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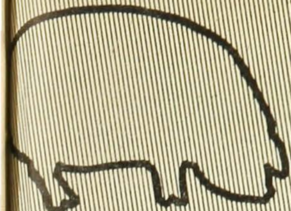

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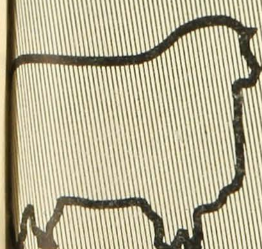

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Experiments with Inbreeding Swine and Sheep[1]

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INBREEDING may be defined as the mating of individuals that are more closely related than the average of their breed. It is clear, therefore, that inbreeding may vary greatly in intensity—from the mating of individuals that are only slightly related to the mating of those as closely related as sire and daughter or full brother and sister. The broad effect of inbreeding is to increase the purity of the stock produced.

The new individual comes into being as the result of the union and fusion of two minute germ cells. One of these germ cells is called the ovum or egg and is produced in the ovary of the mother. The egg is only about 1/200 of an inch in diameter, but it contains all the hereditary elements the mother passes on to her offspring. The other germ cell is the sperm and is produced in the testicle of the male. The sperm is much smaller than the egg (Fig. 1) yet it contains all the hereditary material transmitted by the sire to his offspring, and it is equal to the egg in determining the characteristics of the offspring. Within both the egg and sperm are still smaller structures known as chromosomes. The chromosomes may be thought of as very small rods. Chromosomes are organized in pairs and each germ cell carries one member of each pair; thus at fertilization each germ cell contributes one member of each chromosome pair to the resulting individual.

Chromosomes are the actual carriers of the units of inheritance known as genes. Each gene has an effect on one or more characteristics of the animal in which it is present. The genes may be thought of as very small beads on a string, each bead being a gene and a string of beads being a chromosome. It thus happens that the individual in inheriting pairs of chromosomes also inherits pairs of genes, one member of each coming from each parent. The members of a gene pair may be alike, in which case the individual is pure or homozygous for that gene pair, or they may be unlike so that the individual is impure or heterozygous for that gene pair. **Every mating is therefore fundamentally a mixture of the essentials of inbreeding and crossbreeding** because gene pairings at the time of fertilization include both genes that are alike and genes that are unlike.

The mating of related individuals increases the pairing of like genes. The closer the mating and the more gen-

[1] Data on swine were obtained with the cooperation of the Regional Swine Breeding Laboratory, Bureau of Animal Industry, U. S. Department of Agriculture, Ames, Iowa.

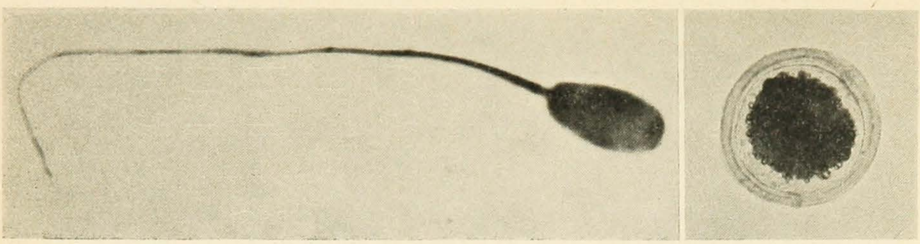


FIG. 1. Swine germ cells. Left: Sperm cell, × 1760. Right: Egg cell, × 208.

erations the inbreeding is continued, the higher the degree of genetic purity that will be attained. One outcross, however, is enough to eliminate all the genetic purity attained through several generations of inbreeding.

The purpose of inbreeding is to increase the purity of the stock inbred. Inbreeding purifies stock for undesirable as well as desirable traits; in fact, inbreeding brings to light many undesirable traits and thereby enables the breeder to discard the individuals concerned. Increased purity of stock is sought after because it tends to increase uniformity in breeding performance.

Practice and Literature

OVER 175 years ago Robert Bakewell demonstrated that inbreeding could be used effectively to improve livestock. The Colling brothers, students of Bakewell and founders of the Shorthorn breed, used inbreeding with good results throughout their long careers. Bates, a student of the Colling brothers, was a strong advocate of inbreeding and developed a highly inbred herd of Shorthorns. The history of the breeds reveals that considerable inbreeding was used in establishing most of them.

While the early constructive livestock breeders believed in and practiced considerable inbreeding, the leading biologists of that period looked upon inbreeding as injurious. Darwin, Weismann, Van Guita, Ritzema-Bos, and Crampe each concluded that degeneration accompanied inbreeding.

By and large, livestock breeders of more recent years have come to look with disfavor on inbreeding. There are exceptions; notable among them are Lovejoy and Gentry, both of whom were very successful in breeding Berkshire swine; Gudgell and Simpson and Hazlett, outstanding breeders of Hereford cattle; and C. G. Good, a successful breeder of Belgian horses.

Biologists have completely changed their earlier views and today look upon inbreeding as a potent tool in animal and plant improvement. The changed viewpoint regarding plant improvement radiated from the early studies of East, Shull, Hayes, and Jones, and it received its greatest impetus from the practical benefits derived from the use of highly inbred strains of corn in the production of hybrids.

Laboratory Animals Point the Way. The studies by King *(5)*[2] on rats and Wright *(13)* on guinea pigs reopened the possibilities of utilizing inbreeding effectively in animal improvement. At the end of 25 consecutive generations of full-brother x full-sister matings, King had rats that were superior in size and fertility to the stock of outbreds carried as a check. At the close of 20 generations of full-brother x full-sister mating of guinea pigs, Wright found that on the average there had been a decline in all the elements constituting vigor; but there were several families which had not suffered any very apparent degeneration. Crosses between different inbred families resulted in a marked improvement over both parental stocks in every respect. The maximum vigor was obtained when crossbred females were mated to crossbred males of a different cross.

