

Genetics and Animal Breeding

by E. J. Warwick*†

INTRODUCTION

It is estimated that approximately fifty-six cents out of each dollar received as income by the farmers and ranchers of the United States comes from the sale of livestock and livestock products, including meat, wool, hides, and dairy products.¹ The nation's agriculture therefore has a terrific stake in the efficiency of livestock in converting feedstuffs into products more useful to man.

Remarkable progress has been made during the past hundred years in breeding animals which are more productive than their ancestors and which at the same time produce products meeting the exacting demands of the consuming public. For example, the average fleece weight of sheep has practically tripled since 1840. At that time it was estimated that the average sheep in the United States produced approximately three pounds of grease wool; today, the average is almost nine pounds. The Texas Longhorn steer, a producer of tough, stringy meat and requiring many years to mature, has been replaced by faster-growing, more efficient types which produce tender, palatable meat. Many other examples of progress in animal breeding could be included here.

In spite of the remarkable progress that has been made, however, much still remains to be done. A glance at the animals being received on any major livestock market any day of the year will convince even the most enthusiastic supporters of improved livestock that the average animal going to market leaves much to be desired from the standpoint of quality. In other words, there are animals which meet the demands of the markets fairly readily, but the average merit is still far too low. Likewise, average productivity is lower than it should be. For example, the average sow in the United States raises less than six pigs per litter. In the better herds where breeding for prolificacy

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¹ Rice, V. A., *Breeding and Improvement of Farm Animals*, (3rd ed., McGraw-Hill, 1942).

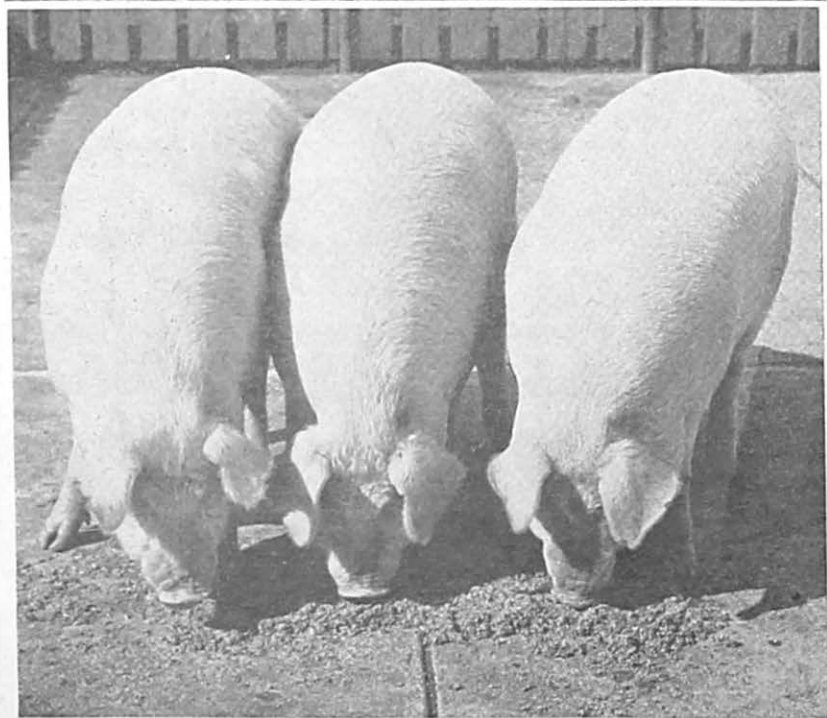
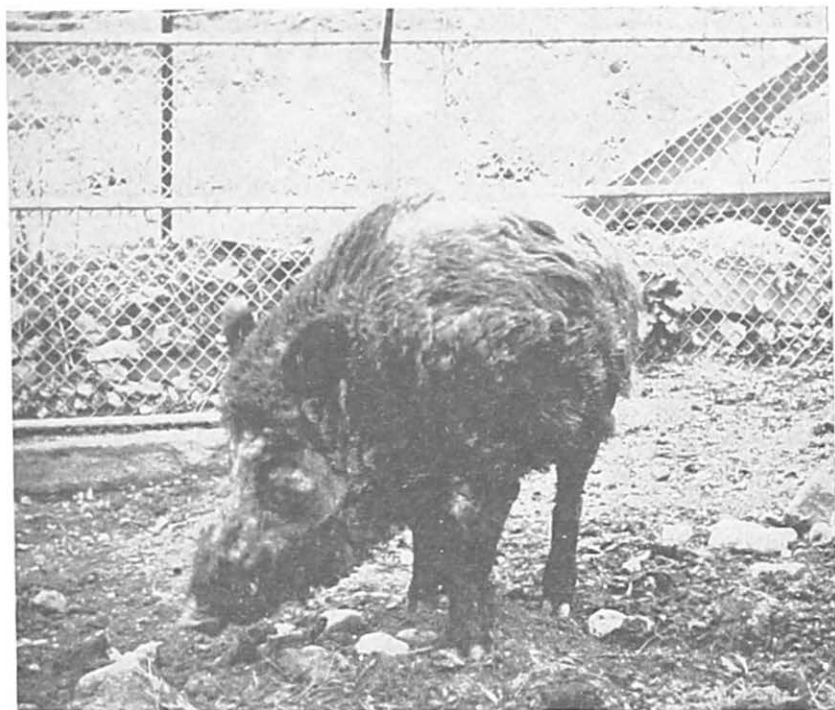


Fig. 1.—A wild boar (top) contrasted with the pen of fat barrows which won the grand championship at the 1944 Pacific International. Modern hogs are believed to have descended largely from wild hogs of the same type as this wild boar.

has received careful attention, this average is improved by 35 per cent or more in many cases.

From time immemorial animal breeding has been an art, and it is only within recent years that definite facts regarding the scientific basis for improved breeding have become available. As is inevitable with any art, certain practices having no scientific foundation have become established. Moreover, in the layman's eye, the entire breeding process has tended to be shrouded in mystery and to partake somewhat of the supernatural. As would be expected under such circumstances, many mistaken fads and fancies, together with many half-truths, are readily accepted as facts. The material in this bulletin is designed to give a condensation of the known facts in regard to animal breeding and heredity, and to briefly summarize their applications to practical operations.

Knowledge of the basic principles of heredity dates from the work of an Austrian monk, Johann Gregor Mendel, who did experimental breeding with peas in the garden of his monastery during the period from 1857 to 1865. Mendel published the results of his work in 1866 in an obscure journal. In it they escaped the notice of the scientific world until 1900 when they were rediscovered independently by three European biologists. Our knowledge of heredity is unique in the fact that it resulted from the work of an amateur who was not trained in science and who did his work merely as a hobby. It is of further interest that Mendel was so far ahead of his time that the worth of his work was not recognized until thirty-four years after publication and many years after his death.

It is of interest to persons residing in the state of Washington that Mr. W. J. Spillman, at that time working with the U. S. Department of Agriculture and stationed at the State College in Pullman, rediscovered Mendel's principles and published his results in 1901 without prior knowledge that they had been rediscovered by European biologists the previous year.

During the forty-seven years since the rediscovery of Mendel's principles, many additional discoveries have been made which add greatly to the knowledge Mendel had. However, the basic principles as set forth by Mendel have been proved correct. Inheritance in both plants and animals follows the biological laws discovered by Mendel.

FUNDAMENTAL BASIS OF HEREDITY

The bodies of all animals are made up of millions and even billions of tiny cells which are microscopic in size. Each cell contains a number of pairs² of bodies called *chromosomes*, which are the bearers of the

² Each species of animals has a certain number of pairs of chromosomes which is constant for all animals in the species. Most farm animals have 20 to 30 pairs.

materials producing hereditary variations. The chromosomes themselves carry the extremely tiny particles called *genes*, which are the basic hereditary material. Each animal has hundreds or even thousands of pairs of genes. Chromosomes and genes are present in pairs in every cell of the body. In the sex glands (the testicles and ovaries), the chromosome structure becomes modified or "reduced" so that each germ cell (*sperm* of the male and *ova* or egg of the female) produced contains only one chromosome and one gene of each pair. Nature has thus provided a mechanism for keeping the hereditary material from doubling at each generation and in this way maintains a balance.

Genes Seldom Change

For all practical purposes, the genes can be thought of as unchanged from one generation to the next. The observed differences between animals are usually due to different combinations of genes being present rather than to the formation of new ones. Genes do change occasionally (each gene probably changes about once in each 100,000 to 1,000,000 animals), but so seldom that such changes are of little importance in breeding operations. These gene changes (technically known as *mutations*) have served as a very important tool in the study of the principles of heredity, however, and ways of producing them artificially in flies and other organisms by means of X-rays and ultra-violet rays have been discovered. Once in a great while a mutation occurs in a farm animal and if it produces a visible effect, the animal carrying it is commonly called a "sport." Such "sports" are occasionally of practical value or of value in establishing such things as breed trademarks.

For example, a dominant mutation from the horned to the polled type has occurred in horned breeds of cattle, and the birth of polled "sports" has resulted. These animals have been used by breeders to establish polled strains of both Hereford and Shorthorn cattle. The best-known example of how this was done is the story of the establishment of the first polled Hereford strain which descended from known purebred Hereford animals on both sides.

In 1901, Mr. Warren Gammon and Son of Des Moines, Iowa, became interested in polled cattle. In order to locate foundation stock, they sent out letters to 2,500 Hereford breeders. As a result of their search, they located ten polled cows and four polled bulls. Several of these were purchased and formed the foundation for the present-day polled Herefords.

A Simple Type of Inheritance

In the simpler types of inheritance, a certain character is usually affected by only one gene. Since the genes are often spoken of as *factors*, we speak of such simple inheritance as being due to a single factor.

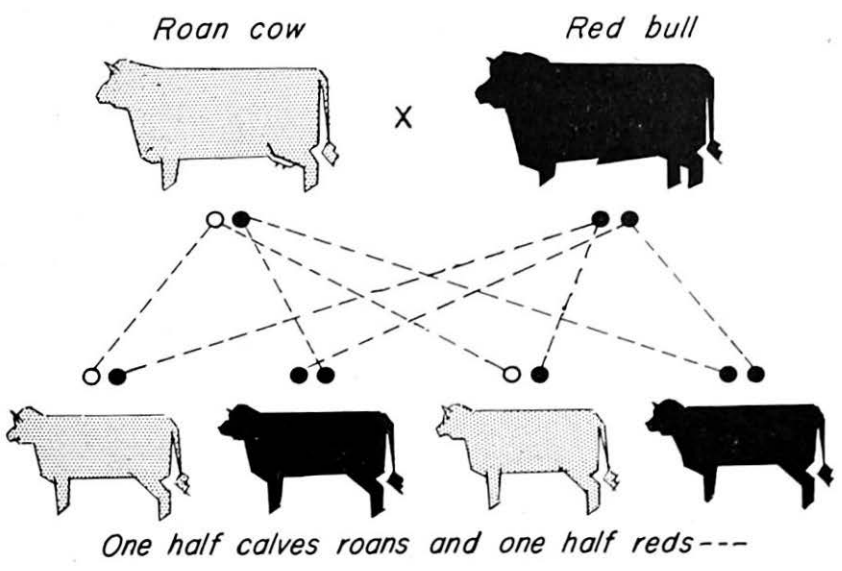
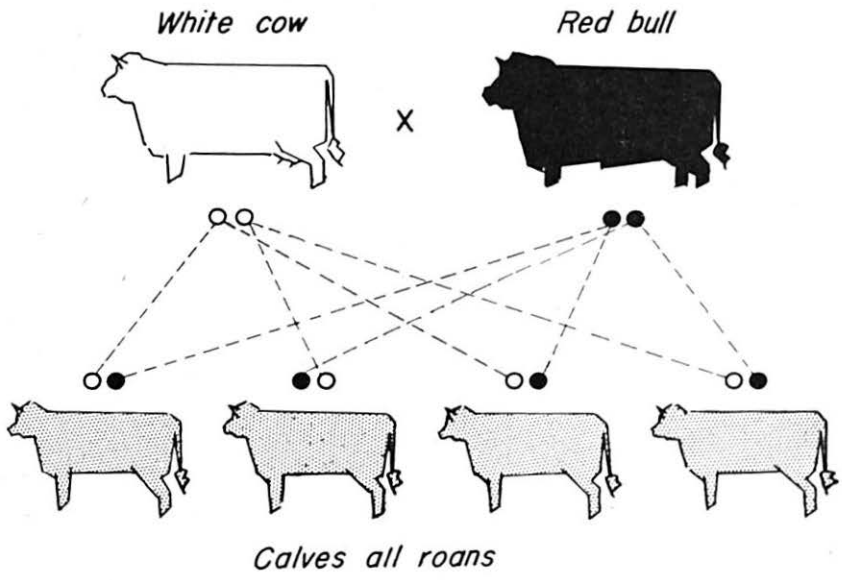


Fig. 2.—Diagrammatic illustration of the inheritance of color in Shorthorn cattle.

Realizing that all genes are present in the body as pairs, a well-known example will illustrate a single-factor difference. In Shorthorn cattle there is a pair of factors (genes) responsible for the color of the hair. One of these factors tends to make the animal red in color, while the other leads to the production of white. Remembering that these factors are always present in the animal in pairs, we find that an animal having two factors for red is actually red and an animal having two factors for white is white, but that an animal which has one factor for red and one for white is neither, but is an intermediate or roan color.³ A consideration of the behavior of these factors will go far toward giving the student an understanding of the basic mechanism of heredity.

Naturally, since the red animal contains only factors for the red color, its germ cells will all carry the factor for red. Likewise, the white animal, carrying only two factors for white, will produce germ cells of only one kind. However, when these two animals are mated, the cells of the resulting offspring will contain one factor for red and one for white. Its color will be roan—a mixture of red and white. The roan animal is mixed in inheritance, and when it becomes old enough to reproduce, it will produce two kinds of germ cells. One kind will contain a factor for red, while the other will contain a factor for white. The laws governing the process are such that equal numbers of the two types of germ cells are produced. Thus, if a roan animal is bred back to a red one, one-half the offspring will be red; the other half will be roan. Likewise, a roan animal bred to a white one (not shown in Figure 2) will produce two kinds of calves, approximately equal numbers of roan and white. It should be borne in mind that the various possible combinations occur at random and that the numbers of offspring will be equal only when relatively large numbers are concerned. This is governed by the laws of chance and operates in just the same manner as the results obtained by flipping coins. Everyone knows that, if a penny is flipped enough times, the number of heads and tails will come out about even. However, the laws of chance make it possible that in a particular series of, say four tosses, a person might get all heads, might get all tails, or he might get three of one and only one of the other. In exactly the same manner, it is entirely possible to get four white calves in a row when we expect half white and half roan.

