARDPAN A hardened or cemented soil horizon.

HARROW (1) An implement used chiefly for seedbed preparation which stirs the soil, breaks clods, smooths the field and kills weeds. Spike-tooth, spring-tooth, and disk harrows are used. (2) To till the field with a harrow.

HAULM A stem.

HAY The herbage of grasses or comparatively fine-stemmed plants cut and cured for forage.

HEAD A dense roundish cluster of sessile or nearly sessile flowers, on a very short axis or receptacle as in red clover and sunflower.

HEADER A machine used to cut the stems of grain crops a few inches below the heads and to elevate the severed heads into a special wagon box called a header barge or header box.

HELIOTROPIC Turning towards the sun.

HERB A plant that contains but little wood and that dies down to the ground each year.

HERBACEOUS Having the characteristics of a herb.

HERBAGE Herbs, collectively, especially the aerial portion.

HERBICIDE A weed killer or any chemical substance used to kill herbaceous plants.

HERMAPHRODITE Perfect, having both stamens and pistils in the same flower.

HETEROGEN A group of heterozygous plants.

HETEROZYGOUS Containing two unlike genes of an allelomorphic pair in the corresponding loci (positions) of a pair of chromosomes. The progeny of a heterozygous plant does not breed true.

HILUM The scar of the seed; its place of attachment.

HIRSUTE Hairy.

HORIZON, SOIL A layer of soil approximately parallel to the land surface with more or less well-defined characteristics.

HOMOGAMY The anthers and stigmas mature at the same time.

HOMONYM The same name for a different plant.

HOMOZYGOUS A plant containing like germ cells. Homozygous plants produce like progeny for the character under observation.

HORMONE A chemical growth-regulating substance that can be or is produced by a living organism.

HULL (1) A glume, lemma, palea, pod, or other organ enclosing a seed or fruit. (2) To remove hulls from a seed.

HUMID CLIMATE A climate with sufficient precipitation to usually support a forest vegetation. In the agricultural sections of the United States the precipitation in humid regions usually exceeds 30 to 40 inches.

HUMUS The well-decomposed, more or less stable part of the organic matter of the soil.

HUSK (1) The coarse outer envelope of a fruit, as the glumes of an ear of maize. (2) To remove the husks.

HYALINE Thin and translucent or transparent.

HYBRID The offspring of two parents unlike in one or more heritable characters.

HYBRIDIZATION The process of crossing organisms of unlike heredity.

HYDROPHYTE A plant adapted to wet or submerged conditions.

HYDROPONICS The growing of plants in aqueous chemical solutions.

HYPOCOTYL The stem of the embryo or young seedling below the cotyledons.

HYPOGYNOUS With parts under the pistil.

IGNEOUS ROCK A rock produced through the cooling of melted mineral material.

ILLUVIATION Deposition of leached or suspended material.

IMPERFECT Flower lacking either stamens or pistils.

INDEHISCENT Not opening by valves or slits.

INDETERMINATE INFLORESCENCE Flowers arise laterally and successively as floral axis elongates.

INDURATE Hard.

INFLORESCENCE The flowering part of the plant.

INSECTICIDE A chemical used to kill insects.

INTEGUMENTS Coats or walls of an ovule.

INTERNODE The part of the stem or branch between two nodes.

INVOLUCRE A circle of bracts below a flower or flower cluster.

ION An electrically charged element, group of elements, or particle.

JOINT (1) A node. (2) The internote of an articulate rachis. (3) To develop distinct nodes and internodes in a grass culm.

KEEL (1) A ridge resembling the keel of a boat, on a plant part as the glume of durum wheat. (2) The pair of united petals in a legume flower.

KERNEL The matured body of an ovule.

KNIFE-SLED A cultivator for crops planted in lister furrows, equipped with wide slanting sweeps or knives mounted on closely spaced runners.

LAMINA The blade of a leaf, particularly those portions between the veins.

LAMINATED In layers or plates.

