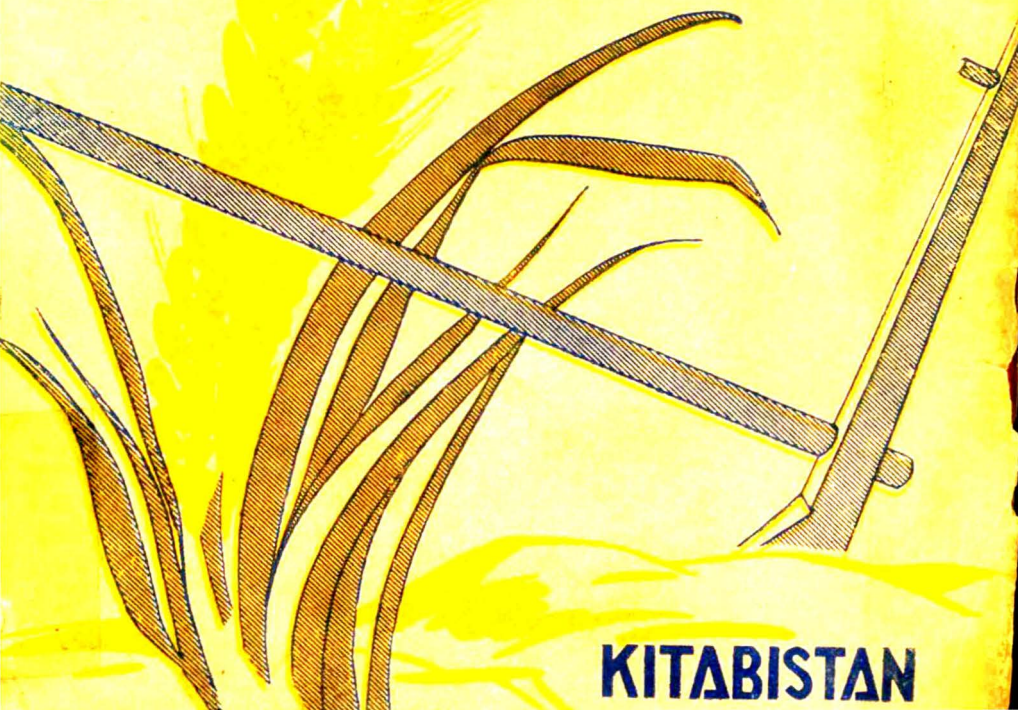


Farm Science & Crop Production In India

By

C. P. DUTT & B. M. PUGH



KITABISTAN

The first edition of this book was published under the title of **THE PRINCIPLES AND PRACTICES OF CROP PRODUCTION IN INDIA**. This is the Second Revised and Enlarged edition. It is in two parts, bound in one volume. Part I deals with general principles of Crop Production and Part II with field crops. The book has proved to be most helpful not only to students but to agriculturists, landlords and tenants.

Farm Science
AND
Crop Production in India
[IN TWO PARTS]

PART I
FARM SCIENCE

By
C. P. DUTT & B. M. PUGH

PART II
CROP PRODUCTION IN INDIA

By
B. M. PUGH & C. P. DUTT

KITABISTAN
ALLAHABAD

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FOREWORD

In a province such as the United Provinces where the bulk of the population depend for their livelihood upon agriculture and where Government depends for its revenue mainly on the produce of the land, any measure for the improvement of agriculture must be welcomed. Mr. Pugh, Professor of Agronomy in the Allahabad Agricultural Institute and at present officiating Principal, and Mr. C. P. Dutt, who was at one time Professor of Botany, have produced a most useful book entitled "The Principles and Practices of Crop Production in India". This book should prove most helpful not only to students at the Institute but to all agriculturists, to landholders and tenants; to the owners of large farms as well as to the cultivator of a small holding. It will no doubt soon get a wide circulation and I hope it may prove possible to translate portions of it, especially those portions which give practical advice to the cultivator, into the vernacular of the province, so that it may reach a wider circle of readers.

It must be remembered that "whoever can make two ears of corn or two blades of grass to grow upon a spot of ground where only one grew before, deserves better of mankind and does more essential service to his country than the whole race of politicians put together." The Agricultural Institute and all connected therewith are rendering this essential service to the United Provinces, and in this book the authors show how it is possible to make two ears of corn grow where only one grew before. At this time when many countries of the world are being devastated by war it is more necessary for all agriculturists to do their utmost to increase the produce of their fields. I commend this book to the notice of all.

MAURICE HALLETT

K.C.S.I., C.R.E., I.C.S.

Governor of the United Provinces

July 17, 1940

DEDICATED TO
THE AGRICULTURAL SCIENTISTS OF INDIA
BOTH PAST AND PRESENT

PREFACE TO THE FIRST EDITION

Several books on agriculture in India have been written from time to time, but it is felt that the materials contained in them are not sufficient to meet the requirements of students of agricultural colleges in this country and do not cover the work that has been done by agricultural investigators in this country in recent times. The authors have also felt that very much valuable material lies buried in journals and magazines which are not often available to the student or to an educated farmer in this country. This book therefore has been written in order to make the great wealth of material, so far published, easily available in a concise form. To some the book may appear to be too technical, and to others it may appear altogether inadequate for their purpose. For the latter group the numerous references at the end of each chapter are given for more detailed study as well as for further elucidation of certain points that are mentioned in the book. Although the authors have tried to cover all the materials on or relevant to the subject matter taken up in the book, they believe that omissions are possible.

In the course of preparation of this book the authors realized the very great difficulty of writing a book on Indian field crops. The large size of the country, the great variety of climate and the very wide diversity of crops and cultural practices in different parts of the country, make the whole subject a very difficult one to handle.

The book has been divided into two parts: (1) the principles underlying crop production, and (2) the field crops in this country.

In dealing with the cultural practices in the production of crops, the authors have attempted to give the practices generally followed by the cultivators, although these

practices may or may not be the best. In the treatment of the subject matter and wherever an opinion has been expressed, the authors take sole responsibility. Any criticisms that readers may wish to make in order to improve the book will be greatly appreciated by the authors.

Acknowledgments are due to the Institute of Plant Industry, Indore, for the facilities made available to the authors in the preparation of this book. The authors also take this opportunity to thank Mr W. B. Hayes, Vice-Principal of the Allahabad Agricultural Institute, and Mr. K. Ramiah, Geneticist and Botanist, Institute of Plant Industry, Indore, C. I., for carefully reading the manuscript and for the suggestions made which have greatly increased the accuracy in many places.

THE AUTHORS

PREFACE TO THE SECOND EDITION

The authors have been so greatly encouraged by the way in which the first edition of this book was received by agriculturists throughout India, and even in foreign countries, that they have no hesitation in putting out the second edition. We hope that the corrections and modifications made in this edition will make the book even more popular than before.

The name of the book has also been modified somewhat, as we hope this also is an improvement on the original.

THE AUTHORS

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PART I
FARM SCIENCE

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CHAPTER I

INTRODUCTION

Beginnings of Agriculture—Agriculture is a very ancient occupation of mankind. It is so old that nobody can say with certainty when and where it was first begun. It probably began when man through necessity discovered that certain wild plants about him would furnish him food in the form of fruits and seeds. Following this discovery, he went from place to place in search of these food materials. Some of the seeds of these food materials dropped around his dwellings, and later bore the fruit and grain which he could use again as his food. This again led him to discover that by scattering seeds near his dwelling, he could have his food materials near his home without having to search for them at long distances. The primitive man perhaps also realized that the fruits and seeds gathered were not sufficient to meet his needs and those of his family. This led him to the cultivation of crops so as to supplement the natural supply. He then had recourse to the clearing of jungles for the growing of his crops. But he probably found out also that the continuous growing of crops in the same place gives diminished yields. So he moved about from place to place. Later as population grew, he was forced to restrict himself to a certain locality. This again must have resulted in competition for certain favourable localities, and the giving up of his nomadic life.

In course of time this primitive man again must have discovered that certain wild plants which he was growing gave him more and better food than others. This must have led him to the selection of certain wild plants for cultivation. In this way, primitive man made a remark-

able choice of crops. Civilization began to centre around the growing of certain crops like wheat in Central Asia, rice in China and south-eastern Asia, and maize and the potato in tropical America. By this time man had also learnt the usefulness of animals as a source of food and clothing. At first he went out to hunt for them, but later he learned that they could be domesticated. He probably noticed that where the animals dropped their excreta the plants grew more luxuriantly. This led him to apply animal excreta to his fields. This was the discovery of the use of animal manure for the growing of crops. And herein lies the beginning of the development of the art of farming. This was the condition of farming in most parts of the country about the time when the Aryans came to India. And although the people of India, through generations of farming, have been able more or less to develop the art of farming, yet the development of scientific agriculture has been the result of only very recent efforts.

Development of Agriculture in India—Scientific agriculture really began when India started to grow certain crops for which there was some demand over and above that needed for home consumption. The trade with the East India Company encouraged the growing of certain crops for export. During the administration of the East India Company, it actually stimulated the growing of certain crops like cotton and sugarcane for export to meet the "home" demand. But the formation of a definite agricultural policy began after the administration of India was transferred to the British Crown. The idea was really started after the report of the Bengal and Orissa Famine Commission during the administration of Lord Lawrence, although it was not taken up until the time of Lord Mayo, when the creation of an agricultural department was considered. The Manchester Cotton Supply Association more or less forced the issue on Government in order to encourage the growing of cotton. So in 1870 a Department of Agriculture with Revenue and Commerce was

established with Mr. A. O. Hume as Secretary. This department did not live long as it was eventually absorbed by the Revenue Department. But once again on the recommendation of the Famine Commission of 1880 the department was brought into existence. One of the main objects of this re-created department was the general improvement of Indian agriculture with the view to increasing the food supply of the people. The proposals of this Commission greatly influenced the agrarian policy of the administration in India for the next twenty years.

Another step forward was made when Dr. J. A. Voelcker of the Royal Agricultural Society, England, was appointed to investigate the agricultural conditions in India, and on his submitting his findings entitled "Report on the Improvement of Indian Agriculture". About this time Lord Curzon assumed the Viceroyalty of India and it was to his administration, acting on the recommendation again of another Famine Commission, that of 1901, and the report of Dr. Voelcker that we owe the development of agricultural departments working on scientific lines for the improvement of agriculture. This Commission pointed out at the time that "the steady application to agricultural problems of research is the crying necessity of the time."

In 1903 the Government of India submitted to the Secretary of State, a scheme for the establishment of an agricultural research institute, which scheme was approved of. About this time Henry Phipps of Chicago (U. S. A.) visited Lord Curzon and made a donation of £ 30,000, to be applied to some object of utility, preferably connected with scientific research. As a result of this, a research station with fully equipped science laboratories was started at Pusa in the Darbhanga district of Bihar. Later in 1912, an Imperial sugarcane-breeding station was established at Coimbatore as a branch of the Imperial Research Institute at Pusa. After the earthquake of 1934, the Imperial Agricultural Research Institute at Pusa was moved to New Delhi.

For the development of agriculture in the provinces the Government of India in 1905, set aside Rs. 24,00,000 with the help of which experiment stations were started at important centres of agricultural tracts, and agricultural colleges were either started or reorganized at Poona, Cawnpore, Coimbatore, Lyallpur, Nagpur, and Sabour. This was again followed by the organization of the agricultural departments in all of the provinces in India. Since then the college at Sabour has been closed, and re-opened and several non-Government colleges have been started, namely, the Allahabad Agricultural Institute in U. P. founded by Dr. Sam Higginbottom, the Udai-bhan Jat Intermediate College (Agriculture) at Lakhaoti, Bulandshahr district, U. P., the Khalsa College, Amritsar, Punjab, the Balwant Rajput College, Agra, U. P., the Agricultural College at Baraut, Meerut district, U. P., and the Government Agricultural College, Dacca, Bengal.

In 1921 the Government of India took up the question of development in cotton growing as regards increasing of yield, and improving the quality. As a result of this the Indian Central Cotton Committee was officially established in 1923 as a permanent body with funds of its own and authority to undertake specific work. One of the first things that the Indian Central Cotton Committee did was to sanction in 1924 the establishment of the Institute of Plant Industry, Indore, as the central agricultural research station for cotton work, the cost of which is being met partly by the Indian Central Cotton Committee and partly by the Central India and Rajputana States. Parallel to this, the Technological Research Laboratory at Matunga in Bombay was established mainly for cotton work.

Another big step forward in the advancement of agricultural science in India was made when the Royal Commission on Agriculture in India was appointed during the Viceroyalty of Lord Irwin. The Commission was ably presided over by Lord Linlithgow.

The main object of this Commission was specifically

to examine and report on the conditions of agriculture and rural economy. The Commission made very far-reaching recommendations, which will, for a long time to come, influence the policy of agricultural development in this country. Consequent to this report, the Imperial Council of Agricultural Research was set up for co-ordinating the work of agricultural research in this country, as it was found that there was a great lack of co-ordination between the Imperial Research Institute and the provincial agricultural departments, and also among the provincial departments themselves.

This is in brief the progress of agricultural development in India.

Importance of Agriculture in India—In order that one may be able to appreciate the fact that agriculture is the premier industry of this country, a table is given below showing the percentage of people engaged in the different occupations in this country. The figures are compiled from the census of 1931.

TABLE I

Percentage of total workers actually employed in different occupations

<i>Occupation</i>	<i>Percentage</i>
Agriculture	67.1
Minerals	0.2
Industry (Textile, Hide, Ceramics, Food Industries, Furniture, Buildings, etc.)	10.0
Trade	5.1
Public Force	0.6
Public Administration	0.7
Transport	1.5
Professions and Liberal Arts	1.5
Miscellaneous	13.3

The figures given in the above table, it should be noted, represent the percentage of the actual workers only. The number of people dependent on agriculture has been com-

puted to be about 75 per cent.

The next two tables are given to show the percentage of the population living in both urban and rural areas in British India and the Indian States respectively, and also in the respective provinces.

TABLE 2

Compiled from the census figures of 1941

	<i>Urban population</i>	<i>Percentage of the total population</i>	<i>Rural population</i>	<i>Percentage of the total population</i>
British India ..	37,546,830	12.7	258,261,892	87.3
Indian States ..	12,149,223	13.0	81,040,010	87.0
TOTAL ..	49,696,053	12.8	339,301,902	87.2

TABLE 3

Compiled from the census figures of 1941

	<i>Urban population</i>	<i>Percentage of the total population</i>	<i>Rural population</i>	<i>Percentage of the total population</i>
Madras	7,864,883	15.9	41,476,927	84.1
Bombay	5,412,169	25.9	15,437,671	74.1
Bengal	5,938,776	9.8	54,367,749	90.2
U. P.	6,855,268	12.5	48,165,349	87.5
Punjab	4,358,964	15.3	24,059,855	84.7
Bihar	1,956,219	5.4	34,383,932	94.6
C. P. and Berar	2,093,767	12.4	14,719,817	87.6
Assam	280,622	2.8	9,924,111	97.3
N. W. F. Prov.	552,193	18.1	2,485,874	81.9
Baluchistan ..	100,463	20.0	401,168	80.0
Delhi	695,686	75.8	222,253	24.2
Sind	891,703	19.7	3,643,305	80.3
Orissa	320,801	3.7	8,407,743	96.3

These figures indicate that India's greatest industry is agriculture, and promises to remain so for many years to come.

The great importance of agriculture to this country may also be realized if one examines the value of some of the agricultural products exported to other countries. The following table shows that the amount of money that is brought into this country from the export of agricultural products is enormous.

TABLE 4

The most important agricultural products exported by sea and their value

<i>Name of article of export</i>	<i>In 1934-35 Value in Thousand Rs.</i>	<i>In 1935-39 Value in Thousand Rs.</i>
Cotton { Raw and waste	354,487	310,416
.. .. . { Manufactured yarns	251,96	819,21
Tea	201,3,19	263,060
Grains, pulse and flour	111,250	436,61
Jute { Raw	10,87,11	198,333
.. .. . { Manufactured	212,462	478,649
Seeds, including nuts for oil	101,607	114,057
Hides, skins and leather { Dressed	456,79	694,34
.. .. . { Undressed	309,89	453,33
Lac	324,23	175,76
Oil cakes of all kinds	189,93	194,61
Tobacco	77,55	180,68

One should not forget, however, that this is only a portion of the total produce, as much of it is consumed in the country itself. It may also be mentioned that there has been a very considerable decline in the exports to foreign countries especially in the case of jute, cotton, rice, tea, oilseeds and wheat during the last few years.

What is meant by Indian Agriculture?—Considering the subject of Indian agriculture, one should not forget, as has been mentioned in the preface, that there is really no such thing as “Indian Agriculture”. Agricultural conditions in India vary so much from place to place that it is impossible to treat the subject as a homogeneous whole. India extends from the Himalayas, where conditions may be found to be similar to regions near the poles, to Cape Comorin, a few degrees north

of the equator. Again it extends from Sind and Western Rajputana where desert conditions exist, to Assam, the region with the greatest rainfall in the world. While some areas are famine-stricken, others are so wonderfully rich that three crops a year are easily obtained from them. Again there are districts where money can be had in abundance, and where therefore the most modern agricultural machinery is found; while in some districts, people are so poor and backward that only a primitive type of agriculture is practised. The subject is therefore of very great complexity and of a very varied nature, differing in different parts of the country.

Agriculture and its relation to other subjects—Whereas

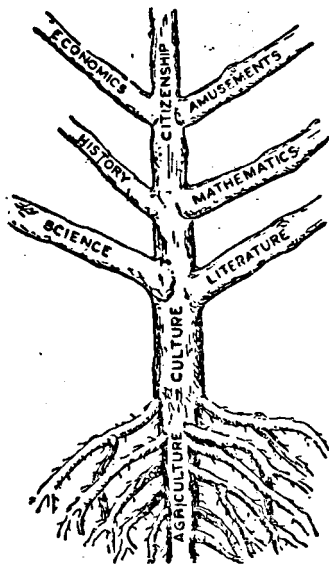


Fig. 2

agriculture, as a science, is more or less a recent development the art of raising crops as well as animals is almost as old as man himself. The science of agriculture within recent years has so developed that it has drawn into its province almost all the modern sciences and arts. With a little study of agriculture one soon realizes that it is not a simple subject but rather a very complex one. Some people who are not acquainted with the subject usually consider that agriculture is the meagre knowledge that a village farmer usually possesses. But the more one studies this subject, the more he realizes its complexity and its far-reaching inter-relationship with other sciences and industries. In order to convey the conception of this complexity to the mind of the reader, the diagram on the preceding page is given which more or less represents graphically that inter-relationship of agriculture with other subjects.

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CHAPTER II

THE PLANT BODY AND ITS WORK

As students of agriculture will not be able to understand certain matters pertaining to crops unless they have some understanding of certain principles of plant growth, this brief discussion dealing with the different parts of the plant and their functions is given here. For the proper understanding of this book it is not essential for an agriculturist to study the detailed structure of the plant, but one should know what functions are carried on by various parts of the plant and how certain factors influence the plant. It is believed that the subject matter of this chapter

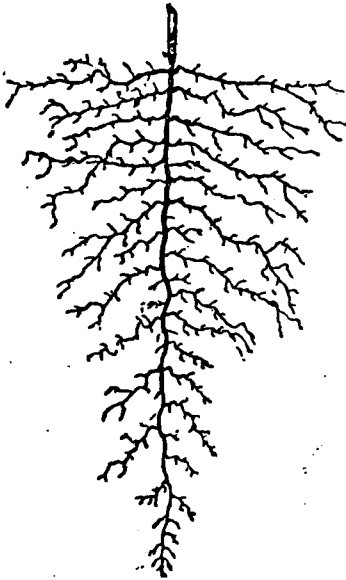


Fig. 3.—Tap Root System

will enable the agriculturist to acquire a better understanding of the principles underlying the better methods of agriculture.

In dealing with plants one should constantly keep in mind that he is dealing with living organisms. And just as animals respond differently to different factors of the environment, in the same way, plants also are equally sensitive to temperature, sunlight, darkness, and various kinds of nutrition. In other words, a plant is a living, growing thing, and makes the most of every opportunity that is afforded

to it. It propagates its kind, just as animals do, and covers the face of the earth.

The plant as a whole may be divided into two parts:

(1) the root, and (2) the shoot. The shoot again consists of stems, leaves, flowers, fruits and seeds. Each of these has different functions to perform. And it is the intelligent understanding of the work of these parts of the plant that makes a brief treatment of this subject desirable at this point.

The Root—The root system of plants is usually of two kinds: (1) the tap root system, which consists of a strong leading central root which runs directly downwards, and (2) the fibrous root system in which is found a mass of slender and thin roots of nearly equal size. Examples of the first type are the root systems of radish, lucerne or alfalfa, castor, cotton and pigeon pea. Examples of the second type are root systems of wheat, barley, maize, sugarcane, sorghum and most of the grasses. There are, of course, various other modifications, the most important being fleshy roots, such as the sweet potato.

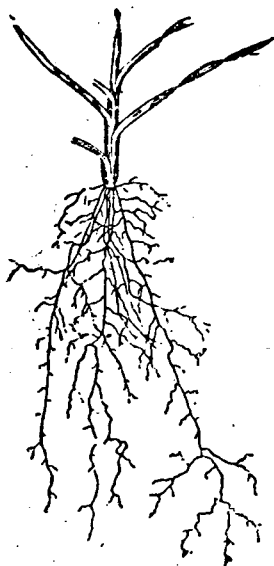


Fig. 4.—Fibrous Root System

The main functions that the root performs are: (1) anchorage, that is fixation of the plant to the soil, (2) the absorption of water and food materials from the soil. Other less important functions of the root are storage and reproduction. Besides, there are occasionally found roots that help the plant to climb, such as the roots of betel vine, and aerial roots which have other functions besides anchorage and the absorption of food from the medium on which they grow, as in the case of the banyan tree.

As a rule, plants with the tap root system can support themselves better than those with the fibrous root system, as the former can fix themselves more firmly to the soil. One of the reasons why certain plants,

such as sorghum and wheat, lodge is because their root systems are shallow. The question of lodging will be dealt with later in connection with those crops that are susceptible to lodging in the appropriate chapter.

But the most important work that the plant has to perform is that of absorption of food materials from the soil. This work, however, is not done by ordinary roots but by special rootlets called root-hairs which are so fine that one can see them with difficulty with the naked eye. These are usually found just behind the growing tips of

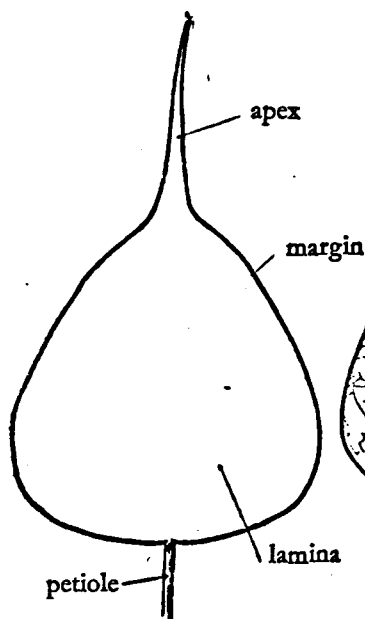


Fig. 5
Leaf and its
parts

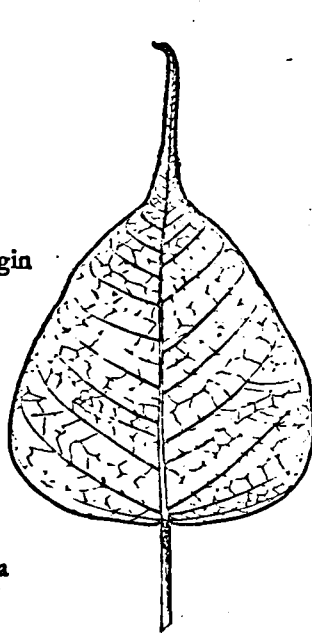


Fig. 6
Netted—Veined
Leaf



Fig 7
Paralleled
Veined Leaf

the roots. One can easily get acquainted with these by putting some seeds like those of maize for a few days on moist blotting paper and allowing them to germinate. These are the special absorbing organs of the root, and

it should be noted that they are near the ends. The large roots function as conducting channels through which water and substances in solution pass. These root-hairs absorb materials from the soil water through the process of osmosis, a special case of diffusion, and not by swallowing soil particles as some earlier people believed. These root-hairs are very delicate but are firmly attached to the small soil particles. In removing plants from the soil for transplanting or for any other purpose the root-hairs are quickly destroyed. Hence care should be taken during transplanting that soil remains around the root so that these useful organs of absorption be not destroyed.

The root and the leaf are the two most important vegetative parts of the plant, and it is therefore the leaf, a portion of the shoot which will be discussed next.

The Leaf—Before dealing with the important functions which the leaf performs the external features of the leaf will be briefly mentioned.

A leaf consists of the blade or lamina and petiole (see fig. 5). The blade is a broad, flat and thin portion and which is the seat of the important activities of the leaf. This is usually green in colour and has a system of veins which are usually of a stouter texture than the rest of the blade. This is sometimes attached directly to the stem but is usually supported by a stalk known as a petiole, whose function is to hold out the blade in a favourable position for the performance of its activities. The petiole functions also as a channel for the conduction of water and food between the blade and other positions of the plant. Leaves vary widely in size, shape, form, venation and other characters. Some leaves are netted-veined while others are parallel-veined. All the grasses, such as wheat, maize, *jowar*, sugarcane and rice, possess leaves with parallel veins. The leaves of some plants, such as cotton, castor and groundnut possess leaves with netted veins.

One of the most important functions of the leaf is the manufacture of food from carbon dioxide and water with the aid of energy derived from sunlight, in presence

of a green colouring substance which is present in the leaf and known as chlorophyll. This process of food manufacture which is performed by the leaf is known as *photosynthesis*. The food manufactured by this process is known as carbohydrate and consists mostly of sugar and starch. Besides the manufacture of carbohydrates, the synthesis of proteins and fats is carried on to a large extent in the leaf. In short, it may be said that leaves are very important food-making organs of the plant.

Leaves also perform the important task of transpiring water (losing water) from the plant. Under normal conditions within the plant there is a continuous stream of water from the roots to the leaves. This process of the rise of sap is important in that food materials from the soil are carried upwards to the various parts of the plant. The rate of transpiration is greatly influenced by such external factors as humidity of the atmosphere, wind velocity, temperature of the surrounding air, and intensity of light.

The Stem—Another important vegetative organ of the shoot is the stem. This is the portion of the plant which connects the root with the leaf. The functions of this organ are the following: (1) the support and display of leaves and flowers in favourable positions for the performance of their respective functions, (2) the transportation of materials to and from various parts of the plant, (3) in certain plants, vegetative reproduction, and (4) in some plants, storage.

The function of support and display consists in bearing the weight of the leaves, flowers and fruit, and in distributing them in space so that they are in positions favourable for the process of photosynthesis in the case of leaves, and for proper development in case of fruits and flowers. Plants can grow luxuriantly where there is an abundance of sunlight; hence the elongation of stems in order to expose the leaves to sunlight is very beneficial and essential for the plant. Such plants therefore as have weak stems, for example beans and peas, are able to

secure more light by climbing on some support. The display of the flowers on the stem favours the transference of pollen for the proper setting of fruits and seeds through the processes known as pollination and fertilization.