As a result of his studies Wright arrived at a very important conclusion as to the application of his findings to livestock improvement. His conclusion was so far ahead of the times that it has not even yet received the recognition deserved. A portion of it follows:

"It is believed that the results point the way to an important application of inbreeding in the improvement of livestock. Nearly all of the characteristics dealt with here, like most of those of economic importance with livestock, are of a kind which is determined only to a slight extent by heredity in the individual. About 70 per cent of the individual variation in resistance to tuberculosis and over 90 per cent of that in the rate of gain and size of litter is determined by external conditions. Progress by ordinary selection of individuals would thus be very slow or nil. A single unfortunate selection of a sire, good as an individual, but inferior in heredity, is likely at any time to undo all past progress. On the other hand, by starting a large number of inbred lines, important hereditary differences in these respects are brought clearly to light and fixed. Crosses among these lines ought to give a full recovery of whatever vigor has been lost by inbreeding, and particular crosses may safely be expected to show a combination of desired characters distinctly superior to the original stock. Thus a crossbred stock can be developed which can be maintained at a higher level than the original stock, a level which could not have been reached by selection alone. Further improvement is to be sought in a repetition of the process—the isolation of new inbred strains from the improved crossbred stock, followed ultimately by crossing and selection of the best crosses for the foundation of the new stock."

From a common foundation, through continued full-brother x full-sister matings accompanied by careful selection, Morris, Palmer, and Kennedy *(9)* developed two strains of rats which in the ninth generation differed markedly in efficiency of food utilization. The low line was 40 per cent less efficient and more variable than the high line.

The studies by King and by Morris, Palmer, and Kennedy have demonstrated that long continued inbreeding is not necessarily accompanied by loss of vigor in the line. Wright found that continued inbreeding was accompanied by an average decline in vigor but he also found that certain families were developed which withstood the inbreeding surprisingly well and that crosses between certain inbred families resulted in a marked improvement over both

[2] Numbers in parentheses refer to Literature Cited—see page 39.

parental stocks. The results of all three experiments lend encouragement to the inbreeding of farm animals.

Inbreeding Farm Animals Studied. King's and Wright's published results were soon followed by several experiments in inbreeding farm animals.

The U. S. Bureau of Animal Industry *(10)* started six inbred lines of Poland China swine, six of Tamworth, and several of Chester White. Full-brother x full-sister matings were made. Several lines were lost in the early generations of inbreeding, and others were lost later or were discarded because of poor results. Two Chester White lines were carried to the seventh generation. In general, the inbreeding was accompanied by a loss of vigor. There was a decline in the number of pigs farrowed and raised, rate of growth decreased, and the feed required to produce a unit of gain increased.

Hughes *(4)* began inbreeding Berkshire swine in 1922 and reported that the inbreeding was not accompanied by any noticeable loss of size or vigor.

Godbey and Starkey *(2)* also inbred Berkshires and reported that the inbreeding did not appear to affect birth weight but that weaning weight appeared to be reduced.

Hodgson *(3)* developed three highly inbred lines of Poland China swine by full-brother x full-sister matings. Hodgson reported difficulties in obtaining matings between litter mates, that the number of pigs born alive was less among the inbreds than the outbreds, and that the losses after birth were much heavier among the inbreds than the outbreds. The inbreds required more time to reach 200 pounds in weight. On the other hand, Hodgson reported that some of the highly inbred individuals performed very satisfactorily. One of the above mentioned three lines has been retained and is reported on later in this bulletin.

Willham and Craft *(12)* reported on a study of inbreeding and outbreeding Duroc Jersey swine. Matings approximating half-brother x half-sister were made for eight generations. The inbred stock was inferior to the outbred stock in number of pigs born alive, birth weight, number of pigs weaned, daily gains, feed per unit of gain, the coefficient of digestibility and hemoglobin level.

Lush and Culbertson *(8)* studied the effects of inbreeding Poland China swine; the herd was closed to outside breeding and four boars were used each year. The project was initiated in 1930 and the report made in 1937. The pigs farrowed in 1937 had an average coefficient of inbreeding of 15.4 per cent from a base date of 1925 with a range of from 3 to 37 per cent. They reported that the more highly inbred pigs tended to be smaller at weaning and gained more slowly than the less inbred pigs.

Waters and Lambert *(11)* inbred White Leghorn fowl over a 10-year period during which time they developed six inbred families with coefficients of inbreeding ranging from 41 to 82 per cent. They found no general decrease in per cent of fertile eggs but there was a gradual decrease in average per cent of hatchability of fertile eggs. The more intensely inbred birds matured sexually 16 days earlier than the birds of the original noninbred foundation stock. The 200-day egg production did not decline markedly for any of the six separate families. Neither egg weight nor growth rate appeared to be affected by the inbreeding. With the exception of one group the mortality rate increased markedly in the more highly inbred birds.

Appraisal of Early Experiments. Taken as a whole, the above-mentioned experiments on farm animals have yielded what may be regarded as negative results. The experiment on fowl by Waters and Lambert is an exception. The results are negative at least in contrast to the results obtained on laboratory animals by King, Wright, and Morris, Palmer, and Kennedy. No one has yet developed inbred strains of farm animals that have even begun to fill the economic place inbred strains of corn are now doing or the place that the above-mentioned inbred strains of laboratory animals fill in many exacting phases of physiological and pathological research. This is no criticism of these earlier experiments for they have yielded valuable information which, if studied carefully, aid in making improved approaches to the problem of developing inbred lines.

It appears that the above-mentioned experiments may have yielded negative results for any or all of the following reasons:

1. Most of the early experiments were of necessity conducted on a small scale. It does not appear that an experiment of this kind is as likely to be highly successful if conducted with small numbers.

2. In some cases, at least, it appears that performance was not given special consideration in the selection of breeding stock. Waters and Lambert make a special point to mention that, in the conduct of their experiment, selection was most exacting for the factors affecting performance.

3. In most of the early experiments attempts were made to follow definite experimental patterns such as continuous full-brother x full-sister matings or half-brother x half-sister matings. A fixed pattern of procedure restricts the use of superior animals to an extent that will conform with this pattern. It appears that when superior breeding animals are uncovered they should be used to a maximum, regardless of how they fit into the experimental pattern.