Dominant Factors

In the case considered above, each gene or factor produced a visible effect, whether it was present with another just like it or

³ This hypothesis seems to fit most cases, but a few Shorthorns are born in which the color does not occur as expected. These cases are apparently due to a number of modifying factors, with small effects.

whether it was present with one of a different kind. In another type of single-factor inheritance, the phenomenon of "dominance" occurs, in which a factor has its full effect regardless of whether it is present with another just like it or whether it is present with the other member of the pair. This is true in the case of horned and polled cattle. The polled character is dominant over the horned condition and it is impossible to determine without breeding tests whether a polled animal is pure for the character or whether it carries a factor for

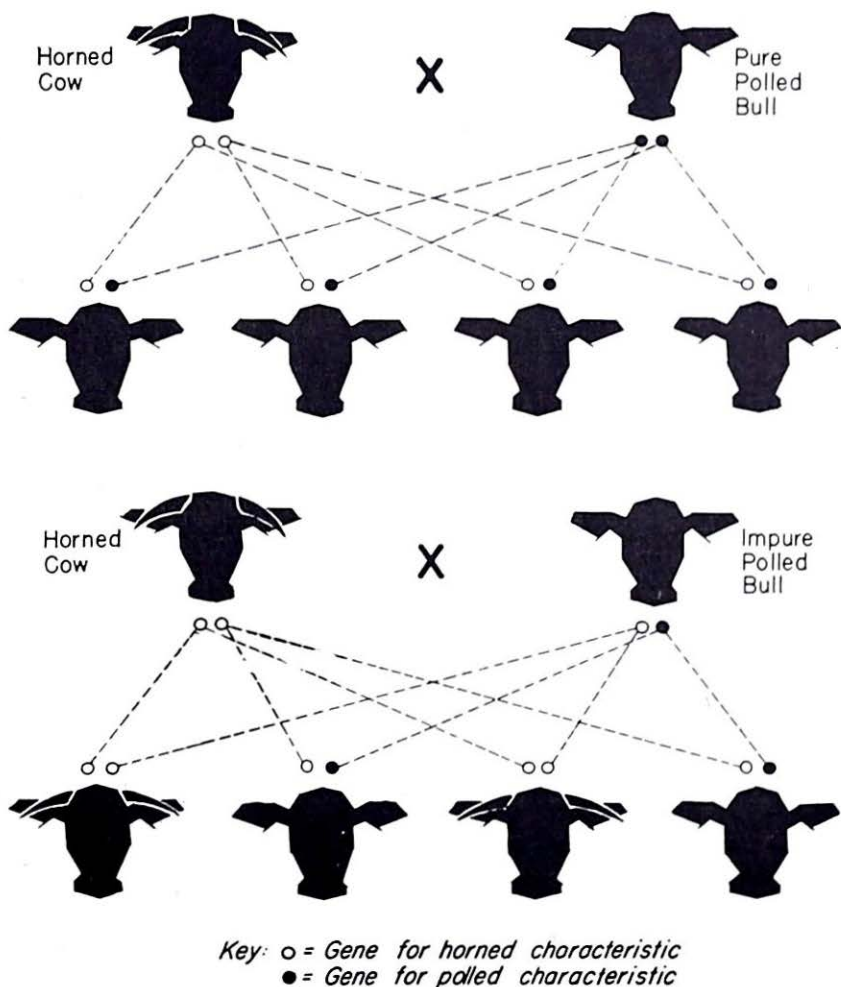


Fig. 3.—Diagrammatic illustration of the inheritance of horns in cattle.

horns in the hidden or "recessive" condition.⁴ In genetic terminology, the animals which are pure for a certain character are called *homozygous*, while those which have one dominant and one recessive factor are termed *heterozygous*. The breeding test is simple and consists of mating the polled animal with a number of horned ones. If he is pure or homozygous for the polled character, all the calves will be polled; but if he is impure or heterozygous, only one half of the resulting offspring will, on the average, be polled and half will have horns like the horned parent.

If a polled bull is bred to a group of four or five horned cows and produces all polled calves, the chances are good that he is pure for the polled character.⁵ Many breeders of polled Shorthorns and Herefords are testing their prospective herd sires in this manner.

Dominance makes the task of identifying and discarding all animals carrying an undesirable recessive factor a difficult one. Because of the long time required for the production of offspring, progeny tests are seldom practical for the female. They are not widely applied even to males. Thus, recessive genes can be passed on from generation to generation and appear only when two animals, both of which carry the recessive factor, happen to mate. Even then, only one out of four offspring produced will, on the average, be homozygous for the recessive factor and show it.

One of the best known cases of this kind is the color of Aberdeen Angus cattle. For almost two hundred years, the accepted color of the animals of this breed has been black, and for a century or more only black animals have been used for breeding purposes in registered herds. A factor for red coat color exists in the breed, however, and has persisted through the years. It is estimated that from one in one hundred to one in two hundred Angus calves is born red. Thus, the occasional appearance of a red calf in this breed does not signify impurity of breeding, but merely the outcropping of a long-hidden recessive gene. Since the factor for red is recessive, the red animals are pure for the color. Thus, the mating of two red animals could always be expected to produce red calves.

Most Characters Are Complicated in Inheritance

Although relatively few characters of economic importance in farm animals are inherited in as simple a manner as those just described, a few have been used by practical breeders to improve their

⁴"Scurs" or small, loosely attached horns are apparently inherited as a recessive independently of major genes for horns. It is possible, however, that polled animals heterozygous for horns are more likely to have scurs than homozygous ones.

⁵To be more exact, the probability is that a heterozygous bull will sire at least one horned calf fifteen out of sixteen times when bred to four horned cows and thirty-one out of thirty-two times when bred to five horned cows.

livestock and several others have been used to establish breed trademarks. The matter of having horns or not having them is, of course, of practical importance, and the Aberdeen Angus breed has been polled for centuries. As mentioned earlier, breeders have taken advantage of the occasional occurrence of "sports" or "mutations" to the polled condition within the Shorthorn and Hereford breeds. Such animals have been propagated and there are now well-established polled strains of both these breeds. Polled Rambouillet sheep are the result of similar breeding. The white face of the Hereford is an excellent example of a single factor which has been used to develop a breed trademark. The white face of this breed is dominant over the type of coloration in which head and body are the same color. Who can say what part this trademark may have played in establishing the Hereford breed in its present popular position?

It is true, however, that most characteristics of economic importance, such as type, milk production, prolificacy, and growth rates, are much more complicated in their inheritance than the cases given above, and their consideration is reserved until later.

SEX DETERMINATION

On the average, when large numbers of offspring are considered, the numbers of males and females born are approximately equal in all common species of animals. It should be emphasized, however, that there may be small variations. Cattle seem to produce a slight excess of males and sheep produce a slight excess of females. Other species may also vary slightly. The reason for these deviations is unknown, and they are slight, since the percentages vary only from about 49 to 51 per cent. The theory of sex determination which has been most widely accepted at the present time is the one which states that sex is determined by the chromosomal make-up of the individual. One pair of chromosomes is called the sex chromosomes. In farm animals, the female has a pair which are of the same type (usually called X chromosomes), while the male has a pair of sex chromosomes which are unlike (usually called X and Y chromosomes). In the bird this condition is reversed, the female having the unlike pair and the male having the like pair. The probable mechanism of sex determination, however, seems to be the same.

The pairs of chromosomes separate when the germ cells are formed, and a particular germ cell receives only one type of sex chromosome. Naturally, the germ cells produced by the female animal are all alike as far as sex is concerned—all containing an X chromosome. The male produces two types of germ cells—one-half containing an X chromosome and one-half containing a Y chromosome. These unite at random with the female germ cells and half of

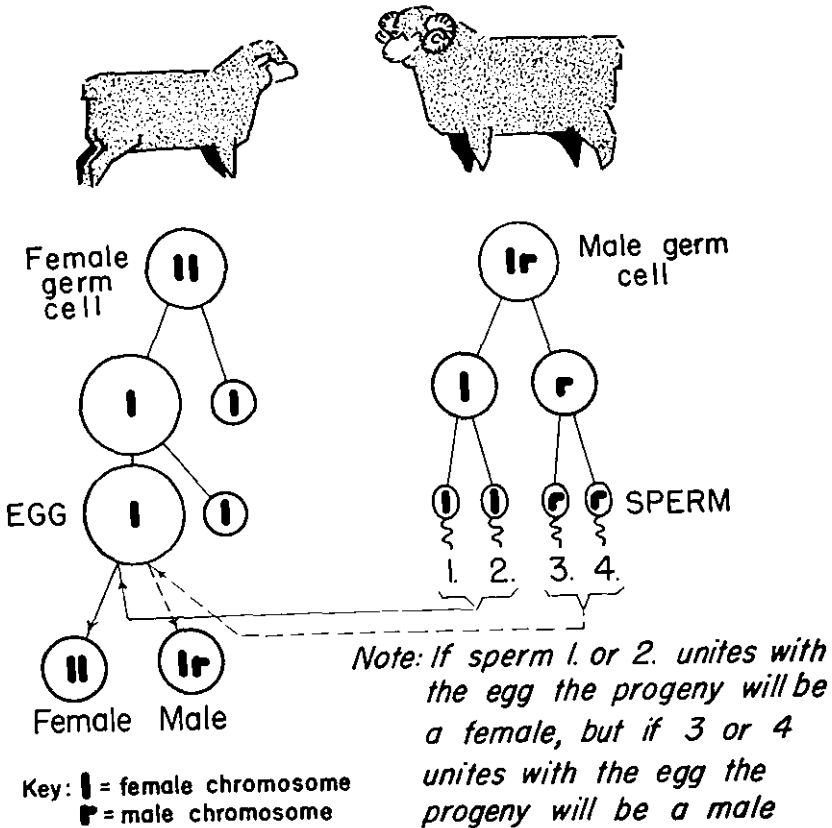


Fig. 4.—Diagrammatic illustration of the mechanism of sex determination in farm animals.

them produce offspring of the chromosomal make-up XX (females) while one-half are XY (males).

Abnormal Development of Sex

Occasionally, in nature, the normal development of sex does not occur, and animals are produced in which the reproductive systems are abnormal in development. Such animals are known as "hermaphrodites" if they have characteristics of both sexes, or "intersexes" if they have definite characteristics of neither sex. Many cases of this kind occur sporadically and usually the breeder has no way of knowing what causes them. Presumably, something occurs before birth

which prevents normal development and the animal is prevented from developing exactly as it should in view of the chromosomal structure which it has.

The most interesting case of this kind, and one which has received a good deal of attention, is that of the "Freemartin" in cattle. The Freemartin is a sterile calf which is born as a twin with a normal bull. The best evidence indicates that the Freemartin is genetically a female, but the blood vessels of her placenta fuse with those of the male twin early in development and sex hormones from the male circulate in the blood and interfere with the normal development of sex in the female. This condition occurs about nine times out of ten when a heifer is born twin with a bull calf. It cannot be told with certainty whether a female calf born twin with a bull is a Freemartin or a normal heifer until she reaches breeding age. However, since the chances are about 9 to 1 against her being normal, the only time such an animal should be tried as a breeder is in the case of particularly valuable blood lines when the gamble would be worth while.

No Method of Sex Control Known

The possibility of controlling the sex of the animals which he breeds has intrigued man from earliest antiquity. Any "sure-fire" method of controlling sex would have tremendous commercial possibilities. The producer attempting to increase numbers in his herd wants as high a percentage of females as possible. On the other hand, the commercial producer usually finds that male animals sell for a somewhat better price than do females on the market. He would, therefore, in many cases prefer to have all or at least a high percentage of males born in his herd.

Literally hundreds of methods have been proposed for controlling the sex of the offspring of a mating. One after another, these methods have been shown to be worthless and, today, in spite of the fact that many persons believe in one or more of them, there is not a shred of scientific evidence which indicates their usefulness.* From a purely theoretical standpoint, it would appear that there might be some possibility of eventually developing a method for the control of sex. In domestic animals, the sperm cells produced by the male are of two kinds, one bearing an X chromosome and the other bearing a Y chromosome. If it were possible to separate these two types of sperm and allow only the X-bearing sperm to fertilize eggs, all the animals would be females. On the other hand, if the Y sperm were allowed to do the job, all the offspring should be males. Easy as this problem

* Lush in his book, *Animal Breeding Plans*, tells of a man who gave 276 "false theories" of sex determination which had been proposed by other people and then proceeded to describe the "true theory" which later proved to be only the 277th false one!

sounds from a theoretical standpoint, the fact remains that it has not yet been accomplished and its accomplishment in the future is highly problematical. To begin with, the sperm cell itself is microscopic in size and the chromosomes it contains are so small, it is impossible to see them distinctly with even the most powerful microscope available. Since the sex chromosomes are only one of about thirty pairs, it follows that their influence on the weight, the chemical reaction, or the electrical reaction will probably be small. Such has been found to be the case and has thus far prevented the successful development of any process for separating the two types of sperm. Until this is accomplished and reliably reported by scientific workers, the animal producer had best look with distrust upon methods for controlling sex.

Chance Is Important in Sex Ratios of Small Groups

The field of sex control is a fertile one for fraudulent operators because of the fact that, due to the laws of chance, the sex ratio will vary from the normal 50:50 in many cases. In small herds or flocks, these chance variations may often appear to be caused by some treatment or something in the way the herd was managed. The laws of probability not only make it possible for a certain cow to have at least four heifer calves in a row, but they also make it probable that out of a certain number of cows one or more may actually do that. Specifically, in a herd of sixteen cows, each having had four calves, it would be expected that one cow would have had four bull calves and another would have produced four heifer calves. Likewise, in a group of sows having litters of eight pigs, one out of 128 on the average would have litters containing only one sex. As an example of this, The State College of Washington Aberdeen Angus herd had no bull calves born during the first four years after its founding in 1909. Later, however, the same animals and their descendants produced about half males and half females. Other examples of this kind could be cited, but the available evidence can be summarized by saying that in farm animals there is no good evidence that certain females tend to produce offspring of one sex or that certain males produce offspring of only one sex.