The conducting function of the stem involves the transportation of water and other materials absorbed by the roots from the soil and the exchange of food and other materials in the various parts of the plant. This work in the stem is done by the conducting tissues. In grasses and allied plants (monocotyledons) these conducting tissues are distributed throughout the stem. These can be best seen in such plants as sugarcane, maize and *jowar*. The stringy portions of the stems of these are mostly composed of these tissues. In other plants (dicotyledons), these tissues occur just beneath the bark. It is this arrangement of these tissues in the second group of plants which makes the practices of grafting and budding possible. For this same reason it is possible to kill plants belonging to the second group by the process known as girdling, as this severs the conducting system, which results in the death of the plant. In the same way, plants of this group may survive even after the inner portion (heart) of the plant has decayed or been removed.

It is a fact well known to agriculturists that certain plants are able to propagate themselves by means of their stems. This fact is made use of by farmers and gardeners in the propagation of such plants by using portions of stems taken from them. This practice is followed in the propagation of sugarcane, potatoes, roses, sweet potatoes and many other plants. This method has the advantage over the usual method of propagation by seed that the plant is able to "breed true", that is, plants may be secured which are true to type. Another advantage is that plants propagated in this way develop more rapidly than plants grown from seeds. In the practice of budding and grafting, this fact is also made use of to produce plants which are true to type. Plants from seed vary more or less from the parent plants.

Stems of certain plants are especially adapted for the storage of food, although food is found in nearly all stems. Such plants as sugarcane and some kinds of sorghum contain large quantities of sugar in their stems while plants like the potato contain considerable amounts of starch in their underground stems. It is this stored material that makes them valuable for food.

The Flower—The flower in crop plants is the organ of sexual reproduction. It is in this organ that the seed is developed. It seems probable that nature in order to help the plant perform this important function of reproduction, has produced flowers of various forms and colours. While some plants are able to reproduce vegetatively the principal way in which most crop plants reproduce is by means of seeds. Seeds are the product of flowers. A flower usually consists of four parts, namely, the calyx, corolla, stamens and pistil. The calyx is the lower and outer portion of the flower and is usually green in colour. It is composed of certain leaf-like structures which are known as sepals. The corolla is the most prominent part of the flower. This is usually highly coloured and is generally made up of parts known as the petals. The stamens are made up of a stalk which is called a filament and a larger portion at the top which is the anther and which bears the pollen grains. The pistil is composed of the ovary, the style and stigma. The ovary is the enlarged portion at the base of the pistil and the slender upward projection above the ovary is the style. The upper portion of the style is known as the stigma.

The stamens and pistils are the essential parts of the flower, in that the former bear the pollen grains which are the male elements, and the latter the female elements which include the ovary in which the seeds are borne. While the other parts of the flower are considered to be accessory or non-essential portions, yet they help to provide protection to the essential organs. The sepals and petals often attract insects, thereby helping in the process of pollination.

While in most plants the male and female elements

occur in the same flower, in some plants such as maize they occur on different parts of the plant. In some others such as papayas, the male and female elements usually occur on different plants.

For the proper development of fruits and seeds it is necessary for the male elements, that is, the pollen grains, to come in contact with the female element, that is, the stigma. This process of the transference of pollen grains from the anther to the stigma is known as *pollination*. The act of the union of the male and female reproductive elements in the flower is known as *fertilization*. It is usually only after fertilization that the proper development of the fruit and seed takes place.

The Fruit and Seed—The mature ovary with its attachments is known as the fruit in which the seeds are enclosed. Seeds are developed from the structures in the ovary known as ovules. In most cases it is quite easy to distinguish between a seed and a fruit, but there are certain “seeds” which are botanically fruits. Tomatoes are fruits, and so also are the pea pods. These are easily known. But in addition to these a grain of wheat or a kernel of maize is also, in the botanical sense, a fruit. In the latter two the ovary wall has become thin and dry, adhering very tightly to the seed, forming what is known as “dry” fruits. Usually fruit is known by the remains of some of the flower parts attached to it. The development of the ovary takes place immediately after fertilization and this results in what is popularly known as the “setting” of the fruit. Simultaneously, with the growth of the ovary, the development of the seed takes place. As most of the crop plants that are dealt with in this book are principally for the production of seeds, it is desirable therefore that the discussion of seeds be taken up next.

Seeds are useful to man in many ways. Seeds of rice and wheat (a fruit known as a caryopsis), sorghum, gram and groundnuts are all used by man as food. Some seeds are also used for the production of various oils and fats such as linseed, cotton seed (also for fibre), sesamum and

seeds of the castor oil plant. The seed is also the structure by which most plants multiply themselves. The seed contains the germ or miniature plant, and stored food which is necessary for its development during the period of germination and the primary stages in the development of the seedling. This food is commonly in the form of starch which provides energy for the growth of the young seedling during germination which is the process by which the germ or embryo begins its active growth. In order that proper germination of the seed should take place, the following conditions are necessary: (1) an adequate supply of moisture, (2) a suitable temperature, and (3) the presence of oxygen.

Water is necessary in order that the embryo may break through the seed covering more easily. Water also helps the oxygen to enter the seed by diffusion.

While a certain degree of warmth is necessary for the sprouting of the seed yet different plants have different requirements of temperature for their best growth. It has been found that the optimum temperature for germinating seeds of wheat, barley, oats, peas and linseed is between 77 and 88 degrees F.; while that for maize, cucumber, melon and lucerne, is from 88 to 99 degrees F.

The germinating power of seeds is dependent to a great extent on their vitality. There are several factors which influence the vitality of seeds. Some of these factors are the following: (1) The maturity of the seed—immature seeds quickly lose their vitality. Seeds of maize when immature usually produce plants which are weak and may therefore be more susceptible to diseases. This weak and unhealthy condition usually results in low yields. (2) The age of seeds—the vitality of seeds decreases with age. Some seeds, however, deteriorate more rapidly than others. Most seeds of our crop plants deteriorate so rapidly that they should not be sown after they are two years old. Seeds of wheat, maize and barley are known to be good for sowing if they have not been kept for more than two years. Seeds of plants such as peas, cabbages,

mustard, pumpkin and many of the leguminous plants may safely be used for sowing even when they are three to four years old. However, it is a good practice always to sow seeds which are not more than one year old. (3) The conditions of storage—that is seeds that are stored properly retain their vitality for a longer period than seeds which are improperly stored. For the best results seeds should be stored in a cool, dry place and protected from insect attack.

The following table gives the result of the testing of the vitality of crop seeds in its relation to age as given by K. M. Sonavne of the Seed Testing Section, College of Agriculture, Poona.

TABLE 5

Common name	Botanical name	Germination percentage				
		1922	1923	1924	1925	1926
Bajra ..	Pennisetum typhoidum	94.5	93.6	89.1	87.0	61.2
Jowar ..	Andropogon sorbhum	89.7	90.7	90.8	84.5	79.1
Wheat ..	Triticum sativum ..	97.6	98.2	97.3	99.1	98.1
Maize ..	Zea Mays	96.0	97.3	96.2	89.6	86.7
Tur or arhar	Cajanus indicus ..	93.5	89.2	91.1	88.1	87.1
Mung ..	Phaseolus radiatus	77.2	93.6	97.1	94.5	96.7
Moth ..	Phaseolus aconitifolius	90.2	93.8	93.7	94.6	93.3
Urd ..	Phaseolus mungo ..	72.2	98.1	97.3	97.7	98.3
Gram ..	Cicer arietinum ..	96.6	99.8	98.0	93.2	97.5
Hulga, kulti	Dolichos biflorus ..	99.0	98.5	98.2	98.1	97.6
Kabuli gram	Cicer arietinum ..	97.0	99.0	98.7	96.7	97.2
Cotton ..	Gossypium neglectum	58.6	67.3	58.0	55.8	53.3
Groundnut (Small Japan)	Arachis hypogea ..	92.6	74.5	60.2	28.5	23.8
Safflower	Carthamus tinctorios	97.3	98.5	96.6	96.6	94.7
Til ..	Sesamum indicum ..	85.6	85.8	85.6	79.2	80.5
Linseed ..	Linum usitatissimum	98.0	97.3	93.7	94.1	93.1

While these figures in the above table indicate that there is generally no deterioration in vitality with age, it should not be inferred that it is good agricultural practice to keep seeds for a period of more than two or three years. The method of storing of the above samples is quite different from the one usually adopted by an ordinary cultivator. It does show, however, that seeds properly stored can retain their vitality for a considerable length of time.

Whenever possible it is advisable to test seeds for their vitality before sowing in order to find out what percentage of the seeds could be expected to germinate. Poor seeds are usually responsible for poor germination, and consequently for a poor "stand", resulting in lower yields.

There are several methods for testing the vitality of seeds. The following method is one that can be easily adopted on account of its simplicity. In order to carry this out, no special equipment is needed except a piece of old cloth usually about 14 or 16 inches wide and about 3 or 4 feet long depending on the number of seeds to be tested. Care should be taken to secure a representative sample of the seeds. Usually three lots of 100 seeds each are taken. First, the cloth is moistened with water and then spread out. Seeds are then arranged in rows of three lots (say). Next, the cloth is folded on each side until the edges meet in the middle. After this the cloth is rolled up carefully so that seeds do not fall out or move from their places. The cloth along with the seeds is now placed in a warm place for two or three days usually depending on the kind of seed. Care should be taken to keep the cloth moist during this period, otherwise, proper germination will not take place. At the end of this period the cloth is unrolled carefully and spread out. The germinated seeds are then counted. The average of the three lots of germinated seeds gives the percentage of germination. This is known as the **RAG DOLL TESTER METHOD.**

The Relation Between Root and Shoot—In the beginning of this chapter mention was made of the fact that the

plant consists of two parts, the root and the shoot. The work of these two is very closely inter-related, and therefore, in order to have a proper development of the plant the maintenance of a proper balance is very important. If either one of these is too greatly reduced or too great in extent the other will not thrive. The practice of removing leaves from young plants during the process of transplanting is an effort to maintain this balance between root and shoot, as, in the removal of the plants from the soil, some of the roots with their root-hairs are destroyed, thereby reducing the absorbing system.

The Naming of Plants—The same plant is known by different names in different parts of the country. And, on account of the difference in language in different parts of the world, different names are applied. A plant known as sorghum is, for instance, known as *chari* in the Punjab, *juar* or *jundri* in the United Provinces, *jowar* in Central India and Bombay and *cholam* in South India. Scientists all over the world therefore have adopted a common system of naming plants which is known as the binomial system of nomenclature, according to which a plant has two, or rarely three names. The first is called the generic name or the name of the genus to which the plant belongs, and the other is called the specific name or the name of the species. This is again usually followed by a letter or letters which represents the name of the person who first gave the name to the plant. This system of naming plants was started by Carl Von Linne, better known as Linnaeus, the great Swedish naturalist. Thus potato is given the scientific name of *Solanum tuberosum* L, *Solanum* being the generic, and *tuberosum* the specific names respectively, and L. standing for Linnaeus who first gave the name to the potato plant. This system does away with a great deal of uncertainty as to which plant is referred to, as this is the name by which the plant is known throughout the whole scientific world.

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CHAPTER III

THE SOIL AND ITS IMPORTANCE TO AGRICULTURE

It is impossible to study agriculture without a proper understanding of the soil. The soil and the atmosphere together make up the environment in which the plant grows, develops, and reproduces. Of these two, the soil is probably the more important, as it is from it that the plant secures most of its essential nourishment. It is for this reason that its origin, development and its important characteristics are briefly discussed here. The study of soil began in very early times; soil descriptions were already in existence in the seventh century before

Christ. Men doubtless very early made certain observations about the soil, beginning when they began to use it in producing crops. But the science of soil, pedology, or edaphology, has only very recently developed, through the work of such men as Docuchaiev and Glinka in Russia, Ramann in Germany and Hilgard in America. This

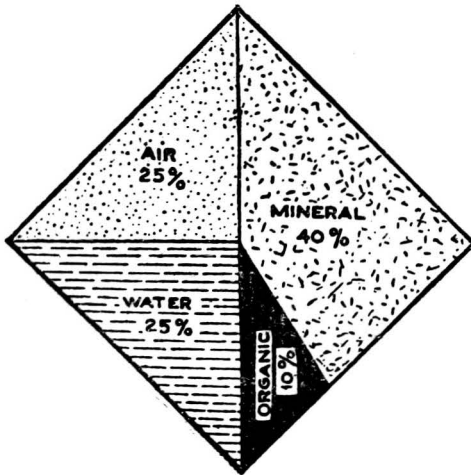


Fig. 8.—Average Composition of Soil

study has shown that soil is very complex and yet at the same time one of the most interesting, and most wonderful things in nature.

The soil may be described as a thin layer on the surface of the earth's crust made up of the complex materials consisting of disintegrated and decomposed rocks, organic matter, substances in solution, water, air and such organisms as bacteria, fungi and protozoa. This is shown graphically in the above diagram (fig. 8).

The figures given in the above diagram, are volume percentages, and, it should be remembered, are only approximate, as the composition of the soil is not constant. In fact, everything in the soil is dynamic, that is, in a state of continuous change; and it is a mistake for one to consider it to be static, *i.e.*, not changing. Rock particles form approximately 90% of air-dried soil.

The development of these particles in order to form soil began in the unknown past; it took thousands and thousands of years before it developed to the state in which crop plants can grow. The small soil particles have been derived from solid rocks through processes known as mechanical disintegration and chemical decomposition, through such agencies as temperature, wind, running water, ice and animal and plant organisms.

MECHANICAL DISINTEGRATION

Through changes of temperature, rocks expand and contract. Due to rocks being made up of a large number of minerals whose rates of expansion are different, this change in temperature sets up a considerable stress within the rock. This repeated expansion and contraction therefore causes the formation of cracks in the rocks or the peeling or "flaking-off" of the outside layers of the parent rock; this latter process being known as "exfoliation."

The *wind* is another factor which helps to a very great extent the process of soil formation. It possesses both erosive and transporting powers. Strong winds are able

to pick up small rock particles and drive these against large masses of rock, thus cutting and wearing them away, thereby reducing them into small particles. The sandstorms that usually occur in the drier parts of this country are examples of this activity.

Water possesses great power of erosion, when solid particles are suspended in it. A large number of our soils have been made by the cutting and carrying power of water. In temperate regions where ice and frost formation takes place, water usually enters into the cracks and crevices of rocks, which, when frozen, expands and breaks open the rocks. Running water also possesses transporting power, and is able to carry great loads of small rock particles. This transporting power of water has been calculated to vary with the sixth power of its velocity. Accordingly, water is able to carry clay, silt, sand, pebbles and stones depending upon its rate of flow. In this way water is able to sort and deposit different sizes of soil particles in different places. This sorting and deposition of soil materials is thus brought about by the increase and decrease in its rate of flow. Most of the soils of the Indo-Gangetic plain have been formed in this way.

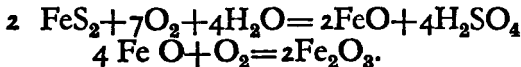
Plant and animal organisms have also a considerable influence in soil formation. The activity of some of the lower plants, such as mosses and lichens which can grow on bare rock surfaces is very important in the early stages of rock disintegration and decomposition. These organisms send their tiny rootlets into the crevices of rocks and bring about a prying and loosening effect on the rocks.

The influence of animals which burrow holes in the soil, such as earthworms, termites, ants, mice and rats is also considerable. Their activities help to loosen and mix the soil. But the indirect effect of plants and animals is even more important than the direct effect. These plants and animals are responsible for the production of organic debris of all kinds and also in the formation of humus.

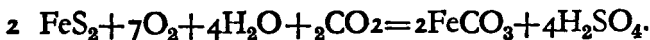
CHEMICAL DECOMPOSITION OF ROCKS

The subject of chemical decomposition of rocks has been studied from many different viewpoints by geologists, soil scientists and chemists. The first group of workers are interested in soil from the viewpoint of soil formation while the last are mainly concerned with the complicated chemical changes which take place in the soil. This process of rock decomposition is brought about by oxidation, carbonation, solution and the activity of soil organisms and roots of plants.

Oxidation—This is the action of oxygen on the various soil minerals. The action of oxygen on iron is exemplified by rusting, a phenomenon familiar to all. In soil containing iron compounds, oxidation makes them fairly soluble. Most minerals in the rocks contain considerable iron which, when oxidized, help to weaken the rock. When the soluble compounds are dissolved in water the rocks are further weakened. This is illustrated by the following chemical reactions:—

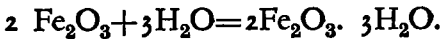


Carbonation is usually associated with oxidation. Carbon dioxide which is found in small quantities in the atmosphere and in greater quantities in the soil air, when in combination with water forms carbonic acid. This is a weak acid but increases the dissolving power of water. In this way, chemical action on the rock masses forms soluble bicarbonates. This is shown by the following chemical reaction:—

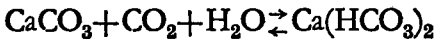


Hydration is the chemical union of water with other substances. This union also weakens rocks, thus bringing about their decomposition into soil. Hydration generally precedes or accompanies the processes of oxidation and carbonation. This process is usually accompanied

by a considerable increase in volume, which may be as much as 88 per cent during the change from rock to soil. Hydration therefore causes some of the rock-forming minerals to become soft and loose thereby quickly breaking down the rocks into soil. This change may be illustrated by the following chemical reaction which shows the change of the mineral hematite to limonite through this process of hydration:—



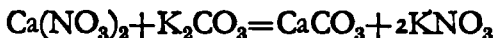
Solution—The chemical decomposition of the rock minerals produces simple compounds which are usually more soluble. When these soluble compounds come in contact with water, solution takes place. This is due to the solvent action of water which is one of its important properties. Carbonate rocks such as limestone, magnesite and dolomite, are particularly susceptible to this solvent action of water, in the presence of other substances such as nitrates, chlorides and carbon dioxide. The following chemical formula illustrates this process:—



BIOLOGICAL ACTIVITIES

The pioneer plants and animals did not live for ever on the same spot. They grew old and died, leaving as a contribution to the soil the substance—organic matter—of their dead bodies, including the elements secured from the rocks. This added wealth of decayed plant and animal tissues in the crevices in the partially disintegrated rocks created better feeding for the soil micro-organisms, such as bacteria and fungi. This supplied better feeding conditions for the higher plants. The simple products of decomposition of the substances thus made available to the higher plants by the action of these bacteria and fungi are carbon dioxide, water and ammonia. Certain bacteria are also responsible for chemical changes of various sorts, the results of which are of great importance to higher plants.

Thus the conversion of nitrogenous organic matter into potassium nitrate is mainly due to the action of these micro-organisms. Waste organic materials, especially those that are rich in nitrogen, when mixed with lime and in the presence of potassium carbonate, are slowly converted into potassium nitrate and calcium carbonate, thus:—



The practice of composting farmyard manure is also dependent to a very great extent on the work of these micro-organisms. In short, without the presence of these organisms the soil would soon become unfit for the growth of higher plants.

ROCKS AND SOME IMPORTANT SOIL-FORMING MINERALS

Soil, as has been mentioned above, is made up largely of rock particles which have been derived from the parent rocks. The character of these particles is similar to the parent rock from which they were derived. The rock particles have no inconsiderable influence upon the soil of which these are components. Geologists have classified rocks into three groups known as (1) igneous, (2) sedimentary, and (3) metamorphic rocks. Some of the soil-forming rocks and the group to which they belong are as follows:—

- (1) Igneous: Granite, diorite, gabbro, syenite, diabase and peridotite.
- (2) Sedimentary: Limestones, sandstones, shale and dolomite.
- (3) Metamorphic: Marble, quartzite, schist, slate and gneiss.

Igneous rocks are those which have been reduced to molten condition by intense heat in the interior of the earth and solidified in the crystalline form when they cooled down after they reached the upper part of the earth's surface.

Sedimentary rocks are those formed from the materials derived from the igneous rocks, and have been deposited generally under water.

Metamorphic rocks again, are either igneous or sedimentary rocks which have been subjected to heat and pressure and have been changed or metamorphosed.

Of these three, the first group is the most difficult to break down, the other two being more easily disintegrated into soil particles.

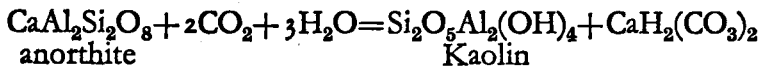
The igneous rocks may again be classified into two groups: the acid and basic rocks. The acidity and basicity is due to the presence of silica and alkalis respectively. Rocks belonging to the acid groups are more difficult to break down. On this evidence, H. O. Buckman has formulated what he calls the law of mineral and rock decay which runs as follows: "The more basic a rock becomes the more rapid is its decomposition; and the more acid the less marked is its decay."

Rocks are complex bodies which are usually made up of minerals. These latter bodies in their pure state possess a definite chemical composition and are usually crystalline in form. By far the most common rock-forming minerals are either carbonates, silicates and sulphates. There are a great number of these minerals, but only a few are of practical importance from the agricultural point of view. Some of the most important soil-forming minerals and their relative amounts in the mass of the earth's crust are the following:—

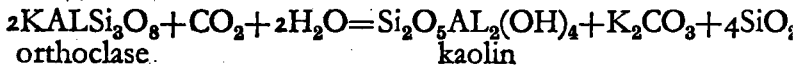
1. Felspars	..	..	..	..	..	48 per cent.
2. Quartz	..	..	..	..	..	35 "
3. Mica	..	..	..	..	..	8 "
4. Talc	..	..	..	..	..	5 "
5. Carbonates of calcium and magnesium						1 "
6. Hornblende, augite, alivine, etc.					..	1 "
7. Other substances			..	..	..	2 "

These various minerals are sooner or later affected by decay or chemical decomposition. Some undergo changes

slowly, while others do so more rapidly. The insoluble minerals are decomposed into soluble salts—compounds which are oxidized, reduced or dehydrated. One of the most important chemical processes in the formation of soils is known as *kaolinization* or the formation of clay or kaolin from feldspars. The importance of this process is due to the presence of clay in the great majority of soils. Clay determines to a considerable extent the physical properties of the soil for agricultural purposes, such as its suitability for growing certain crops. The formation of kaolin from anorthite, the lime feldspar, may be represented by the following equation:



Orthoclase, the potash feldspar, also undergoes a similar change, although the process goes on more slowly. It, however, is ultimately resolved into kaolin, as may be represented by the following equation:



Other minerals, besides feldspars, upon decomposition, not only yield kaolin but also compounds of calcium and magnesium; and usually owing to the presence of a large number of complex silicates, both alkaline and some metallic, some minerals like diorite and diabase sometimes decompose into green and brown clays. But the predominant red colour which is found in many tropical and subtropical soils is due largely to the presence of iron oxide, sometimes associated with manganese hydroxide, while the dark colour in soils is usually due to the presence of decayed organic matter, and not necessarily due to the colour of the rock material from which the soil is derived. The colour of the black cotton soils of Central India is due to other factors, which will be discussed in the chapter on the soils of India.

CLASSIFICATION OF SOILS

Soils have been classified in various ways. They may be classified according to their geological origin, or according to their physical characteristics, or their chemical composition. Among the more recent classifications, soils have been grouped together according to their stages of development which again depend to a great extent on the effect of climate. For the purpose of this book, the geological and physical classifications will be discussed as these are the ones that are most commonly used.

The following is an outline of the GEOLOGICAL CLASSIFICATION OF SOILS.

That is, soils are, according to this geological classification, divided into two main groups: (1) the sedentary soils, or soils that have not been moved from the place of origin, and (2) transported soils, or those that have been moved from their place of origin.

Sedentary soils are subdivided into two groups known as *residual* and *cumulose* soils. The residual soils are those which are formed "in place," that is, they originated from the underlying rocks. This group of soils is usually found in the hilly tracts. They can be easily recognized by their characteristic profile. That is, these soils usually have the finer materials on the surface and the coarser material below underlaid by the parent rock. The surface material is usually in an advanced stage of disintegration. Cumulose soils are similar in origin to residual soils, but differ in character in that they are made up largely of organic matter with but small amounts of minerals. They are usually formed in marshy places. Cumulose soils are more commonly called *peat* or *muck* depending on their stage of decay. In peat soils the stem and leaf structure of the original material can be recognized while in muck, decay has gone further and this identity is lost.

Transported soils are those moved from their place of origin through such agencies as water, wind, gravity and ice. (1) Those that were transported by ice are called

glacial soils. Such soils are commonly found in certain areas near the base of the Himalayas where they were brought down by the action of glaciers, such as the soils of the Dehra Dun region and parts of Kashmir. These soils are not of very great agricultural value in India, but are of considerable importance in other parts of the world, for example, the soils of the northern portion of North America. (2) Those that were transported by the action of gravity are called *colluvial soils.* These are usually made up of rock fragments generally at the bases of cliffs, and consist of materials brought down by landslides. These soils are usually very poor, and are unfavourable for plant growth. (3) Those soils that had been moved by the action of wind, from their place of origin are known as *aeolian soils.* In some parts of the world these are commonly known as *loess.* These soils occupy great areas of China and Siberia. The adobe soils of California are also of aeolian origin. In India these soils are met with in parts of Rajputana, Baluchistan and the Salt Range of the Punjab.

Soils that were transported with the action of water are of three kinds : (1) *lacustrine,* (2) *marine* and (3) *alluvial soils.* The first type of these soils are found near lakes, the second occur near the sea coast, while the third group, which is by far the most important in India, are found practically in the whole of northern India, where these soils were brought down by the network of the three great river systems, the Indus, Ganges and Brahmaputra. Near their places of origin, the materials deposited are generally very coarse, but as these rivers flow more slowly, after leaving the mountainous regions, the finer materials that are carried by them begin to be deposited, as the carrying power of the water is decreased due to its decrease in velocity. As already mentioned, the carrying power of water has been calculated to be directly proportional to the sixth power of its velocity. This means that doubling the velocity increases its carrying power (2)⁶ or 64 times. Due to the variation in the velocity of the water, different-sized

materials are deposited at different times. In this way, layers are formed which differ somewhat in their characteristics. This type of deposition in layers is known as *stratification*, and is a characteristic of alluvial soils. Another characteristic of alluvial soil is that the particles are more or less round in comparison with those of residual soils which are usually angular in shape. This is due to the fact that the sharp edges are worn down by the rolling, rubbing and grinding action of running water. These soils are usually of considerable depth, and are often composed of silt, loams and sandy loams. Sometimes finer materials are usually deposited as alluvial soils when streams overflow their banks, and the water becomes very sluggish and comes to a standstill. Such materials usually form clay soils. Generally alluvial soils occur as long narrow strips along rivers and streams or as "alluvial fans" at the base of mountains or as deltas where the rivers enter lakes or seas.

These soils are found in various parts of the world, and are probably the most important from the viewpoint of agriculture.