MEASURING THE DEGREE OF INBREEDING

With Wright's *(14)* formula for calculating coefficients of inbreeding, the amount of inbreeding possessed by any one individual or group of individuals can be calculated readily. The coefficient of inbreeding (F_x) as pointed out by Wright is not absolute but gives the expected percentage decrease in heterozygosis. An F_x of 33 per cent means that, on the basis of the inbreeding practiced, it is to be expected that the genetic variability that existed at the time the inbreeding was initiated has been reduced one third. Several of the coefficients of inbreeding obtained from different systems of inbreeding are given below:

Type of Mating	F_x Per Cent
Half nephew and aunt	6.25
Full nephew and aunt	12.50
Half brother and sister	12.50
Grand sire and granddaughter	12.50
Full brother and sister	25.00
Sire and daughter	25.00
Two generations	
Half brother and sister	21.87
Full brother and sister	37.50
Sire and daughter	37.50
Three generations	
Half brother and sister	30.44
Full brother and sister	50.00
Sire and daughter	43.75

Swine Experiment

RESULTS from the aforementioned experiments and the results being derived from corn breeding are a challenge to swine breeders, students of breeding, and agricultural experiment stations. Accordingly, directors of the state agricultural experiment stations in the corn belt region requested the Secretary of Agriculture of the United States to establish a regional laboratory to explore the possibilities of further improving swine through breeding by cooperative effort between the states and the United States Department of Agriculture. The Secretary approved the request and a Regional Swine Breeding Laboratory was established in 1937 under the Bankhead-Jones Act of 1935. The Minnesota Agricultural Experiment Station was one of several state agricultural experiment stations that entered into active cooperation with the laboratory. The objective of the laboratory is to explore experimentally the problem of improving swine through the application of breeding methods.

The objects of the Minnesota project were:

OBJECTS

1. To establish inbred lines relatively homozygous for characteristics of greatest economic importance.

2. While in pursuance of the above, to gather data which when interpreted will be useful to livestock breeders.

METHOD OF PROCEDURE

Experimental herds for this project were established at the Central Station located at St. Paul, the Southeast Station at Waseca, the West Central Station at Morris, the Northwest Station at Crookston, and the North Central

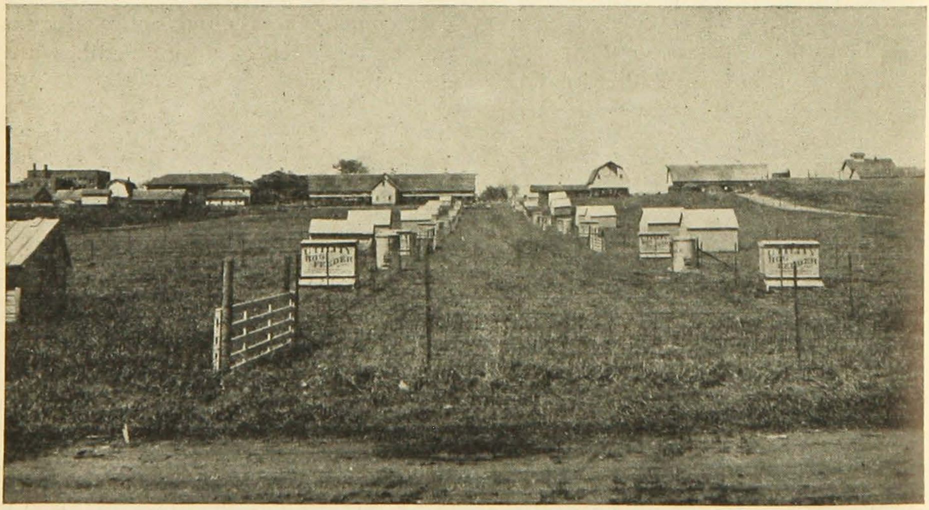


FIG. 2. Type of equipment used for litter testing.

Station at Grand Rapids. The work was limited to the establishment of a number of Poland China lines and one line from a crossbred foundation. The reason for not including more breeds was to allow for a more comprehensive attack on one breed and the Poland China was selected because a small inbreeding project was already in progress with this breed.

In establishing the foundations for the lines an attempt was made to secure as superior stock as was obtainable. Animals with performance records were not obtainable, but an attempt was made to purchase growthy animals of good type from large litters. Foundation stock for the Poland China lines was secured from eight different herds in order to make a rather wide sampling of the breed.

Breeding Program. From the outset the inbreeding program has been a flexible one; the inbreeding has not been advanced at any fixed rate or by any given procedure such as half-brother x half-sister matings. This procedure appeared to offer more room for maneuvering in selections and matings than a fixed program. It was planned, however, to advance the inbreeding as rapidly as possible without sacrificing performance. To accomplish this, matings with a rather wide range in degree of closeness have been made for the most part within each line.

Feeding and Management. Rations and management were standardized as much as possible at the outset. The rations used for the first two years from weaning on proved somewhat unsatisfactory for the proper development of growing pigs. The following rations have been used for the past three years and appear to be quite satisfactory:

Growing-Fattening Rations

Month after weaning	1	2	3	4
Milk	2 lbs. per pig for first two weeks			
	per cent			
Corn	40	80	85	88
Flour middlings	20			
Hulled oats	20			
Soybean meal or linseed meal	10	10	7.5	6
Tankage, dry rendered	10	10	7.5	6
Mineral mixture	To each 100 pounds of feed— Ground limestone ½ lb. Salt ½ lb.			

Some flexibility has been followed in the sow rations, but in general they have been about as shown below:

Pregnant females are put in rather high condition previous to farrowing.

Between one half and two thirds of the litters farrowed are tested by feeding them out separately. Each test lit-

Pregnant Sow Rations

	Old Sows		Gilts	
	Ration 1	Ration 2	Ration 1	Ration 2
	Pounds		Pounds	
Corn	500	100	500	100
Oats	250	300	250	300
Barley	150	500	150	500
Bran	100	100	100	100
Soybean meal or linseed meal	40	40	50	50
Tankage, dry rendered	40	40	50	50
Alfalfa	100	100	100	100
Mineral, 40-40-20	15	15	15	15
Potassium iodide	2½ oz.	2½ oz.	2½ oz.	2½ oz.

ter is given about one-fourth acre of pasture. Alfalfa pasture is used for the most part but some rape has been used. Each lot has its own self-feeder, waterer, and portable house.

Pastures are rotated each year. At two of the stations it has been necessary to use the same ground every other year, but at the others a three-year rotation has been followed.

Records. Careful records of performance have been made on each pig farrowed and raised. Each pig is given an individual number and is identified by an ear notching system that provides for the identification of each pig with numbers running from 0 to 999. The litters are numbered by 10's running from 0, 10, 20, and up to 990. After litter number 990 has been used, the numbering again starts from 0. In the records the letter A is used to designate the second thousand, as for instance, A0, A10, etc.; B is used for the third thousand, etc.

The records of performance kept are:

1. **Birth weight**
2. **Three-week weight**
3. **Eight-week weight (weaning age)**
4. **Weights every four weeks thereafter until each pig weighs 200 pounds or reaches 180 days**
5. **Feed consumption by litters from weaning weight to finish at 200 pounds**

The performance record contains information by litters, on the number of pigs born alive, number of pigs weaned, and number raised.