The exceptional sex ratios noted above, or even more extreme ones, naturally are striking and attract a good deal of attention when they occur. From this the breeder may get the impression that variation in the sex ratio is not random, but that it is under the control of some unknown influence. The available information to date indicates that such variations can be explained on the basis of chance. Only the exceptional cases cause any talk, and if such a case occurs on one farm in 100, one in 1,000, or even one farm in 1,000,000, many

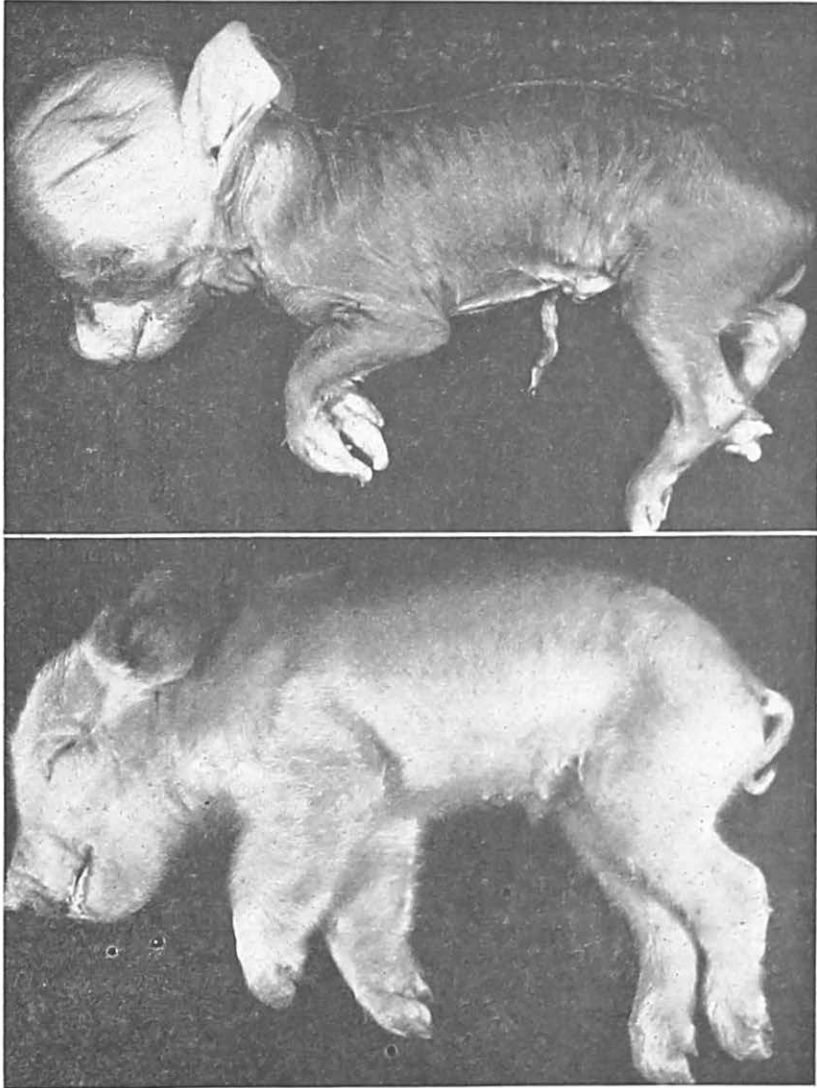


Fig. 5.—Some hereditary lethals in swine. At the top is shown a hydrocephalic (literally meaning "water in the head") Duroc pig which also has a short stub tail. Pigs affected with this condition die soon after birth. It is inherited as a simple recessive. More than 20 pigs of this type were born in the herd from which this pig came. The lower photo shows a Chester White pig with thickened forelegs. This condition is often accompanied by atresia ani (no rectal opening). It is recessive in inheritance, but appears to be more complicated than the above case. These two photos illustrate the many possible effects of genetic lethals. (Photographs by the author.)

persons hear about it; whereas no mention is ever made of the other farms where the sex ratio is apparently within normal limits.

LETHALS AND ABNORMALITIES OF DEVELOPMENT

Congenital abnormalities which result in the death of an animal either at birth or later in life are called "lethals." Other animals may have defects of a less severe nature which do not result in death, but do impair their usefulness. For convenience these two types of abnormalities will be considered together.

Many such defective animals are born on the nation's farms and ranches each year. The process of embryological development (the development of the young from the time the germ cells unite until they are born) is very complicated, and the wonder probably is that so many of the offspring develop normally rather than that a few are abnormal. Defective individuals are often worthless and their production can result in a large loss to the producer if they occur in any considerable numbers. Many such abnormalities are hereditary, being caused by certain genes. Their prevention depends upon the extent to which the germ plasma can be purged of the "bad" genes. Other abnormalities, which are at least superficially similar in appearance, seem to be caused by nutritional deficiencies. In other cases, the abnormalities appear to occur sporadically and no well-defined reason for their occurrence can be put forth. For want of a better explanation, such cases have been termed "accidents of development."

When only a few defective individuals occur within a particular herd, it is often impossible to determine whether their occurrence is due to defective heredity, to defective nutrition, or merely to accidents of development. If the same abnormality occurs in any appreciable number of animals, however, it is probably due to either hereditary or nutritional deficiencies. A careful study is often necessary to determine which may be responsible. If the ration is defective, it should be improved, not only from the standpoint of preventing such deformities, but also since the results obtained will probably be enough better in other respects to more than pay for improving the ration.

The following things would tend to indicate a hereditary defect:

1. If it had previously been reported as hereditary in the same breed of livestock.
2. If it occurred more frequently among near relatives than among animals not so closely related.
3. If it occurred where there had been inbreeding.
4. If it occurred more than one season when different rations had been fed.

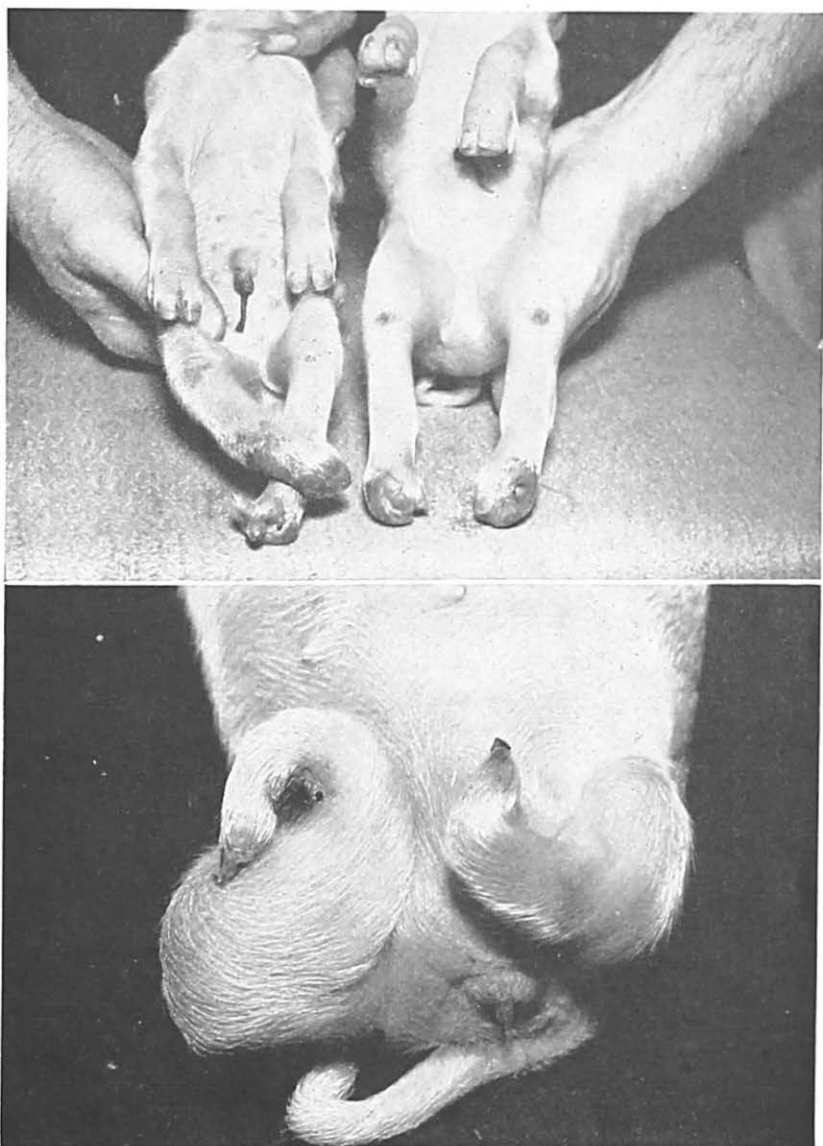


Fig. 6.—Some defects in pigs believed to be due to nutritional deficiencies. The pigs at the top have an abnormal development of the hind feet and the pig below has very abnormal hind legs. The defects appeared in pigs born to sows fed deficient rations and are not known to have a genetic basis. (Photographs, courtesy of Dr. T. J. Cunha.)

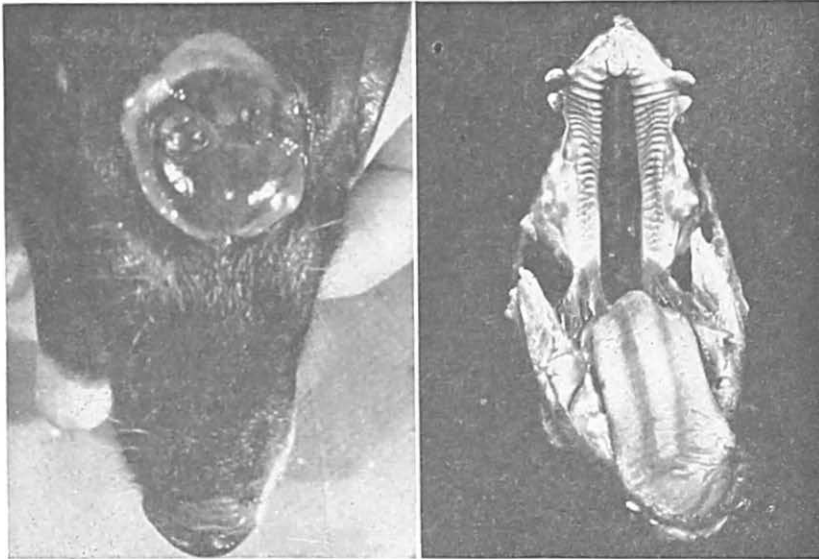


Fig. 7.—Two photos of a defective Poland China pig. His brain extruded to the outside (left) and he had a complete cleft palate (right). This condition appeared in only one pig in a large herd and can best be described as an "accident of development." It is not known to have a heritable basis. (Photographs by the author.)

The following items of evidence might be taken as indicating that the abnormality was due to a nutritional deficiency:

1. If it occurred when the ration of the mother was known to be deficient.
2. If it disappeared when an improved ration was fed.
3. If it had previously been reliably reported to be due to a nutritional deficiency.

It can thus be seen that each case will require special study, and it is well for the average farmer to seek the advice of his county agent or experiment station worker in determining what his policy should be if such an abnormality occurs.

Most Hereditary Defects Are Recessive in Inheritance

Most hereditary defects or abnormalities are inherited as recessives and do not appear unless the animal carries two factors for the abnormality in its own cells. Factors of this kind can thus remain hidden for many generations and be carried along indefinitely without appearing in exactly the same manner as the red coat color in Aberdeen Angus cattle previously mentioned. It is only when two animals,

Some Hereditary Lethals and Other Hereditary Abnormalities Which Have Been Reported in American Livestock*

Type of Abnormality	Probable Mode of Inheritance
I. CATTLE	
A. Lethals	
Bulldog calves—short legs and head, often have hernia and cleft palate	similar conditions caused by two genes, one semi-dominant, one recessive
Imperfect skin—little skin on legs and head	recessive
Muscle contracture—muscles contracted and rigid, head drawn back	recessive
Impacted molars—teeth impacted, parrot-like mouth appearance	recessive
B. Non-lethal	
Wry tail—base of tail set at angle to backbone	recessive
Screw tail—one or more pairs of vertebrae fused	recessive
Duck-leggedness—legs shorter than normal	semi-dominant
Semi-hairlessness—hair coat thin, calves wild	recessive
Notched ears—ears imperfect in shape	dominant
Female sterility—cows fail to settle	recessive
Dwarfism—animals small in size, but well proportioned	recessive
Flexed pasterns—toes turned under	recessive
Cataract—opaque condition of the lens of the eye	recessive
Strabismus—cattle have a cross-eyed condition	recessive
Epilepsy—cattle subject to epileptic type of attacks	semi-dominant

* This list is presented to show the wide variety of defects which can be hereditary. No attempt has been made to make it complete, although it does include most of the well-authenticated conditions which have appeared in America. Many others have been noted in other countries.

**Some Hereditary Lethals and Other Hereditary
Abnormalities Which Have Been Reported in American Livestock (cont'd.)**

Type of Abnormality	Probable Mode of Inheritance
II. SHEEP	
A. Lethals	
Muscle contracture—lambs born with legs rigid	recessive
Dwarfism—short legs, thick shoulders, bulging forehead	recessive
B. Non-lethal	
Overshot jaws—lower jaw shorter than the upper	interaction of several gene
Bulldog jaw—lower jaw longer than the upper	pairs, most of them possibly
	recessive.
III. SWINE	
A. Lethal	
Catlin mark—incomplete development of the skull	recessive
Thick forelegs—front legs thickened, often accompanied by atresia ani	recessive
Legless—pigs born without legs	recessive
Hydrocephalus—fluid on the brain, head enlarged, often accompanied by short tail	recessive
B. Non-lethal	
Hairlessness—little or no hair	incompletely dominant
Inverted nipples—teats inverted and non-functional	recessive
Scrotal hernia—ruptured, intestines extend into scrotum	two pairs of recessive factors
Cryptorchidism—one or both testicles retained in body cavity	recessive
Hemophilia—blood fails to clot properly	recessive
IV. HORSES	
A. Lethal	
Atresia coli—closure of intestine	recessive
Stiff forelegs—front legs stiff	probably recessive

each carrying the condition in the recessive or hidden form, mate that the condition appears. This recessive characteristic makes the occurrence of the abnormalities relatively rare, but it does make them difficult to eradicate because breeding tests are the only thing which will indicate whether or not an animal is carrying such undesirable factors. The expense of making such breeding tests practically prohibits their use under practical farm conditions.