Another method of classification and probably the one most commonly used by practical agriculturists is the one based upon the size of the soil particles. This may be called the "TEXTURAL CLASSIFICATION OF SOILS." By texture is meant the relative size of the soil particles. In this classification, soils are separated into the following main classes:—

- | | | |
|--------------------|----|--------------|
| 1. Gravelly soils | .. | 6. Loam |
| 2. Coarse sands | .. | 7. Silt loam |
| 3. Fine sands | .. | 8. Clay loam |
| 4. Sandy loam | .. | 9. Silt |
| 5. Fine sandy loam | .. | 10. Clay |

Of these ten groups of soils, the first three and the last two are of little importance in agriculture. The gravelly soils and the sands are usually very poor for agricultural

purposes because of their open and porous character. However, sometimes special crops adapted to these soils are grown, such as the watermelon in certain parts of Rajputana. Silts and clays are seldom found in the pure state; and when they do occur in this manner, they are of little importance agriculturally. However, special crops such as rice are sometimes grown on very heavy clays. The bulk of the agricultural crops are mainly grown on the loams. The loamy soils may be composed of clay, silt, sand and other soil materials in various proportions. In other words, they are mixtures of any two or more of these soil materials.

Soil scientists have assigned certain sizes to different groups of soil particles, which are technically called *soil separates*.

The following table gives the range of sizes of the different soil separates:—

TABLE 6

<i>Soil separate</i>	<i>Size in millimetres</i>
Fine gravel	1—2
Coarse sand	1—.5
Medium sand .. .. .	.5—.25
Fine sand .. .. .	.25—.10
Very fine sand .. .. .	.10—.05
Silt .. .. .	.05—.005
Clay	below .005

The separation of the soil materials into these different groups of soil separates is performed by methods which are known as the *mechanical analyses of soils*. These methods are employed by soil specialists in laboratories, and are hardly meant for practical agriculturists. For this and other reasons, one method only will be mentioned by way of general information. This method is probably the simplest

and is known as the sieve method. The method consists of a series of sieves, each sieve possessing holes of equal diameters, but different from those of the other sieves of the series. The upper sieve in the series possesses the largest perforations. The material passing through it goes on to the next sieve, and so on.

In this method the dry soil which should be free of lumps is taken, and is then placed in the upper sieve; and the whole series is shaken thoroughly until the particles are completely separated. The material in each lot is then weighed and calculated on the basis of percentage. For finer materials like silt and clay it is sometimes desirable to use a stream of water for washing the material through the perforations. However, silt and clay cannot be separated accurately by this method.

As previously mentioned, the loams are mixtures of two or more soil materials such as clay, silt and sand. The various loams are therefore made up of various percentages of these materials. The table given below gives the approximate percentages of these materials in the various loams.

TABLE 7

	<i>Clay</i>	<i>Silt</i>	<i>Sand</i>	<i>Other materials</i>	<i>Total</i>
Sandy loam	12%	21%	63%	4%	100
Fine sandy loam	12%	24%	63%	1%	100
Loam	16%	40%	42%	2%	100
Silt loam	15%	65%	19%	1%	100
Clay loam	26%	38%	35%	1%	100

The identification of soils and placing of them in these various classes, such as sandy loam, fine sandy loam, loam,

etc., can be easily performed by one who has had some experience in field work with different soil classes. This is usually judged on the basis of colour and "feel". That is, colour will usually indicate the humus content and the parent soil material, while by rubbing the soil between the thumb and the fingers, the texture of the soil may be determined by the grittiness of sand, or plasticity of clay, or "floury feel" of silt. This method is surprisingly accurate with one who has had considerable experience with soils in the field, and may in most cases be relied upon.

A key for the practical classification of mineral soils as given in "The Nature and Properties of Soils" (1922) by Lyon and Buckman, is given below.

- I. Soils possessing the properties of one size of particle largely:—
1. Particles very large *Gravel*
 2. Particles apparent to eye, feel gritty and non-plastic *Sands*
 3. Particles very small, soil very plastic when wet, hard when dry *Clay or Sandy Clay*
- II. Soils possessing the properties of a number of sizes of particles—a mixture:—
1. A fairly equal exhibit of sandy and clayey properties *Loam*
 2. A mixture but with sand predominating *Sandy Loam*
 3. A mixture but with silty character dominant. The soil has a "floury" or "talc feel" and is quite plastic when wet *Silt Loam*
 4. A mixture but with clayey characters very apparent. Soil is very plastic and approaches a clay in character *Clay Loam*

SOME IMPORTANT PHYSICAL CHARACTER- ISTICS OF SOIL

One of the most important characteristics of soil is its COLOUR. This characteristic is an important aid

in the recognition and description of the different soil groups. The colour of soils is dependent on many factors. Moisture is one of the many factors which affect the colour. That is, certain soils change their colour in the processes of drying and wetting. The colours of most soils stand out more sharply when wet than when dry. The colour of moist soil is dependent to a considerable extent upon the amount of organic matter and colloidal clay present in the soil. Usually soils containing a high percentage of organic matter are dark in colour. However, this dark colour imparted by organic matter may sometimes be masked by the presence of colloidal clay material. But the parent material from which the soil is derived and the mode of its formation often exert a considerable influence upon the soil colour. For instance, the red or yellow colour in soils is usually due to the oxidation of the iron in the original rock material. A soil which is deficient in organic matter with iron absent or unoxidized is usually of a light colour.

The colour of soils is generally a good indicator of their fertility or agricultural value; as the black or light-coloured soils indicate the presence or absence of organic matter which is an important constituent of soils. Red soils often indicate the low amount of humus in the soil. A person with even a little agricultural experience knows that the surface soil is usually of a darker colour than that of the subsoil. This peculiar characteristic is usually made use of in distinguishing between soil and subsoil. However, this line of demarcation is not so distinct in the case of soils of arid regions. The darker colour in the surface soil is very largely due to the higher content of decayed organic matter which is the residue of plants.

Another important physical characteristic of soils is their DENSITY. By this is meant the lightness or heaviness of soils. This usually depends on the texture of the soil. That is, soils possessing larger particles are usually heavier in weight per unit volume, while those with smaller particles are usually lighter. This should not be confused with the common idea that sandy soils are "light" soils,

whereas, clay soils are called "heavy" soils. These terms are applied by farmers to soils which are easy to cultivate or hard to work, respectively. Sandy soils are easy to work because they are granular and therefore loose in character, whereas, clay soils are more plastic and therefore more compact in character.

The PLASTICITY in soils is due to the presence of inorganic colloidal materials. This property enables soils to change in shape continuously when subjected to some applied force and to retain that shape when the force is removed. Plasticity is also closely associated with another property found in soils which is known as COHESION. This again is the property which causes certain particles of soil to cling or cohere to each other. This property is most marked in clay soils. The cracks which are found when clay soils dry out are largely due to this cohesive-ness in such soils. This is also responsible for the formation of hard clods or lumps in fine-textured soils when the latter are ploughed.

SOIL HEAT is another important physical property of soil. The sources of soil heat are many. A certain portion is brought to the soil through rain. A considerable amount is produced by the chemical and biological activities which take place within the soil. But the greatest amount of this heat is derived directly through radiation from the sun. The power of the soil to absorb heat is dependent upon a number of factors such as colour, texture, structure and slope. For instance, the darker soils possess greater heat-absorbing capacity. The addition of organic matter, such as farm manure, to the soil, will impart a dark colour to the soil; and consequently increase its heat absorptive power. The texture and structure of a soil have some influence on the heat absorptive capacity but their importance lies in the fact that these soils possess different capacities for water, which, in turn, influences the heat capacity of the soil.

The slope of the land also influences soil heat. For instance, the southern slopes usually are warmed more

rapidly than those facing towards the north. This is true for the northern hemisphere only.

Soil heat and soil temperature are closely related; and the two should not be confused with each other. Soil heat refers more or less to the quantity of heat contained in the soil, whereas, soil temperature simply refers to the degree of hotness or coldness of the soil. Thus the soil having a high heat capacity will rise or fall in temperature much less rapidly than one with a lower heat capacity. Soils possessing high heat capacity are usually spoken of as cold soils because such soils warm more slowly. For example, clay soils possess the ability to hold more water than sandy soils. And since water has a heat capacity which is approximately five times the heat capacity of the soil particles, therefore clay soils generally possess a higher heat capacity. For this reason the temperature of clay soils rise very slowly. Consequently, these soils are spoken of by farmers in temperate regions as cold or late soils, whereas, sandy soils are spoken of as warm or early soils. In the same way the heat capacity of sandy soils may be increased by the addition of water by irrigation. This will decrease the rapidity in the fluctuation of soil temperature.

While the temperature fluctuates very rapidly in the surface soil, at the depth of about one foot the fluctuation is very slight. According to Leather the diurnal change of temperature at Pusa in Bihar is only 1 centigrade at the depth of 12 inches; but at 24 inches it is doubtful whether it ever exceeds 0.1 centigrade. He also found that the temperature of the soil at a depth of 3 or 4 inches is above the mean air temperature of the day only for about eight hours daily, whilst it is below it for about 16 hours.

The following table gives the comparison of air and soil temperatures taken at Pusa in Bihar (India) throughout the twelve months in the year.

TABLE 8

	Maximum		Minimum	
	Air	Soil 1" deep	Air	Soil 1" deep
January	23.5 C	25.3 C	9.1 C	10.7 C
February	26.3 "	29.3 "	11.6 "	13.6 "
March	31.2 "	34.6 "	13.8 "	15.5 "
April	36.6 "	39.9 "	20.6 "	22.3 "
May	36.4 "	40.1 "	23.0 "	25.5 "
June	33.9 "	38.2 "	24.5 "	26.9 "
July	32.3 "	36.3 "	25.6 "	27.1 "
August	32.2 "	36.7 "	25.5 "	27.4 "
September	33.2 "	37.1 "	24.1 "	26.0 "
October	32.8 "	36.1 "	20.2 "	22.2 "
November	26.8 "	28.6 "	14.1 "	16.1 "
December	23.2 "	24.9 "	9.2 "	10.8 "

An examination of the above table will show that the minimum soil temperature at 1" deep is always higher than the minimum air temperature, the difference being about 1.5° to 2°C (*i.e.*, 2.7. to 3.6°F.). The second point to be noted is that the maximum soil temperature at 1" deep is always higher than the air temperature (in the shade), the difference being from 2 to 4°C (*i.e.*, 3.6 to 7.2°F.). The third point to be noted is that the above soil temperatures were taken in the alluvial soil of the Gangetic plain in Bihar. The figures therefore do not apply to other parts of India and to other soil types such as the black cotton soils, which on account of their dark colour probably become hotter at the surface than the above figures would indicate. Another point to be noted is that these figures are monthly averages and therefore do not indicate the absolute extremes of both minimum and maximum temperature, nor do they indicate the absolute difference in temperature which occurs in any single day, as the averages tend to smooth out these differences. It may be expected that during the hot dry weather when the sky is

clear, a condition which is usually found in many parts of India, the daily difference in temperature is probably much greater. During the monsoon, however, when the sky is cloudy, the difference between air temperature and that of the soil at 1" deep is very much reduced being probably not more than 2 to 3°C (*i.e.*, 3.6 to 5.4°F.). These soil temperatures are also greatly affected by rainfall. This effect may be expected to be greater during the dry season than during the monsoon. It was also found that the effect of a crop especially one that almost completely covers the soil, such as cowpeas has a very marked effect on the soil temperature, as it prevents the temperature of the soil from rising to the same degree as occurs in the fallow land.

One of the most important physical properties of a soil from the agricultural point of view is the arrangement of its particles. This arrangement of the particles is known as SOIL STRUCTURE. At least four different arrangements are generally recognized. The first is "columnar" that is, one in which the soil particle is touched by its neighbours at four points. The second is the oblique arrangement in which the particle is touched at six points by its neighbours. The third is called the compact arrangement which is one in which smaller particles of soil occupy the spaces unoccupied in the more or less oblique arrangement, thus reducing the space between the particles. The puddled condition is an extreme form of this arrangement, in which the space between the particles is reduced to the minimum. This is detrimental to plant growth, as it prevents the proper circulation of air and water. The fourth type of arrangement is known as granular. In this arrangement several particles come together forming a group which behaves more or less like a large soil particle, so that large spaces occur between such groups. Each group of particles functions more or less separately. This condition occurs only in fine-textured soils such as loam, silt and clay. This condition produces what is known as a crumb structure. A fine-textured soil may be prevented

from being puddled by increasing the tendency towards granulation. Some of the practices which tend to develop a granular structure in soil are the addition of organic matter, or lime, and tillage.

The SOIL AIR is a physical component of soil and is only an extension of the atmospheric air into the spaces unoccupied by the particles in the soil. The soil air cannot move so readily as the atmospheric air due to the fact that it is locked up more or less in the empty spaces in the soil. This reduced movement of air in the soil produces variation in the composition of the soil air.

The following table is given in order to show the difference in composition between atmospheric air and that of an average soil air.

TABLE 9

				<i>Carbon dioxide</i>	<i>Oxygen</i>	<i>Nitrogen & other gases</i>
Atmospheric Air	..	..		.03	20.99	78.95
Soil Air	..	..	..	.20	20.60	79.20
Difference	..	..	..	.17	.39	.26

From the above table, it will be noted that the average composition of soil air is not materially different from that of atmospheric air. However, the soil air contains about seven or eight times as much carbon dioxide as atmospheric air. But there is a considerable variation in the amount of carbon dioxide in the soil air, depending to a very great extent on the type of soil or on the amount of organic matter added to it. It has been found, by Boussingault and Lewy, for instance, that the amount of carbon dioxide in sandy soil ten days after manuring is 9.74 per cent, which is approximately 324 times the amount of carbon dioxide in ordinary atmospheric air. J. W. Leather, working on

soil gases in Bihar (India), gave the following composition of gas of three samples of swamp rice lands.

TABLE 10

			<i>Carbon dioxide</i>	<i>Oxygen</i>	<i>Nitrogen</i>	<i>Other gases</i>
Sample A	..	..	4.34	.32	84.35	11.095
Sample B	..	..	4.23	.31	86.60	8.855
Sample C	..	..	4.69	.99	85.91	8.409

It will be noted from this table that the amount of oxygen is very much reduced under swampy conditions, while the percentage of carbon dioxide is very much higher than even in ordinary soil air.

The following figures are taken from J. W. Leather to show the composition of the soil air present in the neighbourhood of the roots of certain crops. The samples were taken at a depth of 3 to 6 inches.

TABLE 11

<i>Crop</i>		<i>Dates when samples were taken</i>	<i>Carbon dioxide</i>	<i>Oxygen</i>	<i>Nitrogen</i>
Sann hemp	..	27-7-14	16.99	2.23	79.77
..	..	25-8-14	12.12	4.67	81.63
Maize	..	4-9-14	3.34	13.82	81.59
..	..	10-9-14	12.30	7.25	79.47

The above figures show that the amount of oxygen near the roots of plants is much less than what is found in ordinary soil air, while, on the other hand, the amount of carbon dioxide is very high. It seems very probable that during the growth of the crop the soil air is used up by the

the roots and large quantities of carbon dioxide are formed. Another interesting point to notice in the above table is the difference in the amount of oxygen near the roots of sann hemp and that near those of maize. Sann hemp is usually a non-cultivated crop, while maize is usually cultivated, and is also believed to be profited by frequent cultivations. Leather, however, is of the opinion that the movement of gases in soils even down to the depth of 12 to 15 inches is so efficient that the cultivation of the surface soil is unnecessary for purposes of aeration, and that the well-established value of this agricultural practice must be referred to other causes.

Another factor which influences soil air in India is the rainfall. Rain water filling up the spaces between the soil particles would tend to exclude air. Similarly irrigation also would tend to drive out soil air. But as the water moves downward a new supply of atmospheric air is pulled in, thus facilitating the interchange of air in the soil.

SOIL WATER is another component of soil which affects its physical properties.

Water in the plant functions in three ways. (1) It is itself a form of plant food as some of it ultimately becomes chemically a part of the plant. (2) It maintains the turgidity of the tissues. That is, it helps to keep them in a rigid or inflated condition which is necessary for the proper functioning of the plant. If this condition is not maintained, the plant collapses or wilts. (3) Water acts as a solvent and a carrier of plant food. It not only dissolves the various substances contained by the soil mass and makes them available for the plant but it also acts as a medium of transfer of these food materials from the soil to their proper places in various parts of the plant. Plants, it should be remembered, can only take their food materials in the form of a solute and never in a solid condition.

Three forms of soil water are generally recognized. The first is called *hygroscopic water*, which is the moisture held by an air-dried soil, or, in other words, it is the moisture absorbed by a completely dried soil when exposed to the

atmosphere. This form of soil water is held very tightly to the soil particles, and therefore is not available to the plant. The second form of soil water is usually known as *capillary water*, which is the moisture held in the spaces between the particles of soil over and above the hygroscopic film of moisture, and is held in place (*in situ*) against the force of gravity. This is the form of water which is most useful to crop plants, exclusive of water plants (hydrophytes) such as rice, etc. The third form of soil water is known as *gravitational* or *hydrostatic* water. This is also known as "free" water. It is the form of water in the soil which moves freely in the soil mass under the action of gravity unless it is somehow otherwise restricted in its movement. This form of soil water is usually harmful to certain crop plants (mesophytes) if it remains long in the part of the soil occupied by roots, but is useful only to water plants (hydrophytes).

B. A. Keen of the Rothamsted experiment station, England, and some others have suggested other methods of classification of soil water. In one of these methods of classification the capillary water is further divided into (*a*) pendular, (*b*) funicular and (*c*) capillary water. This classification is based on certain mathematical reasoning which lies outside the scope and purpose of this book.

Plant development depends on a great variety of intricate physical, chemical and biological factors which interact in the soil. On the resultant of all these factors depends its crop-producing power.

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CHAPTER IV

CLASSIFICATION OF CROPS

For purposes of study, crops may be classified in various ways. They may be classified: firstly, according to their botanical relationships; secondly, according to their use; thirdly, according to their cultural methods; fourthly, according to the season in which they grow; and so on.

I. In the botanical classification, crops are classified as follows:

1. Gramineae or grass family:

Wheat, rice, barley, *jowar*, oats, maize, *bajra*, sugarcane, *sawan* or *cheena*, *kodon*, *kakun*, *marua* or *ragi* (finger millet), Job's tears, Napier grass, Guinea grass etc.

2. Leguminosae or pea family:

Gram, peas, *mung*, *urd*, *masur*, *sem*, *tur* and *arhar*, soybean, sann hemp, indigo, lucerne, *guara*, horse gram, groundnuts, *berseem*, *dhaincha*, and various beans.

3. Cruciferae or mustard family:

Cabbage, cauliflower, kohlrabi, turnip, radish, *taramira* or *seoba*, *rai*, *sarson*, *toria*, etc.

4. Cucurbitaceae or gourd family:

Watermelon, cucumber, bitter gourd, *phut*, muskmelon, pumpkin, *kakri*, *chichinda*, *taroi*, *ninua*, etc.

5. Liliaceae or lily family:

Onion, garlic, asparagus, etc.

6. Solanaceae or potato family:
Potato, brinjal, chillies, tomato, tobacco, cape gooseberry, etc.
7. Malvaceae or cotton family:
Cotton, *patsann*, roselle, *bbindi*, etc.
8. Compositae or sunflower family:
Sunflower, artichoke, lettuce, niger, safflower, etc.
9. Euphorbiaceae or milkweed family:
Castor, etc.
10. Convolvulaceae or morning glory family:
Sweet potato, etc.
11. Aroideae or dasheen family:
Arui, *kachalu*, *banda*, etc.
12. Zingiberaceae or ginger family:
Ginger, turmeric, etc.
13. Lineae or flax family:
Linseed, etc.
14. Tiliaceae or jute family:
Jute, etc.
15. Umbelliferae or carrot family:
Carrot, coriander, anise, etc.
16. Onagraceae:
Singhara or water caltrop, etc.

II. In the economic classification all the crops are classified according to their use as follows:

1. Cereals:—This includes wheat, rice, maize, barley, oats, *jowar* and millets.

2. Pulses:—This includes gram, peas, *tur* or *arbar*, *urd*, *mung*, *masur*, cowpea, etc.
3. Oilseeds:—Linseed, niger, castor, groundnut, *toria*, *sarson rai*, *til*, etc.
4. Fibre crops:—Cotton, jute, sann hemp, flax (linseed), etc.
5. Sugar crops:—Sugarcane, beets, etc.
6. Fodder crops:—*Jowar*, *bajra*, maize, Napier grass, Guinea grass, lucerne, clover, etc.
7. Dyes:—Indigo, safflower, etc.
8. Stimulants or drugs:—Tea, coffee, tobacco, poppy, *bhang*, etc.
9. Spices:—Coriander, ginger, turmeric, chillies, anise, cardamom, *supari*, etc.
10. Root crops:—Turnips, carrots, potatoes, beets, yams, sweet potatoes, radishes, etc.
11. Vegetables:—Brinjals, *bhindi*, tomatoes, beans, onions, garlic, cabbage, cauliflower, kohlrabi, lettuce, etc.
12. Pot-herbs or greens (sags):—Spinach, fenugreek, etc.
13. Fruits:—Mango, papaya, orange, guava, jack-fruit, etc.
14. Special purpose crops:—Silage crops (*jowar*, etc.) Soiling crops (*jowar*, *bajra*, etc.) Green manure crops (Sann hemp, *guara*, etc.). Catch crops (*Bajra*, some cucurbits, etc.).

III. In the classification according to cultural methods, crops may be grouped as *irrigated and non-irrigated*. However, there is not a very distinct line of demarcation between the two groups; as some crops may be grown under

irrigation under certain conditions, and by dry-farming under other conditions. For instance, wheat may be grown with or without irrigation. Sugarcane also under humid conditions, such as those existing in Bengal and certain parts of Bihar, is grown without irrigation, but in most other parts of India it is being grown as an irrigated crop. In most parts of northern India, a crop that is grown without irrigation, is known as a "*barani*" crop. Crops may be grouped also according to whether they are "cultivated" or "non-cultivated". Thus crops like potatoes and maize usually require interculture; while barley and wheat are usually considered as crops not requiring any interculture.

Sometimes again, certain crops are grouped together because of the similarity in their cultural treatments. Thus crops like carrots, radishes, turnips, beets, etc., although they belong to different families botanically, they are usually placed in one group which is known as root crops.

IV. The other system of CLASSIFICATION which is most commonly used in India, is BASED ACCORDING TO THE SEASONS in which the crops are grown. Thus crops are classified as *kharif*, *rabi* or *zaid* crops. *Kharif* crops are those which are sown in the beginning of the south-west monsoon, hence they may also be designated as monsoon crops. The *rabi* crops are usually sown in the beginning of the cold weather and may therefore also be designated as cold weather crops. The *zaid* crops are those that are sown in the beginning of the hot weather, and are usually not considered to be as important as either the *kharif* or the *rabi* crops, and may therefore be designated as the inter-season or catch-crops. The following is a list of crops, grouped according to this system of classification. It will be noted that certain crops which require one or two seasons before they reach their maturity, have been placed in one or the other of the three groups.

Kharif crops:—*Jowar*, maize, rice, *bajra*, castor, sesamum, brinjals, chillies, tobacco, sweet potatoes, minor millets, *mung*, *masur*, *arhar* or *tur*, cowpeas, sann hemp, indi-

go, *moth*, *guara*, groundnuts, *sem*, soybeans, jute, *bhindi*, roselle, niger.

Sugarcane and cotton more naturally fall into this group also, although the former requires one year for its growth, and when left as a ratoon crop, more than one year.

Rabi crops:—Wheat, barley, oats, potatoes, peas, gram, *khesari*, linseed, mustards, cabbages, tomatoes, cauliflower, kohlrabi, turnips, onion, garlic, radishes, lettuce, beets, carrots, etc.

Zaid crops:—*Arui*, watermelons, muskmelons, cucumbers, pumpkins, *taroi*, and *ninua*.

V. Crops may also be classified into annuals, biennials or perennials, depending on whether they complete their life cycle in one, two or more than two years. An annual crop is one which grows, matures and dies in the course of one year: whereas a biennial crop requires two years, and a perennial requires more than two years. Wheat is an example of an annual crop. The beet is more often a biennial crop if permitted to grow to its full development. It will not flower in its first year of growth but will do so only in the second year. Lucerne is a good example of a perennial crop as it is usually grown in this country for a period of five to six years, and in some parts of the world, like California, it is grown for a period of twenty to twenty-five years. But twelve years is the most common practice in that region. Sugarcane is normally an annual crop, but sometimes it is grown as a ratoon crop, in which case it becomes a biennial or a perennial crop. Similarly cotton may behave as an annual, biennial or perennial depending upon the type of cotton as well as the climatic conditions under which it is grown.

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CHAPTER V

IMPROVEMENT OF CROPS

Anyone connected with agriculture or working with crops is acquainted with the fact of the existence of numerous varieties of plants. The question at once arises in one's mind as to how these different forms came into existence. The causes or reasons for the beginning of these variations or differences is a question that is perplexing the minds of many scientists. On this question there is rather a considerable difference of opinion. Still it is proposed to explain here, how these variations have been produced.

Two remarkable tendencies, *heredity* and *variation*, are common to all organisms whether plants or animals. The first is a tendency of the offspring to resemble the parents and therefore to resemble one another. This is evidently a conservative tendency, that is, one which tends to reproduce the parental characters in the offspring. Variation, on the other hand, is a tendency for the offspring to be unlike their parents and therefore to be dissimilar to one another. This apparently is a progressive tendency, without which it would be impossible for new types to arise from pre-existing types. New types were probably formed with both of these tendencies in action.

One of the earliest theories which was advanced to explain this variation was expounded by Charles Darwin in his theory of "Natural Selection." According to this theory, plants and animals in nature produce many more progeny than can possibly survive. For instance, a single plant of tobacco produces at least 360,000 seeds in one generation. If all of these seeds produced offspring, in a few years' time the tobacco plants would be more than

sufficient to cover the entire surface of the earth. Some other plants are even more prolific than tobacco. Naturally, this results, on account of this high production of individuals far beyond the earth's facilities to support them, a *struggle for existence*. For instance, there is great competition between different individuals in nature for food, light and water. This competition may extend to different individuals of the same type, to individuals of one type of plants and those of other types, or to individuals of one plant type and certain animals. This struggle leads, according to this theory, to the early death of individual organisms not suited to a given environment. Thus plants such as rice or the water caltrop (*singhara*) are not fitted to grow under dry conditions. Through this struggle for existence there is a natural selection which results in the *survival of the fittest* and the elimination of the unfit. In this way nature itself is instrumental in the production of certain plants which are most fitted to survive. In other words, the struggle for existence may be considered as being itself a cause of individual differences, since any continued pressure from without awakens an adaptive response in the plant or merely selects the individual which happens to vary favourably. But the individuals of a type are not exactly the same, and even the offspring of the same parents possess certain slight differences. To illustrate this point, it may be pointed out that in man also, sons of the same parents are not exactly alike.

This theory has not been universally accepted on account of a number of serious objections, detailed discussion of which lies outside the scope of this book.