At the completion of the feeding trial each pig is measured for:

1. **Length from a point midway between the ears to the root of the tail**
2. **Width back of the shoulders**
3. **Depth of body taken back of the forelegs**
4. **Length of foreleg**

Each animal is scored at birth, at three weeks, at eight weeks, and at completion of the trial. The objective of the scoring is to make appraisals of the animals when in various stages of development on the basis of their appearance.

Selection. From the outset selection has been intensive for the factors affecting performance. This is true regarding individuals, litters, and lines. Selection is a continuous process extending throughout the entire year.

Not all the litters farrowed are placed on a litter test. An excess is farrowed to allow for culling at weaning. The selection at weaning time is based almost entirely on size of litter; but litters that are obviously lacking in thrift are culled. The average weight per pig of those culled is about the same as that of those put in test lots. The gilts that produce the best litters are kept over for one or two additional years and the original mating is usually repeated.

If one of these repeat litters is smaller than those normally selected for testing, it may still be put on test because if a sow has once produced a good-sized litter, this is evidence that she has a genetic constitution capable of satisfactory reproduction. It is well known that a gilt which has produced a small litter may at the next farrowing produce a large litter, but again she may not. This method of selecting for fertility is much like that of the gambler who plays for the percentage. Selection of test litters is therefore based primarily on number of pigs

Pig Number	A130	A131	A132	A133	A134	A135	A136	A137	A138	A139	A130
Sire	...	...	...	...	...	...	...	...	...	...	N.W. 783
Dam	...	...	...	...	...	...	...	...	...	...	N.W. 565
Age of dam	...	...	...	...	...	...	...	...	...	...	14
F_x—dam	...	...	...	...	...	...	...	...	...	...	.30
F_x—litter	...	...	...	...	...	...	...	...	...	...	.33
Number born alive	...	...	...	...	...	...	...	...	...	...	10
Number born dead	...	...	...	...	...	...	...	...	...	...	0
Birth weight	3.5	3.0	3.0	3.1	2.7	2.9	2.6	2.6	2.4	1.5	2.73
21-day weight	14	14	15	13	10	14	14	13	12	9	12.80
Number weaned	...	...	...	...	...	...	...	...	...	...	9
Weaning weight—individual	45	40	41	42	...	36	41	39	36	28	38.67
Weaning weight—litter	...	...	...	...	...	...	...	...	...	...	348
Number raised	...	...	...	...	...	...	...	...	...	...	9
Sex	F	M	F	Boar	F	M	F	F	Boar	F	...
180-day weight	285	277	270	276	...	270	288	256	276	244	271
Rate of gain—individual	1.72	1.76	1.71	1.74	...	1.76	1.79	1.64	1.78	1.69	1.73
Rate of gain—litter	...	...	...	...	...	...	...	...	...	...	...
Score	49	47	49	49	...	49	49	47	48	47	48.2
Feed per 100 pounds gain	...	...	...	...	...	...	...	...	...	...	309

FIG. 3. A litter summary sheet showing performance for 1941 of Black Star Litter A130 at Northwest Station.

weaned, and selection of sows to be held over for a second or third farrowing (due allowance being made for age of sow) is based almost entirely on total pounds of pig weaned.

During the first four years of the experiment, the pigs were taken off the test when they weighed between 215 and 230 pounds. The fifth year they were taken off trial when they reached a weight of 200 to 210 pounds. The reason for lowering the weight was that late farrowed litters frequently did not attain the heavier weights before it was necessary to move the pigs from summer quarters.

At the time the pigs are weighed from the test lots a litter summary sheet as illustrated is made up for each litter on test. All the information regarding each pig and each litter that is to be used in making selections is entered on the litter summary sheet. The 180-day weight and rate of gain for the individual and the litter are calculated factors. Score is an appraisal made on each animal as judged by the eye. The scoring involves six factors, namely: (1) vigor and thrift, (2) quality, (3) length of body, (4) conformation, (5) animal as a whole, and (6) grade. Each factor is scored independently and 9 constitutes a perfect score in each; thus 54 is a perfect total score.

The litter summary sheets give a summary by litters. In most lines there are only about 10 test litters each year. The summary sheets are spread on a table and an attempt made to arrange them in the order of merit. Usually this is not especially difficult even though no attempt is made to group all of the factors affecting performance into one index figure. If two litters are rather close, no serious attempt is made to distinguish which is the better because if they are the better litters the best gilts will be taken from both. The factor given most consideration at this time is rate of gain from weaning to finished weight. Fertility received special emphasis at weaning time but receives some attention again. It frequently happens that some litters which are smaller than are desired are placed on test, in which case the smaller litters are discriminated against in selection at this time. Score receives some consideration; it receives most consideration in lines that possess obvious defects such as crooked legs and light hams.

Feed requirements also receive consideration. An attempt is made to select breeding stock from litters whose feed requirements are less than the average for the line. For purposes of selection, actual feed requirements are corrected to a uniform weaning-weight basis. The reason is that lighter weight animals put on gains at a lower feed requirement and the pigs which were lightest at weaning have an advantage in subsequent feed requirements. On the basis of the Minnesota data each additional pound per pig at weaning raises the feed requirements 0.8 of a pound per 100 pounds gain. For selection purposes feed requirements are corrected to a 33-pound weaning-weight base; thus litters that average 34 pounds at weaning have 0.8 pound taken from their feed requirements per 100 pounds gain, and litters that wean at 32 pounds have 0.8 pound added.

Next the records of the best-performing gilts within a line are all recorded on another litter summary sheet (Fig. 4). The litter summary sheets therefore serve two purposes: (1) as a permanent record of each litter and (2) as a means of comparing the records of the better-performing individuals and litters.