Assuming that an abnormality has occurred and has been proven to be hereditary, and that it is recessive in nature, the breeding program to be followed to prevent or minimize the possibility of its future occurrence will depend somewhat on the type of herd in which it occurred. In the ordinary commercial herd, the breeder will do well to find a male which is unrelated to his females and use him in future generations. Thus, he will have quite a good chance of acquiring a male which does not carry the undesirable recessive factors. In spite of the fact that he knows his female herd is carrying it, he can usually protect himself against its future occurrence.

Rid Purebred Herds of Lethals

If the defect occurs in a valuable purebred herd, the steps to be taken should be more drastic. The purebred breeder has an obligation, not only to himself, but to his potential customers to produce the best possible animals. If purebred herds and flocks were purged of lethals and other undesirable genes, they would no longer be of importance in commercial stock since most sires used in the latter herds are purebreds. The purebred breeder can go far towards eliminating undesirable genes from his herd:

1. By eliminating those sires which are known to have transmitted the abnormality.
2. By eliminating the dams which produce offspring showing the abnormality.
3. By eliminating the normal offspring produced by these same animals. (Half or more of these animals will carry the undesirable factor in the recessive condition.)
4. In some cases it may be desirable to breed prospective herd sires to a number of females known to carry factors for the defect in order to be sure the new sire is free from it. For example, cryptorchidism (or the "ridgling" condition) in hogs is believed to be inherited as a simple recessive. When cryptorchids appear in a litter, it usually means that both sire and dam carry the factor in hidden form. If one or more sows which had previously produced cryptorchids were bred to a new herd boar and no defective pigs were born, it would be fairly certain that he did not carry a factor for the condition.

MULTIFACTOR INHERITANCE

Economically Important Characteristics Complicated in Inheritance

Early in the study of genetics it was hoped that the characteristics which are economically important in farm animals, such as growth rates, efficiency of feed utilization, milk production, type, etc., would be found to be controlled by only one or two genes each and that selection for these characteristics would then be a very simple matter once the inheritance was understood. This early hope has not been realized. It is now understood by all persons in the field that the complex physiological characteristics influencing the economic usefulness of animals are usually not controlled by one or a few genes. They are controlled by many genes, and the individual effects of single genes are seldom, if ever, recognized. It furthermore appears that it will always be impossible to determine the exact number of genes influencing each of these characteristics or to determine their exact mode of inheritance.

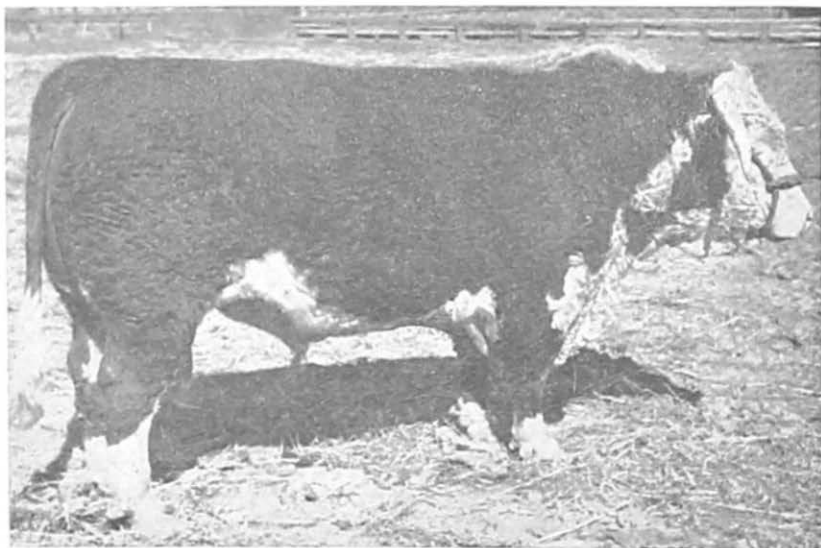


Fig. 8.—A Hereford bull which transmitted the ability to make rapid and efficient gains to his offspring.

A brief consideration of a few items will indicate the reasons why this statement is necessarily true. The following statements summarize the reasons:

1. Animal physiology is extremely complex, and there are undoubtedly many physiological factors influencing the development of the economically important characteristics of farm animals.
2. As an example of the foregoing statement, a few of the more obvious factors which can influence the rate of growth might be cited. These include the animal's appetite, influencing the amount of feed eaten; the efficiency of assimilation, that is, the proportion of the feed eaten which is absorbed into the blood stream; and the use to which the food is put after assimilation, i.e., for growth, for fattening, etc.
3. Each of the above factors has been shown to be influenced by heredity.

The inherent complexities in regard to the physiology of these economically important characteristics could be discussed much further, but the examples given will serve to illustrate the situation.

Usefulness Affected by Many Genes

Estimates of the number of pairs of genes affecting each economically important characteristic vary greatly, but it has been estimated that for most characteristics the number is at least ten and probably many more. The many genes involved result in a continuous distribution of various types of animals instead of the discrete classes we have in cases where characteristics are affected by only one or a few genes. For instance, in the case of coat color in cattle, an animal is usually either white, red, roan, or some other discrete color, with no possibility of mistaking one for the other. When, however, we speak of an animal which is high in productivity, the expression is relative and has meaning only when that particular animal is compared with a number of other animals from the same herd or the same breed. Thus, a ewe shearing ten pounds of wool per year might be considered a high producer in an area or a flock where the average production is low, but in one of the best flocks it might be considered an average or even a low producer. Likewise, within a certain flock, there is little or no likelihood of having a group of twelve-pound producers and another group of eight-pound producers. Rather, the distribution will be continuous, with a larger number of ewes producing amounts near the average and fewer animals producing amounts far from the average.

This point is well illustrated by the following tabulation of the grease fleece weights of the Columbia ewe flock at The State College of Washington during the years 1943, 1944, and 1945:

Fleece Weights (in pounds)	No. of Fleeces in Each Weight Class
8.0-9.0	1
9.1-10.0	1
10.1-11.0	10
11.1-12.0	16
12.1-13.0	27
13.1-14.0	10
14.1-15.0	6
15.1-16.0	5
16.1-17.0	1
Average for 77 fleeces was 12.8 pounds	

Genetic Variation Is Great

Variation of the type described above is due to two possible factors: (1) differences in hereditary materials, or (2) differences in the environment of the animals concerned. Without forgetting the importance of variation due to environmental causes, let us consider the hereditary variation.

As explained earlier, only one member of each pair of genes found in an animal is transmitted to any one offspring. Which member of the pair goes to a particular offspring is determined by chance.

If an animal gets similar determiners or genes from each parent, it will be homozygous and will produce a uniform set of offspring because any half of its inheritance is just like any other half, i.e., regardless of what combination of genes and chromosomes go into a particular germ cell, it will be just like any other egg or sperm from the same individual. Unfortunately, few if any of our farm animals are in this happy hereditary state at the present time. Thus, a parent will sometimes transmit to one offspring much better inheritance than it does to another, simply as a result of chance differences in the genes which go to different germ cells at the time of the reduction division. This explains why there may be wide differences among the offspring of any sire or dam. Even between such closely related animals as full brothers or sisters there is often wide variation in type and productivity.

Thus variation between the offspring of parents which are not pure or homozygous is not to be marveled at, but is to be expected. To take a comparable situation, no one would expect to draw exactly 35 sound apples and 15 rotten ones every time he took a random sample of 50 from a basket containing 70 sound and 30 rotten ones; although, on the average—if enough samples were drawn—he would expect to get about that proportion of each. Exactly the same situation applies to the relative number of “good” and “bad” genes which may be

present in different germ cells from the same animal. Because of this situation, the mating of, for example, an outstanding ram with an excellent ewe will not always produce a lamb of merit equal to that of its parents. It could be markedly poorer than the parents, it could be of about the same merit as the parents, or, happily, it could in some cases be even better than either parent.

SELECTION

Variation in the young produced from carefully planned matings is often called both the hope and the despair of the animal breeder—the despair because of the disappointing results often obtained, and the hope because of the hope for the future when the best are selected for breeding purposes.

What Is Selection?

Put in the simplest terms, selection in livestock breeding is the problem of selecting or picking out the animals in the *current generation* which will be the parents of the *next generation*. Obviously, the skill with which selections are made is all important in determining the future of the herd or flock. The use of the best animals from a genetic standpoint is the only basis for progress in animal breeding. Mistakes in selection resulting in the use of genetically inferior animals for breeding purposes has ruined many a herd or flock.

Since each sire leaves many more offspring than any one female, the selection of sires is a matter of the greatest importance. The sire is truly “half the herd” in the sense that he provides half the inheritance of all his offspring. In a broader sense, he is more than half the herd, since a succession of sires provides most of the hereditary material carried by their descendants. Thus, the selection of sires deserves the most careful attention.

Regardless of how many records are available, judgment must be exercised in making selections. As a general rule, it is best to select animals which are well “balanced” and are at least reasonably good in all the things desired. Occasionally an animal is exceptionally good in some respect, but has one or more glaring faults. Unless the fault is in some minor detail or item of conformation, the “balanced” animal will be a better risk in most cases.

Environment Differences May Cover Genetic Differences

The breeder cannot be certain, after looking at an animal or studying its production record, whether it is genetically a high producer or a low producer (most animals will be neither but will be somewhere near the average). Environment, including feeding,

management, and disease, plays a tremendous part in determining the extent to which hereditary differences which are present will be expressed in animals. For instance, it has been shown repeatedly that no matter how well bred an animal may be and how many good genes it may have affecting type, it will resemble more and more an animal of poor breeding, insofar as type is concerned, if it is improperly fed. Likewise, no matter how many genes an animal may have for fast growth rate, it cannot express these characteristics if the ration is limited. Growth rate will be slow, regardless of the genetic materials in the animal.

The foregoing are extreme examples and, in general, the breeder who is interested in improving a breed of livestock would not have to contend with situations of this kind. However, the environment is always of great importance in animal breeding. Even in the best herds under the best conditions of management, the animals vary according to the season of the year in which they are born, the milking ability of their mothers, the feed conditions in the herd, the health record of the herd, and many other factors which are affecting the productivity of the herd, but cannot be identified.

Only a Small Percentage of Variation Is Due to Heredity

In many cases, the breeder is completely unaware of these environmental factors which are affecting his herd. However, statistical methods have been used to determine the relative effects of heredity and environment in determining the final usefulness. Within the pure breeds of livestock managed under average or better than average conditions, it has been found, in general, that only 15 to 30 per cent of the observed variation in a characteristic is actually brought about by hereditary variations.

If we contrast animals which differ very greatly in heredity (for example, a well-bred beef animal and a scrub, or a chuffy with a very rangy hog), 90 per cent or more of the apparent differences in type may be due to heredity. However, this does not help in improving a given breed of livestock (except possibly in a few cases where a radical change in type is needed), because the introduction of extreme types would lead to no improvement.

Task of Livestock Breeder Is a Difficult One

The purebred livestock breeder or the commercial breeder who is attempting to improve his herd thus works under a number of handicaps. These handicaps slow down the rate of progress which can be made in animal breeding, but at the same time they make the occupation a much more fascinating one. The problem of the livestock

breeder is that of selecting the very best animals available to be parents of the next generation of offspring in his herd. The fact that only 20 to 30 per cent of the variation is due to differences in inheritance, and the fact that environmental differences can produce misleading variations, makes mistakes in the selection of the best animals almost inevitable. However, if the breeder has a well-defined ideal in mind and adheres to it closely in selecting his breeding stock, it will be possible for him to make very definite progress, especially if he inbreeds mildly to fix the hereditary material.

Profitability with Livestock Depends upon Efficiency of Production and Selling Price

The following two factors determine the profitability of any animal or herd of animals:

1. Ability to produce meat, milk, or wool efficiently from the feed which it is given. This includes the ability to reproduce regularly and to produce large litters in the case of litter-bearing animals.
2. Ability to produce products which are of high quality and which sell for a good price on the market.

The first of these points may be referred to as *productivity* and the second as *type*. Thus, the animal which is of the best type and therefore most nearly suited to the demands of the market, and which is at the same time the most productive, will be the one which is the most profitable. Insofar as possible, the breeder should strive to get both of these characteristics into the animals in his herd. There may, however, be certain incompatibilities between having animals which are the most productive and at the same time of the best type. For instance, from the packer's standpoint, a meat animal should have bones and internal organs which are as small as possible since these materials are of less value to him than meat. It is necessary, however, for the breeder to have animals which have fairly good bone and a fairly large set of internal organs in order that they may produce efficiently. Thus, if there are important conflicts between type and productivity, the most profitable animals will be those which strike the most desirable average. It may be that the animals in the best herds and flocks will always represent somewhat of a compromise between outstanding type and outstanding productivity. In the past, in the herds of many purebred breeders, selection has been very largely on the basis of type, with little or no attention being given to the productivity of the animal. This situation is not good, but is almost inevitable unless production records are kept.



Fig. 9.—An outstanding representative of the Standardbred horse—the first breed whose development was based largely on performance records.

PERFORMANCE RECORDS

The ease of measuring speed, milk production, and egg production in race horses, dairy cows, and laying hens, respectively, led to the use of production or performance records in selecting breeding animals in these classes of stock long before such records were used for meat animals.

Performance records have been used for centuries in breeding horses for speed and were particularly important in the development of the Standardbred horse—an American creation. For several years after the breed was officially recognized in 1879, admissions to the stud book were based on speed at the trotting gait. Before they could be admitted to the stud book, animals must either have themselves trotted a mile at the standard rate of 2:30 or better or have begotten animals meeting this qualification—hence the name, “Standardbred.”