LANCEOLATE Lance-shaped, as a grass leaf.

LAND PLANE A large, wheeled machine used to level the land.

LATERALLY COMPRESSED Flattened from the sides as the spike of emmer.

LAX Loose.

LEACH To remove materials by solution.

LEAF The lateral organ of a stem.

LEGUME (1) Any plant of the family *Leguminoseae*. (2) The pod of a leguminous plant.

LEMMA The outer (lower) bract of a grass spikelet enclosing the caryopsis.

LETHAL A substance or hereditary factor that causes death.

LIGNIN A constituent of the woody portion of the fibrovascular bundles in plant tissues.

LIGULE (1) A membranous projection on the inner side of a leaf at the top of the sheath of wheat and many other grasses. (2) A strap-shaped corolla as in the ray flower of the sunflower.

LIME Calcium oxide or quicklime (CaO), but often refers also to calcium carbonate ($CaCO_3$) and to calcium hydroxide or hydrated or slaked lime [$Ca(OH)_2$].

LIMESTONE Rock composed essentially of calcium carbonate.

LINEAR Long and narrow, with nearly parallel margins.

LISTER. An implement for furrowing land, often having a planting attachment.

LOAM A soil composed of a mixture of two or more of the separates, clay, silt, sand, and gravel.

LOBE A rounded portion or segment of any organ.

LODICULE The organs at the base of the ovary of a grass floret that swell and force open the lemma and palea during anthesis.

MANGUM TERRACE A broad-base ridge-type terrace with a gradual channel grade.

MARL A crumbling deposit of calcium carbonate mixed with clay or other impurities.

MASLIN (MESLIN) Grains grown in mixture or the milled product thereof.

MEADOW An area covered with fine-stemmed forage plants, wholly or mainly perennial and used to produce hay.

MEIOSIS The division of the sexual cells in which the number of chromosomes is halved.

MELLOW SOIL A soil that is easily worked or penetrated.

MEMBRANE A thin soft tissue.

MESOCARP Middle layer of pericarp (when present).

MESOCOTYL A term applied to the subcrown internode of a grass seedling.

MESOPHYLL Tissues between two epidermal layers as in the interior of a leaf.

MESOPHYTE A plant that thrives under medium conditions of moisture and salt content of the soil.

METABOLISM The life processes of plants.

METAXENIA Direct effect of the pollen on the parts of a seed or fruit other than the embryo and endosperm.

MICROPYLE Opening through which the pollen tube passes.

MIDDLE BUSTER A double shovel plow or lister.

MITOSIS Cell division involving the formation and longitudinal splitting of the chromosomes.

MONADELPHOUS Stamens united in one set.

MONOCOTYLEDON Plant having one cotyledon as in the grasses.

MONOECIOUS With stamens and pistils in separate flowers on the same plant.

MONOFACTORIAL Controlled by a single gene (factor) difference in inheritance.

MORMON DERRICK A swinging-boom hay stacker mounted on a portable derrick.

MORPHOLOGICAL Referring to structure or texture.

MŌW To cut with a mower or scythe.

MOW (1) A place for hay storage inside. (2) To place hay in a mow.

MUCK Fairly-well decomposed organic soil material, relatively high in mineral content, dark in color, and accumulated under conditions of imperfect drainage.

MUTATION A sudden variation that is later passed on through inheritance.

NECTARY Any gland or organ that secretes sugar.

NERVE A vein on a leaf, glume, or lemma.

NEUTRAL SOIL A soil neither acid nor alkaline, with a pH of about 7.0 or between 6.6 and 7.3.

NICHOLS TERRACE A broad channel terrace.

NITRIFICATION Formation of nitrates from ammonia.

NITROGEN FIXATION The conversion of atmospheric (free) nitrogen to nitrogen compounds, chemically, or by soil organisms, or by organisms living in the roots of legumes.