Pig Number	A261	A332	A335	A338	A410	A457	A500	A501	A505	A506	A507	A693	A697	A700	A703	A704	A705
Sire	126	126	126	126	126	570	570	570	570	570	570	570	570	570	570	570	570
Dam	387	378	378	378	127	793	920	920	920	920	920	802	802	A141	A141	A141	A141
Age of dam, months	23	24	...	...	35	13	12	...	...	...	...	12	...	12	...	...	...
F_x—dam	.08	.08	...	...	.08	.29	.23	...	...	...	...	.29	...	.26	...	...	...
F_x—litter	.23	.29	...	...	.29	.20	.25	...	...	...	...	.26	...	.29	...	...	...
Number born alive	10	10	...	...	13	11	10	...	...	...	...	10	...	8	...	...	...
Number born dead	0	1	...	...	0	0	0	...	...	...	...	0	...	0	...	...	...
Birth weight	3.1	3.6	3.2	3.0	2.6	2.4	3.5	3.8	3.2	3.3	2.8	3.5	3.2	3.6	3.2	3.1	3.0
21-day weight	12	15	16	15	8	11	13	12	8	11	10	15	14	8	11	10	11
Number weaned	9	9	...	...	12	11	10	...	...	...	...	9	...	7	...	...	...
Weaning weight—individual	29	37	33	35	31	31	39	36	25	41	31	39	35	30	34	34	37
Weaning weight—litter	267	325	...	...	401	334	327	...	...	...	...	318	...	232	...	...	...
Number raised	9	9	...	...	10	11	10	...	...	...	...	9	...	7	...	...	...
Sex	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
180-day weight	235	245	240	245	229	231	263	248	223	265	239	250	256	233	240	229	229
Rate of gain—individual	1.61	1.60	1.61	1.62	1.55	1.56	1.69	1.64	1.56	1.71	1.61	1.61	1.68	1.59	1.60	1.52	1.50
Rate of gain—litter	1.62	1.61	...	...	1.59	1.33	1.61	...	...	...	...	1.57	...	1.53	...	...	...
Score	51	47	47	50	50	50	50	50	50	50	50	50	50	50	50	50	47
Feed per 100 pounds gain	318	305	...	...	321	303	303	...	...	...	...	307	...	311	...	...	...

FIG. 4. Litter summary sheet used for grouping the performances of the better Viola gilts for 1941 at the West Central Station

After the selection has been made on paper, the pigs are gone over individually and if any possess serious defects such as light hams or bad legs, they are eliminated. In practice, very few pigs that have been selected on paper have been eliminated by this later individual inspection.

More females are saved for breeding than are wanted for farrow. If it is planned to farrow about 15 sows in a certain line about 20 are saved for breeding. The extra 25 per cent has proved a sufficiently generous allowance so that females that do not settle on first service are usually discarded. It is recognized that failure to settle may be the boar's fault or be due to a poor service, but it is also possible that difficulty in settling may be due to low fertility. The extra 25 per cent also allows for discarding the occasional gilt that does not remain thrifty or does not develop as well as expected. Selection of females is therefore almost a continuous operation throughout the year.

Selection of boars is made in essentially the same manner as that of females excepting that fewer individuals can be retained and more emphasis is placed on the performance of the boar's litter mates and also on strength of pedigree.

In an inbreeding program where the lines are rather small, little opportunity is offered for systematic sire testing. The general policy has been to use the young untested sire on only a few females the first year and, if his litters perform well, then he is put into heavier service the following year or years. It has not always been possible to do this; occasionally none of the tested sires has been satisfactory or something may have gone wrong with the tested sire intended for use on most of the females.

RESULTS

Lines Discarded. At the outset of this experiment it was decided to cull very closely both individuals and lines. Three rather highly inbred Poland China lines were already on hand at the Southeast Experiment Station. Two of these lines were culled at the outset because of poor performance, especially in fertility, and because of inferior body form. Seven of the lines started have been culled because of poor performance. Three of the seven were culled before they were even inbred, one was culled when the inbreeding reached about 12 per cent, and three at about 20 per cent. All of these lines originated from stock coming from what were supposed to be some of the very best so-called "bloodlines" in the corn belt.

Southeast Experiment Station. At the start of this project three lines of Poland China hogs with F_x's ranging from 50 to 80 per cent were on hand, two of which were discarded at the outset. Four new lines were started, but all have been discarded because of poor performance in one or more respects. *The M line* is one of the three original inbred lines. Some pigs in this line had been carried to eight generations by full-brother x full-sister matings, but the general level of performance was low so it was culled closely and crosses made between two of its sublines. The results were that the F_x was lowered to about 45 per cent and the size of the line greatly reduced. During 1937 and 1938 fall litters only were produced. Their records are not included because environmental conditions differ so much between fall and spring pigs that a comparison of the performance records made during 1937 and 1938 with those made in 1939, 1940,