Milk production has been used as a criteria for selecting dairy cattle since dairy breeds developed, and the invention of the Babcock test in 1890 provided a simple test for butterfat content. All the major dairy breeds have their “Advanced Registries” to give special recognition to outstanding producers. Dairy herd improvement associations are in existence throughout the dairy sections of the United States. They make it easy for dairymen to keep production records on each cow.

The invention of the trap nest shortly before 1900 made it possible to keep individual egg production records on hens. The tremendous improvement in average egg production in the United States during the past 50 years doubtless depends to a large extent upon the use of production records in breeding flocks.

The problem of using production records in meat animals is more difficult than in the classes of stock just mentioned because no one measurement accurately evaluates the worth of an animal. Extensive studies have been made of the factors which should be considered in breeding meat animals, however, and today we have a fairly clear idea of the things which should be considered, although the exact importance which should be given to each factor is not known. It probably varies under different conditions. For example, in a discriminating market, quality of product may be the most important factor influencing profitability. On the other hand, in a market which does not pay for quality, economy of production is the most important.

Giving due recognition to the difficulties of measuring production, the outstanding fact brought out by research work during the past twenty years, and capable of ready application in the practical breeding establishment, is that selection on the basis of performance with meat animals is *absolutely necessary if breed improvement is to take place at the maximum rate*. To select intelligently on the basis of performance, the *breeder must have adequate records and use them*.

To unfailingly select the animals with the lowest production costs, it would be necessary to have individual feed records on each animal in the herd—a procedure which is obviously impossible under most conditions. It has been found, however, that certain things which are

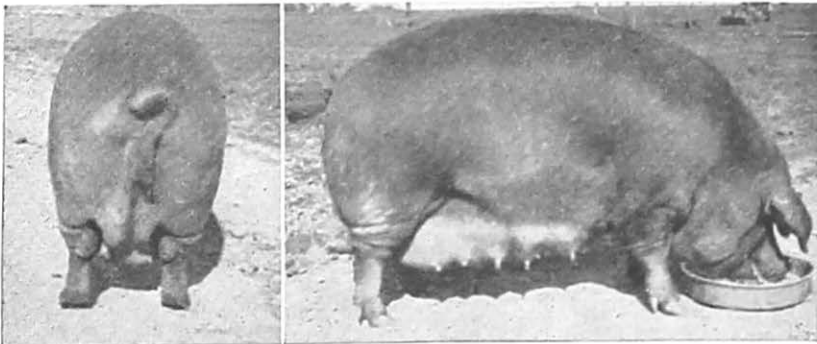


Fig. 10.—An outstandingly productive Duroc sow, Fancy Princess 1st, shown above, farrowed and raised a litter of 14 pigs in 1944 which weighed 3,320 pounds at six months of age. The pigs sold for a total of \$2,592 when slightly over six months of age. (Photograph, courtesy United Duroc Record Association, Peoria, Ill.)

relatively easy to recognize and measure are also fairly accurate guides in estimating the economy of production. A discussion of these things for each class of stock follows.

Hogs

If selection with hogs is based on the following things, progress toward developing more efficient and profitable animals should be possible:

1. Litter size.
2. Weight per pig and per litter at weaning time.
3. Daily gains between weaning and marketing.
4. Body type.

It is probable that the amount of emphasis each of the above points should receive vary somewhat from herd to herd, but, as a general rule, the first three items (all measuring efficiency of production) should collectively receive at least as much, and probably more,

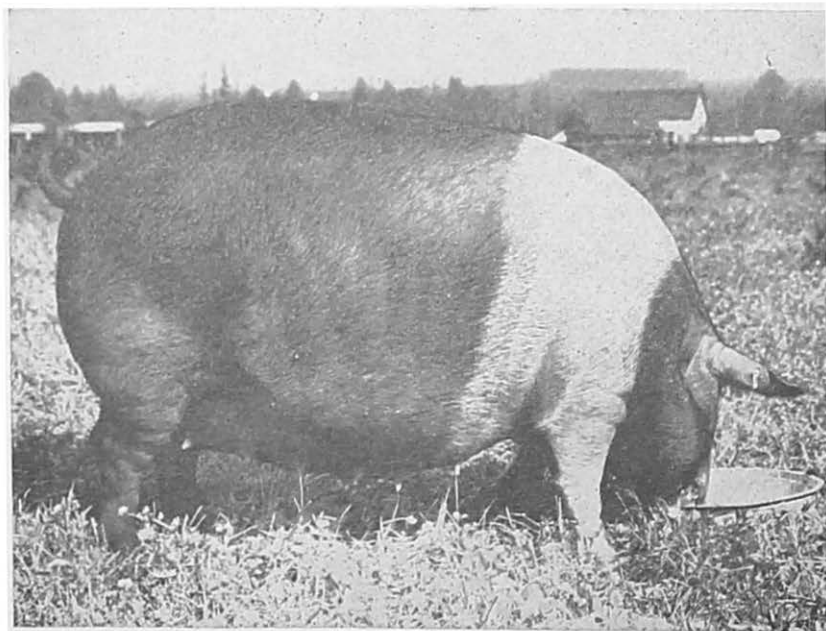


Fig. 11.—An outstanding PRODUCTION REGISTRY Hampshire sow bred and owned in Washington. Janalu Roller Susabelle 845676*** P.R. No. 297, shown above, was farrowed Oct. 9, 1944. Her first three litters made records as follows: No. 1. Farrowed Oct. 9, 1945. Nine pigs raised to 56-day wt. of 387 pounds; No. 2. Farrowed March 31, 1946. Nine pigs raised to 56-day wt. of 333 pounds; No. 3. Farrowed September 27, 1946. Ten pigs raised to 56-day wt. of 340 pounds. (Photograph, courtesy of Neal E. Tourtellotte, Seattle, Washington.)

attention than the item of body type which measures market desirability.

The number of pigs farrowed and raised, and their weight at weaning time, measures the prolificacy and mothering ability of the sow and is particularly important since it has a tremendous influence on profitability. On the average, a sow will have consumed a total of 1,500 to 2,000 pounds of feed during the period between breeding and the date her litter is weaned. If this all has to be charged against a litter of only four or five pigs, the chance of eventual profit is small. In addition to number of pigs farrowed and raised, the weaning weight of the pigs is important since it has been definitely shown that the pigs which are the heaviest at weaning time reach market weights the soonest.

The purebred swine breed associations use the two items of litter size and weaning weight as the basis for "PRODUCTION REGISTRY," which is an advanced registry giving special recognition to productive animals. Details of this program are given in the Appendix. Every purebred breeder interested in improving purebred hogs should be in this worth-while program. For further information, he should write to his own breed association.

The item of daily gain from weaning to marketing is highly indicative of efficiency of feed utilization. On the average, the faster gaining pigs use less feed per 100 pounds of gain than slower gainers.

Sheep

Some easily obtained indicators of profitability in sheep are:

1. Prolificacy of ewes (regularity of lambing and twin production).
2. Weaning weights of lambs (preferably at a constant age).
3. Type and finish of lambs at weaning time.
4. Fleece weight and quality.

Sheep are successfully raised under a greater variety of feed and climatic conditions than any other class of livestock. However, under virtually all conditions commonly encountered, the above factors are important. Different breeds of sheep are adapted to different conditions and their performance under a given set of conditions may be taken as a measure of how well they are adapted for use there.

Assuming that the best-adapted breed is being used in a certain location, the use of performance records in selecting breeding animals should result in the production of even better animals within the breed.

The importance of regularity of lambing in any area and of twin production in areas where feed conditions make it possible for ewes

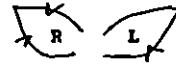
STATE COLLEGE OF WASHINGTON
DEPARTMENT OF ANIMAL HUSBANDRY

Individual Sow Record

Name and Registry No. Purdue's Miss Lamb⁸

Breed: Chester White

Ear Nicks:



615564
Hard No. 56

Pedigree:

Sire:

460141 Found at Last 448655
Missie Lane
Br. by: Lena Catal Lovely Lane 558416

Dam:

5M Purdue's King Model 450913
Purdue's Double Miss
Br. by: 504616 Purdue's Double Miss 58468
Purdue Univ.

Date farrowed June 2, 1942 Date of disposal 6-22-42

No. in litter 14 Reason for disposal _____

No. raised 11 Dead

Ave. 56 day weight _____ (see 12-B)

Own 56 day weight _____ Buyer _____

Ave. 180 day weight _____

Own 180 day weight _____

Bred by _____ Price _____

Purchased from Purdue Univ.

W. Lafayette, Indiana

Date Nov. 20, 1942

Price _____

* Score at 225#

Vigor, health, and thriftiness _____
Quality _____
Length of body _____
Details of conformation _____
Animal as a whole _____
Grade _____
Defects _____
Total _____

Remarks about conformation:

A nice smooth
meaty appearing
ear with especially
plump hams. Could be
longer in body. Only 10 teeth

photograph

* points from 1 to 9 with 9 a perfect score except in the case of length of body where 9 merely means a long body.

(See 12-B)

Fig. 12a.—One side of an individual sow record sheet giving pedigree and other information regarding a sow before she reached breeding age.

Production record of sow no. Gurden's Miss Gene 6th 615564 Head No. 34

RECORD OF LITTERS PRODUCED

Litter No.	1	2	3	4	5	6
Sire	<i>Pullman Special 499937</i>	<i>W.C. Specialist 510915</i>	<i>Deeiger 515629</i>	<i>W.S.N.A. Standard No. 2601</i>		
Season	<i>Spring '43</i>	<i>Spring '44</i>	<i>Fall '44</i>	<i>Spring '45</i>		
No. services for this conception	<i>?</i>	<i>1</i>	<i>1</i>	<i>1</i>		
No. farrowed	<i>10 (all alive)</i>	<i>19 (13 living)</i>	<i>16 (10 living)</i>	<i>18 (9 living)</i>		
Total birth wt.	<i>25 lbs.</i>	<i>32 lbs. (living pigs)</i>	<i>29.3 lbs. (living pigs)</i>	<i>31.5 lbs. (living pigs)</i>		
Number at 21 days	<i>9</i>	<i>9</i>	<i>9</i>			
Total wt. at 21 days		<i>112 lbs.</i>	<i>80 lbs.</i>			
Number at 35 days	<i>9</i>	<i>9</i>				
Total wt. at 35 days	<i>167.4 lbs.</i>	<i>179.5 lbs.</i>				
Number at 56 days	<i>9</i>	<i>9^a</i>	<i>9</i>	<i>9</i>		
Total wt. at 56 days	<i>291 lbs.</i>	<i>318 lbs.</i>	<i>205 lbs.</i>	<i>280 lbs.</i>		
Ave. weaning score						
Ave. 180 day weight						
Ave. 225# score						

Notes: (health of sow, fertility record of boar to which bred, etc.)

** two other pigs from this litter grafted to Litter No. 71 and raised by her. Developed mammary tumor, spring 1945. Died June 22, 1945 during tumor operation.*

Fig. 12b.—Reverse side of the sheet shown in Fig. 12a. A summary on one sheet of all the litters a sow has produced makes it easy to evaluate her productivity.

WASHINGTON STATE COLLEGE
DEPARTMENT OF ANIMAL HUSBANDRY

Cardinal's Pencil Henne 6th
61556A

LITTER RECORD, Farrowing to Weaning

Sow No. 58
Litter Serial No. _____

Date of birth, sow 6-2-42 Age 1
Sow's sire Aling 42141 (years)
Sow's dam Cardinal's Pencil Henne 5th 577616
Coef. of inbreeding (F): _____
Sow _____
Litter _____

Farrowing date of litter June 5th 1942
Litter 12
(1st, 2nd, etc.)
Sire of litter, No. Calloway Special 41927
Litter castrated _____
(date)
Litter vaccinated: Erysipelas 6-5-42
Cholera 7-7-42

At farrowing: _____ Description, sow _____ At weaning:
1. Condition Good: _____ Medium: _____ Thin: _____ 1. Condition Good: _____ Medium: _____ Thin: _____
2. Temperament Gentle: _____ Mod. Gentle: _____ Wild: _____ 2. Number functioning teats _____
3. Number good teats _____ 3. Remarks _____
4. Special traits _____

Pig No.	Sex	At birth weight (lbs.)	Condition (1)	At 56 days weight (lbs.)	Disposal after weaning	Remarks (2)
120	F	2		56		
131	F	2		21		
132	M	4		10		
133	F	3		60		
134	F	2½		27½		Died after weaning - Overheated
125	F	2		51		
136	F	2		31		
127	F	3		33½		
137	F	2		20		
139	F	1½		-		Died 6-5-42
Total		25		291		
Avg.		2½		32.3		

At birth: _____ Description, litter as a whole: _____ At weaning:
1. General appearance: Good _____ Medium _____ Poor _____ 1. General appearance: Good _____ Medium _____ Poor _____
2. Defects and abnormalities (3): _____ 2. Defects _____
3. Color markings _____

- (1). Record as excellent 9; good 7; medium 5; fair 3; inferior 0.
(2). Record date and cause of death.
(3). Record notes of abnormalities for individual pigs under remarks or on back of this sheet.

Litter Qualified for Chester White Q.P.D. 7-11-42

Fig. 12c.—Litter record, including information on pigs up to weaning time.

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LITTER RECORD AT 180 DAYS AND 225# WEIGHT

Name and Number of Dam *Pardue's Miss Lucy 6th 615569* Litter No. 1

Pig No.	Sex	Wt. at 180 days	Score at 225# (animal as a whole)	Remarks on conditions which might influence validity of weights and scores	Disposal of pig
130	F	172			Keep for brood sow
131	F	187			Sold as brood sow to C.W. Mendenhall, Colbyford \$130.00 (2-18-42)
132	M			a thick deep bodied good hammed pig when sold at 143 days of age	Sold to Wencatchee F.F.R. \$62.50 (10-22-42)
133	F	174			Marketed
135	F	164			Marketed
136	F	167			Keep for brood sow
137	F	200	8		Keep for brood sow
138	F	179			Marketed

Ave.