Hugo de Vries, the great Dutch botanist, was of the opinion that the principal objection to Darwin's theory of Natural Selection is removed if we give up the idea that species can come into existence by natural selection through small fluctuating variations. He has suggested what is now known as the mutation theory. The principal features of this theory are:

- (1) There arises suddenly from among the individuals of a species one which differs widely in one or more characters from the rest of the group. This process is believed to take place from time to time.
- (2) The new characters of these mutant individuals are inherited, in most cases.
- (3) These mutations arise quite independently of fluctuating (non-heritable) variations.
- (4) Mutation may take place in any direction.
- (5) The mutants differ sufficiently from the rest of the members of the group to make them subject to natural selection.
- (6) Consequently all mutants that are unfit will be eliminated through the process of natural selection.

The students of evolution to-day lay more emphasis upon small rather than large mutations, because, in nature, very wide variation from the old existing types will tend to be eliminated immediately by natural selection, whereas the smaller mutations which are fitted to the environment may slowly accumulate, thus producing at first new varieties and then new sub-species and finally new species.

Plants through variation adapt themselves to selection. In other words, variation is a primary factor in the process of selection for crop improvement. In order to carry out selection properly, one must have an understanding of the different kinds of variations and whether they are heritable or non-heritable. In general, variations are of three kinds: (1) Modifications, (2) Combinations and (3) Mutations. Modifications are variations which are not heritable. These kinds of variation may be brought about in general by external influences due to the environment in which the plants grow. These external influences may be the amount of food supply, soil

moisture, and other climatic factors. This type of variation is not taken into consideration for the fundamental reason that these are not inherited and therefore no useful purpose will be served. Combination of characters is usually produced when plants of two different varieties or species are crossed (*hybridized*). There may be among the offspring certain individuals which are like one parent, certain others which resemble the other parent and still others which on account of a combination of characters are in some ways, unlike either of the parents.

Mutations are sudden, and, sometimes very large, differences which now and then arise among a great number of plants. Such occurrences are rare in nature. The characters arising by mutation are heritable, except in the case of some bud mutations. Mutation is not due to characters but to changes in the nuclear substance. Many of our valuable varieties of ornamental or other economic plants have arisen through mutations. Most of the improvement made in mangoes is due to bud mutation or bud sports. However, these bud sports do not breed true and have to be propagated vegetatively by cutting or grafting.

METHODS USED FOR THE IMPROVEMENT OF CROPS

A. Improvement by selection: (*a*) *Mass Selection*:— This is a method of selecting from a large field a number of plants that conform most nearly to some ideal type. Mass selection, to be of greatest value, must be continued until the limit of improvement is reached. Consequently selection must be carried on for a number of years, and seeds from these selected plants grown every year. This system has been used for cotton, maize, *jowar*, rice and cereals in general.

A modified form of mass selection which is also an improvement on it, known as compartmental selection, consists of dividing the whole field into small plots of say, 10' by 10', and of selecting the best plants from each plot.

This system eliminates the effect of the variability in the fertility of the soil, and therefore is more efficient.

(b) *Pure line selection*:—This consists in the testing of the progeny of single individual plants and is therefore sometimes known as the “progeny row” method of selection. This method is not materially different from mass selection except that fewer individuals are selected and each selected parent plant is tested separately. The most important point in pure line selection is the isolation or picking out of the best single strain. This system was followed at the Swedish seed station at Svalof where it is known as the “Pedigree System.” This system may be conveniently adopted for plants which are naturally self-fertilized, for example, wheat. If the system is used for naturally cross-fertilized plants, care should be taken that crossing does not take place. In order to prevent crossing the heads or flowers should be covered before they open.

(c) *Clonal selection*:—This is a modified method of pure line selection which is applied to a pure line produced asexually. Improvement by this method is obtained by isolation or selection of the best clon (sometimes written clone). This method has been used in the improvement of such crops as sugarcane, sweet potatoes, pine-apples and cassava.

Bud selection is a form of clonal selection. This method is applied largely to selection in the improvement of fruits, such as oranges and mangoes.

B. Improvement by Introduction and Acclimatization:—This method consists in the introduction of new varieties of crop plants from other parts of the world, and of testing them under local conditions for a period of years. If the variety proves to be promising, further selection may be made.

C. Improvement by hybridization:—Improved varieties may be produced by hybridization. This is a slower process than selection and requires a more technical knowledge of the genetic principles involved in the process. Untrained men should not attempt to produce improved

varieties of crops by this method. The Royal Commission on Agriculture in India made the following remark in this connection:

“Hybridization is a much slower process than selection and requires greater scientific experience and a higher level of scientific aptitude. We are, however, of opinion that the plant breeder in India will be well advised to adhere to the selection method until its possibilities [...] have been much more nearly exhausted than is at present the case and that hybridization should only be undertaken by officers, who, in addition to special training, have had the experience of Indian crops and conditions which is necessary for successful work.”

However, one should not get the impression that selection is an easy process and that it does not require technical knowledge. In order that one may be a successful plant breeder, he should not only be well versed in genetic principles, but he should also be a keen observer so that plants of the most desirable characters only will be selected.

One of the *pre-requisites of a good hybridizer* is a knowledge of sex in crop plants. There are certain types of plants in which the male and female organs are located in the same flower (hermaphrodite or perfect flower), as for example, the flowers of cotton, wheat and peas. There are certain others in which the male and female parts occur in different flowers on the same plant (monoecious). Examples of this type are maize, cucumber, pumpkin and gourd. There are still others in which the sex organs occur in different flowers located on different plants (dioecious). For instance, the male flowers of papaya usually occur in one plant and the female ones in another. Dates also have the flowers of different sexes in different plants. It is interesting to note that this fact was known to Assyrians and Babylonians thousands of years ago. It is probable that the crossing of flowers and the selection of improved varieties was known in ancient times. In more recent times, Rudolph and Camerer in the seventeenth

century, proved the existence of sex in higher plants. Kolreuter in 1760 crossed two species of tobacco, and obtained the first plant hybrid on record. Wiegmann carried on experiments on the general *Pisum Vicia* and *Ervum* and was successful in producing hybrids. He then pointed out the phenomenon of dominance in hybrids. But it was not until 1900 that modern genetics began to develop when Hugo de Vries, Correns and Tschermak working independently on the same kind of experiments and while in search of literature on the subject came across Mendel's paper which was published in 1866. These workers revealed Mendel's work to the scientific world. The results are now universally known as *Mendel's Laws of Inheritance*. This work is now known all over the world and the principles are made use of in hybridization.

Gregor Mendel was an Austrian monk. He conducted a large number of experiments on the hybridization of garden peas. His experiment relating to the inheritance of tallness and dwarfness in garden peas is probably the most useful for the discussion of his theories. Mendel took tall plants (6 to 7 feet tall) and dwarf plants ($\frac{3}{4}$ to $1\frac{1}{2}$ feet tall) as the parents and crossed them. He observed that from the seeds obtained from this first cross, that is, of the first generation, commonly designated as F_1 , the plants were all tall. The dwarfed character of one of the parents used in crossing had apparently disappeared. The character of tallness expressed in these plants (hybrids) Mendel called *dominant*; and the character which became hidden from view he called *recessive*. Mendel grew plants from the seeds of this F_1 generation which were previously self-fertilized and observed that the plants of the second generation (F_2) were composed of two classes, one group of tall (dominant) plants and the other of dwarf (recessive) plants. The number of individuals in each class were in the ratio of three tall and one dwarf. In order to determine whether these plants were pure like their parents or whether they were hybrids, Mendel grew them for another generation and obtained offsprings (F_3) which showed that

the dominants of the F_2 generation separated into two classes, one class breeding true for the dominant character; and the other class producing both dominants and recessives in the same ratio as in the F_2 generation, that is, three dominants to one recessive. Mendel further observed that the ratio of these two classes of dominants in the F_2 generation is one pure dominant and two hybrid dominants. He thus finally observed that the F_2 progeny ratio of three dominants to one recessive is resolved into the ratio of one pure dominant: two hybrid dominants: one pure recessive. All of the characters with which Mendel worked conformed to this formula which operates as one law, in all his experiments.

Many improvements in agricultural crops have been made, some of which have been attributed solely to effects of cultivation. Methods of cultivation as such have not been of any importance in the production of improved varieties, although they may influence the yield of the crop. On the other hand the science of genetics has shown that new varieties are the results of hybridization or, of an inherent change, such as mutation. Selection from these variations has resulted in the creation of a large number of cultivated varieties some of which breed true, and in practice, are reproduced by sexual (seeds) or asexual (plant parts) means, (such as stems of sugarcane, etc.).

Much improvement has been made since the beginning of this century, in the breeding of agricultural crops for special purposes. Much breeding work with agricultural crops has been done recently in order to combine such characters as (1) size of plants, (2) yield, (3) resistance to drought, (4) immunity to disease, (5) length of cotton fibre, (6) resistance to cold or frost, (7) chemical composition, such as oil content, (8) flavour, (9) colour, (10) strength of stem and (11) earliness.

Even as early as 1799 Knight in England, through hybridization, was able to combine the sweet flavour found in certain peas with other desirable seed characters, and produced certain varieties which were known in the Lon-

don market as Knight's Superb, British Queen, etc.

More recently (1933) Hackbarth and others with him working with tomatoes, found by crossing the small fruited *Lycopersicum racemigerum* which ripens early, with *Lycopersicum esculentum*, were able to produce a certain number of early-maturing plants, some of which bear good-sized fruits.

The most outstanding work in the hybridization of crop plants is, however, in connection with wheat. Marquis wheat, one of the most outstanding bread wheats of Canada and the United States of America was the result of crossing Red Fife (male) and an early ripening Indian wheat commercially known as Hard Red Calcutta (female). The cross was made in 1892, but the particular selection, later to be known as Marquis, was made by the cerealist of the Dominion of Canada, Dr. C. E. Saunders, in 1904. This selection was particularly suitable for areas that are seriously subject to frost. In yield also it was found that Marquis exceeded Red Fife, the standard variety of that region up to that time, by about 35 to 40 per cent. The seed of this variety was distributed to the public in 1909. And up till very recent years this was the standard variety of wheat in Canada as well as in the United States of America.

In India considerable hybridization work has been done in connection with the wheat crop. Pusa 4 and Pusa 6 wheats had been selected for high yield. But these two varieties were awnless and therefore were more susceptible to damage by birds. This was a serious defect from the farmers' viewpoint. Hence, in order to produce a high-yielding strain which also possesses awns, a search was made for suitable material. Punjab 9, a bearded type, was selected as the material for crossing with Pusa 6, a high-yielding, and rust-resistant variety. As a result of this cross Pusa 32 was developed. This new variety possesses the desired combination of characters of being bearded, rust-resistant and high-yielding.

The improvement of the linseed crop in India has been

done mainly by the method of selection. The high quantity of oil present in the seed is the character on which much of the value of linseed depends. It was found that the Indian linseed crop is mainly composed of two types which are respectively called the "Peninsular" and the "Alluvium" types. In order to produce a strain possessing the above desirable character, a search is being made among these two types so that certain desirable characters of these types may be combined. Up to the present two high-yielding types, Type No. 12, white-flowered, and Type No. 121, purple-flowered, which exceed the local varieties in yield by 40 to 50 per cent, have been selected. The oil content of Type No. 12 varies from 37.96 to 39.39 per cent; whereas that of Type No. 121 varies from 41.07 to 42.65 per cent. The latter type is also said to possess a high degree of resistance to linseed wilt.

The work for the improvement of the sugarcane crop in India really began in 1912 with the opening of the cane-breeding station at Coimbatore, with Dr. Barber in charge of the work. He introduced the wild species, *Saccharum spontaneum*, into the parentage of cross-bred canes. The type Co. 205 is the product of the direct cross between a wild species and a Noble cane, a thick type generally grown in northern India. This variety is one of the popular canes of the Coimbatore series. Among other popular improved types are Co. 214, Co. 210, Co. 213, Co. 285, Co. 290, Co. 313 and Co. 357. The success of the work in the improvement of the sugarcane crop may be evaluated according to the Indian Tariff Board Report, 1931, where it is mentioned that 877,000 acres are planted with Coimbatore seedling canes. The main sugar tract, the United Provinces and Bihar, has a total sugarcane acreage of 1,644,000 acres, out of which 700,000 acres are planted to Coimbatore seedling canes. Coimbatore canes are now not confined only to India, but have spread to many of the sugarcane-growing countries throughout the world.

More recently the workers at Coimbatore have succeeded in hybridizing sugarcane and sorghum (*jowar*). In

this way they were able to shorten the period of growth, and thereby can grow some other quick-maturing crops in the same field the same year. This production of sugarcane-sorghum crosses is undoubtedly a great achievement. However, its practical possibilities are yet to be determined.

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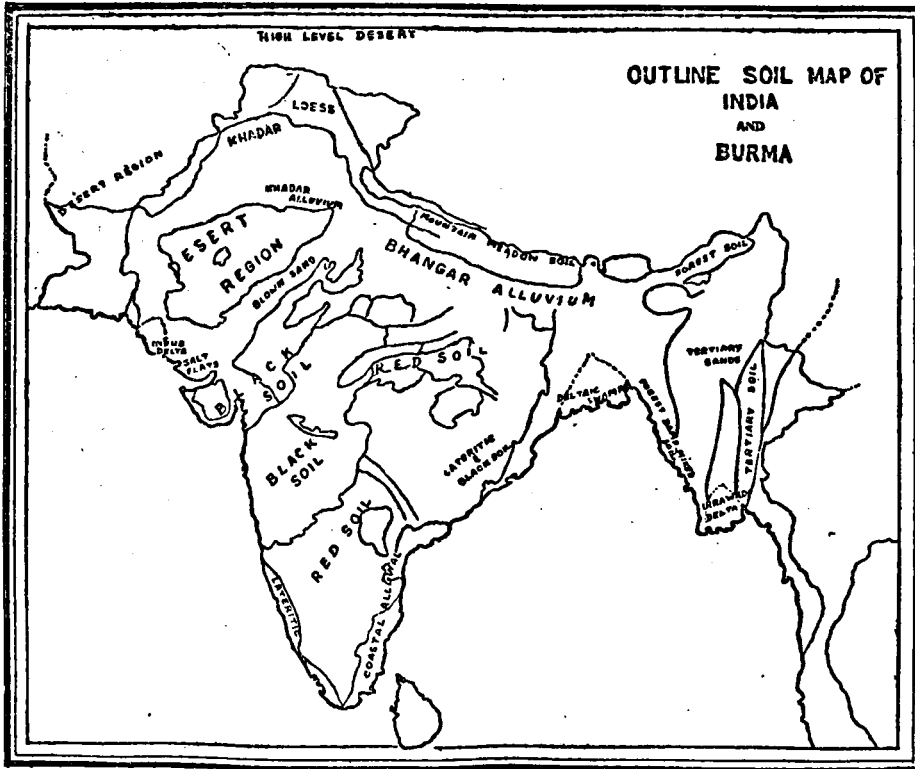
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CHAPTER VI

THE SOILS OF INDIA

The character of the agriculture of a country is dependent to a large extent on the nature and properties of its soils and its climate. The nature and character of soils is again greatly dependent upon the climate of the region in which the soil occurs. Because of this fact soils of this country which extends from the temperate regions through the subtropical and into the torrid zone therefore vary considerably. The development of the scientific study of soils has taken place almost entirely in the temperate regions. But in recent years the study has been extended to the tropical and subtropical soils. Hilgard, Ramann and Glinka were among the first to point out that the climatic agencies of the locality in which the soil occurs and the parent rock, are jointly responsible for the formation and distribution of different types of soils. Mohr and Pendleton working in the Dutch East Indies and China, in recent years, have also expressed a similar opinion, regarding the importance of climate in soil formation.

While the same climatic agencies are at work in both temperate and tropical regions, yet there is a material difference in the effects of weathering in the two regions. This difference is due mostly to the degrees of intensity of climatic action, as well as to the length of duration of the action of climatic factors, since there is, in the tropics, no winter to interfere with these intense soil-forming processes. Vageler claims that since the temperature is 10° to 20° C. higher in the tropics than in temperate regions, all chemical reactions proceed at from twice to four times the speed usually taking place in temperate climates. He further claims that the changes effected by rainfall are in



some cases, 20 to 30 times greater in the humid tropics, than in the temperate zones.

Another influence of climate on the soil is shown clearly by the humus colouration which is lacking in many tropical soils. But, to conclude that the humus content of tropical soils is low is incorrect as the presence of iron and sometimes of manganese compounds may mask the colour due to humus. The larger portion of the humic substance in the tropical regions is usually colourless or only faintly coloured and usually blackens easily when exposed to air. It is easily decomposed and therefore the water-soluble constituents of the decomposing plant materials are quickly absorbed in the soil. When the original plant material is low in calcium, the soil formed in the presence of the humus from such material is more often clayey or of a clayey and loamy texture. The loams are usually bleached and usually become light yellow in colour. This mistaken idea that humus is practically absent from tropical soils has led some people to believe that clean cultivation cannot destroy the humus. However, the humus content in tropical regions is not always high and the soil could therefore be considerably improved by the addition of organic matter, as has been shown by numerous experiments in the Dutch East Indies as well as in this country.

The researches of Mohr have shown that the soil colloids are formed continuously and more rapidly in the tropical regions, as residues of decomposition or by actual synthesis; and that these release large quantities of plant food which are further increased by tillage. This is an important factor to consider in the evaluation of tropical soils. That is, farming operations affect the decomposition of soil materials to a very marked degree in tropical soils as compared with soils of temperate regions.

Natural vegetation is another very important factor influencing the nature and properties of soils, due to the fact that the nature of the humus is dependent upon the character of the plants from which it is derived. For

example, the peat soils of the temperate zone known as the Sphagnum peats are very different in composition from those found in the tropics. These peaty soils are more common in the tropics than they are usually supposed to be. These peaty soils in India are exemplified by the forest peats in humid regions like Travancore in the south-west, and Assam in the north-east of India and by the peaty soils of swamps and *jhils* or by the peaty layers of soil which occur as intercalations in the loams or silts of the river deltas.

Mohr, as a result of his researches in the Dutch East Indies, divided the soil into three groups based more or less on the influence of the climatic factors on the soils, especially the influence of rainfall and evaporation.

The first group comprises of soils in regions where rainfall exceeds evaporation throughout the year, that is, in humid regions. In the soils of these regions percolation is very active and results in the dissolution of soluble mineral and organic materials leached into rivers and ultimately into the sea, leaving the soil in an impoverished condition unless fertilizing constituents are again supplied from other sources.

The second group comprises the soils in regions where evaporation exceeds rainfall throughout the year. This condition is found in arid regions. In the soils of these regions the water which falls in the form of rain is not sufficient to percolate downwards to any great depth and after a time returns upward and is lost by evaporation. The solution passing upwards contains many dissolved mineral substances, which on evaporation are left on the surface of the soil. This process therefore enriches the surface soil, but if the deposition of salts on the surface soil is very great, the soil becomes unproductive and such soils are called *usar* in India. It may be of interest to note that some of the great agricultural civilizations of the past were developed in regions in which *usar* has since developed.

The third group comprises soils in regions where there is an alternation of wet and dry seasons. In such

regions the rainfall is usually slight compared with the torrid zone and the temperature is also low, so that there is very little downward and upward movement of soil materials.

According to this classification the soils of India would fall into all the three groups. The soils of Travancore, Assam, some portions of the Western Ghats, Bengal, Bihar and the southern slopes of the Himalayas including the *terai* soils, fall under the first group.

The second group of soils will be found in Rajputana, Sind, Kathiawar, the western Punjab and some parts of the United Provinces, especially the districts of Meerut and Aligarh.

The third group of soils would perhaps be represented in India by soils of the eastern Punjab, the south-eastern United Provinces, Madras, Bombay, the Central Provinces and Central India, in which there is more or less a balance between the upward and downward movements of soil materials. The placing of the above soils in these groups is somewhat difficult, as there is no definite line of demarcation and as they gradually merge from one group into another. Most soils in temperate regions fall into the third group.

With the above preliminary and general introduction, the soils found in different parts of India will now be discussed. There is a great lack of detailed information regarding the soils of India and therefore only a very general survey can be given.

The soils of India have been investigated to some extent by the geological survey of India. J.W. Leather and more recently D.N. Wadia and others have made further notable contributions towards our knowledge of the soil types of India. As a result of their work four main soil types have been recognized in India. These four types are: (1) The Indo-Gangetic alluvium including that brought down by the Brahmaputra, (2) the *regur* or "black cotton soils" which overlie the Deccan trap, (3) the red soils derived from the rock of the Archaean system and commonly found in

Madras and Mysore and (4) the laterite soils which form a belt around the peninsula extending through East Bengal into Assam.

THE ALLUVIAL SOILS

This type of soil is by far the most extensive and agriculturally the most important of all the soil groups in India. This soil is usually referred to as the Indo-Gangetic alluvium as the greatest portion of this soil is found in that region. But these alluvial soils are also found in the Brahmaputra valley, the Surma valley in the south of Assam, and in the valleys of the Godavari, Kistna and the Cauvery. These soils cover an area of about 300,000 square miles. They are found in the greater part of Sind, the northern part of Rajputana, the greater part of the Punjab, the United Provinces, Bihar and Bengal, and about half of Assam. These soils are derived mainly from the Himalayas having been brought down by the three great river systems of northern India, the Indus, the Ganges and the Brahmaputra. These rivers bring down the soil materials and deposit them in the plains below. The maximum thickness of these deposits has not been found out, but some borings indicate that the depth exceeds 3,000 feet. The soils of this group differ according to their local origin and vary in texture and physical consistency from sand through loams and fine silts to stiff heavy clays that entirely prevent drainage, sometimes resulting in the accumulation of injurious salts, producing a sterile condition commonly known as *usar*. The accumulated salts are largely those of sodium and magnesium.

Chemical analyses of these soils show that in general they are low in nitrogen and organic matter, that the amount of potash is adequate, and that phosphoric acid though adequate, is usually less than in other Indian soils. The lime content of these soils shows a great variation. For example, in the Tirhut district of Bihar, the soil often contains over thirty per cent of carbonate of lime, whereas the soils of the adjoining districts are completely lacking

in lime. However, the amount present may be generally considered sufficient. The Indo-Gangetic plain represents the drainage of the southern slope of the Himalayas, whereas the Brahmaputra valley represents the drainage of the northern slope. The Brahmaputra represents a region of very heavy rainfall, and southern Assam a region of highest rainfall known. Consequently the soils brought down by the Brahmaputra are to a large extent leached of their soluble salts. A comparison of the chemical composition of the alluvial soils of these two regions indicates that the soils of the Brahmaputra contain an extremely low percentage of lime; .08 per cent is a general average as against 1 per cent for the Indo-Gangetic soils. In the latter soils potash ranges between .65 and .70 per cent while the Brahmaputra soils in Assam contain from .25 to .35 per cent. Magnesia averages about 1.30 per cent against .50 per cent in the Indo-Gangetic and Brahmaputra soils respectively. These figures indicate considerable leaching in the Brahmaputra soils, as the result of rainfall.

Another important characteristic of the Indo-Gangetic alluvium is the formation of nodular calcareous material known as *kankar*. This material is formed at a depth of a few feet below the surface of the soil, sometimes forming an impervious layer of what is known as "hard pan". Such layers occur very generally in the United Provinces and also in Bengal and parts of the Punjab.

These alluvial soils of the Indo-Gangetic plain are also characterized by ease of cultivation and rapid response to irrigation and manuring. Generally speaking, there are few soils in the world which are more suited to intensive cultivation of crops, so long as the water supply is adequate.

In the Punjab, the Indo-Gangetic alluvium extends westwards as far as Lahore. From Lahore westwards for some distance, the Indo-Gangetic alluvium is overlaid by wind-borne soil (*loess*). Beyond this loess area the Indo-Gangetic alluvium again occurs. The Indo-Gangetic

alluvium as far as Lahore, is within the influence of the south-west monsoon and is benefited by it, whereas the area west of Lahore is not subject to a regular and systematic rainfall in the monsoon season, although there is a general increase in the amount of rain from Sind towards Lahore where the annual rainfall is about 15 inches. The rainfall continues increasing eastward, amounting to about 25 inches in the eastern Punjab and to about 70 inches in Bengal. The region west of Lahore presents physical characteristics differing in many ways from those of the Indo-Gangetic alluvium to the east. In the western tracts the climate is hot and dry, whereas, as one travels eastward the climate is characterized by a greater amount of rain and humidity during the monsoon. Thus the entire area of the Indo-Gangetic alluvium may be divided into four fairly distinct regions on the basis of rainfall, the first extending from Lahore to Delhi with an annual rainfall varying approximately from 15 to 25 inches, the second area extending from Delhi to the eastern border of the United Provinces with an annual rainfall varying from about 25 to 40 inches, the third extending from the eastern border of the United Provinces to the east of Bihar with a rainfall of 40 to 55 inches and the fourth area extending from Bihar to the Bay of Bengal where the annual rainfall varies from about 55 to 70 inches, and where the humidity is also very high almost throughout the year.

The types of alluvial soils that are most predominant in the PUNJAB AREA are the loams and sandy loams interspersed with patches of clay especially in the western portions of the Lahore district. In Jullundur, loams, sandy loams with patches of clay predominate. In these soils are also found patches of kankar. In the southern portion of this area, comprising of the districts of Ferozepore and Hissar and Patiala State, loams with patches of clay are fairly common with the sandy loams predominating. The outstanding characteristic of the soils of these districts is the shifting sand dunes. The soils in the eastern portion of the Punjab comprising the districts of Ambala, Karnal

and Rohtak are very variable in character, ranging from fertile loams to heavy clays.

Results of experiments conducted in the Punjab have shown that the alluvial soils of this region possess the following chemical characteristics. (1) It has been found that these soils are capable of fixing nitrogen very rapidly. (2) The nitrogen content of the Punjab soils varies from 0.025 per cent. to 0.100 per cent. This when compared with the nitrogen content of European and North American soils, indicates that the Punjab soils are poor in nitrogen. (3) It has been found that in general the Punjab soils are not deficient in potash, the average of the analyses made, being 0.72 per cent. (4) The phosphoric acid content of the Punjab soils has been found to vary on the average from 0.1 to 0.3 per cent. These figures show that in general the alluvial soils of the Punjab may be considered to contain a sufficient amount of phosphorus. (5) The lime content of the Punjab soils is very variable, but there appears to be a tendency for the lime content to increase from the Himalayas to the south-west. (6) The alluvial soils of the Punjab are on the whole deficient in organic matter, most of them containing on an average from 2 to 4 per cent. of organic matter.

In the UNITED PROVINCES AREA, approximately 53,776 square miles are included in the Indo-Gangetic alluvium. The soils of this area, while appearing to be uniform, really vary considerably from drifted and blown sand through loams, and silts to very heavy clays.

These soils have been brought down mainly from the Himalayas, and the many physical differences that are found in these soils depend mostly on the sorting action of water, the deposits varying largely with the velocity of the water.

Chemically, these soils have been found to contain sufficient quantities of lime, potash and phosphoric acid, but the amount of nitrogen when compared with the soils of western countries is low. But it would appear from various experiments conducted in this country that these

soils can renew their supply of nitrogen much more rapidly than those of the colder European countries.