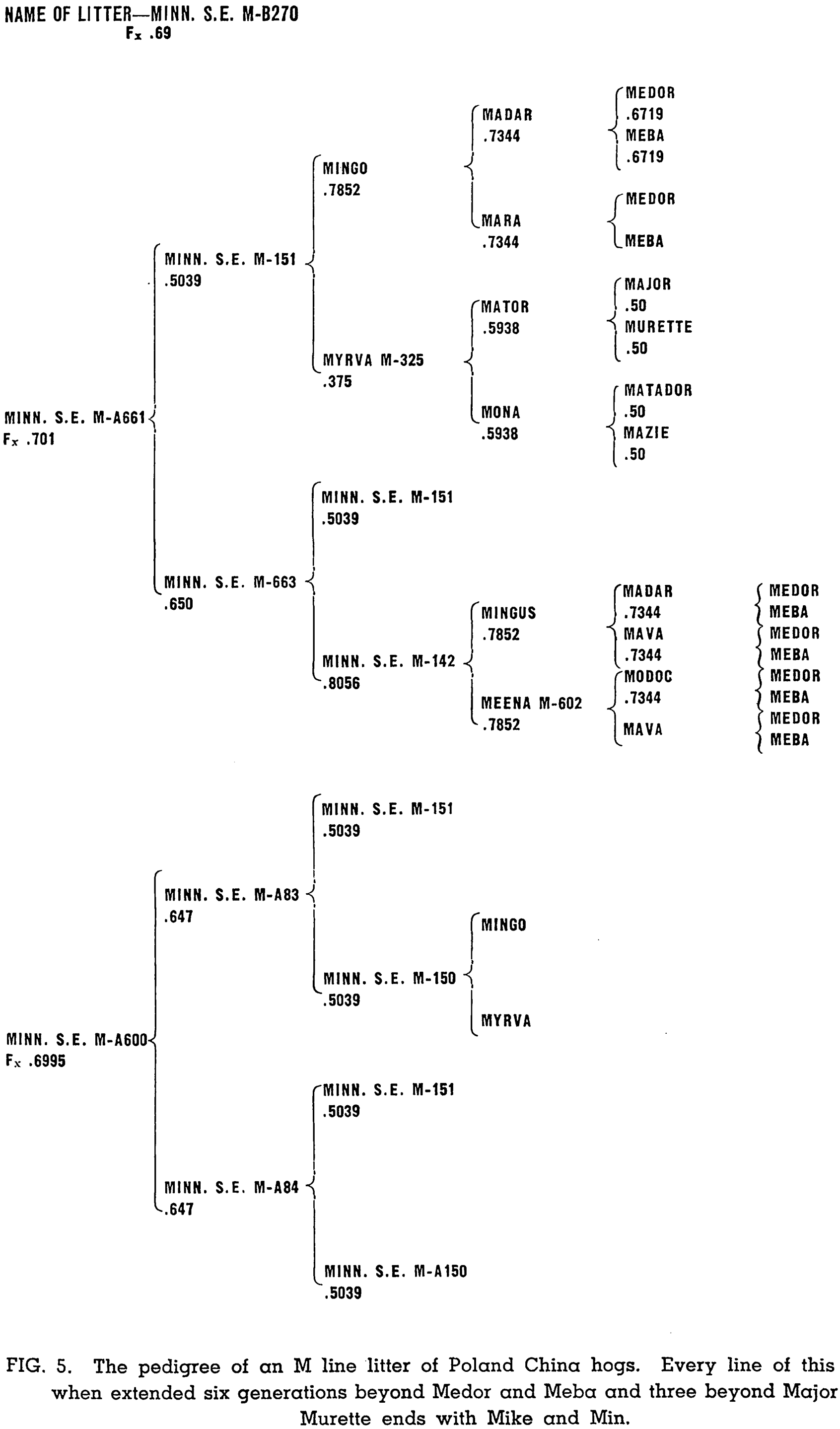


FIG. 5. The pedigree of an M line litter of Poland China hogs. Every line of this pedigree when extended six generations beyond Medor and Meba and three beyond Major and Murette ends with Mike and Min.

Table 1. Performance of M Line by Years

	1939	1940	1941
F_x	.52	.70	.69
Number of pigs born alive	7.3	5.3	7.5
Number of pigs weaned	5.3	2.4	5.8
Weaning weight	32	29	34
112 day weight	86	92	89
180 day weight	185	185	197
Rate of gain—weaning to 200 pounds	1.25	....	1.32
Feed per 100 pounds gain	325	....	345

and 1941 would be very misleading. In 1940 the herd was severely affected with what, for lack of a better term, is called "little pig disease." The losses were so heavy that litter testing was not attempted. This was overcome in 1941 and it is believed that the performance record made in 1941 is a rather correct portrayal of the line's true inherent capacity for production. The animals are quite satisfactory in type although they tend to be a bit heavier in the jowl and somewhat more flabby in fleshing than many critics of swine type demand. A large number of the individuals have erect ears. On the other hand, they are rather short of leg and have plump hams.

This line is highly inbred and is now being tested in various combinations of crosses with inbred lines both of the Poland China and of other breeds.

Central Experiment Station. The original stock secured for the foundation of a line at this station was selected from what was generally considered some of the very best breeding within the Poland China breed. A mature boar that was regarded as a proved sire was selected to head the line. The performance of this stock was so poor that the entire line was discarded at the end of the first year.

The C.1 Line. A second line, the C.1 line, was started from the mating of females in the University outbred herd to a boar secured from one of the leading herds in the country. The boar was an excellent individual. The performance record of the line is presented in table 2. The record is not at all impressive. Several weaknesses not revealed by the table were: (1) the sows were poor milkers, (2) the pigs lacked thrift until they reached weights of about 150 pounds, (3) considerable infertility was encountered in the boars, and (4) close matings were made each year but no success was achieved in advancing the F_x beyond 20 per cent. Despite the above-mentioned weaknesses in performance, when the gilts and barrows in this line weighed between 220 and 250 pounds many of them were considered excellent individuals by nationally recognized critics of type. Because of its persistent poor performance the line was discarded at the close of 1941.

The C.2 Line. This line originated from a cross of C.1 and the W.L. line at the West Central Station. The two

Table 2. Performance of C.1 Line by Years

	1938	1939	1940	1941
F_x	.05	.16	.20	.19
Number of pigs born alive	9.2	6.5	5.9	6.8
Number of pigs weaned	5.7	4.7	3.9	3.7
Weaning weight	30	26	32	31
112 day weight	89	80	104	99
180 day weight	195	192	218	207
Rate of gain—weaning to 200 pounds	1.33	1.33	1.44	1.39
Feed per 100 pounds gain	335	317	385	381

Table 3. Performance of C.2 Line by Years

	1940	1941
F_x	.13	.25
Number of pigs born alive	11	7.9
Number of pigs weaned	10	6.0
Weaning weight	27	35
112 day weight	91	101
180 day weight	207	210
Rate of gain—weaning to 200 pounds	1.50	1.38
Feed per 100 pounds gain	372	357

years' performance of this line is presented in table 3. The line is definitely superior to the C.1 but it possesses many of the weaknesses of the C.1 line and apparently possesses no advantages over the Western Lady line.

The Northwest Experiment Station. Foundation stock for this herd was secured from three nationally known herds. The 1937 crop was produced from mating the boar, Black Star, secured from one of the herds, to females secured from the other two herds. The progeny of the females secured from one herd performed so much poorer than those secured from the other herd that this stock was all culled at the end of the first year. The remaining stock arising from two separate herds was then separated and inbred so as to concentrate the breeding of each of the original herds.

The Black Star Line. A son of the original boar, Black Star, was mated to his dam, aunts, and sisters for the 1938 crop of Black Stars. In the fall of 1938 Black Star was brought back in the herd and used on his daughters and double granddaughters; thus the entire 1939 crop of pigs had F_x's of 27 per cent. As will be noted in table 4, the fertility, livability, and rate of gain for the line as a whole decreased in 1939.

Two sons of Black Star were used in the fall of 1939. A mild outcross was also introduced at this time. Two daughters of Black Star out of Western Lady sows from the West Central Station were introduced in the herd. These two sows were mated to a boar that was both a son and grandson of Black Star. One of the litters was very outstanding in performance; the other was above average. A herd boar with an F_x of 20 per cent was saved from the first mentioned litter and it appears that he is proving to be rather outstanding as a sire. Apparently this slight outcross did much for the line.

A rather typical pedigree of a litter in this line is presented in figure 6.