Fig. 12d.—Litter record at 180 days and 225 pounds live weight per pig. These record forms are more detailed than the average breeder will keep, but do present ideas which may be useful to a breeder in setting up records for his own operations.

STATE COLLEGE OF WASHINGTON

Department of Animal Husbandry

INDIVIDUAL EWE RECORD

FLOCK NO. 446 P 9

Breed Columbia Reg. No. 611 Ear Nick _____ Tattoo _____ Birth Date April 3, 1913

Sire C 1018 Type of birth (Single, Twin) Twins Date _____
 Bred by Mortimer J. Galt Temperament _____
 Bought from Wash. St. Coll. (Lambton) (Gentle, nervous) _____
 Address Bozeman, Mont. Face Covering* 2.5
 Date Purchased January '13 (As a lamb) _____
 Type, Weaned* 2 Date 8-26-43 Face Covering* 3
 Type, Yearling* 2.5 Date 7-27-44 (As yearling) _____
 Dam 2072 (H.C. 148) Back* 2 Rump* 2 Leg* 3 Disposed to _____ Date _____
 Defects & Abnormalities* Ch. Undershot jaw Why Disposed** _____

LAMBS (Use one line for each lamb)

Date of Birth	Ear sick and No.	Vigor at Birth	Type of Birth	Type of rearing ¹	Sex	Birth Wt.	Defects and abnormalities ¹	Sire	Milking ability - ewe ³	Weaning age, days	Weaning weight	Weaning condition ⁴	Weaning type ⁵	Disposition ⁶ or remarks
2-9-45	201	Good	Twins	Twins	Rams	11		4285 K		140	79	3	3	able milk registered
	202	Good	Twins	Twins	Ewe	8		4285 K		140	86	3	1.5	Specialty breeding
2-10-46	265	Good	Twins	Twins	Rams	8.5		4265 K		170	31	4	3	Sold to Dr. H. H. Hays, Wyo. \$125.00
	266	Good	Twins	Twins	Ewe	8.5		4265 K		160	30	2	2	Specialty breeding
2-8-47	64	Good	Twins	Twins	F	10		4265 K		140	80	2	2	
	65	Good	Twins	Twins	F	10.5		4265 K		140	87	2	4	

¹ True to breed appearance and desired matron conformation:
 "1" Excellent; "2" Good; "3" Medium; "4" Fair; "5" Poor.
² Brightness, strength, and spring of rib at withers:
 "1" Excellent; "2" Good; "3" Medium; "4" Fair; "5" Poor.
³ Width and levelness: 1-2-3-4-5 as above.
⁴ Plumpness of ribs: 1-2-3-4-5 as above.
⁵ Inclining overhead or undershot jaw, acute, black fiber, etc.
⁶ Not covered beyond p.d.; "1" Covered to eyes; "2" Covered slightly below eyes, but open faced;
 "3" Covered partially below eyes, but not subject to wool blindness; "4" Face covered and subject to wool blindness.

¹ S—Single; T—Twin; Tr—Triplet.
² S—Single; T—Twin; Tr—Triplet; Gr—Graded on foster mother and give her number.
³ Good, medium, poor.
⁴ Condition or degree of lameness:
 "1" Excellent; "2" Good; "3" Medium; "4" Fair; "5" Poor.
⁵ Cause of death, reason for disposal, kept for breeding purposes, whom sold to.

Fig. 13a.—Individual ewe record form which gives pedigree and production data on a ewe together with an easily visualized summary of her lamb production record.

34

WEIGHT RECORD OF EWE

Date	Age	Weight	Condition ¹	Remarks ²
8-30-43	149/40	69	2.5	
5-31-44		129		
10-18-48		165		
6-8-45		136		
5-28-46		149		
8-30-46		176		

REMARKS

(For example: bad udder, poor mother, aborted, veterinary treatment and nature of ailment.)

Date: _____ Remarks: _____

FLEECE
(Use one line for each year)

Length Inch ³	Fleeciness ⁴			Date of Shearing	Days Growth	Grease Weight	Per cent of Yield	Clean Wt.	Color of Skin	Purity ⁵	Remarks About Fleece
	Shoulders	Side	Thigh								
13.5	60	60	58	5/29/44		14					
6.9	58	58	56	5/1/45		14 1/4					Less fleece
8.0	60	58	58	5/14/46		14					
8.0	56	56	50	5/10/47		16					

- 1. Condition or degree of fatness: "1" Excellent; "2" Good; "3" Medium; "4" Fair; "5" Poor.
- 2. Factors affecting weight: e.g. just shorn, soon lamb, etc.
- 3. Length of staple, middle at side, to nearest 0.2 cm. just before shearing.
- 4. Numerical grade as determined by U.S.D.A. samples, just before shearing.
- 5. Kemp, black fibers, etc.

(over)

Fig. 13b.—Reverse side of the sheet shown in Fig. 13a. Weights and fleece records are kept in a form which permits a rapid appraisal of a ewe.

to raise twins successfully hardly needs discussion. Many of the costs of maintaining breeding ewes are fixed and fluctuate little or not at all, no matter whether the ewe raises a lamb or not. The greater the number of lambs raised, the easier it is to pay these fixed costs.

Lambs are usually weaned at 100 to 150 days of age and under many management systems are of marketable weight and finish at that time. Thus, this is an admirable time to evaluate both the productivity of the ewes and the quality of their lambs.

On the average, wool produces about one-third of the income from the sheep enterprise and should therefore receive that much emphasis in selection. Obviously, however, the relative importance of wool production varies from area to area, being relatively more important in dry areas where the production of fat lambs off-range is impossible and relatively less important where fat lamb production is the rule.

Beef Cattle

The following items appear to be of greatest importance in evaluating the profitability of beef cattle:

1. Regular reproduction on the part of cows.
2. Weaning weights of calves (preferably at a constant age).
3. Growth rate from weaning to market weights.
4. Body type.

As with other classes of farm animals, regular reproduction is necessary if beef cattle are to return a maximum profit. Ideally, every cow should produce a calf each year; but in practice this record is seldom attained. The closer a herd can be brought to this figure, however, the more profitable it will be. Definite knowledge that reproductive rates are dependent upon heredity is lacking in beef cattle, but many things point toward their being affected by heredity in at least some cases. Therefore, it should be given some attention in a breeding program.

The weaning weight of the calf is important because it measures the milking ability of the cow—a point in which many beef cows are deficient. Heavy weaning weights are important because gains put on before weaning are ordinarily cheaper than those put on later.

Growth rate from weaning to market weight (probably best expressed as average daily gain) is important because rate of gain is highly correlated with efficiency of gain. Both these factors have been shown to be under the control of heredity to a large extent in beef cattle. To evaluate the ability of animals to gain rapidly, many breeders are following the practice of full-feeding all prospective breeding animals (both bulls and heifers) under uniform conditions from weaning to about a year of age. This practice is to be encouraged.

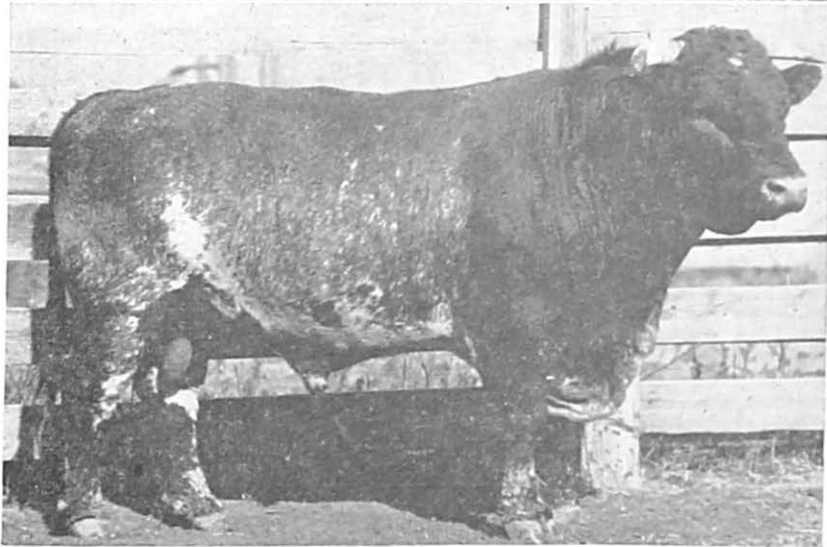
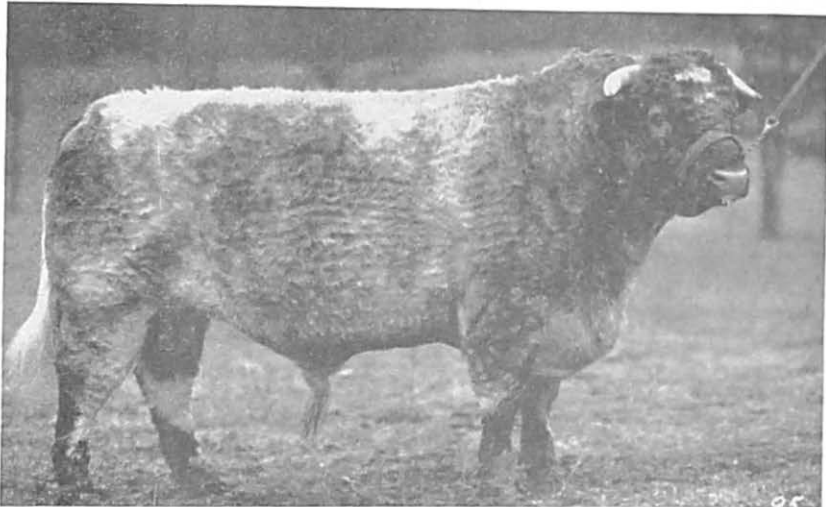


Fig. 14.—Progeny tests of these two Shorthorn bulls showed that their appearance was not a reliable indicator of breeding ability. These two bulls are full brothers and all would agree that the top bull is the most attractive in appearance. However, the bull in the lower picture produced calves 42 pounds heavier at the end of a feeding period and produced higher-grading carcasses. The average return per calf was nearly \$5.00 greater than from those sired by the top bull. (Photograph, courtesy of the Bureau of Animal Industry, U. S. Department of Agriculture.)

INDIVIDUAL-LIFE RECORD OF DAM

Owner _____
 Breeder _____
 Address _____



Name _____ Reg. No. _____
 Herd No. _____
 Date of Birth _____

						INDIVIDUAL WEIGHT AND GRADE RECORD OF DAM				
						Date	Age	Weight	Condition	Grade
Sire	Grade	WL	Breeder		Grade	Wt.				
			No.	Grade	Wt.					
Dam	Grade	WL	Breeder		Grade	Wt.				
			No.	Grade	Wt.					

REMARKS:

DISPOSAL:

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PRODUCE RECORD

Herd No. of Calf	Sex of Calf	Date of Birth	Name of Calf	Reg. No. of Calf	Name of Sire	Weaning Data					Dues				Remarks	
						Date	Weight	Wt. Adj. to 100 lbs.	Rating on Wta. and Gain	Grade	Date	Weight	Wt. Adj. to 100 lbs.	Grade		

Fig. 15b.—Individual Life Record of Dam. This form is now in use with cooperating beef cattle breeders in Washington with the W.S.C. Agricultural Extension Service supervising the studies.

General Considerations in Record of Performance

Positive identification of animals by means of ear notches, ear tags, or tattoo markings is necessary for record keeping. This, together with taking weights, represents additional time and labor which must be expended in the breeding operation—an expenditure which is highly worth while, however.

The matter of body type had best be evaluated for the records at a standard weight or a standard age, and probably should be put in terms of a numerical score. It is important that *all animals be evaluated and their scores made a part of the records*. Consistently good production is to be desired, and it is all too easy for a breeder to remember the good individuals produced by a given ewe, cow, or sow, and to forget those which are mediocre or culls.

It is essential that records kept for the purpose of evaluating the animals in the herd or flock upon the basis of the things enumerated above be simple so that keeping them does not become a burden. Furthermore, they should be in a form that will permit easy summarization; i.e., the record for one cow, one ewe, or one sow for a period of years should be on one sheet if possible. The suggested record forms have been designed with that thought in mind.

Progressive breeders are beginning to look for sires backed by performance records. This trend is logical and represents a desirable development. *The far-seeing purebred breeder will start now to get his herd on a Record of Performance basis.*

USE OF RECORD OF PERFORMANCE DATA

In the final analysis, the task of the livestock breeder is *selection*—picking out the animals which are to be the parents of the next generation. He will succeed or fail as a breeder depending upon his ability to make the correct decisions in determining which animals to retain for breeding purposes and which to cull, and in determining which animals (especially sires) to introduce into his herd. Assuming that production data are available, certain general procedures which will aid in making logical selections can be outlined.

Selection on the Basis of the Individual Animal

Although, as noted earlier, environmental variations have a tremendous influence on animals, the fact remains that the performance and type of the animal itself are the *best single indicators* of the germ plasm it carries (its genotype) and are, therefore, the *most useful single factors* for use in guiding selection. Naturally, this applies only to those characteristics which the animal itself can express.

From a practical standpoint, this means that only those animals which are themselves at least average or preferably better than average should be used for breeding stock, regardless of the merit of near relatives.

Selection on the Basis of the Performance of Relatives

Information on the productivity of close relatives can supplement that on the animal itself, and thus be a distinct aid in selection. The information gained may give important clues as to the genetic composition of the animal.

The productivity records of close relatives, including the sire, dam, brothers, and sisters, are of value, but those of more distant relatives are of little significance because individually they contribute only a few genes to an animal. The sampling nature of inheritance makes it probable that information from animals as distantly related as grandparents will add little of value beyond that contributed by the parents.

From a practical standpoint, the use of pedigree information should in most cases determine choices to be made between individuals which are rather doubtful. The best individuals should be saved regardless of the excellence or mediocrity of relatives, and poor individuals should be discarded no matter what their pedigrees. Use of information on relatives will result in saving some border-line cases and discarding others of somewhat better than average merit.