NITROGEN-FREE EXTRACT The unanalyzed substance of a plant (consisting largely of carbohydrates) remaining after the protein, ash, crude fiber, ether extract, and moisture have been determined.

NODE The joint of a culm where a leaf is attached.

NUCELLUS The ovule tissue within the integuments.

NUCLEOLUS A small spherical body within a cell nucleus.

NUCLEUS A body of specialized protoplasm containing the chromosomes within a cell.

NUTRIENT (PLANT) A chemical element taken into a plant that is essential to its growth, development, or reproduction.

OBOVATE Egg-shaped outline with larger end above.

OBTUSE Rounded at the apex.

OCEANIC CLIMATE A climate modified by the tempering effect of ocean water.

ONE-WAY A tillage implement

having a gang of disks that throw the soil in one direction.

OUTCROSS A cross to an individual not closely related.

OVARY Seed case of the pistil.

OVATE Egg-shaped outline with larger end below.

OVOID An egg-shaped solid.

OVULES Unripe seeds in the ovary.

OXIDATION A chemical change involving addition of oxygen or its chemical equivalent, or involving an increase in positive or decrease in negative valence. Burning is oxidation.

PALEA (PALET) Inner (upper) bract of a floret in grasses lying next to the caryopsis. It usually is thin and papery.

PALISADE CELLS Elongated cells perpendicular to the epidermis on the upper side of a leaf.

PALMATE Radiately lobed or divided.

PANICLE An inflorescence with a main axis and subdivided branches as in oats and sorghum.

PAPILIONACEOUS Butterfly-shaped as the flower of legumes.

PAPPUS The teeth, bristles, awns, etc., surmounting the achene of the sunflower and other *Compositae.*

PARASITIC Living in or on another living organism.

PARENCHYMA Soft cellular tissue.

PARTHENOGENESIS The development of a new individual from a germ cell without fertilization.

PASTURE An area of land covered with grass or other herbaceous forage plants, and used for grazing animals.

PERMANENT PASTURE A pasture of perennial or self-seeding annual plants kept for grazing indefinitely.

TEMPORARY PASTURE A pasture grazed during a short period only, not more than one crop season.

ROTATION PASTURE A pasture used for a few seasons and then plowed for other crops.

TAME PASTURE A pasture covered with cultivated plants and used for grazing.

NATIVE PASTURE A pasture covered with native plants or naturalized exotic plants.

PASTURE SUCCESSION A series of crops for grazing in succession.

PEACOCK MACHINE A tillage implement that leaves the soil surface covered with small pockets to hold rainwater and check runoff.

PEAT Slightly decomposed organic matter accumulated under conditions of excessive moisture.

PEDALFER The soil of a humid region in which iron and aluminum have leached into the B horizon, but which has no carbonate zone.

PEDICEL A branch of an inflorescence supporting one or more flowers. The stalk of a spikelet.

PEDOCAL A soil of a semiarid or arid region having a distinct carbonate zone.

PEDOLOGY Soil science

PEDUNCLE The top section of the stalk that supports a head or panicle.

PEPO The fruit of cucurbitaceous plants, as the pumpkin, squash and gourd.

PERENNIAL Living more than one year but may produce seed the first year.

PERFECT FLOWER Having both pistil and stamens.

PERIANTH The floral envelope including the calyx or calyx and corolla.

PERICARP The modified and matured ovary wall, as the bran layers of a grain.

PERIGYNOUS Parts around the pistil.

PERISPERM Nucellus.

PETAL A division of the corolla.

PETIOLE The stalk of a leaf.

*p*H The designation for degree of acidity or hydrogen ion activity. *p*H value = logarithm 1/CH, in which CH is the concentration of active hydrogen ions expressed in gram ions per liter of a solution.

PHENOTYPE The organism as exemplified by its expressed characters but not necessarily as all its progeny will appear.

PHLOEM Portion of a vascular bundle containing the sieve tubes through which are transported the food materials manufactured in the plant leaves.

PHOTOPERIODISM The response of plants to different day lengths or light periods.