In general the alluvial soils of this area will be found to have a tendency to become progressively heavier as one proceeds from the north-west to the south-east portion of the area. This is probably due to the fact that the rivers deposit heavier materials first and lighter materials farther down when the velocity of the water is decreased, or it may be due to the fact that the amount of rainfall in the eastern regions is greater than in the west of this area.

The soils of this area sometimes contain sub-soil layers of nodular limestones or kankar at a depth of a few feet from the surface.

In the north-west area where the conditions are semi-arid, patches of alkali soils frequently occur, especially in the districts of Meerut, Aligarh, Muttra, Agra and Partabgarh.

The alluvial soils of this area are of considerable depth. Borings made at Lucknow to a depth of 1,336 feet indicate the great thickness of these alluvial deposits.

On the whole, these soils possess a loose subsoil, usually made up of different layers of soil material of varying texture.

In the BIHAR AREA, most of the Indo-Gangetic alluvium lies on the northern side of the Ganges where the land slopes gradually from the Himalayas towards the south where a belt of fairly high land occurs, which is being continually built up by the flooding of the Ganges. Between these two extremes the general elevation is lower and consequently considerable areas are liable to damage by floods. The soil consists mainly of the older alluvium known as *bhangar*, a yellowish clay with frequent deposits of kankar. This type of soil extends up into the north-east corner of the United Provinces. But in many parts the soil of this area has been cut away by the torrents that rush down from the Himalayas through the lowlands which these rivers have had to pass before they join the

Ganges, and in its place more recent deposits of sand and silt have been laid down, which were brought down by them when in flood.

In general the alluvial soil of this tract contains a sufficient amount of lime and potash, but is somewhat lacking in phosphoric acid, and quite low in the amount of nitrogen and organic matter.

In the BENGAL AREA the Brahmaputra joins the Ganges, and consequently the alluvial soils brought down by these two rivers are found. Here the amount of rainfall is greater than in the "Bihar area". Therefore the character of the soils is greatly influenced by the climatic factors prevailing in this area, and also by the fact that the rivers have become somewhat sluggish. The finer material that is deposited all over Bengal consists of fine silt along the banks, and clay a little distance from the banks of the rivers. The soil of this area may be classed as either old alluvium or new alluvium, the former being found for the most part to the west and the latter to the east of a line running north and south approximately a little to the west of Calcutta and Darjeeling. The recent alluvium is periodically fertilized by fresh deposits of silt from the overflowing rivers. Usually at the deltas the soils are found in layers with peat and other organic matter.

The topography of the new and the old alluviums are somewhat different in that the latter is in the process of being denuded while the former is in the process of formation or building up. The surface of the new alluvium is therefore more or less a level plain, whereas that of the older alluvium has become undulating due to the scouring action of the rivers. Recent alluvial deposits with the exception of strips of high lands along the banks of the rivers, make the whole country low and swampy.

This alluvium extends eastward into the Brahmaputra and Surma Valleys in Assam. The Brahmaputra, flowing with a steeper gradient through regions of high rainfall possesses a greater velocity, and consequently only larger materials are deposited. As a result, the soils of

the Brahmaputra valley in Assam are largely sands and sandy loams. On the other hand the Surma river and its tributaries are very sluggish streams because they flow almost on a level plane. As a result finer materials are deposited along their banks. This tends to make the soils of the Surma valley consist largely of heavier types of soil like silt and clay. The clayey or colloidal character of the soil in the Surma valley is further increased by the larger amount of rainfall which occurs in this region.

Closely related to the type of soil of the Indo-Gangetic alluvium are the DESERT DEPOSITS OF ARID REGION lying between the Indus valley proper in the west and the Aravalli hills in Rajputana to the east, and from the coast in Sind to Delhi, Lahore and the north-west area of the Punjab. The greater portion of this area consists of soils which were brought down from the Himalayas by rivers some of which are now extinct, like the Saraswati which is believed by some geologists to be the river flowing in the bed now occupied by the Ghakar and an extension of it through Rajputana to the sea near the mouth of the Indus.

This section is now covered by wind-blown sand from the western coast, and consequently the whole region is sandy and unproductive, although there are certain patches marked by present towns where underground or canal water is available, thus enabling a certain amount of cultivation to be carried on. The soil in this area, however, improves gradually from the coastal regions towards Delhi. Most of this area is occupied by the so-called Thar or Great Indian Desert, which occupies an area of about 40,000 square miles. Shifting sand dunes is the outstanding characteristic of the soil of this entire region. This is also the soil characteristic with more or less variation, of the whole north and north-west Rajputana and parts of the southern Punjab, although certain parts have better soils than others. The sandy wastes shade off into loam soil in the direction of the Luni river flowing in the eastern part of the area to the Rann of Cutch. A greater part of

this area, although lying in the track of the south-west monsoon winds from the Sind and Kathiawar coast, does not receive rain. A greater portion of the rain that falls in this area, especially in the south-western portion of it, comes from cyclonic downpours from storms which have travelled westward from the head of the Bay. Some of the soils are impregnated with alkali salts which are believed to have been blown in from the coast of the Arabian Sea.

In SIND the outstanding soil type is plastic clay which is a deltaic alluvium that has been brought down and deposited by the Indus river. Where water is available this soil becomes very productive.

The only figures available giving the chemical composition of the soils of these regions, are for soils near the Indus river in the district of Dera Ghazi Khan. These figures indicate that these soils contain a sufficient amount of potash, a fairly high percentage of lime, a greater amount of phosphoric acid than is generally found in the soils of other parts of the Indo-Gangetic alluvium, but less nitrogen, and are therefore greatly in need of this fertilizing constituent.

In addition to those areas mentioned above in which alluvial soils are found, may also be mentioned the soils found in THE SUBMONTANE REGIONS at the base of the Himalaya mountains. These soils are also of alluvial origin. But they are usually gravelly and more sandy in texture than those found in the plains. They are therefore more porous and well drained, and are usually characterized by the presence of fairly large pebbles deposited by streams which came down from the Himalayas. They thus form a continuous belt along the Himalaya mountains. These soils are usually known as *bhabar* or "alluvial fan" deposits. Below this belt of soil and mostly confined to the United Provinces, Bihar and Bengal, there is a belt of low marshy land where the soil is of a heavy texture, and therefore poorly drained, which is known as *terai* or bog soil. The regions in which these soils occur usually possess a high rainfall and also a comparatively

high humidity which favour these marshy conditions. The texture of the soil in this region usually ranges from clay loam to heavy clay. A great portion of these areas where the soil is not too swampy is covered with dense forests such as in the Pilibhit, Bahraich and Gorakhpur districts of the United Provinces, and in north Bihar.

Another type of soil found alongside of the Indo-Gangetic alluvium is that known as loess or WIND-LAID SOIL. This is a type of soil found in the northern Punjab. In character it is similar to the loess soil found over a very large part of the valley of the Hwangho in China, in the central part of the United States and also in the valley of the Rhine in Germany and in northern France and Belgium. This is a fine silty soil and is usually of a yellowish colour.

THE BLACK COTTON SOIL.

The second important soil group of India is that known as the *regur* or "black cotton soil", which covers an area of about 200,000 square miles. It covers a large portion of the Bombay Deccan, the Malwa plateau, the greater portion of the Central Provinces, Berar and parts of Hyderabad, Gujerat and Kathiawar. It is also found scattered in patches as far south as the Tinnevely district of the Madras Presidency. Similarly such patches of this soil occur in Rajputana to the east of the Aravalli hills and northward as far as the States of Bundi and Tonk. In the east they are bounded by the Bundelkhand region. This soil is especially adapted to the growing of cotton, hence the name of black cotton soil given to it.

This soil varies greatly in colour, consistency and fertility, but possesses the constant character of being highly argillaceous (clayey) and somewhat calcareous. It has also a tendency to become very adhesive when wet, and to develop deep cracks when dry. Some of these cracks have been found to be four to eight inches or even more in width, and may penetrate several yards into the soil. Considerable quantities of soil material fall into the cracks

on account of the action of wind and water, which leads to the mixing and slow circulation of the soil by the swelling and contracting of the colloidal masses when wet and dry respectively. This process is mainly responsible for the characteristic of the soil of having no change in colour to the depth of six to ten feet. The high degree of fertility of the black cotton soil is well known. Some of these soils are said to have been under cultivation with practically no manuring for a period of about 2,000 years and are still fairly productive, although some especially those in the higher regions, are rather poor.

These soils contain a large quantity of calcium and magnesium carbonates, and are fairly rich in iron, lime and alumina; but their nitrogen content is very low, which makes it difficult to explain their fertility. The potash content is very variable, with a maximum of 1.14 per cent, but on the whole the average is fair. The soils are also lacking in phosphorus and organic matter.

As to the origin of the black cotton soils of India, it is generally believed that they are soils formed in place (*in situ*), that is, they are residual soils, which have been formed by the weathering of the "trap" material, which consists largely of basaltic rocks brought up through fissures due to volcanic eruptions of a previous geological age. While on the whole this theory appears to be the most probable, it cannot be generally applied to such soils as are found in Gujrat and Kathiawar, where these soils are probably of estuarine or marine origin or they might have been brought down by rivers flowing through the higher black soil areas. In some cases these soils might have been formed by lagoons or back waters near the sea, as Blanford has pointed out in connection with the formation of the black soil found in Trichinopoly and Pondicherry. In the latter place regur was noticed to be in process of formation in a nearly dry lagoon separated from the sea by a sand pit.

The black colour of these soils was formerly attributed to the presence of accumulated humus. But Annett assigns their black colour to the presence of titaniferous

magnetite and of one to two per cent of humus. Leathers also attributes the black colour to some mineral substance rather than to humus. Harrison and Ramaswami Sivan claim that the colour of the black soil is probably due to a colloidal hydrated double iron and aluminium silicate which possesses the properties of ordinary clay, as well as to the presence of some organic compound of iron and aluminium.

Black cotton soil is the predominating type in the Central Provinces. The whole province may be divided into four soil areas. The first is the Narbada valley and the open and level portions of the plateau of the Vindhya and Satpura Ranges. The second is found as a shallow black soil in a thin sheet over the surface of the basaltic rock from which it has been derived. The area which comprises this type of soil includes Nimar, Wardha, West Nagpur and the regions south of Chhindwara. The third is mainly sandy, or gravelly soil with stony uplands of the Vindhya and Satpura ranges and the hilly country to the south of these ranges. The fourth is a yellowish sandy soil derived from metamorphic or crystalline rock, and is found in the basins of the Wainganga and Mahanadi rivers including the south of Balaghat, Bhandara and Chanda and the three Chhattisgarh districts. Of these four areas, the first two contain different types of black cotton soil. The former, that is, the soil found in the Narbada valley and in the level spaces of the Vindhya and Satpura plateau, is of considerable depth. It is believed to be alluvial (formed by the deposits of decayed vegetable matter through the agency of rivers and streams), or the result of the weathering of "trappean" or volcanic rocks, or of both agencies. The type of black soil found in Nimar, Wardha, West Nagpur and south Chhindwara is on the whole a residual type, that is, one derived from the rock underneath it. The soils of the other two areas in the province are strictly not black cotton soils, and therefore form a class by themselves. They are generally poor soils but respond readily to the application of manure and water.

In Berar, the central valley possesses a better soil than any in the Central Provinces as it is deep, rich, and black and an exceedingly fertile loam. This soil is usually of very great depth with a thick underlying stratum of yellow clay and lime. In the vicinity of the hills, however, the soil is light and shallow, and consists mostly of *murum*, and is on the whole a poor soil.

In Hyderabad the soil area may be roughly divided into the western and eastern portions. In the former the soil is mostly black cotton soil, while in the eastern area the soil shades off into the red soils of Madras. However, patches of one may be found interspersed in the other.

In the Bombay Presidency the black cotton soil is confined mostly to the Deccan area. It covers the regions around Khandesh, Nasik, Ahmadnagar, Sholapur, Bijapur and Dharwar. Beyond Dharwar, to the south, lateritic soils are found which will be discussed later. In the Broach and Surat districts of Gujrat an alluvial type of black cotton soil predominates. In addition to the black cotton soil there are also sandy soils of alluvial origin which occur mostly in the Ahmedabad district, and these shade off into the rich loams of Kaira.

In Central India we find a greater variety of soils, although the black cotton soil predominates, especially in the Malwa plateau. To the north of the Malwa plateau, in northern Gwalior, the black cotton soil gradually shades into poor soils more or less reddish, or at least lighter in colour than the typical black cotton soil. The soils in the Bundelkhand region are also poorer in texture than those of the Malwa plateau, and are somewhat reddish in colour. In the Nimar area of Central India south of the Malwa plateau, there is a preponderance of lighter soils compared to those of the Malwa plateau.

The northern limits of the black cotton soil are the States of Bundi and Tonk in Rajputana.

THE RED SOILS

The red soils form another important group of soils in India. These are commonly found in the Madras Presidency, Orissa, the Garo and Khasi Hills in Assam, Eastern Bundelkhand, in the United Provinces, and to some extent to the south-east of the Aravalli hills in Rajputana. They are derived from ancient crystalline and metamorphic rocks which consist mostly of granites, gneisses and schists, with subordinate rocks rich in ferro-magnesian minerals. They are believed to be of sedentary formation. In comparison with the black cotton soils, these are found to be poorer in lime, potash and ferric oxide, and are also low in phosphorus content. However, they are very variable in character, and cannot therefore be easily classified either chemically or according to their physical characters. Although practically all of them possess the red tint, many of the so-called "red soils" of Madras have no red colour.

The term is used in a very vague sense, apparently to distinguish such soils as are not black. Consequently some alluvial soils are probably also included in this group. Some red soils, however, are laterites or lateritic soils and are of quite a different nature from the other red soils. The predominating form of red soil is a sandy clay, coloured red by iron peroxide.

In Madras these red soils cover the part of the Deccan plateau not occupied by black soils as above mentioned, and central and southern Madras as far south as Trichinopoly. The typical red soils predominate in the district of Chingleput, Salem, Trichinopoly, South Arcot and the upland soils of Vizagapatam and Ganjam. The black soils sometimes occur in patches throughout these areas.

THE LATERITES

Laterites and lateritic soils compose the fourth type of soil which is characteristic of India and the tropical regions. Normally laterites are argillaceous material impreg-

nated with iron peroxide, and are mottled with various tints of brown, red and yellow while a considerable proportion sometimes consists of white clay. They usually harden when exposed to air. Laterites occur in a large number of forms and contain a considerable quantity of hydrates of alumina. There has been a great deal of confusion as to the use of the term laterites, as there is a lack of agreement among soil scientists as to the nature of the rock from which it is derived and the character of the soil associated with this term. The term laterite should be used to denote a soil formed (*in situ*) by the leaching of the bases and much of the silica from the original rock, leaving a residue having certain amounts of alumina uncombined with silica. Laterite soils are more often formed under conditions of high rainfall which helps to remove silica in solution through the process of leaching, leaving behind the hydroxides of alumina. Chemically it is very difficult to indicate the common characters of laterite soils. In general, the best classification of laterite soils is possibly one based on the examination of the complete soil profile and the determination of the amount of hydrated alumina in the soil.

These soils are found on the summits of plateau and hills of the Deccan, Central India, the Central Provinces, the Eastern Ghats, South Canara in the Bombay Presidency, and Malabar, and in certain parts of the hills of Assam.

Agriculturally these soils are found to be poor in plant nutrients. They are low in nitrogen content as well as lime, magnesia and potash. Sometimes the amount of phosphoric acid and humus is high, the phosphorus present being probably in the form of iron phosphates.

While these soils are on the whole poor, they may be improved by tillage and proper manuring.

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CHAPTER VII
SOIL MANAGEMENT
PART I—TILLAGE

From the viewpoint of agriculture, soil is really a medium for crop production. Therefore consideration is given here mainly to such scientific principles as have some bearing on practical soil management. It is hoped that this will help the farmer and practical agriculturist to adopt better systems of soil management which will result in the economic production of crops, and also in passing on to the future generations a soil with a fair degree of fertility.

One of the most common and practical methods which the agriculturist adopts in his management of the soil is what is known as tillage. This operation influences not only the physical condition of the soil but also its chemical and biological condition. One of the practical agriculturists of the eighteenth century in England made the remark that "Tillage is manure". Although this statement may not be literally true, yet it is common knowledge that tillage improves soil. By tillage is meant the working of the soil by the use of certain implements. This term therefore includes such farm operations as ploughing, harrowing, grubbing or cultivating, planking, hoeing, ridging and furrowing.

Some of the main objects of tillage are the following:

- (1) To loosen the soil for the deposition of seeds.
- (2) The destruction of weeds.
- (3) To cover up rubbish, manure and crop residues.

- (4) The loosening of the soil to allow the maximum absorption of water.
- (5) The exposure of the sub-surface soil to air and sunlight for the destruction of disease organisms.
- (6) The destruction of insects by exposing eggs and larvae to birds and climatic elements.

In short, tillage aids in the production of suitable physical, chemical and biological soil conditions. Most farm operations are done with the object of producing the most desirable physical condition in the soil which is known as "good tilth". Such a condition is very essential for the proper germination of seed.

PLOUGHS

Of the different forms of tillage, ploughing is perhaps the most universal and is one of the most indispensable operations on the farm. Although the plough is probably the best granulating agent under favourable soil moisture conditions, it may become very harmful, as it is also the best and most effective puddling agent when the soil is too wet. Consequently this implement should be used with considerable judgment especially in the case of clay soils. The correct stage at which the various types of soil should be ploughed is roughly determined by taking a mass of soil and pressing it in the hand. If the soil retains its form and does not show the presence of free water, the soil is fit for ploughing. Sandy soil, however, can be ploughed when the moisture content is high or low without any detrimental effect to the soil.

In general, ploughs are of two types, the *desi* and the mouldboard. A DESI PLOUGH consists of the following parts:—

1. A tongue of wood fitted with an iron point.
2. A handle for holding the plough.
3. A beam for attaching it to the bullocks.

The desi plough varies considerably as to its size and form in different parts of the country depending mainly on the size of the bullocks of the local breed, but also on the type of soil in the region. These ploughs have been evolved through generations of experience and they generally suit the height of the bullocks in the district. Any change or adjustment made in these ploughs is likely to make them unsuited for the bullocks of the locality. This may be due to the fact that the forces acting on the implement as summed in the resultant or line of draught do not pass through the centre of resistance of the implement, and therefore the plough does not ride steadily at a uniform depth. If the angle is too great, the plough may proceed in a series of jumps, doing very poor work and making it harder for the bullocks to pull. The effect of a slightly incorrect adjustment in a plough of this type is not so apparent as it is in a plough drawn by a flexible draught rope or chain. In Bundelkhand the plough is very heavy, weighing about $3\frac{1}{2}$ maunds and stirs the soil to a depth of nine to twelve inches. On the other hand, the desi plough in Bengal is very light and ploughs to a depth of about 2 to 3 inches only. Usually the local conditions determine the form and size of the plough. It is always advisable for a new-comer to a locality to use the local plough or implements approximating its action on the soil until he has gained sufficient experience of local conditions. Later he may wish to make a change.

The chief characteristics of the desi plough are as follows :—

1. It possesses no mouldboard and consequently cannot invert the soil.
2. The furrows are v-shaped and therefore unploughed strips are left between furrows. The land has therefore to be ploughed in different directions in order to break up these unploughed strips.

3. It ploughs a smaller area in a day than that usually covered with a mouldboard plough.

A MOULDBOARD PLOUGH consists of the following parts:—

1. The body or frame to which other parts are attached.
2. The beam.
3. The mouldboard.
4. The share.
5. The handle.

There are several types of mouldboard ploughs that are now being used in this country. The most common are the Meston and the Chattanooga ploughs. The Rajah plough at one time was more commonly used but at present it is being displaced by other types of ploughs, such as the Chattanooga in the Punjab. Mouldboard ploughs have a special characteristic of being able to invert the soil. They also plough deeper than a desi plough. This type of plough is particularly useful in the ploughing under of green manures, manures and crop residues. It is equally useful in weedy fields since it buries weeds and aids in keeping the land clear. Most of the mouldboard ploughs are heavier than the common desi plough, which fact makes the former unpopular with the Indian farmer. The Meston plough is, however, not very much heavier than a desi plough and can easily be drawn by the average Indian bullocks. It can also be carried to the field like a desi plough. Some of the other disadvantages of the mould-board ploughs are usually their higher cost and the difficulty of getting them repaired. The Meston plough, being light, is almost useless in heavy soils because it does not work well. For such soils a heavier type of plough, such as the Rajah is necessary, although it is more expensive. It has been claimed by some people that a further disadvantage of the mouldboard plough is that it tends to form a "hard pan" where used at a uniform depth from year to year. Of the

different types of mouldboard plough, the Meston plough is probably the lightest and cheapest. Wooden parts for it can be easily made and fitted by a village carpenter.

As to the depth of ploughing, there exists considerable difference of opinion. Some believe that deep ploughing is beneficial in Indian soils, whereas some others believe it to be detrimental as it brings to the surface the subsoil which is lower in fertility than the surface soil. However, recent experiments in this country tend to show that deep ploughing in the Gangetic alluvium is beneficial to the crop. Experiences in the "black cotton soil" area, tend to show that increased depth and inversion show little advantage in crop yield, cost considerably more, and demand heavier and more costly ploughs which an average farmer cannot afford. However, for the more valuable crops, periodic soil inversion coupled with increased depth has usually given better results. But better yields and better returns on capital invested may be secured by substituting organic manures in place of the more expensive deep-ploughing.

HARROWS AND CULTIVATORS

Harrows, *bakbars* and cultivators (or grubbers) are also useful implements on the farm. These are of various

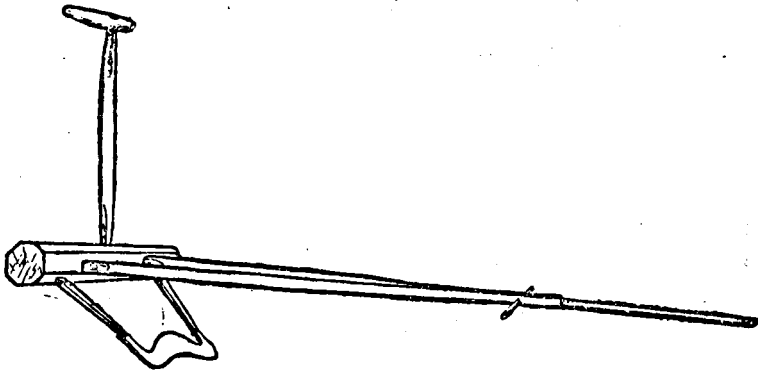


Fig. 11.—Bakhar

types. The main object in the use of these implements is to pulverize the soil and comb out the weeds. They are also used to cover seeds that have been broadcast.

A harrow usually consists of a frame with teeth fixed to it with the object of stirring and breaking up the soil surface. The lighter ones tear through the soil, simply breaking up the lumps, while the heavier ones also do some dragging or levelling.

Some of the harrows used in this country are the following : (1) The spike-tooth or peg-tooth harrow, (2) The spring-tooth harrow, (3) The bar harrow, (4) The drag harrow and (5) The chain harrow. Of these, the spring-tooth or spring-tined harrow, as it is sometimes called, works a little differently from the others. In the spike-tooth harrows the teeth are rigidly fixed to the frame, whereas in the spring-tooth harrow the teeth are curved and possess a certain amount of springiness so that when a serious obstruction is encountered by one of the points, the tine will spring back and release itself from the obstruction. In this way the obstruction is prevented from throwing the entire implement off its level. There is also a certain amount of vibration of the springtine which is believed to increase its pulverizing action in the soil. However, the springiness often prevents this harrow from properly tearing up matted patches of *dub* or other grasses which produce sods. This type of harrow is most useful in lumpy clay soil or in stony land. But a spike-tooth harrow may be conveniently used on light alluvial soils. These harrows can cover about 3 to 4 acres in a day with one pair of bullocks.

The bar harrow is a modification of the spike-tooth and is made locally by village carpenters. Hence it is cheaper than the two previously mentioned. It consists of a wooden frame with pointed iron pegs. A drag harrow is very much like the bar harrow except that it is heavier. The extra weight of a drag of a harrow causes it to drag, thereby enabling it to level and compact the soil in addition to breaking the lumps or clods.

The chain harrow is generally used for covering up the seeds after sowing.

A disc harrow is another type which is heavy and rather expensive and hence not commonly used in India. It sometimes takes the place of a plough.

Cultivators (or grubbers) are extremely varied in design. They are used chiefly to perform functions intermediate between those of the plough and the harrow. They remove weeds by cutting and bringing up their underground parts to the surface and pulverize the soil. In general they stir the soil just as does a desi plough. The following types of cultivators are commonly used in India.

- (1) The horse-hoe cultivator.
- (2) The *bakhar* of Central India and Madras.
- (3) The Planet Junior Cultivator, a type of wheel-hoe.

The horse-hoe cultivator is adapted for use between the rows of a crop sown in lines, such as cotton, or it may be used on fallow land. Most horse-hoes can be changed to any width varying from eighteen to thirty-six inches. Such a cultivator can cover about three acres a day when used for cultivating an unplanted field. When used for interculture between rows it can also cover about three acres in a day. This cultivator can also be used for ridging, and when so used it can cover about two acres a day.

A *bakhar* is another type of cultivator commonly used in Central India. It consists of a blade usually about a foot long fixed to a body to which a beam is attached. It is used for interculture, most of the crops in the region being usually sown in lines. This is an indigenous implement, and is cheap, light and inexpensive, and can be easily constructed and repaired by a village carpenter.

A wheel-hoe is a modification of the horse-hoe cultivator. It is light and is pushed by a man, instead of being pulled by bullocks. It possesses numerous attachable parts, and is therefore adapted to a large variety of uses on the farm especially in vegetable gardening.

SOIL-COMPACTING IMPLEMENTS

Another group of implements known as plankers, packers, crushers and rollers are commonly used on the farms in India. Their action is to compact the soil, to break clods and to level the surface. The best known and the most widely used in India is the planker, or *patela*. In Western countries a planker consists of several planks put together, each plank usually about six feet by ten inches by two inches, and arranged so that they overlap each other. In India it either consists of one large plank

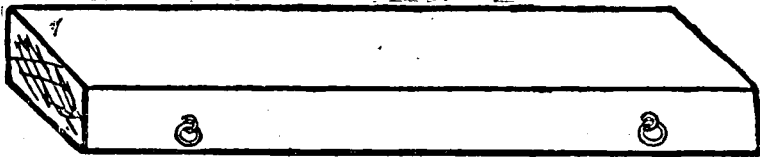


Fig. 12 Beam

or a heavy wooden beam; hence the operation is sometimes known as 'beaming' or 'planking'. The planker when dragged over the soil, crushes the clods and grinds them together, thus reducing their size. The soil is thus leveled, smoothed and to some extent compacted, depending to a great extent on the weight of the planker. Planking helps to bring more moisture in contact with the seeds sown, and hence the operation is usually adopted in the preparation of a seed bed.