Consciously or unconsciously almost every breeder uses pedigree information in making selections, and so long as it is intelligently done this is desirable. The dangers in the use of pedigree selection are:

1. Undue emphasis on remote relatives.
2. Unwarranted favoritism toward the progeny of favored individuals.

The history of purebred beef cattle breeding has been marred by numerous instances of unwise pedigree selection on the basis of remote relatives or meaningless family names. The Duchess family of Shorthorns forms the most notorious example of this. The noted pioneer Shorthorn breeder, Thomas Bates, founded the Duchess family of Shorthorns, the members of which, in their time, were the best of the breed. Unfortunately, years after the death of Bates, American breeders began placing undue emphasis on the Duchess strain and propagated them, irrespective of their individual merit. This craze culminated in the famous New York Mills, New York, sale in 1873 in which 109 head of Duchess cattle averaged \$3,504 and one cow sold for \$40,600. Indiscriminate inbreeding and lack of selection made the strain virtually extinct a few years later.

Family names are used in two senses in animal breeding. Most commonly, the family name is traced through the dam (in a few breeds, names are traced through the sires) in an unbroken line of females to a foundation female who was outstanding enough to have a family named for her. Obviously, if the foundation female is very many generations back in the pedigree, her genetic superiority is halved so many times by the sires used that there is no reason to think one family is superior to another (see Fig. 16). Such family names have about as much significance as human family names. Who would be so foolish as to think that the Joneses as a group are alike and different from the Smiths?

Family names lend themselves readily to speculation. However, most breeders will do well to pay attention to individual excellence and the excellence of near relatives rather than to remote and genetically insignificant family names.

Some linebred families are in existence in which there has been line breeding to the foundation male or female with the result that the family is kept highly related to it. Such families do have genetic significance. The Anxiety 4th Herefords constitute probably the best-known family of this kind in meat animals. The danger of paying too much attention to line bred families is that certain pedigrees rather than real excellence, may become sought after. There would seem to be no reason why an "airtight" or "straightbred" Anxiety 4th tracing in every line of its pedigree to Anxiety 4th or North Pole should be superior to a better individual with a few lines tracing to other bulls.

Use of Information on Progeny in Selection

The objective in selecting breeding stock is to select those which have the best hereditary material and which will produce the best offspring. Animals transmit to their offspring the genetic characteristics which they have and the effects of environment are apt to be much less misleading when applied to a group of offspring than to a single animal. Thus, selection of animals on the basis of their progeny or on the basis of a progeny test represents the ideal. As V. A. Rice has so aptly put it: "Individuality tells us what an animal seems to be. His pedigree tells us what he ought to be, but his performance as a breeding animal tells us what he is."

Every intelligent breeder will use progeny testing to a certain extent, although it may consist of no more than retaining longer than others those animals which produce the best offspring in the herd. A plan which is successfully followed by many larger breeders is to retain and use a number of young males and a few females each during their first season of breeding. When the offspring be-

¹ *American Hereford Journal* 36:45. 1944.

come available, they are carefully evaluated, and only those males retained for further use which have been proved to be best on the basis of their progeny. Due to the relatively small numbers of offspring which the average female produces, progeny testing with females is somewhat more difficult and as a rule a female cannot be thoroughly progeny tested until she has spent half or more of her lifetime in a herd. The intelligent breeder, however, studies his females and culls those which consistently fail to produce good offspring.

NICKING

Nicking is a popular term used to designate a mating in which the offspring are apparently of higher quality than would have been expected from a knowledge of the quality of the sire and dam. Presumably it occurs as the result of particularly favorable combinations of hereditary factors. That is to say, the sire and the dam each carry factors which, when put together in the offspring, are complementary and result in extremely desirable offspring.

The history of animal breeding includes records of several supposedly favorable nicks, the most famous of which is the favorable results secured from crossing sons of Anxiety 4th with daughters of North Pole in the Gudgeall & Simpson herd of Hereford cattle.

It is impossible at this late date to determine whether these matings actually were nickings in the usual sense or whether they depended upon the fact that the sons of Anxiety 4th were outstanding breeding bulls and merely happened to be mated mostly with daughters of North Pole because the available cows were of this breeding.

Experimental evidence is conflicting in trying to determine whether or not nicking is important enough to be given consideration in a breeding program. Certainly, it is not as important as many breeders believe, and the hunt for a superior nick which is not based upon high-quality parents on both sides is apt to be disappointing.

PREPOTENCY

Correctly speaking, the term "prepotency" refers to the ability of an animal (in practice usually a sire) to stamp his or her characteristics upon the offspring to the exclusion of the characteristics of the other parent.

From a genetic standpoint, prepotency depends upon the animal being homozygous for many dominant factors. Such an animal will tend to have the same factors in each germ cell. The dominant factors will be expressed immediately in the offspring.

In spite of popular beliefs to the contrary, there is no evidence that prepotency can be predicted from the appearance of an animal.

To be more specific, there is no reason why a vigorous, masculine-appearing sire will be any more prepotent than one less desirable in these respects.

It is impossible to determine just how important prepotency may be in animal breeding, although many sires of the past have enjoyed a reputation of being extremely prepotent. Perhaps they were, but, on the other hand, it may well be that their reputation for producing outstanding animals rests upon the fact that they were mated to the best females of the breed. Theoretically at least, an animal would have to be inbred to a certain extent for prepotency to be an important factor.

Under most conditions it appears that the influence of the sire and dam on the offspring is about equal. Genes which are carried in the sex chromosomes might conceivably make sows resemble their dams and daughters resemble their sires more than would be expected. This influence is very slight, however, and cannot usually be detected.

In view of the approximately equal influences of sire and dam on the offspring, most breeders will do well to seek excellence in both sires and dams than to gamble on finding prepotent sires. If an apparently prepotent sire is found, however, he should naturally be used as much as possible.

"PURE" OR PEDIGREE BREEDING

A breed is a group of animals of common origin and descended from a common ancestry. Most breeds developed originally in certain local areas and spread over larger territories when their value was recognized. Usually the animals of a breed have certain distinguishing characteristics for which they breed true in all cases or at least a high percentage of the time.

A purebred breeder is a person who breeds animals of a particular breed, keeps their pedigrees registered with the breed association, and usually sells animals to other breeders for breeding purposes. The term "purebred" merely indicates that an animal is descended from registered stock. The word "purebred," unfortunately, does not guarantee genetic purity for good type or high productivity; and, as many a person has found to his sorrow, there are such things as "scrub purebreds."

In spite of the fact that being a purebred does not guarantee the worth of an animal, the fact remains that purebreds are on the average probably better animals than non-purebreds. It is always recommended that commercial livestock breeders use *good* purebred sires, whether they are following a crossbreeding or grading program or are maintaining herds or flocks of high-grade females and breeding them to sires of the same breed.

The purebred breeder is thus the leader in livestock improvement. The gains made in purebred herds or flocks are transmitted to the herds or flocks of commercial producers. The use of improved purebred sires is usually the only way in which improvement is made in commercial stocks.

The purebred breeder can therefore be thought of as the kingpin of the livestock industry. The obligation upon him to work for true improvement in productivity and not be misled into developing animals which merely meet the requirements of certain arbitrary standards for fancy points is truly great.

The opportunities for the successful purebred breeder to gain fame and fortune are practically unlimited, but since the prices of purebred livestock fluctuate greatly with economic conditions, the possibilities for loss are also great. Thus, the breeding of purebred livestock should be limited to those with experience and knowledge, vision, love for stock, and adequate financial backing to weather an occasional bit of adversity. In short, the breeding of purebred livestock is a job for a specialist.

BREED REGISTRY ASSOCIATIONS

Each of the present breeds of livestock has a breed registration association. These associations usually have come into being when a useful strain of animals has been developed in a particular locality. Their basic purpose was that of protecting the purity of the strain and allowing the breeders to reap the rewards of their work.

Present-day breed associations have the functions of: (1) keeping records of the pedigrees of animals of the breed—thus keeping the breed pure; (2) advertising and promoting the breed—thus acting as a business agent for the breeders, and (3) exerting an influence to improve the quality of animals within the breed.

The first two functions mentioned have been the ones in which breed associations have primarily been active, leaving the matter of quality of animals pretty much to the breeders themselves. For several years, however, the dairy associations have been giving special recognition to high-producing cows through their Advanced Registry programs. The swine associations have recently developed Production Registry programs which give recognition to productive sows. Thus, there is apparently an increasing tendency for breed associations to fulfill their third function.

INBREEDING AND LINE BREEDING

In a broad sense, inbreeding is the mating of related animals. Since all animals in a breed are descended from a common ancestry and are therefore slightly related, all matings within a pure breed

might be thought of as inbreeding. However, for practical purposes, inbreeding is considered to be the mating of animals which have common ancestry within the first four to six generations—relationship further back in the pedigree having such small effect that it can be ignored. In usual terminology, inbreeding is divided into two forms which are defined as follows:

Close inbreeding—the mating of closely related animals such as full brother and sister, half brother and sister, sire and daughter, son and dam, etc.

Line breeding—a less intense form of inbreeding in which animals less closely related are mated. It is often used to intensify the blood of some admired ancestor by mating his descendants together.

From a biological standpoint, inbreeding and line breeding are the same thing, differing merely in intensity. In general, close inbreeding has been frowned upon by breeders but line breeding (the less intensive form) has been looked upon with favor in many quarters. Let us, therefore, examine the known general effects of inbreeding upon animals.

The process of inbreeding results in making the resulting offspring pure or homozygous in a larger proportion of the gene pairs than is the case with outbred animals. The speed at which homozygosity or purity is attained is much more rapid in the case of close inbreeding than if line breeding is used, but the end results are, in general, the same.

Outward Effects of Inbreeding

As a result of increasing homozygosity, inbreeding or line breeding has the following outward effects:

1. If carried on for a period of time, it tends to create lines or strains of animals which are uniform in type and other characteristics. Thus, if many breeders in a breed are inbreeding at the same time, several lines uniform within themselves but differing widely from each other may be formed.
2. Since "good" and "bad" genes are made homozygous indiscriminately under an inbreeding program, inbreeding often leads to the production of many animals lacking in size and vigor—due to the fixing of undesirable genes.
3. Undesirable recessive genes are uncovered by inbreeding. Therefore, lethals and other genetic abnormalities often appear with increased frequency in inbred animals.

It would therefore appear that, judging from outward manifesta-

tions alone, inbreeding is predominantly harmful in its effects—often leading to the production of defective individuals or animals lacking in the vitality needed for successful and profitable production.

However, this is by no means the whole story. While it is true that inbreeding often leads to the production of animals of low value, the animals that successfully withstand it are often outstanding individuals and in addition can confidently be expected to be homozygous for a greater than average number of good genes, and thus more valuable for breeding purposes. Inbreeding may thus figuratively be called “trial by fire,” and the breeder who practices it can expect to obtain many animals which fail to measure up and have to be culled. If the program is properly planned, he can also expect to get animals of exceptional value.

Effects of Inbreeding on Breeding Value

The effects in inbreeding on breeding value can be summarized as follows:

1. Since an inbred animal is homozygous in more gene pairs than non-inbred animals, a higher proportion of genes are identical in all germ cells produced, with the result that offspring produced tend toward uniformity.
2. If the inbred animal is homozygous for desirable genes it transmits these genes uniformly, with the result that its breeding value is increased.
3. Since desirable genes are often dominant, good inbred animals are usually *prepotent*; that is, they have the ability to stamp their characteristics on their offspring to the exclusion of those of the other parent.

Who Should Inbreed or Line Breed?

From the foregoing, it can be seen that inbreeding is essentially an intensification process—undesirable factors being intensified in some animals to the point that they are fit only for the butcher, and desirable factors being intensified in other individuals with a resultant increase in breeding value.

The process of inbreeding or line breeding intensifies what it finds. Therefore, poor or mediocre stock is not good starting material for an inbreeding program.

Even the best animals in existence today have many undesirable genes and an inbreeding program can be expected to bring them to light. Thus, in order to maintain quality, rigid culling must be practiced. Particularly when line breeding is practiced, and when the herd is composed of outstanding stock, it is possible to discard those ani-

mals in which a large proportion of undesirable genes are fixed and retain only those with an intensification of good characteristics. Thus, mild inbreeding, combined with intensive selection, becomes a tool for the genetic improvement of the breed.

The herd or flock in which any form of inbreeding can be successfully used must usually have the following qualifications:

1. The animals in the herd must be of the best quality. Usually this means that the quality is high enough that it is difficult or impossible to effect improvement by going outside the herd for sires. In brief, they are considerably above the breed average.
2. If a particularly outstanding animal is owned (usually a sire), the only way of keeping it closely related to the herd is by interbreeding among its descendants. If the characteristics of this animal are sufficiently good, line breeding should be practiced.
3. The owner must be prepared to follow a rigid culling program.
4. The owner must have the financial resources to follow the culling program through without disaster.
5. The herd must be large enough to permit culling and to prevent inbreeding from occurring too rapidly.

The following types of herds should almost never inbreed or line breed:

1. The grade or commercial herd owner can seldom, if ever, afford to inbreed since he runs the risk of undesirable results and cannot sell his stock at increased prices for breeding purposes if results should be good.
2. It is usually a mistake for the owner of a purebred herd of only average quality to inbreed. More rapid progress can usually be made in herds of this type by introducing superior sires from outside. Furthermore, the probability of disastrous results increases as quality of foundation stock goes down. Undoubtedly, poor results from indiscriminate inbreeding in herds of this type have been largely responsible for the undeservedly poor reputation inbreeding enjoys in many quarters.
3. Because of limited numbers the owner of a small purebred herd cannot inbreed for a very long time without the introduction of outside blood. Oftentimes a breeder of this type can profit by buying all his sires from a larger breeder who follows a successful linebreeding program—thus, in effect, following the program of the larger breeder.

4. It is often cheaper to inbreed than to replace a sire. Where done merely as an economy measure with mediocre animals, failure is almost certain.
5. When the owner has only limited finances and cannot afford to wait for delayed returns.

Many livestock breeders are aware of the phenomenal success which has been attained by inbreeding corn and then producing cross-breeds which are used commercially, popularly known as "hybrid corn." In general, such corn has been found to yield some 10 to 15 per cent higher than the best open-pollinated varieties; and today about 95 per cent of the corn grown in the corn-growing sections of the United States is of hybrid origin. From a biological standpoint there appears to be no reason why similar methods should not bring about equally effective improvement in the quality of our commercial livestock; that is to say, highly inbred strains of hogs, cattle, and sheep could be formed, the inbred strains crossed, and the resulting animals used for commercial production.