PHOTOTROPISM Growing or turning towards the light.

PHYLLOTAXY The arrangement of leaves upon the stem.

PHYTOBEZOAR A ball in the intestinal tract of an animal, formed from plant hairs.

PICKUP An attachment for a combine or other implement to gather cut crops from a windrow and convey them to the machine.

PILOSE Covered with soft slender hairs.

PINNATE LEAF Compound, with leaflets arranged on each side of a common petiole as in the pea leaf.

PISTIL The seed-bearing organ of a flower consisting of the ovary, style, and stigma.

PISTILLATE Provided with pistils but without stamens.

PLACENTA The part of the ovary to which the ovules are attached as in the pea pod.

PLANT (1) Any organism belonging to the plant or vegetable kingdom. (2) To set plants or sow seeds.

PLANTER A machine for opening the soil and dropping tubers, cuttings, seedlings, or seeds at intervals.

PLASTID Protoplasmic bodies in cells, including those containing chlorophyll.

PLUMOSE Featherlike.

POD Any dry dehiscent fruit.

PODZOL SOIL A soil having an organic mat and a very thin organic-mineral layer above a gray leached layer, formed under a forest in a cool humid climate.

POLLEN The male germ cells produced in the anthers.

POLLINATION The transfer of pollen from the anther to the stigma.

POLYADELPHOUS (STAMENS) Separate, or in more than two groups.

POLYPLOID Plant having three or more basic sets of chromosomes.

PRAIRIE SOIL A soil having a very dark brown or grayish-brown surface horizon grading through brown to lighter-colored material, formed under tall grasses in a temperate climate under relatively humid conditions and without a carbonate zone below.

PRIMARY ROOT (1) A seminal root. (2) A main root.

PROCAMBIUM Fibrovascular tissue formed before it is differentiated into xylem and phloem.

PRODUCTIVITY (OF SOIL) The capability of a soil for producing a specified plant or sequence of plants under a specified system of management.

PROFILE (OF SOIL) A vertical section of the soil through all its horizons and extending into the parental material.

PROSTRATE Lying flat on the ground.

PROTANDROUS Having anthers shed their pollen before the stigmas are receptive.

PROTEIN Nitrogenous compounds formed in plants, composed of 50 to 55 per cent carbon, 19 to 24 per cent oxygen, 6.5 to 7.3 per cent hydrogen, 15 to 17.6 per cent nitrogen and usually 0.5 to 2.2 per cent sulfur, and 0.4 to 0.9 per cent phosphorus. Carbohydrates, the chief constituents of carbonaceous feeds, contain only 40 to 44 per cent carbon.

PROTOGYNOUS Having pistils ready for fertilization before anthers are matured.

PROTOPLASM The contents of a living cell.

PUBERULENT Minutely pubescent.

PUBESCENT Covered with fine, soft, short hairs.

PULSE Leguminous plants or their seeds, chiefly those with large seeds used for food.

PULVINUS The swelling at the base of the branches of some panicles which causes them to spread.

PUNCTATE Dotted.

PURE LINE A strain of organisms that is genetically pure (homozygous) because of continued inbreeding or self-fertilization, or through other means.

RACE A group of individuals having certain characteristics in common because of common ancestry —generally a subdivision of a species.

RACEME An inflorescence in which the pediceled flowers are arranged on a rachis or axis.

RACHILLA (LITTLE RACHIS) The axis of a spikelet in grasses.

RACHIS The axis of a spike or raceme.

RADICLE That part of the seed which upon vegetating becomes the root.

RANGE An extensive area of natural pasture land. If unfenced, it is an open range.

RAY The branch of an umbel; marginal ligulate flowers of a composite head.