Rollers and crushers generally resemble the planker in their function. In Western countries these are usually made of iron, but in India the farmers usually make them out of wood, as the iron ones are too expensive. These are not commonly used in this country except in certain localities such as Karnal and Rohtak near Delhi.

Another important agricultural implement is the drill. This is one of the most valuable implements in modern agriculture. The indigenous method of sowing seed is usually by dropping the seeds behind the desi plough or by

broadcasting. Drilling, however, should be preferred to broadcasting for various reasons. Firstly, drilling aids in the proper distribution of seed. Secondly, the seed is placed at an even depth in the soil, thus enabling all of the seed to be properly placed in the moist soil. Thirdly, germination is more uniform. Fourthly, the plants have equal opportunity of obtaining food, light and air. Fifthly, this facilitates hoeing and interculture. Sixthly, bullock power can be used for the interculture of most crops, thus reducing hand labour, and thereby reducing costs of production. This method of sowing is most desirable especially in dry-farming areas where there is a limited amount of moisture in the soil.

The method of sowing with a drill is not new to India. While the Indian farmer generally sows his seed through a tube attached to a desi plough and therefore is able to sow or drill only one row at a time, other types of drills have been developed which can sow or drill more than one row at a time. Even these have been used for centuries in some parts of India.

These drills usually consist of a body or frame to which a beam is fixed for attaching it to the bullocks, and a handle for holding. To the frame are attached furrow-openers, fixed at a definite distance from each other depending on the desired width between the rows, and to each of these openers seed tubes are attached. On the top of these tubes a cup is securely tied through which the seeds are dropped into the furrows.

THE LEVELLER OR SCRAPER

The leveller is another implement commonly used on the farm. It is used for grading and levelling of uneven land, for the removal of alkali incrustations from the surface of the soil, for "bundling" or throwing up embankments, and for the making of irrigation channels. Grading or levelling is a necessary operation for preventing soil erosion or excessive water run-off. The leveller is an especially useful implement in the levelling

of land devoted to irrigation farming. This implement consists of a metal scoop with a device for attaching bullocks, and a pair of handles. The front edge of the lower portion of the scoop is kept sharp and is usually made of good

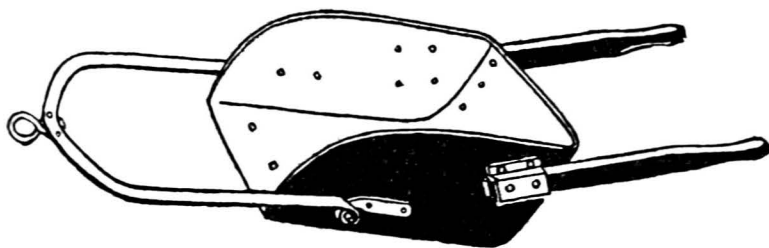


Fig. 13.—Leveller

iron. The implement is simple in construction. An ordinary American leveller holding about three cubic feet of earth, which can be drawn by a pair of bullocks is found to be most satisfactory.

HAND IMPLEMENTS USED IN TILLAGE

Besides the larger implements mentioned above, the following are some of the common hand tools used for various types of farm operations:

(1) The *pharwa*—This is a general purpose hand implement. It is used for hand digging, erection of small bunds, digging of trenches, irrigating, digging of certain root crops and for various other types of farm work.

(2) The *khurpi*—This is probably the most widely used hand implement for weeding and mulching in India.

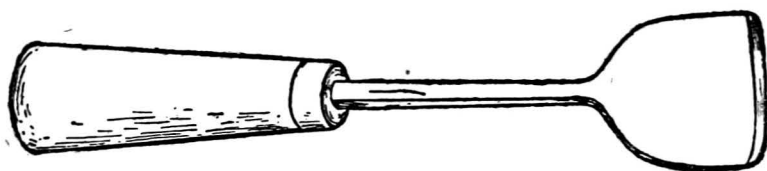


Fig. 14.—Khurpi

There are various types and modifications in the various parts of the country. It consists of an iron blade and a wooden handle for holding.

(3) A hand-hoe—This is a western implement introduced into India, and its function is the same as that of the khurpi, namely, weeding and mulching. But this can also be used for earthing and for irrigating. In this respect its function also resembles that of the pharwa.

(4) A hand ridger or *jandra*—This is an implement commonly used for making small ridges as used in the production of irrigated wheat. It consists of a flat board usually about three to four feet long, about five inches wide, and one inch thick. At the centre of the board a pole about five feet long is attached. Near the ends of the flat board two rings are attached for fastening a rope. This is operated by one man holding the pole slightly on one side of the place where the ridge is to be made and slightly pressing downwards, and another man holds the rope and pulls it towards himself. In this way a ridge is made.

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CHAPTER VIII

SOIL MANAGEMENT

PART II—IRRIGATION AND DRAINAGE

In a country like India where long periods of drought occur, the continuous supply of water for the crops becomes a very important factor in economic crop production. For these periods of drought, irrigation, which may be defined as the artificial application of water to the soil for the purpose of growing crops, becomes very necessary, in places where the rainfall is deficient. The rainfall in India is also very unevenly distributed, most of it coming within a very short period followed by a period of drought. Again, while some regions in India receive too much rain, other regions, on the whole, do not get sufficient for normal crop production. For these latter regions, the application of water by irrigation becomes essential. Thus the areas including Sind, the North-West Frontier Province, the Punjab, the United Provinces, a large portion of Bihar, most of Madras, most of the Bombay Presidency, portions of the Central Provinces and the major portion of Rajputana are included in this region. Aside from this, the Indian rainfall is liable at times to fail entirely or to be seriously deficient. Hence the method of storing water has been practised in India from very early times.

TANK IRRIGATION

The most primitive means of storing water in India for irrigation purposes is the tank. Tanks vary in size from works like Lakes Fife and Whiting in the Bombay Presidency or the Periyar Lake in Travancore, holding several billion cubic feet of water, to small village tanks irrigating

only a few acres. Another important group of such tanks are found in the Chingleput district (Madras) which irrigate about 4,000 acres and are said to be 1,100 years old. The highest development of tank irrigation is in Madras. The total area irrigated from tanks in India is approximately 8,000,000 acres.

There are usually two types of tanks: (1) the submerging tank, and (2) the irrigating tank. The first is used for storing water during the rains, and is then emptied in the month of October to expose the tank bed in order to allow the preparation of the soil for sowing the rabi crop. But an irrigating tank is meant to hold as much water as possible; and the water is withdrawn from time to time for irrigating the adjacent fields.

A tank usually consists of: (1) a bund for retaining the rain water, (2) an escape weir for the removal of surplus water in years of heavy rain, (3) a sluice to draw off the water in order to empty the tank, and (4) one or more channels for distributing the water.

CANAL IRRIGATION

This system of irrigation has been known in India from very early times. The remnants of an ancient irrigating channel of the submontane districts of northern India which have been covered by forest growths and the Grand Anicut or the Cauvery in Madras, indicate the early attempts at canal irrigation. In Sind and the western Punjab the practice of withdrawing the flood waters of the river Indus for purposes of irrigation is very ancient. In the Rohilkhand region, some of the modern canal systems follow the older canals of early centuries. In more recent times Feroz Shah and Akbar constructed canals to take water to the Hissar district in the Punjab. In fact, the early British engineers directed their efforts towards the improvement of the existing indigenous works, instead of the construction of new irrigation projects. Some of the recent works of the British Government have enormous capacities and serve very large areas. In 1878-79 the acreage under

canal irrigation was estimated to be ten and a half million acres. But during the last fifty years the Government's new projects have increased this area to approximately thirty-one and a half million acres. This development of networks of canals and other irrigation structures has been very phenomenal; so that India can now boast of some of the most magnificent irrigation projects in the world.

The areas under canal irrigation according to provinces is given below:—

	<i>Acres</i>
Punjab	11,343,000
Madras	7,489,000
Sind	4,728,000
United Provinces	3,786,000
Bihar and Orissa	869,000
North-West Frontier Province	399,000
Bombay Deccan	388,000
Central Provinces (excluding Berar)	352,000
Bengal	48,000
Rajputana	29,000
Baluchistan	21,000

Some of the most important irrigation systems in India are:

(1) The Lloyd Sukkur Barrage in Sind. This is the greatest work of its kind in the world. The area irrigated by this canal is approximately 2,70,000 acres.

(2) The Cauvery (Mattur) project in Madras. This scheme is designed to irrigate about 1,300,000 acres of rice fields, situated 125 miles away from the dam, in the Cauvery delta.

And (3) The Sutlej valley canals in the Punjab. This project is designed to irrigate 5,108,000 acres or eight thousand square miles in the Punjab, and in Bhawalpur and Bikaner States.

WELL IRRIGATION

About 30 per cent of the total irrigated area in India is supplied by wells. This water is more carefully used, as every drop of it has to be lifted, and is also used for high-grade crops. It is therefore estimated that well-irrigated lands produce at least one-third more than the canal-irrigated lands. Wells in India are of various types. Some are very *kuchcha* and are simply holes to the strata of soil where subsoil water exists, whereas some others are made of masonry and are more permanent. In some places these wells are also quite deep, as for example, those found in the Bikaner State.

Wells which are sunk through pervious strata only to subsoil water are known as "shallow wells", while those that are sunk through an impervious layer of soil usually clay, and tap subsoil water below the impervious strata are known as "deep wells". Besides these, there is another type known as artesian wells in which the water rises to the surface without being pumped. But the possibilities of artesian water supply in India are not fully understood and have been very imperfectly tested. But even if they are as good as some would believe them to be, there appears to be no utility in any great scheme of irrigation from them for agricultural purposes.

METHODS OF LIFTING WATER

There are various ways of lifting water in India. The most common water-lifts used are the following: (1) the *mot* or *charsa*, (2) the Persian wheel, (3) the Baldeo *balti*, (4) the chain pump, (5) the swing-basket, (6) the Egyptian screw and (7) pumps.

The **MOT or CHARSA**:—This is the most common indigenous method of lifting water from deep wells. It consists of a large leather bag which holds from about 24 to 42 gallons of water, attached to a rope which usually passes over a pulley and is drawn by a pair of bullocks. The animals are made to walk down a slope (or inclined

plane) when lifting the leather bag full of water. This bag is sometimes provided with a self-delivery tube which empties the bag when it reaches the top of the well. In certain regions the mot is not provided with a self-delivery tube and therefore requires an additional man for the purpose of emptying the bag. When the bag is not provided with a self-delivery tube the rope is released from the bullocks and the bag falls in the well by its own weight, while the bullocks turn around and walk back. In the meantime the bag is filled again with water, and the rope is again attached to the yoke of the bullocks. Sometimes two pairs of bullocks are used, and this requires an additional man to handle them. By this method more water is lifted within a certain period of time. But in the case of the mot with the self-delivery tube only one pair of bullocks is used, and the rope is not unhooked from the bullocks which are required to back up to the well. In this method of operating the mot, only one man and one pair is required, but the backing of the bullocks to the well considerably slows up the work. Sometimes more than one mot is used in one well, but generally not more than two. By this method of lifting water using one mot from a well about 60 feet deep, about 60 tons or 1,620 maunds of water can be safely raised in eight hours. This is equivalent to approximately a half acre-inch of irrigation water.

THE PERSIAN WHEEL:—Lifting water from wells which are not too deep can be successfully carried out by means of a Persian wheel. This method of lifting water is common in the Punjab and parts of the United Provinces, in Kathiawar and parts of Rajputana. In its simplest form a Persian wheel consists of a wooden drum which turns on an axle and rotates a chain of buckets. In the old indigenous type the chain consists of a special type of small clay pots, tied together by means of ropes usually made of some kind of straw; but in the present-day improved types the drum and axle are made of iron as well as the chain, and the buckets are usually made of galvanized iron. The old type is very heavy, where-

as the improved type is much lighter. Recently Persian wheels have been made with the axle turning on ball bearings which makes this machine much easier to operate and more efficient. In places where the water is near the surface, larger buckets are used; but in wells where the water is deeper, the size of the buckets is generally reduced, because the weight of the chain and the number of buckets increases with the increase in the depth of the well, and consequently less water is lifted.

This type of lifting water is not only confined to wells but is also used sometimes for raising water from streams, or tanks.

This water-lift is generally operated by bullocks or a camel; and usually only one man is required to work it. In general a farmer leaves a boy to operate it while he attends to the irrigation water in the fields. The improved Persian wheel is becoming more and more popular because it is probably more efficient than the mot.

The **BALDEO BALTI**:—This consists of two boat-shaped water-lifts which are tied with a rope or string which passes over three pulleys. They are arranged in such a way that when one of these boat-shaped lifts rises and discharges its water, the other one goes down and refills, the water entering the lift by means of a valve. This water-lift may be arranged in such a way that it may be operated with one or two bullocks.

The **CHAIN PUMP**:—In construction this is similar to the Persian wheel. A pulley is fixed to a shaft which is turned either by a handle when human labour is used or by a gear when bullocks are employed. An endless chain passes over the pulley and is fixed in an iron pipe usually about four inches in diameter and which extends from the top of the well to a bell-mouthed end fixed about two feet below the surface of the water in the well. This pipe, for depths of more than 10 feet should be fixed on a beam built into the masonry of the well. The chain is fitted with circular discs which have about the same diameter as the tube and therefore fit the tube. These discs are arranged about

one foot apart on the chain. The chain ascends inside the pipe, bringing the water with it and discharging it into the channel at the top. The discs are sometimes fitted with leather washers which help to reduce the leakage of water back into the well. However, these washers have to be repaired or renewed from time to time. This pump works well to a depth of about 26 feet, but it is doubtful whether it will work efficiently for lifting water from wells more than 20 feet in depth, on account of leakage of water from the discs. The capacity of the chain pump depends upon the depth of the well and the size of the pipe.

The size of the pipe usually varies with the depth of the well; that is, the deeper the well the less is the diameter of the pipe.

The following are the approximate capacities of the Chain Pump at different depths and varying diameters of the pipe:—

TABLE 12

<i>Depth of well in feet</i>	<i>Diameter of pipe in inches</i>	<i>Approximate quality of water in gallons per hour</i>
10	5	6,000
20	4	2,500

The SWING BASKET—This usually consists of a metal *tagari* (basket), to which ropes are fastened on opposite sides. It is operated by two men who swing the basket by swinging the ropes. Each swing catches some water and lifts it to an upper channel usually one to three feet higher. This is most commonly used for lifting water from ponds or *jhils* to a channel on a higher level. The quantity raised depends largely upon the ability and strength of the men operating it.

The EGYPTIAN SCREW—This consists of a wooden cylinder about 16 inches in diameter and four to five feet

long, containing a screw made of a series of planks. The cylinder is fastened to a support in the water and at the delivery trough. It is usually fixed in an inclined position at an angle of about 35 to 45 degrees. The cylinder is operated by turning it, thus causing the water to rise up through the screw into the delivery trough. This water-lift is commonly used for shallow depths varying from two to three feet. Its use is for similar conditions to those for the swing basket, that is, for lifting water from ponds or *jhils*.

PUMPS:—Pumping from wells using mechanical power, either oil or steam engines, is now becoming more and more common in this country. Power pumps may be used economically where considerable water is required, say at least 10,000 gallons per hour. Most wells will not stand the withdrawal of such large quantities of water as blowing or the sanding or silting up of the well may take place. In order to avoid this, a special type of well known as the tube-well is generally employed. For the proper installation of a tube-well, it is essential that the proper strata of water be tapped or found. The installation of a tube-well is usually expensive and requires technical knowledge.

There are various types of pumping plants which are successfully used in this country for lifting water from tube-wells. Local conditions and requirements must determine the type and motive power best suited for individual cases.

SEWAGE IRRIGATION

A more recent development in the field of irrigation in this country is sewage irrigation. In large cities sewage disposal is a pressing problem. But this sewage water, when conducted to cultivated fields, has been found to be valuable in crop production. Hence there are two main objects sought in the use of sewage in irrigation. The first and foremost is to oxidize and render harmless the bacterial organisms which it contains. The second object is to utilize the water together with the organic matter and

fertilizing materials which it contains, in the production of crops. Sewage is mainly organic matter in the form of human excreta and water. However, the character of its contents varies with the miscellaneous refuse which it sometimes contains, such as rags, papers, vegetable trimmings and the like. The organic matter consists chiefly of proteins in various stages of decomposition, urea, carbohydrates, fats and oils.

Conditions in most parts of India are very favourable for sewage irrigation. In the first place, in most parts of India there is a continuous dry period, during which time of the year water containing these important manurial ingredients is of the greatest value in crop production. Secondly, loams and sandy loams, the types of soils which predominate in most parts of India, are well suited for this type of irrigation, because there is less danger of water-logging, even in humid climates. From the agricultural viewpoints, sewage may be applied to any type of soil as long as it is not used continuously or in too large quantities. Sandy soils usually need artificial fertilization and are also usually deficient in water, and therefore are best suited to this type of irrigation. The agricultural value of sewage when properly applied to the soil has been sufficiently demonstrated, under varying conditions of soil and climate; and there is little doubt that it is desirable to use sewage for irrigation.

METHODS OF IRRIGATION

There are several methods of irrigation. But these different methods may be grouped under two main heads: (1) Surface, and (2) Sub-surface irrigation. In the sub-surface irrigation, the water is applied from below the surface of the soil and is thus subjected to less direct evaporation. Nevertheless, this method is not commonly used in this country and therefore it will not be further dealt with. Surface irrigation is the method generally employed in irrigated countries. There are several kinds of surface irrigation, the most common being the flooding and furrow methods.

The oldest and most common method of irrigating is to flood the surface of the land with water. This is known as wild or *open* flooding. Sometimes the areas to be flooded are ridged; that is, a ridge is built on each side of a strip to be irrigated, the ridges serving as borders. This method is known as the *border* method of irrigation. The field is divided into compartments or long strips and the water is applied to one compartment at a time. This is probably the most common method of irrigation in India. When the compartments or *kiaris* are made very small, the method is sometimes known as the *check* or compartment method.

Sometimes a series of furrows are made close together throughout the field and water is allowed to run in these for some time. This method is commonly known as the *furrow* method of irrigation. The type of soil, the slope of the land and the crop usually determine the length of the furrow and the distance between furrows.

Although the border method is most commonly used in India, the furrow method possesses several advantages which may be enumerated as follows: (1) The furrow method allows the farmer to control the quantity of water applied to his fields. (2) It enables the farmer to cover a larger area with a given amount of water. (3) It prevents washing of light soils. (4) It reduces evaporation. (5) It tends to prevent over-irrigation. (6) In regions where there is a possibility for the land to become saline, it tends to delay the rise of alkali. (7) It reduces baking of the surface soil. But this method has one great disadvantage which may outweigh all the advantages, especially in canal-irrigated lands; and that is that large volumes of water cannot be used in the small furrows. Further, it is difficult to add the same quantity of water to each furrow, and more difficult to give the same amount to the lower portion of the furrow as to the upper. It is also difficult to avoid run-off at the lower end.

WATER REQUIREMENTS OF CROPS

The application of the correct amount of water to the crop can be practised only when the farmer understands the quantity of water which is necessary to mature the crop. In canal-irrigated areas, where water is plentiful, it is generally not efficiently used; and as a rule, greater quantities of water are used than are necessary. As the result of this, there has been in some areas a rise in the water-table, followed generally by alkali deposition or the formation of water-logged soils.

As regards the amount of water required by a crop, it is to be expected that a large plant or crop will require more than a small one of the same kind. Hence it becomes necessary to adopt a method of expressing the quantities which may be applied in all cases. One common method of expressing this quantity is the use of the "transpiration ratio", which is the amount of water in pounds, transpired in order to produce a pound of dry matter. This ratio varies with different crop plants, soils and climatic factors. Thus, if the transpiration ratio of wheat is assumed to be 500, this would mean that for every maund of dry matter produced, that is, grain and straw combined, it would require 500 maunds of water. Again, assuming that the amount of grain produced per acre is 15 maunds and that the yield of straw is 45 maunds; then the total dry matter produced is 60 maunds per acre. Therefore the amount of transpiration water necessary to produce this crop would be 500×60 or 30,000 maunds, or 2,460,000 lbs. of water. Now since an acre of water 1 inch deep weighs approximately 227,000 lbs. the amount of transpiration water necessary is equal to $2,460,000 \div 227,000 = 11.3$ inches. If it is assumed that 50 per cent of the water applied to the soil is lost by evaporation, then the amount of irrigation water required to produce the above crop of wheat is 22.6 acre-inches. It should be noted that rainfall has not been accounted for in the above calculation. The following table gives the figures of the transpiration ratio of the different crops as worked out by

J. W. Leather at Pusa. The figures taken are from the pot culture experiments only; no attempt is being made to summarize the results of the field experiments.

TABLE 19
Showing the Transpiration Ratio of Crops

<i>Crop</i>							<i>Transpiration Ratio</i>
Wheat	..	..	..	..	..	..	450—650
Linseed	..	..	..	..	..	..	600—1000
Mustard	..	..	..	..	..	..	400—550
Peas	..	..	..	..	..	..	600—800
Barley	..	..	..	..	..	..	450—650
Oats	..	..	..	..	..	..	400—500

DRAINAGE

Drainage, which may be defined as the removal of surplus water from the soil whether by natural or artificial means is as important as irrigation. Drainage is especially important in those regions like the Punjab where extensive systems of canal irrigation are being developed. However, in the greater portion of India, land drainage is necessary, especially during the monsoon season. The following kinds of land more especially require drainage: (1) heavy clay soils from which rain water cannot drain easily, (2) low-lying flat areas, especially those more or less surrounded by hills, (3) lands with little slope and with an impervious subsoil, (4) delta lands at the mouths of rivers, which generally require drainage in order to make them suitable for agricultural purposes and (5) swamps, marshes, and jhils, such as those found in the terai regions at the foot of the Himalayas, especially in the United Provinces and in Bihar.

The following are some of the effects of drainage on the soil:—

- (1) By removing the excess moisture which is in the form of gravitational water occupying the pore space in the soil, air containing oxygen is brought into those pores, which helps crop growth.
- (2) Drainage improves the structure of a water-logged soil.
- (3) Where the water-table is too close to the surface soil, drainage is very essential, as the water-table is lowered by this process which thus encourages root development.
- (4) Drainage in regions where there is a possibility of the rise of "alkali" becomes very important as it helps in the permanent removal of certain salts which are dissolved in the excess water.
- (5) Drained land can also absorb more rain water than undrained land, hence the process of drainage helps to prevent soil erosion.

It should also be remembered that drainage does not remove the available water from the plants. It does remove, however, the water that is in most cases detrimental to the proper development of most plants.

There are different types of drainage that can be used. The method depends on a number of factors, such as the topography of the land, the nature of the soil, the natural facilities for outlet, the area to be drained and the cost of labour and material. However, two types of drainage are generally used : (1) open channel, and (2) closed drains.

Open channels are the most common in India, because they involve less capital. They work satisfactorily where there is a large volume of water to be removed. But the main objections to open channels are that they are difficult to keep free from weeds, they limit certain farm operations, and they occupy valuable land which might have been used for the growing of crops.

Open channels are usually v-shaped in cross section, but the slope of the ditch depends upon the type of soil, being steeper in clay soil and less steep in loose sandy soils. These channels should also be kept as straight as possible, as erosion generally occurs wherever there is a bend in the channel. In the construction of an open channel, care should also be taken to place the soils several feet away from the edge of the channel, lest this be washed back into the ditch when heavy rain occurs.

Under-drains are covered drains running underground and allowing the water drained from the soil to flow away. In the construction of under-drains many methods and materials have been used. Among these stones, brush, rubbish and tiles have been commonly used. The tiles are probably the most common. But these are rather expensive, which is probably responsible for their limited use in this country. In regions where stones are plentiful these may be used satisfactorily in the construction of the under-drains. In regions where timber or brush is abundant, these may be placed in a trench and covered with soil. The water will usually flow through the porous space around the brush or timbers. After these are decayed, spaces are left which allow the passage of water for some years before they are filled up. Of these different types of under-drains the tile drainage, although expensive, is the most permanent and satisfactory. In connection with the laying of tile drains, one point should be noted. That is, that the tiles are loosely laid so that their ends do not fit tightly to one another, but a small space is left at the joint to allow the drainage water from the soil to enter the tile drain. Another important consideration in the laying of tile drains is to give sufficient slope to the drain, so that the water will flow off as fast as it reaches this drain.

The depth and distance between drains are matters of importance and usually depend upon a number of factors, the most important of which are: (1) the slope of the land, and (2) the character of the soil. In general, the steeper the slope, the greater is the distance between drains.

In fine-textured soils the distance between drains should be less than in the more open and light-textured soils. The depth of drains in sandy soils should also be greater than in clay soils. In general the depth in clay soils should be about 2 feet, while in sandy soils it may be about 4 feet deep. In clay soils the drains may be placed at a distance of about 60 to 80 feet apart, whereas in sandy soils the distance may be made 150 to 200 feet.

SOIL EROSION

The prevention of soil erosion is now being recognized as one of the most important problems in agriculture. The losses in plant food nutrients caused by soil erosion in a country like India, where the entire cultivated area is subject to the monsoon rains, is tremendous. The losses in plant nutrients due to erosion have been estimated to be several times greater than the removal of plant food from the soil by the crops. This impoverishment of the soil is largely due to the uneven distribution of the rainfall. Large amounts of nutrients are carried away in the run-off water to the low-lying lands or ultimately find their way to the rivers and then into the sea. Other factors which influence erosion are: (1) the slope of the land, (2) the nature of the soil and (3) the amount of vegetation on the surface of the soil. A heavy downpour during the monsoon causes the water to run off the surface of the soil and collect into a stream which removes more earth as it goes along. When this goes on unchecked a small gully or *nallah* is formed. The gullies usually increase in depth and width year by year forming small ravines, thus making the land, in a course of a few years, unfit for cultivation. Thus two types of erosion are generally recognized: (1) *sheet erosion*, or that taking place evenly over the surface of the soil, usually over a large area, and (2) *gully erosion*, or that which produces gullies or *nallahs*, and is thus more or less localized but slowly results in deep ravines. Such conditions are found in many parts of India, especially in that tract of the country south of the Jumna in Bundelkhand and in the

Etawah district in the United Provinces, in parts of the Bombay Presidency, in Central India and in certain hilly areas in the Punjab.

Sheet erosion may usually be prevented by a ground cover, such as grass of some kind, a cover crop, bunding, the spread of artificial mulches like litter or some organic refuse, and sometimes deep ploughing. This last method helps the absorption of rain water by the soil; but, at the same time, ploughing makes the soil loose, and, under certain circumstances, it may be washed away more readily. Of the different types of grasses used in this country as a ground cover, *dub* or *bariali* grass (*Cynodon dactylon*) has been found to be very effective in binding soil particles. In cultivated lands sometimes a leguminous cover crop such as cowpeas and sann hemp may also be used. Where bunding is resorted to, clumps of grass, such as those of *sarpat* (*Saccharum arundinaceum*) are sometimes grown on the bunds in order to bind the soil and thus minimize washing. Bunding refers to the construction of small bunds or embankment around fields to hold the rain water and thus prevent run-off, and ultimately erosion. This is widely used by farmers in India, as it helps also to conserve rain water in the soil by maximum absorption, and thus raises the water-table in the soil, and increases the available ground water in the wells.