The fertility for the line is lower than desired, but an encouraging feature is that several of the more highly inbred sows possess rather high fertility. This indicates possibilities through further intensive selection. The rate of gain for the line is very good.

The Market Lady Line. The 1937 crop in this line was the same as the Black Star line mentioned above. In the fall of 1937 the stock was divided,

Table 4. Performance of the Black Star Line (Northwest Station) by Years

	1937	1938	1939	1940	1941
F_x	.02	.16	.27	.31	.34
Number of pigs born alive	8.4	7.9	5.6	7.5	6.5
Number of pigs weaned	5.7	6.1	4.8	4.6	5.3
Weaning weight	32	34	34	28	34
112 day weight	100	95	93	98	115
180 day weight	204	201	193	227	252
Rate of gain—weaning to 200 pounds	1.39	1.33	1.28	1.56	1.65
Feed per 100 pounds gain	331	403	348	290	333

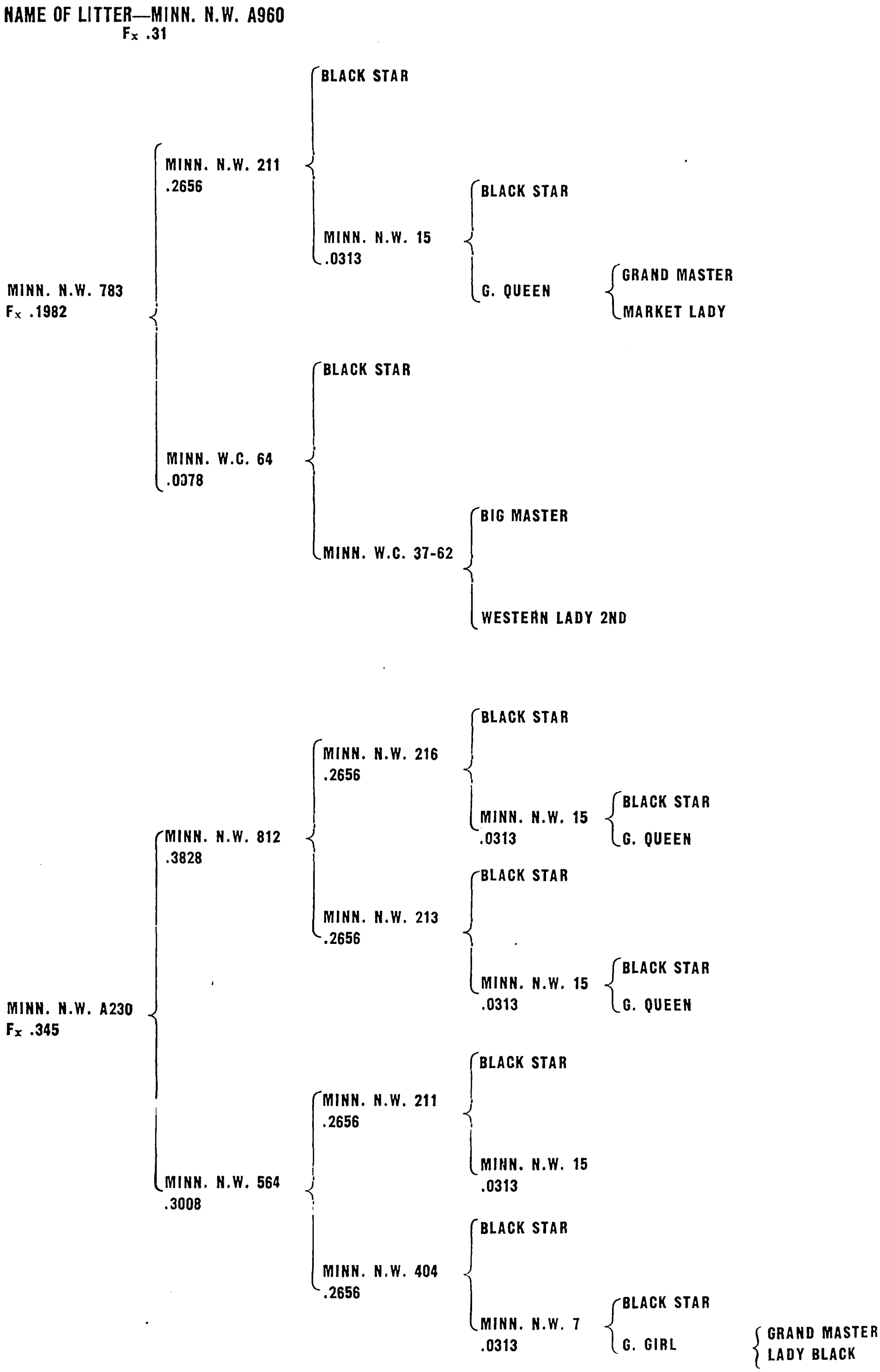


FIG. 6. The pedigree of a Black Star litter at the Northwest Station.