REACTION (OF SOIL) The degree of acidity or alkalinity of the soil as follows:

Extremely acid, *p*H below 4.5,
Very strongly acid, *p*H 4.5 to 5.0,
Strongly acid, *p*H 5.1 to 5.5,
Medium acid, *p*H 5.6 to 6.0,
Slightly acid, *p*H 6.1 to 6.5
Neutral, *p*H 7.0 (6.6 to 7.3)
Mildly alkaline, *p*H 7.4 to 8.0
Strongly alkaline, *p*H 8.1 to 9.0

Very strongly alkaline, pH 9.1 and higher.

RECEPTACLE Swollen summit of flower stalk.

RECESSIVE A transmissible character possessed by one of the parents of a hybrid which does not appear in the first-generation hybrid plant because it is masked due to the presence of the dominant member of that factor pair, coming from the other parent.

RECIPROCAL CROSS A cross between the same two strains but with the pollen and pistillate parents reversed.

REPLICATION Multiple repetition of an experiment.

RESPIRATION Process of absorption of oxygen and giving out of carbon dioxide.

RETICULATE In a network.

RHIZOME A subterranean stem, usually rooting at the nodes and rising at the apex. A rootstock.

RICK (1) A long narrow stack rectangular at the base. (2) To place in a rick.

RIDGE-BUSTER A disk implement used to break down the ridges and fill the furrows of listed land.

RILL EROSION Erosion producing small channels that can be obliterated by tillage.

ROGUE (1) A variation from the type of a variety or standard, usually inferior. (2) To eliminate such inferior individuals.

ROOT The part of the plant (usually subterranean) which lacks nodes.

ROOTCAP A mass of cells protecting the tip of a root.

ROOTHAIR A single-celled protrusion of an epidermal cell of a young root.

ROOTLET A small root.

ROOTSTOCK A rhizome.

ROSETTE A cluster of spreading or radiating basal leaves.

RUDIMENTARY Underdeveloped.

RUGOSE Wrinkled; rough with wrinkles.

RUNNER A creeping branch or stolon.

RUSH A plant of the family *Juncaceae*.

SAC A pouch.

SAGITTATE Shaped like an arrow head.

SALINE SOIL A soil containing an excess of soluble salts, more than approximately 0.2 per cent but with a pH less than 8.5.

SALT The product, other than water, of the reaction of a base with an acid.

SAND Small rock or mineral fragments having diameters ranging from 1 to 0.05 mm.

SAPROPHYTIC Living on dead organic material.

SCABROUS Having a rough surface.

SCALE Any thin appendage; morphologically a modified degenerate leaf.

SCLERENCHYMA Lignified tissue as applied to thick-walled fibers.

SCRAPER A machine for beating the spikelets from broomcorn fibers. (2) A blade to remove soil from revolving disks or wheels on field implements.

SCUTELLUM A shield-shaped organ surrounding the embryo of a grass seed, morphologically a cotyledon.

SECOND BOTTOM The first terrace level of a stream valley above the flood plain.

SECONDARY ROOT A branch or division of a main root.

SEDGE A plant of the family *Cyperaceae*, especially of the genus *Carex*.

SEED (1) The ripened ovule, enclosing a rudimentary plant and food necessary for its germination. (2) To produce seed (a plant). (3) To sow.

SEEDLING (1) The juvenile stage of a plant grown from seed. (2) A plant derived from seed (in plant breeding).

SEGREGATION Separation of hybrid progenies into the different hereditary types representing the combination of characters of the two parents.

SELECTION The choosing of plants having certain characteristics for propagation. Natural selection occurs under competitive conditions or adverse environment.

SELFED (SELF-POLLINATED) Pollinated by pollen from the same plant.

SEMIARID CLIMATE A climate in which scattered short grass, bunchgrass, or shrubs prevail. In the United States, the semiarid regions usually have an annual precipitation between 10 and 20 inches, or higher.

SEMINAL Belonging to the seed.

SEMINAL ROOT A root arising from the base of the hypocotyl.

SEPAL A division of the calyx.

SEPTUM Partition or dividing wall.

SERRATE Having sharp teeth pointing forward.

SESSILE Without a pedicel or stalk.