If the land is not level, erosion may be reduced by having the slopes graded into horizontal terraces, which will vary in size according to the steepness of the slope. The terraces thus made usually resemble a series of steps along the slope. This system is especially useful for paddy cultivation where the country is hilly, but has a plentiful supply of water for irrigation purposes. Such terraces are also constructed for fruit and vegetable gardens and other crops on steep hillsides. In the construction of these terraces, a low ridge is usually made on the front side of the terrace, in order to prevent the washing off of the soil. Around its entire border, a narrow drain or furrow with the proper slope should be arranged to collect surface

water, and direct it into drainage channels.

Gully erosion is an advanced stage of sheet erosion, and will not be serious if sheet erosion is prevented. The methods of controlling gully erosion depend very largely on the volume of water that runs in the gullies. Where gully erosion has just started to damage the fields, a farmer can prevent further erosion, and also can fill up the depressions by such methods as bunding or field embanking. A small earthen bund from 2 to 6 feet high is thrown up along the side of the field which is crossed by the gully. In this way one or two feet of water can be held until after the end of the rains. Or sometimes the farmer can stake stems of plants like *arhar* or *tur* and cotton, at intervals of a few feet along the gully. These stakes are then made to support some straw or brush, which helps to slow down the flow of the water in the gully, and in course of time fill it up with soil. In some cases old gunny bags may be partially filled with sod and these placed across the drain which may form into a gully. The bags are usually only about one-half filled with sod and placed in such a way that they lie flat on the ground across the small washes at the upper ends of gullies.

Where the gullies are larger, dams may usually be constructed across them. These dams are of various kinds depending usually on the amount of water to be taken care of. Among these the woven wire and the concrete or *pucca* brick dams are most commonly used. A woven wire dam consists of a row of strong iron or wooden posts, set firmly in the ground across the gully, generally placed about four feet apart. The posts should be set about 4 feet deep in the soil. The woven wire is then stretched across, touching the ground at all places and firmly secured to the posts. Brush and rubbish are then placed on the upper side of the wire in order to fill the meshes and thus catch the soil.

A concrete dam is more elaborate but also more permanent. It is usually constructed where a large area of

eroded land is to be reclaimed. The foundation of the dam should be set in fairly deep, in order to prevent seepage along the bottom and sides of the dam. This precaution is all the more important if the dam is high and is meant to take care of a large volume of water. In a concrete dam, provision for an outlet is very necessary in order to prevent undermining.

A *kuchcha* dam may be made to serve the same purpose, but in this case, a spillway is more essential; and adequate precaution must be taken to avoid erosion of any portion of the earthen dam.

Where rocks and stones are plentiful, gully erosion may be further prevented by filling in the gully at intervals with rocks. In this case also precaution is to be taken to prevent erosion around the rock or stone pile in the gully.

WATER-LOGGED SOIL

Water-logging is a phenomenon commonly found in different parts of India, especially in Bihar, the United Provinces and the deltas of rivers. This is due to improper draining of water from the soil. The phenomenon depends on several factors. Some soils are water-logged because the water-table is too close to the surface. When such is the case, the lowering of the water-table by proper drainage is very necessary. Certain soils are more subject to water-logging than others. Usually light sandy soils are free from water-logging, especially if the water-table is low, as these soils drain more easily than the impervious clay soils. However, some soils are subject to water-logging due to the presence of such deflocculating substances as sodium carbonate, which also results in the appearance of what is known as the "black alkali". This substance breaks up the soil structure, making it more compact, and thus more or less impervious to the percolation of water. During the last few years there has thus been an increase of water-logged soils in canal-irrigated areas where the seepage water has raised the water-table and has thus increased the evaporation of subsoil water, producing alkali incrustations

on the surface. It is therefore of extreme importance to see that, wherever irrigation systems are installed, the water-table does not rise near to the surface, as this may increase the acreage of barren lands in the area. Irrigation and drainage should therefore, go hand in hand in any scheme of soil improvement.

The evils caused by water-logging are mainly due to the exclusion of oxygen which is necessary for chemical changes as well as bacterial development in the soil, and to the breaking down of the soil structure. Plants growing in water-logged soils usually show a diseased appearance and a yellowing of the leaves. This results in the stunted growth of a crop.

ALKALI SOILS

The term "alkali soils" as commonly used has quite a loose or wide application. Alkali soils are so called, when they contain a greater or less amount of water soluble mineral salts which exert an injurious influence on vegetation. The distinctive characteristics of these soils is the presence of an actual excess of sodium or potassium salts. The most commonly occurring groups are the "white" alkali which is saline in character and the alkaline "black" alkali. In white alkali the salts frequently present are the chlorides and sulphates of sodium and potassium, and also sometimes the nitrates and carbonates of these metals, as well as the sulphates and chlorides of magnesium and calcium. The black alkali contains sodium carbonate usually in addition to the others. Some of the organic matter contained in the soil is dissolved by this compound imparting a dark colour to the soil. Where these salts are present in considerable quantities, they appear on the surface in the form of snow-white or brownish-black incrustations, known as *reb* or *kallar*. These salts originate usually from the underground water where the water-table is relatively near the surface. The salts have in some cases been present in the parent soil material, or they may represent the remains of former salt lakes or

inland seas. In some cases salinization has taken place by a rise in the salt-bearing ground water, due directly to canal irrigation. The alkali soils of the Punjab and of some parts of the United Provinces and Sind have been attributed to this rise of the water-table. Prior to 1884, alkali was unknown in the Nira Valley in the Bombay Presidency. In that year the Nira Valley irrigation canal was opened, and since then, the area of alkali is steadily increasing, so that it now covers thousands of acres.

Alkali soils are generally associated with arid conditions where the annual rainfall is not sufficient to leach the salts out of the surface soil, and also where the hot rays of the sun cause the underground water to rise to the surface soil, and on evaporation, leave the dissolved salt as an efflorescence on the surface. In consequence, most of alkali lands in India are found in the United Provinces, the Punjab, Sind, the North-West Frontier Province and in the Nira Valley and Kaira district in the Bombay Presidency.

The different methods of reclaiming alkali lands may be grouped as follows:

1. Chemical methods.
2. Mechanical methods.
 - (a) Flushing.
 - (b) Leaching.
 - (c) Scraping.
 - (d) Trenching.
- and (e) Drainage.

3. The use of alkali-resistant plants.

Amongst the *chemical methods* usually adopted, the most common is the application of a calcium compound usually calcium sulphate, by which the sodium in the alkali is replaced by calcium. Sometimes calcium carbonate is applied, and this, in the presence of farmyard manure, evolves carbon dioxide, forming the soluble bicarbonate from which the calcium can easily exchange with the sodium,

resulting in the washing out of the exchanged sodium. However, chemical methods of reclamation are rather expensive. It is estimated that it will cost approximately Rs. 700 to Rs. 800 per acre for reclaiming lands affected with sodium carbonate, by the application of gypsum or calcium sulphate. These figures are given for lands heavily charged with alkali salts.

Flushing by flooding with water is another method which has sometimes been used. In this method the salt is removed by water running on the surface of the soil. This method can only be recommended if water is plentiful and cheap.

The Daulatpur reclamation scheme in Sind, as well as the work done in Egypt for improving alkali lands, shows that water may be used to leach out or wash down the soluble salts from the soil, thus rendering it fit for cultivation. The practical goal is reached when the salt content has been reduced to an amount which is harmless for crop production. This method also requires a good deal of water which must be cheap in order to make it practicable. In cases where the land is affected with black alkali, this method is very slow, as the water percolates very slowly through the soil since this alkali deflocculates the soil, and renders it more or less impervious to water. The water therefore must be allowed to stand for some length of time before any considerable amount of this substance can be leached out.

Sometimes the removal of alkali incrustations on the surface of the soil is done by *scraping* two to four inches of the surface soil. But this method is very inefficient, as the surface soil is usually also heavily charged with alkali salts. Hence removing the surface incrustations by scraping is practically useless, in that it does not remove the salt in the lower soil horizons.

Trenching consists in digging a ditch, placing all of its soil on one side, and digging another trench alongside the first one, placing the soil in the first trench, so that the surface soil is placed at the bottom and the subsoil is

brought to the surface. Thus the alkali-bearing soil is buried at the bottom of the trench. This method requires considerable labour and is expensive. Further, the buried alkali soil at the bottom of the trenches usually moves upward again by capillarity in the course of a few years.

Drainage is commonly used in connection with either flooding or leaching. But drainage itself is a method generally used to prevent the further rise of alkali, as in this way, the permanent removal of the dissolved salts is secured through drains put in the soil.

Some people have advocated the removal of alkali by growing certain *alkali-tolerant plants*. It must be remembered, however, that plants cannot remove any large quantities of such salts. It is therefore almost always impracticable to remove alkali by cropping alone. However, certain plants may render the soil better suited for cropping. Some of these resistant plants are *babul* (*Acacia arabica*), wild indigo, beets, rice, *patsum* (*Hibiscus cannabinus*) and lucerne.

ACID SOILS

Unlike the alkali soils, there are some soils which are sour or acid. These soils are also unsuitable for the growth of most agricultural crops. Two main causes have been advanced for the development of acid in soils: firstly, the existence of free acids and, secondly, a deficiency of basic substances in the soil. These acid soils occur more commonly in humid regions, or in regions of high rainfall; although they are sometimes found in arid regions where swampy conditions exist. The development of acid conditions is generally attributed to the washing out of calcium or other basic substances, by drainage or percolation. This acid condition may also be produced by the removal of basic substances by plants. The formation of salts of the bases with the soil organic matter may also produce acid soils. Sometimes these conditions may also be caused by the application of an excess of an acid fertilizer.

Acid soils have been found to be very injurious to such crops as lucerne, spinach, *jowar*, cauliflower, cabbage, carrots, lettuce, onions, muskmelons and beets. The following are also moderately sensitive to acid soils: wheat, barley, maize, cowpeas, cucumbers, brinjal, oats, pumpkins, radishes, soybeans, strawberries, watermelons, beans, tomatoes and turnips. Potatoes, rice, sweet potatoes and castor beans are considered to be adapted to acid soils.

This acidity in soils is generally determined by finding out chemically what is known as the pH value of the soil. A soil having a pH value of 7.0 is considered to be neutral. But if the value is below this, the soil is considered to be acid. In general, a soil with a pH value varying from 5.5 to 7.0 is considered to be medium or slightly acid, whereas a soil with a pH value varying from 5.0 to 5.5 is considered to be strongly acid. If the pH value is less than 5.0, the acidity is said to be very strong.

This acid condition in soils may usually be detected by the use of a blue litmus paper. This method consists of placing a blue litmus paper in contact with the moist soil to be tested. If the paper turns red, the acid condition is indicated. The deepness of the red colour usually indicates the degree of acidity in the soil.

In most cases, this acid condition of the soil is corrected by the application of lime or basic fertilizers. But where swampy conditions produce this acid condition, the acidity may be reduced by proper drainage. The addition of lime to this drained soil, in most cases, will improve its crop-producing power.

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CHAPTER IX

MANURES AND FERTILIZERS

Manures and fertilizers are substances applied to the soil in order to increase the amount of crop produced. The term "manures", as used at present, is applied to organic manures and more especially to animal manures, whereas the term fertilizer is usually applied to chemical or commercial fertilizing materials. When green crops are ploughed under, with the object of increasing the organic material in the soil, such practices are referred to as green manuring, and the materials are known as green manures", or "green plant manures." Some writers sometimes make the distinction between substances which supply nutrients to the crop and those which improve the soil in some other way. The former are called fertilizers while the latter substances are known as "soil amendments." Thus sodium nitrate is regarded as a fertilizer, whereas lime is known as a "soil amendment". Such a fine distinction is not possible because these two substances serve both purposes; that is, they supply nutrients as well as influence the condition of the soil. This is more true of animal manures which not only supply food materials for plants, but also materially improve the physical condition of the soil.

The soil is the store-house of the food materials which are being continually removed by crop plants, some of these do not naturally become available as rapidly as they are removed. It is therefore obvious that this continual removal of nutrients will ultimately impoverish the soil unless something is done to replenish the supply. The application of manures and fertilizers is the practical way of keeping up the fertility of the soil.

Materials which are commonly used as manures and fertilizers may be grouped as follows:

1. *Animal manures*:—These include the solid and liquid portions of animal excreta.
2. *Green manures*:—These include any crop grown and ploughed under for the purpose of increasing the organic matter in the soil.
3. *Chemical fertilizers*:—These include mostly the inorganic materials applied to the soil largely for increasing the supply of soil nutrients, especially nitrogen, phosphorus and potash.
4. *Special manures*:—These consist of materials which do not fall into the first three groups.

ANIMAL MANURES

On the farm where animals are kept—and they should be kept on every farm—their manure is a very important by-product. This material, if properly stored and applied to the soil, is one of the ways of returning a portion of the nutrients removed from the soil by crops. The proper storing and handling of manure on the farm is very important. One should also know the probable composition of different kinds of animal manures which are commonly produced on the farm. A proper knowledge of the importance of these manures would tend to discourage the wasteful practice of burning cattle dung. Of the animal manures, the cow and buffalo manures are by far the most common in India. However, small quantities of sheep and goat manures, as well as poultry manure, are available in some localities. The composition and value of the animal manure will usually vary with the kind of animal; the age, condition and individuality of the animal; the food of the animal; and the handling and storing of the manure before it is applied to the soil.

In general, poultry manure is the richest in the amount of fertilizing materials, as it contains per unit weight almost

twice the amount of ammonia found in cow manure, almost three times the amount of phosphoric acid, and it also contains a little more potash than is commonly found in the cattle manure. Sheep or goat manure is also chemically better than cow manure. But this deficiency in fertilizing elements in cow manure is more than made up by the quantity of manures produced per animal. In addition to this, the large number of cows and buffaloes makes the cattle manure the most common and important of the animal manures in India. On account of the small quantities available, the other animal manures such as those obtained from poultry, sheep and goat, and horse, are relatively unimportant in this country.

The composition of animal manure is affected by the age, condition, and individuality of the animal within the class. Usually a young, growing animal will retain a large amount of the fertilizing elements, and consequently, the manure produced will be poorer than from a fattened animal which will return most of the nutrient elements in the manure produced.

The character of the food given to the animal also affects the quality of manure produced. In general the richer the food, the richer will be the manure produced, since the animal usually retains only its bodily requirement and the remainder is returned in the manure.

Cow or buffalo manure is made up of two parts, the solid and the liquid. These are produced in the ratio of three to one. But the chemical composition as well as the physical properties of these components varies considerably. Hence their relative proportions will greatly affect the agricultural value of the manure. As the urine contains about 3 times the amount of ammonia per unit weight contained in solid or dung; the fertilizing elements in the whole manure are derived in approximately equal quantities from the liquid and the solid portions of the manure. Hence if the liquid portion is lost or not conserved, approximately half of the fertilizing constituents is lost and therefore wasted.

Usually conditions under which manure is stored in India are so unfavourable for the proper conservation of the fertilizing constituents, that more than half of the agricultural value of the manure is lost or wasted. This is a tremendous and unnecessary loss to the country which can be prevented, if the farmer is acquainted with the proper storing of manure.

The best method of storing manure has as yet not been worked out in this country. Even under the best conditions of storage so far known, about fifteen per cent of the manurial constituents are usually lost or wasted. However, probably one of the most efficient methods of conserving these fertilizing elements is the use of litter as an absorbent of the liquid portion of the manure. Some of the materials which may be used as absorbents of the liquid manure by spreading them in the animal shed for bedding are wheat, barley or rice straw, dry grass, dead leaves, unused fodder and even substances like sand or saw dust where easily available. The litter is removed daily with the dung and properly stored in a pile or pit.

If a pile is made, it should be located on high land where there is good drainage, and the spot under the pile should be made slightly hollow so that the liquid portion does not run off during heavy rains. The pile should preferably be protected from the sun and rain by some sort of cover or by a tree. The sides of the pile should be vertical or more or less steep so as to shed water during heavy rains. The top should be made so that it does not absorb too much water in the rainy season. The pile may be built up by spreading the manure in layers, the older at the bottom and the fresh one at the top. This will usually ensure the pile being moist and not too dry.

At times pits have been recommended for the storage of manure. These may be either *kuchcha* or *pucca*. The *pucca* is to be recommended wherever possible, as it prevents leaching and therefore the loss of the manurial elements due to percolation. The pits are usually rectangular in shape and should be covered if possible.

Farm manure is usually applied at the rate of ten to fifteen cartloads per acre, a cartload weighing approximately 15 maunds. However, a great deal depends upon the quality of the manure and the kind of crop to be grown. It should be applied uniformly over the whole field.

If an insufficient quantity of manure is available it is better to add a smaller quantity per acre, and cover a larger area, rather than spread it thickly on a smaller area. This practice results in a more economical use of the manure. The general practice is to apply manure once in three years by rotation.

GREEN MANURES

Sometimes it is not possible to obtain sufficient animal manure to apply to the soil, in which case the practice of green-manuring is to be recommended. This consists in growing of quick-maturing crops, preferably legumes, and ploughing them under to be incorporated with the soil for the purpose of increasing the amount of organic matter in the soil. This improves the physical, chemical and biological condition of the soil. It should be pointed out here, that most of the soils in India are lacking in organic matter, and can therefore be greatly improved by the addition of green manures. A crop suitable for green-manuring should possess these characteristics: (1) rapid growth, (2) succulence, (3) abundant foliage and (4) ability to grow on poor soils. Most of the plants used in this country for green-manuring are legumes, although non-legumes, such as *bhang* and *rai* may be used for this purpose. The reason why leguminous plants are usually preferred to non-legumes for green-manuring, is that the former are able to fix atmospheric nitrogen in the soil with the aid of symbiotic bacteria which are usually located at the nodular formations on the roots of legumes. The most common green-manuring crops in this country are the following: Sann-hemp (*Crotalaria juncea*), guara (*Cyamopsis psoralioides*), dhaincha (*Sesbania aculeata*), senji (*Melilotus*

parviflora), cowpea (*Vigna sinensis*), and soybean (*Glycine soja*).

Of these, sann-hemp has been well tested by the agricultural departments and is widely recommended. It is probably the most outstanding green manure crop in India. Next in importance are *guara* and *dhaincha*; the former being mostly grown in northern India, whereas the latter is largely confined to Bengal, Assam, Bihar and Madras.

These crops are usually ploughed under while they are still succulent, before the stems begin to harden. The usual practice in the case of sann-hemp is to make the plants lie flat on the ground by planking, when they are about two or three feet high, and then turn them under by means of a mouldboard plough. An acre of sann-hemp will usually yield from 350 to 400 maunds of green matter. If .31 per cent is taken as an average amount of nitrogen, the amount of nitrogen per acre added to the soil is about one maund or approximately eighty pounds.

This practice of green-manuring produces three desirable results in the soil. Firstly, it increases the nitrogen content of the soil, especially if the crop is an inoculated legume; secondly, it improves the physical condition of the soil; and thirdly, it supplies additional organic matter to the soil. The effects of all these on the next crop are usually very marked.

CHEMICAL FERTILIZERS

Farm manures do not always completely meet the needs of the soil, especially under modern methods of intensive cultivation. Farm manure also is not balanced in composition as regards the three important plant food constituents, namely, nitrogen, phosphorus and potash. The amount available is also insufficient to meet the annual losses through the removal of crops. Hence it is sometimes necessary to use substances known as chemical or commercial fertilizers. Chemical fertilizers also possess certain advantages over farm manures, in that the for-

mer are not so bulky and may also be applied in definite proportions, according to the requirements of the crops. Some chemical fertilizers are also readily available to the crop. For most money crops therefore farm manure may be supplemented with chemical fertilizers.

Chemical fertilizers are usually classified according to whether they contain one or the other of the important plant food constituents. They are therefore known as: (a) nitrogenous fertilizers, (b) phosphatic fertilizers, (c) potassic fertilizers and (d) calcareous fertilizers.

THE NITROGENOUS FERTILIZERS are so called because they contain available nitrogen in large quantities. The influences of nitrogen on crop growth are many: (1) it encourages the development of foliage, (2) it imparts deep green colour to the leaves, (3) in the case of cereals, it tends to produce plumpness in the seeds and (4) it tends to produce succulence or tenderness in the plant, a character which is desirable in certain crops. However, if improperly used in large quantities nitrogen may produce the following harmful effects on the crop: (1) it may lower the quality of the crop, (2) it may delay maturity, (3) it may decrease resistance to disease and (4) it may weaken the stems and cause lodging in cereals.

Some of the most common nitrogenous fertilizers which have been tried out in this country are the following: sodium nitrate— NaNO_3 , ammonium sulphate— $(\text{NH}_4)_2\text{SO}_4$, calcium cyanamide— CaCN_2 , cotton-seed meal, linseed meal or cake, mustard cake, castor cake or castor pomace, *neem* (*Melia azadirachta*) cake, groundnut cake, *mohwa* (*Bassia latifolia*) cake, *til* (*Sesamum indicum*) cake, poppy cake and *kusum* (safflower) cake.

Sodium nitrate as it comes on the market is a yellowish white crystalline substance, very soluble in water, and it very readily absorbs moisture from the air. When applied to the soil, it diffuses very rapidly, and is immediately available to plants. This fertilizer is applied to the crop at the rate of 100 to 300 lbs. per acre, depending upon the kind of crop and the nature of the soil. Sodium nitrate, however,

leaves an alkaline residue in the soil. This is probably due to the absorption of the sodium by the soil and the releasing of the nitrate ions which are generally lost by leaching or are used up by the plants. Thus the effect of large applications of sodium nitrate, over a series of years, is to produce a poor tilth in some soils due to the deflocculating action of sodium. This condition may be prevented by applying sodium nitrate and ammonium sulphate alternately, since the latter leaves an acid residue which will neutralize the alkaline reaction in the soil. In regions where there is a tendency towards the development of soil alkali, this fertilizer should be used judiciously.

Ammonium Sulphate is a by-product from the production of coke and illuminating gas from coal. As it appears on the market, it is in the form of greyish or greenish coloured crystals. In commercial forms it contains about 25 per cent of ammonia or 20 per cent of nitrogen. Ammonium sulphate is also very soluble in water. When applied to the crop, the ammonia has to be converted into nitrate with the help of certain nitrifying bacteria. For this reason it is not as readily available as the nitrate of soda, although certain crops like rice may be able to use the ammonium nitrogen without conversion to nitrate nitrogen. But this transformation is quite rapid, so that ammonium sulphate may be considered to be almost as quickly available to plants as the nitrate of soda, and may therefore be applied to such rapid-growing crops as sugarcane, where nitrogen is found to be deficient. Unlike nitrate of soda, this fertilizer leaves an acid residue in the soil. This is believed to be due to the absorption of ammonia by the soil or the plant, and the consequent accumulation of the sulphate ions. This fertilizer therefore is more especially applied on land which has a more or less alkaline reaction. Or, as suggested in the preceding paragraph, it may be applied alternately with sodium nitrate. On the other hand, this fertilizer should not be mixed with such alkaline-fertilizing materials as wood-ashes, basic slag, potassium carbonate and lime, as the combi-

nation with any of them will liberate the ammonia in the ammonium sulphate, and thereby decrease its value as fertilizer.

Experiments carried out in different parts of India seem to show that ammonium sulphate is more effective than the nitrate of soda, as a source of nitrogen. The fertilizer has been extensively applied for such crops as wheat, rice, sugarcane and potatoes. And even in certain acid soils in Assam, the application of ammonium sulphate at the rate of 160 lbs. per acre has given the best yields of tea.

Calcium Cyanamide is found in the market as a black crystalline powder, and is very light in weight. It is a product made possible by the development of electricity. It contains about 20 per cent of ammonia. It is not very readily available to plants, and undergoes some very complex changes in the soil. It is believed that ultimately urea is produced. As these changes take place, toxic compounds are also produced. Evidently it is a slow-acting fertilizer, and therefore should be applied some time before the crop is sown.

Experiments in India so far have shown no distinct advantage in the use of this fertilizer.

There are materials besides these three mentioned above which are carriers of nitrogen and have been used extensively in other countries; but so far their use in India is very limited. Some of the substances used are basic calcium nitrate, potassium nitrate and ammonium nitrate. The first of these three occurs naturally in many parts of India but most of the product is exported to other countries for use in the manufacture of gunpowder.

PHOSPHATIC FERTILIZERS are those which are carriers of phosphorus. This element is also very essential for plant growth, and in some soils it may be found to be lacking; hence the need for the application of a phosphatic fertilizer. The functions of phosphorus in the plant are various, namely : (1) it hastens the maturity of the crop, (2) it encourages root development,

(3) it decreases the ratio of straw to grain in cereals, (4) it strengthens the stems and thereby reduces the tendency to lodge in cereals, (5) it sometimes increases resistance to disease and (6) in some cases, it improves the quality of the crop. Unlike nitrogen, phosphorus if applied in excessive quantities generally produces no bad effect on the crop. On the other hand, the lack is not usually apparent to the eye, from the colour of the plant, as in the case of nitrogen, so that a phosphorus deficiency may occur and not be easily detected. One of the important functions of phosphorus is to balance or off-set the harmful effects of excessive nitrogen.

The most common phosphatic fertilizers are superphosphate, basic-slag and bone phosphate.

Superphosphate $[\text{CaH}_4(\text{PO}_4)_2]$ is one of the earliest substances used as a fertilizer, the process of manufacture having been invented by Sir John Lawes of the Rothamsted Experiment Station in 1843. It is made by treating ground rock phosphate, or any material which contains a large percentage of the tricalcic or bone phosphate, with sulphuric acid. The object is to render the phosphate more soluble. The term superphosphate is thus generally applied to any material containing as its chief constituent soluble phosphoric acid, whereas a phosphate is one which contains phosphoric acid as its chief constituent. Superphosphate occurs on the market as a brownish grey powder. It is partially soluble in water and gives an acid reaction to litmus paper. But the fertilizer on the whole does not impart an acid reaction to the soil, but on the other hand, it has a light neutralizing effect by making aluminium and iron insoluble. This fertilizer is sometimes known as an "acid phosphate."

Basic Slag $[(\text{CaO})_5\text{P}_2\text{O}_5 \text{SiO}_2]$ is a by-product of the manufacture of steel from ores containing phosphorus, and contains a large amount of iron and calcium hydroxides. It is a heavy dark grey powder and is extremely alkaline to litmus. It contains from 14 to 20 per cent of phosphoric acid. The phosphorus of this fertilizer is practically all soluble in citric acid and is therefore consi-

dered as available phosphoric acid. When applied to the soil it becomes almost immediately available, but is not considered to be as readily available as superphosphate.

Superphosphate when applied alone has been found to be beneficial for sugarcane in Gaya (Bihar) and rice in Manganallur (Madras Presidency).