There are, however, several production difficulties which make this plan more difficult to follow with animals than with corn. They are as follows:

1. Corn can be self-pollinated and, therefore, self-fertilized; whereas the closest inbreeding that can be accomplished with livestock is brother-and-sister matings. From a genetic standpoint this brings about homozygosis less than one half as fast as self-fertilization.
2. It is much more expensive to maintain animals, and numbers necessarily have to be limited. With corn it is easily possible to start a thousand inbred lines in any one year and maintain them as long as they show desirable characteristics. However, the maintenance of a thousand inbred lines of any of the classes of livestock by one breeder or experiment station would be an almost impossible task.

These difficulties do not appear to be insurmountable, however, and the problem is being attacked vigorously by the United States Department of Agriculture in its regional swine, sheep, and beef cattle breeding laboratories. In these laboratories inbred lines of swine, sheep, and beef cattle are being formed with the eventual purposes of (1) determining whether crosses between them will produce more desirable commercial animals than are now available, and (2) using them to improve purebred livestock. This work is still in experimental stages and it is impossible at this time to predict whether or not it will be as successful as the production of hybrid corn has proved to be. However, it can be said that early results are promising, and it may well be that in years to come inbred lines of livestock will be

maintained and crossed for the production of commercial animals. The slow speed at which this can occur puts the wide-scale production of commercial livestock by this method far in the future. It would appear, however, to be one of the most promising methods for the improvement of commercial livestock.

OUTCROSSING

An outcross is the mating of relatively unrelated animals within a breed, and is thus the opposite of inbreeding or line breeding. The results of this practice are in general about the opposite of those expected from line breeding and may be summarized as follows:

1. It tends to cover up undesirable recessive genes, since it is unlikely that unrelated animals will carry the same ones.
2. It increases the individual merit of animals.
3. It tends to lower or at best only maintain the breeding value of animals.

Thus, a continuous outcrossing program is not likely to lead to any great improvement through the fixation of desirable genes. It is, however, the type of program which had best be followed in the average or below-average purebred herd. The owner of a herd of this type has the problem of maintaining individual merit rather than of making undesirable genes homozygous.

GRADING UP

The process of grading or, as it is popularly called, "grading up" is a method which is used to improve the average quality of commercial livestock but has no power to improve animals over the best which exists during the time the program is being carried out. *Grading is the practice of using purebred sires of high quality on low-quality native grade or scrub females and on their female descendants generation after generation.*

The first generation of such a program results in offspring carrying 50 per cent of the hereditary material (or "blood," as many breeders speak of it) of the pure breed and, depending upon the quality of the original females, can usually be expected to give a considerable improvement in quality. The next generation gives offspring carrying 75 per cent of the blood of the pure breed, and in subsequent generations the proportion of inheritance remaining from the original scrub females is halved with each cross. After four or five crosses, the offspring become virtually indistinguishable from purebreds. After this point is reached, further improvement depends upon the use of purebred sires of better quality than were previously used. Grading can thus be thought of as a process by which a few good sires can

be used to improve the average quality of a herd very rapidly. On the other hand, the improvement which can be wrought by this process is limited by the quality of the pure breed itself, and its usefulness rests upon the use of really outstanding purebred sires.

High-grade animals which are the offspring of several generations of outstanding purebred sires can be and often are superior to average or inferior purebreds. Thus, the use of just any purebred sire for grading cannot be recommended.

CROSSBREEDING

Crossbreeding is the practice of mating purebred sires of one breed with purebred females of another breed or with high-grade females of another breed. There have probably been more disagreements and more heated arguments over this practice than is the case with any other thing connected with animal breeding work. It is the purpose of this discussion to point out the relevant facts regarding the desirability or undesirability of crossbreeding without attempting to make any wholesale recommendations regarding the adoption of this particular plan.

Theoretical Basis for Advantages of Crossbreeding

Various studies have shown that in the pure breeds of livestock, even where little or no planned or intensive inbreeding is done, there is a certain amount of inbreeding—partly intentional and partly due to geographical limitations upon free exchange of breeding stock from one part of the country to another. As a result of this slight degree of inbreeding, there is a slow but rather constant increase in homozygosis within each of the pure breeds of livestock. Over the period of the last 100 to 150 years this increase has been appreciable, and the various pure breeds at the present time are actually slightly inbred and therefore homozygous for more factors than was originally the case. Many of the factors fixed in the homozygous state are desirable, but inevitably some undesirable genes resulting in lowered vigor, slower growth rates, less ability to live, etc., have probably become fixed. It would be a strange coincidence if the same undesirable genes were fixed in all breeds. Therefore, on purely theoretical grounds, it would appear that crossbreeding should result in a certain increase in vigor due to the fact that the desirable genes from both breeds would be combined and the undesirable genes from each breed would be overshadowed. This increase in vigor with crossbreeding, if it actually occurs, is probably small due to the relatively small amount of inbreeding which has occurred in our pure breeds of livestock to date. With this brief background of the theoretical basis of crossbreeding, let us examine some of the practical results.

Crossbreeding Hogs

There is probably more experimental data on the subject of crossbreeding with hogs than is the case with any other breed of farm animal. The results obtained at various experiment stations located in several countries of the world have varied rather widely in the effects which have been observed in crossbreeding. For example, workers at the University of Minnesota obtained data over a number of years which indicated quite a marked advantage in favor of crossbred hogs over those of pure breeds. On the other hand, fairly extensive tests conducted at the University of Illinois failed to show that there was a significant advantage in favor of the crossbred animals. In general, other experiments are intermediate between the two just mentioned. The author has summarized the data from a large number of crossbreeding experiments and has found that on the average crossbred animals apparently exceed the average of the purebred animals used in making the crosses by a matter of about 3 per cent in pounds of pork produced per litter at six months of age. This difference is relatively small, but, on the other hand, it might be the difference between profit and loss in the hog business. Many other factors, including management methods, disease prevention, and feeding, are, however, of very much greater importance. Furthermore, crossbreeding has certain disadvantages which will be mentioned later.

Crossbreeding Beef Cattle and Sheep

Data on crossbreeding beef cattle are much less extensive, but in general they too indicate a certain advantage in vigor and growth rate from the crossing of two of the established breeds.

The different breeds of sheep differ greatly in type, growth rate, and adaptability. Therefore, the data which might be obtained on the growth rate and vigor of crossbred as compared to purebred sheep would not be very reliable. However, the practice of crossbreeding with sheep has probably been followed more widely, particularly in this country and in England, than has crossbreeding with any other class of farm animal. In the United States this is due to the fact that the fine-wool types, the Rambouillet and the Merino, are particularly adapted to use on the range because of their vigor, hardihood, and flocking instinct. It is thus desirable to have ewe flocks which are largely of fine-wool breeding. The fine-wool breeds, however, have the disadvantage of being rather inferior from a carcass standpoint, with the result that their lambs do not fatten readily nor have the conformation which is desired in market lambs. The western sheepman has therefore resorted to the practice of crossing his fine-wool ewes with mutton rams of breeds such as the Hampshire or Suffolk and producing crossbred lambs. These are usually larger and

are an improvement over their dams insofar as carcass conformation is concerned. A higher percentage of the mutton crossbreds make top market lambs than is the case with lambs of straight, fine-wool breeding. The lambs follow their mothers during the summer and are all marketed in the fall so that the loss of flocking instinct is not serious in the first cross. This practice has been used very widely and will continue to be used until breeds are developed which are vigorous, have a strong flocking instinct, and desirable mutton characteristics.

Use of Crossbred Females

It has long been considered undesirable to maintain crossbred females in a herd, particularly for more than one generation. The prejudice against their use has been due to the supposed degeneration which will occur after two or three generations of the continued use of crossbred females and the difficulty of maintaining a uniform herd or flock of females if this process is followed. Recent experimental work tends to indicate that the use of crossbred females is not nearly so undesirable as was previously thought. It has been demonstrated that such animals may actually be more vigorous and more productive than purebred females of the same type. The fact remains, however, that it is difficult to maintain a uniform herd or flock of females under conditions of continued crossbreeding and that often the producer is ultimately forced to go back to one of the pure breeds to get new foundation stock.

Some Disadvantages of Crossbreeding

If the breeder maintains purebred females and produces crossbred offspring, he is faced with the problem of sooner or later breeding the females back to a purebred sire of the same breed in order to get a supply of replacement females to take the places of those lost through old age or accidental death. If such a program is followed, the tendency is to make little or no selection and to keep all the females produced for breeding purposes. This plan does not allow for the improvement of the existing herd or flock of females through careful selection of replacement stock which give evidence of possessing better productive characteristics than their dams had. Under such a plan it is usually found that the breeder does well to maintain the quality of his females. If he were breeding to purebred sires of the same breed year after year he could make effective selections among the female offspring produced and thus be able to effect a continued improvement.

Likewise, if he uses crossbred females generation after generation, he is faced with the problem of breeding first to one breed of

male and then to another, and it is extremely difficult to maintain uniformity in the offspring produced. Unless the herd or flock is very large so that a systematic breeding program can be followed and the females of each generation bred according to a definite plan, the producer will almost inevitably end up with a motley collection of females varying greatly in type and color. Naturally, if the females in the breeding herd vary in this manner, the offspring produced also will vary. Even though such animals may individually be good, they will possibly be penalized on the market because of the fact that a good, uniform lot of animals nearly always appeals more to the buyer than a motley collection of animals varying in type and color.

In summary, then, it can be said that upon both theoretical and practical grounds, there appear to be some advantages from crossbreeding insofar as vigor, growth rate, and efficiency of production are concerned. These differences are small, but they may be large enough to mean the difference between profit and loss in certain operations. On the other side of the fence we have the disadvantage of the difficulty of maintaining desirable productive herds or flocks of breeding females if crossbreeding is practiced. Thus, each producer should make his own decision in this regard and weigh the advantages against the disadvantages carefully before deciding whether to follow a plan of pure breeding or crossbreeding.

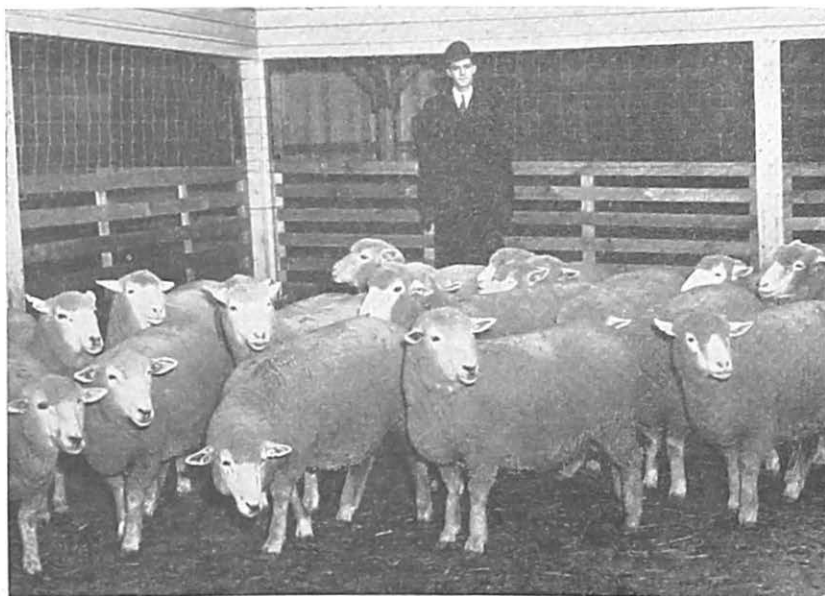


Fig. 16.—A representative group of Columbia ewes. This breed has been developed since 1912 from crosses between the Lincoln and Rambouillet breeds. (Photograph from The State College of Washington.)

Creation of New Breeds through Crossbreeding

Sometimes no existing breed has the genetic make-up suiting it to a specific set of conditions. Under such conditions, it sometimes happens that a combination of hereditary material from two existing breeds can be used to develop a new type suited to the particular conditions.

Many present-day breeds of livestock were formed in this manner long ago. The initial crosses were followed by long years of selection to fix the desired type.

The most recent recognized breed to be formed in this manner is the Columbia sheep and, since definite records of its establishment are available, a brief story of its development follows:

When the Western sheep industry began shifting from a "one-crop" industry—wool—to production of both lambs and wool, the need for a true breeding type of sheep combining the vigor, hardiness, and flocking instinct of the fine-wool types, with the size, prolificacy, and desirable carcass characteristics of the mutton types, was clearly indicated. Recognizing this need, U. S. Department of Agriculture scientists began about 35 years ago to develop such a breed from the descendants of crosses between Rambouillet ewes (a fine-wool type) and Lincoln rams (a mutton type).

Today, after more than 30 years of intense selection for desirable characters, the breed has been released to the public and seems to be filling a real place in range-sheep production.

The development of the Santa Gertrudis breed of cattle from crosses between Shorthorns and an Indian breed of cattle, the Brahman, is another recent example of the same process. This breed was developed for use in a hot, insect-infested area in South Texas. The heat and insect resistance of the Brahman was combined with the beef qualities of the Shorthorn, and, under the special conditions where it is used, the breed appears to fill the need.

It should be possible to establish a virtually unlimited number of new breeds in this manner. However, the development of a new breed is an expensive process (attempts along this line had best be undertaken by experiment stations) and, since one or more existing breeds seem to fit most conditions at least fairly well, their improvement is possibly a more pressing problem than the establishment of new ones.

COMMERCIAL HYBRIDS

Crosses between species are occasionally possible and often result in the production of animals which are valuable for commercial purposes. These animals are usually sterile.

The best known of these in the United States is the mule. The mule is a cross between the jack (male of the ass family) and a mare (female of the horse family). Mules have the reputation of being much more able to withstand abuse and work under hot conditions than the horse. They have more size and power than the ass. Thus, they are ideal work animals under certain conditions. They have been popular for centuries. Mules are ordinarily sterile, although occasional cases of fertile mare mules have been reported.

Other crosses of this nature, such as those between horses and the zebra and between the Yak and domestic cattle, are fairly popular in other parts of the world.