SETACEOUS Bristlelike.

SHEATH (BOOT) The lower part of the leaf that encloses the stem.

SHEET EROSION Removal of a more or less uniform layer of material from the land surface.

SHOCK (1) An assemblage or pile of crop sheaves or cut stalks set together in the field to dry. (2) To set into shocks.

SHOOT (1) A stem with its attached members. (2) To produce shoots. (3) To put forth.

SIBLINGS (SIBS) Offspring of the same parental plants.

SILAGE Forage preserved in a succulent condition by partial fermentation in a tight container.

SILO A tight-walled structure for making and preserving silage.

SILT Small mineral soil particles of a diameter of 0.05 to 0.002 mm. (formerly 0.05 to 0.005 mm.).

SIMPLE (1) Botany—Without subdivisions, opposed to compound, leaves. (2) Heredity—Character inheritance controlled by not more than three factor-pair differences.

SINUOUS Wavy.

SLICKER A weeding implement with a knifelike blade or blades running under the soil surface.

SLIP A cutting, shoot, or leaf to be rooted for vegetative propagation.

SOD (1) Turf. (2) Plowed meadow or pasture.

SOIL The natural medium for the growth of land plants on the surface of the earth, composed of organic and mineral materials.

SOLUM The upper part of the soil profile, the A and B horizons.

SOW To place seeds in a position for growing.

SPATULATE Shaped like the tip of a spatula.

SPICATE Arranged in a spike.

SPIKE An unbranched inflorescence in which the spikelets are sessile on the rachis, as in wheat and barley.

SPIKELET The unit of inflorescence in grasses, consisting of two glumes and one or more florets.

SPORE Single-celled reproductive bodies produced by fungi.

SPORT An abrupt deviation from type of a plant.

SPROUT (1) A young shoot. (2) To produce sprouts. (3) To put forth sprouts from seeds. (4) To remove sprouts as from potato tubers.

SQUARE An unopened flower bud of cotton with its subtending involucre bracts.

STACK A large pile of hay, grain, or straw.

STACKER A device for lifting bunches of hay and dropping it on a stack with animal or mechanical power. The chief types are the (1) overshot and (2) swinging stackers for lifting a load from a sweeprake, (3) the swinging boom, or Mormon derrick, and (4) cable-track stackers that lift the hay on slings or forks.

STALK A stem.

STAMEN The pollen-bearing organ of a flower.

STAMINATE Having stamens but no pistils.

STANDARD (See banner.)

STELLATE Star-shaped.

STERILE Incapable of sexual reproduction.

STIGMA The part of the pistil that receives the pollen.

STIPULE Leaflike appendages arranged in a pair at the base of the petiole.

STOCK A supply of seed of a crop or variety.

STOLON A modified propagating creeping stem above ground that produces roots.

STOLONIFEROUS Bearing stolons.

STOMA An opening in the epidermis for the passage of gases and water vapor.

STOMATA Plural of stoma.

STOOL The aggregate of a stem and its attached tillers, i.e., a clump of young stems arising from a single plant.

STRAIN A group of plants derived from a variety.

STRAW The dried remnants of fine-stemmed plants from which the seed has been removed.

STRIATE Marked with parallel lines or ridges.

STRIP CROPPING Growing crops in long narrow strips across a slope approximately on a line of contour with dense-growing crops alternating with intertilled crops.

STROBILE An inflorescence or fruit with conspicuous imbricated bracts as in the hop.

STROPHIOLE (caruncle) A swollen appendage near the micropyle of a seed.

STRUCTURE The morphological aggregates in which the individual soil particles are arranged.

STUBBLE The basal portion of the stems of plants left standing after cutting.

STYLE The slender part of the pistil supporting the stigma.

SUBHUMID CLIMATE A climate with sufficient precipitation to support a moderate to dense growth of tall and short grasses but usually insufficient to support a dense deciduous forest. In the United States this usually is a precipitation of 20 to 30 inches, or more.