POTASSIC FERTILIZERS are those that contain potash as their chief constituent. Potassium like nitrogen and phosphorus is also a very essential element for crop growth. This element may also be found to be in insufficient quantities in the soil for proper plant development. Hence the addition of a potassic fertilizer may sometimes be found necessary. The different functions of potash on the plant are: (1) it helps the transference of food materials from one part of the plant to another, (2) it is necessary for the development of the chlorophyll or green colouring matter in the plant, (3) it tends to increase plumpness in grains and (4) it tends to have a balancing effect between the phosphatic and nitrogenous fertilizer materials. Like phosphorus its presence in large quantities in the soil produces no detrimental effect on the crop.

The most common potassic fertilizer materials are the sulphate of potash, chloride of potash, potassium nitrate, wood-ashes, leaf-mould or garden compost, water hyacinth, garden weeds and the like.

Potassium Sulphate (K_2SO_4) and Potassium Chloride (KCL), also sometimes known as the muriate of potash, are the two most common sources of potassium for manurial purposes. Both these products generally occur together in nature in France and Germany, and are then known as kainit. These substances are immediately soluble in water and diffuse very readily in the soil, where they are absorbed by colloidal substances. The sulphate was one of the earliest fertilizers used for its potash, but muriate is becoming more and more popular as it has been found to be more effective. Both these fertilizers have a tendency to leave an acid residue in the soil.

An application of these fertilizers in this country has

not met with success, except in a very few cases. The experiments in Bombay with these fertilizers indicate that they are beneficial only for chillies and tobacco. In the Punjab, experiments on potassic fertilizers have resulted in financial loss. The experiments conducted at Meerut and Cawnpore on the value of the application of potassic fertilizers on wheat, indicate that the crop is not benefited by the application of this fertilizer. And even in Sambalpur (Orissa), where the soil is reported to be lacking in potash, the application of these fertilizers has not appreciably increased the yield of rice.

Other Sources of Potash which may be increasingly used in this country are wood-ashes, leaf-mould, garden weeds, water-hyacinth, etc. Wood-ashes generally contain from 5 to 6 per cent of potash in the form of potassium carbonate, which is alkaline in reaction. The potash obtained from these sources is even more desirable than from that of chemical fertilizers, in that the former do not leave an acid residue in the soil.

CALCAREOUS MANURES are those which are rich in calcium, or calcium and magnesium. Calcareous manures, however, were not generally considered as fertilizers because it was believed that they were not plant foods, but only soil amendments, or substances which modify the physical condition of the soil. This distinction, however, is not generally held at present, as calcium is also an essential food element for the plant. Among the most common calcareous manures are lime in its different forms and gypsum. The application of lime to Indian soils is very limited, being restricted to the correction of soil acidity or the improvement in the structure and tilth of clay soils. Gypsum is sometimes used for the correction of soil alkalinity in the presence of sodium carbonate. The application of lime in this country has not proved beneficial to crops, probably because soils in this country, especially the alluvial soils of the Indo-Gangetic plain, contain the calcium element in sufficient quantities for crop production. Even with acid soils in

Assam, experiments carried out in the Tocklai Experiment Station indicate that no advantage has resulted from the application of lime. The use of gypsum for the correction of soil alkalinity is limited because of the high cost of this material. But where it can be had at low cost, the material may be used more profitably in the conversion of sodium carbonate into sodium sulphate which is a salt less injurious to plants than the carbonate.

Under the term MIXED FERTILIZERS the following fertilizing materials that have been tried in this country may be mentioned:

- | | |
|-------------------|---------------------|
| (1) Niciphos, | (4) Nitrophoska, |
| (2) Leunephos, | (5) Nitrochalk, |
| (3) Diamminophos, | (6) Sennaphos, etc. |

These are mixtures of materials containing phosphorus and nitrogen in someone of the available forms. Ammophos, for instance, is a mixture of materials containing ammonia and phosphates mixed in certain proportions. These names are only trade names and do not therefore signify any definite chemical composition. For instance, ammophos as sold in the Indian market is found in the following ratios: 13/48 and 20/20. While the mixing of fertilizer is very advisable in cases where soils are known to be lacking in more than one of the essential elements, the soil conditions in India are such that in the majority of cases, the addition of phosphates is unnecessary; and therefore the application of ammophos, for instance, may mean a waste of the phosphate-bearing material. It would be more economical in such cases to add more of the nitrogen-bearing material. This is undoubtedly one of the disadvantages of a mixed manure. On the other hand, soils which are deficient in both nitrogen and phosphorus, could be greatly benefited by the application of such a mixed fertilizer. The rice crop in certain parts of Bihar and Orissa has been found to be benefited by the application of phosphatic fertilizers. In such soils the

application of a fertilizer carrying both the elements, nitrogen and phosphorus, may be found useful.

ORGANIC MANURES

There is another class of substances generally known as "CAKES"; and their use in India as fertilizers is growing in popularity. The following are some of those commonly used in this country: (1) castor cake or pomace, (2) cotton seed meal, (3) mustard cake, (4) linseed cake, (5) *neem* cake, (6) groundnut cake, (7) *mohwa* cake, (8) *til* cake, (9) poppy and (10) *kusum* cake.

Experiments in India with these cakes generally indicate a definite advantage in their use as fertilizers. In general, their value compares favourably with animal manure. In Madras, oil-cakes have been found beneficial for sugarcane and rice; and their more extensive use is advocated. In Bombay, oil-cakes have been found to be good in all cases, and particularly for such crops as sugarcane, rice and tobacco. Punjab experiments indicate that castor and *mohwa* cakes do not give as good results as mustard (*toria*) cake. In the United Provinces oil-cakes are used even more extensively than in the other provinces, and for various crops. While mustard cake and also linseed cake may be used as fertilizers, the practice, is not to be recommended; because these are generally fed to animals and are therefore more expensive. However, if the urine and droppings from the animals thus fed with these substances are properly conserved, much of the nitrogen in these fertilizers will ultimately reach the soil.

The non-edible oil-cake like *neem*, *mohwa* and castor should be the ones to be extensively used for manurial purposes. While poppy and safflower (*kusum*) cakes have been found to give a large increase in yield, yet these cannot be used extensively as they are available in small quantities only. The application of oil-cakes in the United Provinces has been found to be advantageous for such crops as potatoes, sugarcane, wheat and rice.

The amount of oil-cake to be applied to the soil varies

with the soil in different localities; but an application of 300 to 400 pounds per acre may be considered as an average. One point in favour of the application of oil-cakes is that no detrimental effect is known to result from their application.

From the national standpoint, a large export of oil-seeds to foreign countries should be discouraged; as this would rob the country of the fertilizing materials which the soil needs so badly. The Board of Agriculture also made reference to this point as early as 1919. The oil may be exported after it has been extracted thus allowing the oil-cakes to be fully available for manurial purposes.

BONE PHOSPHATE—Bones are the chief source of phosphates that exist in combination with organic matter and were for a long time the main source of phosphorus for manurial purposes. In India, bone phosphates are available in two forms: bone meal and bone-char. Bone meal, as it comes on the market, is a dusty powder possessing a characteristic odour. It contains about 27 per cent of phosphoric acid. Bone meal is slow in its action, and is therefore not immediately available to the crop. However, its availability is dependent to a large extent on the fineness of the substance when applied to the soil. In the soil it is slowly converted, in the presence of water, into a soluble mono-calcium phosphate which becomes available to the crop.

Bone-char is usually made by lightly firing the bones so as just to char or blacken them throughout their thickness. This makes them brittle and porous and easily crushed to powder. In this form the phosphoric acid, for which this material is applied to the soil, becomes more quickly available to the crops. Although about 50 per cent of the nitrogen is lost in the process of charring, nearly all of the phosphoric acid is preserved. Bones of cattle and other animals can always be easily had around the villages in India, and are probably the cheapest source of phosphates for crops. The process of charring can easily be carried out on the farm and does not require any skill.

In connection with phosphatic fertilizers, experiments in India, on the whole, indicate that most soils in this country are not lacking in phosphorus. However, there are a few areas in which the addition of phosphatic fertilizers, such as bone meal or superphosphate, has been found to be beneficial in increasing the yield of crops. Experiments at Pusa show that the soil of that area can profitably be improved by the addition of bone meal in the production of such crops as potatoes, gram, oats or wheat. Experiments at the Aduthurai farm indicate that the soils of the Tanjore delta in the Madras Presidency are generally deficient in phosphates, and therefore would probably be benefited by the application of phosphatic manures. The soils of the Assam Valley on the other hand, though found lacking in phosphates, have not been benefited by the application of bone-meal.

Bone meal alone, has also been found to be beneficial for rice in Bombay and Bihar. In the United Provinces the only experiment which shows an increase in yield due to the application of bone meal, is the one reported from Partabgarh on rice.

POUDRETTE, a material which consists largely of night soil (human excreta) and which is sometimes available near large cities and towns, is one of the most valuable form of fertilizers, as it is rich in nitrogen and all the necessary elements for plant growth. Experiments carried out in different parts of India with this form of fertilizer have shown that large increases in yields of crops are obtained by its application. The experiments at Cawnpore, in the United Provinces, with poudrette have shown that the yields of potatoes, sugarcane and maize were nearly doubled. Experiments carried out at the Arbhavi and Dharwar farms in the Bombay Presidency for a series of years have shown that this form of fertilizer is very suitable for such crops as sugarcane, maize, *jowar* and cotton.

MUNICIPAL SWEEPINGS are another source of organic manure which can be had near cities and large towns. This is a heterogeneous material which consists of vegetable

wastes, rags, papers, droppings from animals, leather, hair, factory wastes, etc.

A COMPOST is a material generally made of alternate layers of manure and vegetable or other organic matter. The manure supplies the organisms which help to decompose the mass through their biological activities. For the proper functioning of these organisms, the mass should be kept moist. This moistening also helps to retain the ammonia evolved in it. In making compost on the farm, the following materials are usually made use of: (1) the farm wastes, which may consist of grasses and weeds of all kinds, crop residues, etc., (2) the cow dung, (3) the litter and sweepings from the cattle sheds and (4) wood-ashes. A Municipal compost is made of alternate layers of municipal wastes and night-soil, which is then allowed to ferment and decay, until the foul odour is considerably reduced. This material generally becomes ready in about three months from the time the making of the compost is begun. Both of these composts are rich in plant food constituents. Results of experiments in this country seem to show that the latter, that is, the municipal compost, is even richer than the former in those food elements necessary for plant growth.

EVALUATION OF MANURES

The value of farmyard manure and other kinds of manures produced or obtained on the farm, depends on several factors, such as the kind of manure, the method of storing, the manurial ingredients contained in them, and also the amount of supply. But farmyard manure cannot be properly evaluated because of the fact that it not only supplies certain manurial ingredients to the soil; but it also more or less improves the structure of the soil, which improvement cannot be easily measured. Commercial fertilizers on the other hand, are usually bought for the amount of those fertilizing ingredients which they contain, and their values can therefore be compared with one another.

Supposing, for instance, that the price of ammonium

sulphate, containing 20 per cent of nitrogen is quoted at Rs. 4-8-0 per maund. This means therefore that the price of 20/100 of 1 maund, or 8 seers, of nitrogen, is Rs. 4-8-0, that is, the price of one seer of nitrogen in ammonium sulphate is nine annas.

Taking the price of nitrogen in the ammonium sulphate as a standard, the value of castor cake may be calculated in this way.

Since castor cake contains 5 per cent of nitrogen, one maund of castor cake therefore will contain about 2 seers of nitrogen. Its value will therefore be (9×2) or Re. 1-2-0. Castor cake also contains about $2\frac{1}{2}$ per cent of P_2O_5 . If its value is considered to be half that of nitrogen, then the value of a seer of phosphoric acid contained in a maund of castor cake will be Re. 0-4-6. Therefore the value of these ingredients in a maund of castor cake is Re. 1-6-6. The potash contained in the cake may be considered to be of no value, as most Indian soils are not lacking in it. However, the cake contains organic matter which has some value in improving the structure of the soil. If this is priced at 3 annas a maund, the total value of castor cake will be about Re. 1-9-6 per maund.

This valuation of animal manures and oil-cakes does not give the real agricultural value, as it is difficult to estimate the residual effects and consequent improvement in various ways in the soil.

ARE FERTILIZERS PROFITABLE

As to whether the application of a certain fertilizer will be profitable or otherwise is not an easy matter to decide. The only way of finding out is to apply a particular fertilizer to the soil in question. This may be tried in a small area. Before doing this, a farmer would be well advised if he would first consult the local authorities of the agricultural department.

The maximum profit to be derived from the application of manures and fertilizers depends to a large extent on various factors such as soil, the price of the fertilizer,

the kind of crop for which the fertilizer is being applied, the climate, the system of cropping, the price obtained for the crop produced and various other factors. The amount of fertilizer applied should therefore be determined largely by local conditions. And, as the price of chemical fertilizers in this country is rather high, and the prices obtained for the crop produced are generally very low, it is probably more advisable in most cases not to apply large amounts of these fertilizers.

At the present time a great number of investigations regarding the utility or otherwise of the various fertilizers in question are being carried on; so it is hoped that as time goes on more definite information will be available on this question of fertilizers.

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CHAPTER X

WEEDS

Weeds constitute an important problem in agriculture. The losses due to weeds, although generally recognized, are often far greater than are usually realized. The presence of weeds directly and indirectly reduces the yield of crops, for they not only directly rob the crops of their plant food and water, but they also occupy the space where crop plants may grow, or, by competing with crops for sunlight and moisture, considerably affect the yield of crops. Weeds also frequently harbour insect pests and fungous diseases which later attack the crop. The cost of removing weeds also adds to the cost of production and consequently reduces profits. It therefore becomes desirable for one to know how to control weeds, in order to get the maximum profits from the crop. However, the subject of weed control has not had the attention it deserves from agricultural scientists in this country, so that methods of weed control have not been thoroughly worked out.

A weed may be defined as being any plant growing out of place. That is, even a crop plant may become a weed if it grows in places where it is not wanted. A plant becomes a weed because of its persistence in growing amongst crop plants. This aggressive character of weeds is due largely to several factors such as their methods of propagation, habits of growth and hardiness.

Weeds propagate themselves in various ways. They may either reproduce themselves vegetatively, that is, by roots, tuber, bulbs, pieces of stems; or sexually by means of seeds. Thus some of the most troublesome weeds like *doob*, *kans* and *motha* propagate largely by means of their underground stems, whereas the bind weed propagates

largely by means of its roots. On the other hand, most plants like *bathua* and *churai* spread very rapidly because of the large number of seeds produced in each plant. It is therefore very important for one to know the general life-history of each plant in order to be able to combat them judiciously.

The control measures that have so far been adopted for combating weeds may be grouped as follows:

1. Preventive measures:
 - (1) Use of pure seeds.
 - (2) Clean cultivation.
 - (3) Use of irrigation water free from weed seeds.
2. Remedial measures:
 - (1) Biological.
 - (2) Chemical.
 - (3) Mechanical.

PREVENTIVE MEASURES

1. USE OF PURE SEEDS—One of the important ways by which weeds are introduced into cultivated fields is by the use of impure seeds. This can be prevented by the use of pure seeds, that is, by sowing crop seeds which do not contain weed seeds. In this connection, it may be pointed out, that countries like America have special laws against the sale of impure seeds and officers whose main duty is to test crop seeds and certify their purity. No seeds are allowed to be sold for sowing purposes which have not been certified by seed-testing officers. Some of our most troublesome weeds have been introduced not only from different parts of India but also from foreign countries.

2. CLEAN CULTIVATION—The spread of weeds may also be discouraged by clean cultivation, which consists in the removal of all weeds by various ways such as

pulling, hoeing and cultivating. Boundaries of fields, corners, waste places, irrigation channels and roadsides, all should be kept clean of weeds, so that they are not allowed to produce seeds. After a crop is harvested any weeds growing at that time should be removed so that they do not produce seeds for the next year's crop.

3. USE OF IRRIGATION WATER FREE FROM WEED SEEDS—Another very common way by which weed seeds are introduced into an irrigated farm is through irrigation water. When the irrigation channels lie unused, weeds growing along their banks drop their seeds in the channels; consequently, when the first water comes along, it washes the seeds into the fields where this water is applied. In canal colonies one should take care not to use the first water in the fields for the simple reason that it usually contains a great number of weed seeds. In sewage-irrigated farms also, weeds, find their way into the sewage irrigation water from various sources, such as kitchen wastes and undigested seeds, and seeds from sweepings and rubbish; and they ultimately find their way into the fields.

REMEDIAL MEASURES.

1. BIOLOGICAL—It is a well-known fact that certain crops are almost completely destroyed by certain diseases and pests. This knowledge is made use of in some places in the attempt to eradicate certain of the most serious weeds. That is, certain fungous diseases or insect pests which are known to attack and destroy such weeds, are propagated and then liberated, in places where those weeds are found to be serious. In some cases good results have been reported. However, this method is quite new and has not been used to any extent in this country. As an example of what can be done in the control of weeds by such methods, the work carried on in Madras and Bombay in connection with the eradication of certain species of cactus with cochineal insects may be cited.

These insects which belong to a genus of mealy bugs, protect themselves with a covering of a waxy substance. It has been reported that these insects feed on *Opuntia elatior*, a species of cactus, and ultimately destroy it. In a work of this kind it is necessary that expert supervision and guidance be obtained, as otherwise it may prove disastrous to crop plants which may be attacked by the same disease or insect. This method therefore cannot be adopted by farmers, but is one that Governments can take up.

2. CHEMICAL—The use of chemical compounds in the eradication of weeds is becoming more and more common. Some of the most common chemicals used in the control of weeds are copper sulphate and sodium arsenite. Some others of less importance are iron sulphate, sulphuric acid, carbolic acid, sodium chloride and ammonium salts. The strength of the solution depends on several factors, and it has therefore to be found out by actual field trials on the particular weeds which are to be eradicated.

The method of application is also dependent on the character of the chemical as well as of the plants on which it is to be used. Materials such as copper sulphate or sodium arsenite may be used in the form of a liquid spray or in the form of dust. In either case, application is usually made by the aid of a machine. Care should be taken that live-stock are not allowed to come to the fields where such chemicals are used, as these substances are poisonous.

The use of chemical substances as weed-killers is still in an experimental stage in this country, and has not as yet been extensively adopted as it is rather expensive.

3. MECHANICAL—Some of the mechanical means by which weeds may be controlled or eradicated are ploughing, sometimes with special types of ploughs, cultivating, harrowing or using the bakhar, mowing, hoeing and pulling. These are the methods now commonly used, although they also involve a great deal of labour and expense.

SOME OF THE MOST COMMON WEEDS

It is not possible to give a complete list of weeds, hence only a few of the more obnoxious and widely distributed are discussed in this chapter.

Weeds may be classified in various ways, but in this country they are often referred to as *kharif* and *rabi* weeds, depending upon the crop with which they are associated. The life-history, distribution and control measures of some of the most common and troublesome weeds are given below.

A: SOME KHARIF WEEDS

1. *Cynodon dactylon* Pers:—*Doob* or *hariali*, a member of the grass family, is one of the most common weeds on the farms in this country. It is found all over India from Cape Comorin to Kashmir. In the south it is generally known as hariali grass, while in north India it is commonly known as doob. While this weed is most troublesome in cultivated fields, it is also one of the most valuable of pasture or fodder grasses in most parts of India, and is also used extensively for lawns, and as a soil-binding plant for bunds in order to prevent erosion. This grass is commonly found in good soils, and will not grow well in the shade. It is a very hardy plant, much-branched, fairly leafy and possesses numerous underground stems. The above-ground branches may be erect or prostrate which later often develop roots at the nodes. This grass usually grows in patches forming, when thick, a mat-like appearance on the surface of the soil. It has been noted that this grass is peculiarly subject to a type of smut.

It is very difficult to eradicate this grass by ploughing, as bits of the stems that are broken by the plough may be buried and produce new plants. For this reason the mould-board plough is preferred to the desi, as the former generally does not break the stems up into small pieces but loosens clumps which can be removed. However, the soil infested with this grass should not be ploughed too deep as the broken portion of the stems are apt to be buried deeper

in the ground. After ploughing the uprooted grass should be removed either by hand or by harrows.

Land badly infested with this grass, if planted to *jowar*, wheat or any dense growing crop, for a year, or two, will be more or less free from it as it is smothered out by such crops.

2. *Saccharum spontaneum* L. (*Kans*):—This is another member of the grass family and is also very commonly distributed all over India. It is a tall perennial grass with a creeping root stock. The stems are usually erect and grow to a height of about 4 to 6 feet. The grass propagates itself by means of the underground creeping stems or rhizomes, and also by seeds carried by the wind. The grass is not altogether useless as it is sometimes used in thatching, the stems are also used for making country pens, and the grass is sometimes grown on banks of channels and bunds in order to prevent erosion. More recently it has been used as a parental stock for the improvement of sugarcane varieties in India.

This weed may be controlled by deep ploughing followed by harrowing, in order to remove the uprooted stems. Or it may be controlled by frequent cultivation of the soil. There have been developed special ploughs in various parts of the country for the purpose of eradicating this very troublesome weed. Wherever this weed occurs, care should be taken not to allow it to produce seed, as the fields may again become contaminated with *kans*.

3. *Eragrostis cynosuroides*, Beauv.:—*Kus* or *kussa* is also another member of the grass family. It is a perennial grass with stout and creeping root stocks. It is very common throughout the plains of India and in the Deccan. It grows in all kinds of soils including the low-lying usar lands of the plains. The stems are more or less erect and grow to a height of 1 to 3 feet. This grass is also not useless as it produces fibre which is used for making ropes.

The usual method of eradicating this grass is by ploughing the land with a mouldboard plough as deep as possible. The land is then harrowed, in order to remove the uproot-

ed rhizomes. This method should be repeated several times until the fields are free from this weed.

4. *Cyperus rotundus*, Linn. (*Motha*):—This plant, although it is similar in appearance to grasses, is, botanically, not a grass but a member of the Cyperaceae or the family of sedges. The common English name for it is *nut grass*. It is so called on account of its grass-like appearance and also because of the nut-like underground stolons which it possesses. It is a perennial, but it thrives during the rainy season, or whenever there is sufficient moisture for its growth. Unlike the grasses, *motha* has a triangular stem and possesses three-ranked leaves and can therefore be easily distinguished from other grasses which possess round stems and alternate or two-ranked leaves. The plant usually possesses a single stem.

The plant reproduces itself in two ways: by means of seeds and by the underground stolons or tubers. These tubers contain stored food material which enables them to produce new plants. The tubers are also quite resistant to extremes of temperatures and to drought, thus rendering this plant quite hardy and therefore very troublesome to eradicate. The depth at which these tubers occur in the soil depends much on the nature of the soil and the amount of moisture it contains. In moist heavy soils they are usually found near the surface, while in dry sandy soils they occur at greater depths, even two feet or more.

This is one of the most difficult weeds to eradicate, as it reproduces both by the tubers and by seeds. The tubers are very numerous and small in size, making their removal extremely difficult. Deep ploughing in the case of this weed is not very effective in eradicating it, as it simply digs up the soil and buries the tubers deeper. Clean and frequent cultivation, which will deplete the stored food in the tubers, thus slowly starving the plant to death may be adopted as one of the control measures.

This weed also spreads itself rapidly by seeds. So every effort should be made not to allow the plants to mature and produce seeds. One of the easiest ways to

check seed production is by cutting the aerial shoots before flowering by sickles or other means, if clean cultivation is impracticable.

In some countries spraying with sodium arsenite has been tried with some success in the control of this weed. But under Indian conditions this method may not be economical.

5. *Tribulus terrestris*, Linn. (*Gugru*):—This plant is a member of the *Zygophyllaceæ* or the caltrop family. It is a native of the Mediterranean regions and has therefore been introduced into this country. It is a low, trailing, annual plant, much-branched with hairy stems which spread on the ground in all directions to a distance of about four to six feet from the centre. It is common almost throughout India, ascending the Himalayas up to a height of about 11,000 feet.

It propagates itself by means of seeds contained in fruits which possess sharp spines. These spines help the dispersal of the seeds by sticking to objects which may come in contact with them. For instance, they may stick to the rubber tyres of cycles, motor cars and aeroplanes, and in this way be carried long distances. The sharp spines, however, sometimes puncture the tyres, whence this plant got its popular name of "puncture vine" in the United States of America.

The young leaves and stems of this plant are sometimes used as pot-herbs or greens, and other parts of the plant are claimed to possess some medicinal value.

The weed may be controlled by removing the plants before the development of fruits, as each plant is able to produce from ten to twenty thousand seeds.

6. *Trianthema monogyna*, Linn. (*Pathri*):—This plant is a member of the *Aizoaceæ* or carpet weed family. It is common throughout India. It constitutes one of the most conspicuous and aggressive weeds of cultivated fields. While it grows in all kinds of soils, it thrives best on rich lands; and if not controlled, prevents the growth of crops. The plant is pro-cumbent and trailing in habit

producing a mat-like growth. The stems are succulent. The plant propagates by means of black seeds which are contained in a sac-like structure at the axil of the petiole of the leaf.

The best method to control this weed is not to allow the plant to produce seeds. It should therefore be destroyed before it reaches maturity. Mature plants should not be fed to cattle as the seeds of this plant pass through the digestive tract of an animal without being digested. This weed cannot be controlled by a smothering crop.

B: SOME RABI WEEDS

1. *Chenopodium album*, Linn. (*Bathua*):—This plant is a member of the Chenopodiaceae or “goose-foot” family. The weed is one of the most troublesome in wheat fields as well as in the vegetable gardens throughout northern India. The plant is either erect or ascending, growing in the plains of India to a height of one to three feet. It is sometimes used as a pot-herb.

The plant is best controlled by not allowing it to produce seeds. It should therefore be cut or removed before it is mature. When cutting, one should be careful to cut the plants below the ground as otherwise they may sprout again. If the plants have reached maturity they should not be fed to cattle as the seeds usually pass through undigested, and ultimately reach the fields along with the manure.

2. *Argemone Mexicana*, Linn. (*Leb*):—This plant is a member of the Papavaraceae or the poppy family. It is a native of America and has been introduced into this country. It is now commonly found all over India. It grows along roadsides and in waste places, but is also common in cultivated fields particularly in *barani* lands. The plant is a spiny, herbaceous annual, stands erect and varies in height from 2½ to 4 feet approximately. The flowers are bright yellow, and the leaves are lobed and very prickly. Its juice is also yellow. The seeds are borne in

bristly capsules which, when mature, break open and disclose a great number of seeds. Each plant is able to produce from 20,000 to 30,000 seeds.

The weed may be controlled by removing the plants when young and not permitting them to produce seeds.

3. *Convolvulus arvensis*, Linn. (*Chandvel*):—This plant is a member of the Convolvulaceae or the morning glory family. It is also very common in cultivated fields almost throughout India. It is a very troublesome weed almost throughout the temperate and subtropical regions of the world.

The plant is a perennial and possesses fleshy root stocks which produce slender stems which twine around other plants. Hence the plant is more commonly known as a bind weed. Its deep-rooting habit makes it very hardy and by twining it chokes out crop plants. It propagates itself by seed as well as by root cuttings.

The weed is very difficult to eradicate as any portion of the root stock is able to produce a new plant. It may be controlled by practising clean cultivation for one season and thereby starving out the root stocks.

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