SUBSOIL That part of the solum below plow depth or below the A horizon.

SUBSPECIES A taxonomic rank immediately below that of a species.

SUCCOTASH Grains grown in mixture, e.g., oats and barley.

SUCCULENT Juicy, fleshy.

SUCKER (1) A tiller. A shoot produced from a crown or rhizome, or in tobacco from axillary buds. (2) To produce suckers. (3) To remove suckers.

SURFACE SOIL The upper 5 to 8 inches of the soil, or in arable soils, the depth commonly stirred by the plow.

SUTURE The line of junction between contiguous parts.

SWARD Turf.

SWATH A strip of cut herbage lying on the stubble.

SWEAT To emit moisture from damp hay or grain, usually accompanied by heating.

SWEEP A double-bladed V-shaped knife on a cultivating implement.

SWEEPRAKE A haying implement with long teeth to pick up hay from the swath, windrow, or cock, and carry it to a stack.

SYMBIOTIC NITROGEN FIXATION The fixation of nitrogen by bacteria infesting the roots of legumes, while benefiting the legume crop.

SYNONYM A different name for the same species or variety.

TAPROOT A single central root.

TASSEL (1) The staminate inflorescence of maize composed of panicled spikes. (2) To produce tassels.

TAXONOMY The science of classification.

TEDDER An implement for stirring hay in the swath or windrow.

TENDRIL A leaflet or stem modified for climbing or anchorage as in the pea.

TERETE Cylindric and slender as in grass culms.

TERMINAL Referring to the extremity or upper bud, flower, or leaf.

TERRACE A channel or embankment across a slope approximately on a contour to intercept runoff water.

TESTA The seed coat.

TETRAPLOID A plant with four times the primary chromosome number.

TILLER (1) An erect shoot arising from the crown of a grass. (2) To produce tillers.

TILTH The physical condition of the soil with respect to its fitness for the planting or growth of a crop.

TOPSOIL The surface soil. Usually the plow depth or the A horizon.

TRAILING Prostrate on the ground but not rooting.

TRANSPIRATION The evaporation of moisture through the leaves.

TRICHOME A plant hair.

TRUNCATE Ending abruptly as if cut off across the top.

TUBER A short thickened subterranean branch.

TURF The upper stratum of soil filled with the roots and stems of low-growing, living plants, especially grasses.

TURGID Swollen, or distended with water.

UMBEL An indeterminate type of inflorescence in which the peduncles or pedicels of a cluster seem to rise from the same point as in a carrot flower cluster.

UNDULATE Having a wavy surface.

UNISEXUAL Flower containing either stamens or pistils but not both.

UNIT CHARACTER A hereditary trait that is transmitted by a single gene.

VALVE One of the parts of a dehiscent fruit or a piece into which a capsule splits.

VARIATION The occurrence of differences among individuals of a species or variety.

VARIETY A group of individuals within a species that differ from the rest of the species.

VEIN A bundle of threads of fibrovascular tissue in a leaf or other organ.

VENATION The arrangement of veins.

VENTRAL On the lower or front side.

VERRUCOSE Warty.

VERTICILLATE Whorled.

VILLOUS Bearing long, soft, straight hairs.

VIRUS Ultramicroscopic protein bodies, the presence of certain types of which in plant tissues cause mosaic and other diseases. They reproduce in plant tissues.

VISCID. Sticky.

WEED A plant that in its location is more harmful than beneficial.

WHORL An arrangement of organs in a circle around the stem.

WINDROW (1) Curing herbage dropped or raked into a row. (2) To cut or rake into windrows.

WING The lateral petal of papilionaceous flower of a legume.

WINTER ANNUAL A plant that germinates in the fall, and blooms in the following spring or summer.

XEROPHYTE A plant adapted to arid conditions.

XYLEM Woody part of fibrovascular bundle containing vessels; the water-conducting tissue.

ZYGOTE Product of united gametes.

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