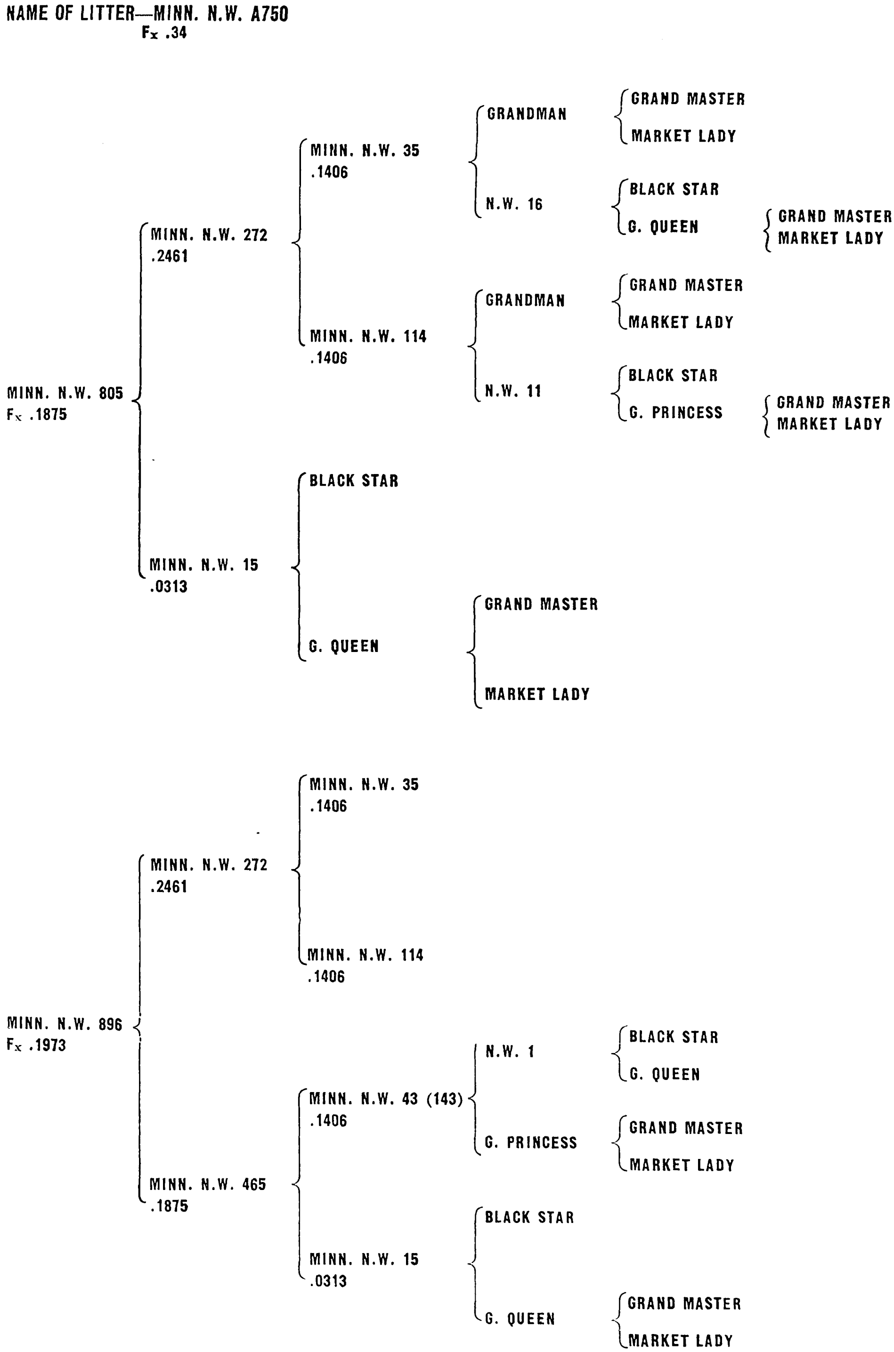


FIG. 7. A rather typical pedigree of a Market Lady litter.

Table 5. Performance of Market Lady Line by Years

	1937	1938	1939	1940	1941
F_x	.02	.12	.20	.22	.31
Number of pigs born alive	8.4	8.7	6.4	6.7	6.4
Number of pigs weaned	5.7	6.4	4.8	3.9	5.3
Weaning weight	32	37	33	28	34
112 day weight	100	107	98	100	104
180 day weight	204	235	206	226	235
Rate of gain—weaning to 200 pounds	1.39	1.52	1.38	1.55	1.55
Feed per 100 pounds gain	331	378	348	306	324

one half being used to develop the Black Star line and the other half used to develop the Market Lady line. In mating for 1938 farrow, a yearling boar included in the original purchase was used on his sisters and nieces. Since then two or three boars, developed in the line, have been used each year. The performance of the line is presented in table 5. A number of cryptorchids (males with undescended testicles) have appeared in this line. This is the most pronounced lethal or sublethal character that has been brought out by the entire inbreeding program.

The line differs some from the Black Star line. The rate of gain is not quite as rapid, the pigs tend to be shorter legged, and they take on market finish at a younger age, yet they do not differ sufficiently so the animals can be identified by appearance as to the line in which they belong.

West Central Experiment Station. During the winter of 1937 a number of bred sows were purchased for the foundation of this herd. One group of sows was purchased from one of the best known herds in the country, and three sows were purchased from a nearby local breeder. These latter three sows were, however, well bred as judged by the usual standards of judging merit, for their pedigrees contained the names of numerous prize winners at state and national fairs. The differences in performance in the two groups were very striking; all the sows and their progeny secured from the first-mentioned herd were culled at the close of the first year. The three lines being developed at this station have all descended from the three bred sows secured from the local breeder, and actually one of the three has contributed very little to the present herd. In the fall of 1938 the boar, Black Star, was mated to most of the females; he therefore introduced something of an outcross.

The Western Lady Line. The performance of this line is presented in table 6. It takes its name from the foundation sow, Western Lady 2nd.

Table 6. Performance of the Western Lady Line by Years

	1937	1938	1939	1940	1941
F_x	0	.01	.15	.24	.25
Number of pigs born alive	....	7.5	8.4	7.4	8.9
Number of pigs weaned	7.7	6.5	6.5	6.1	7.8
Weaning weight	47	34	33	32	31
112 day weight	125	92	91	101	93
180 day weight	249	209	202	220	209
Rate of gain—weaning to 200 pounds	1.57	1.38	1.36	1.47	1.42
Feed per 100 pounds gain	363	347	342	325	306

NAME OF LITTER—MINN. W.C. A990
F_x .31

- MINN. W.C. A215, F_x .25
  - MINN. W.C. 3
    - BIG MASTER
      - IDEAL MASTER
        - GRAND MASTER
        - NONE SUCH MAE
      - JEWEL'S LADY
        - GOLDEN LAD
        - STYLISH JEWEL
    - WESTERN LADY 2ND
      - FASHION PARADE
        - SILVER FASHION
        - BEAUTY PARADE
      - WESTERN LADY
        - WESTWARD HO
        - EVELYN DIAMOND
  - MINN. W.C. 37-62
    - BIG MASTER
    - WESTERN LADY 2ND
- MINN. W.C. 703, F_x .25
  - MINN. W.C. 3
  - MINN. W.C. 37-50
    - BIG MASTER
    - WESTERN LADY 2ND

FIG. 8. A rather typical Western Lady pedigree.

The line carries some breeding from both the Viola and the Black Star lines, but in its development the breeding program has been centered around linebreeding to Western Lady 2nd.

The inbreeding for this line has been advancing at the rate of a little over 8 per cent each generation since 1938 even though two or three sires have been used each year. The performance of the line has not changed markedly during the five years. Feed costs are reduced but it is likely that some of this reduction is due to improved equipment and management.

The Viola Line. The line takes its name from the two bred gilts, which were full sisters, purchased during the winter of 1937. Only one of the two gilts has contributed materially to the animals now in the line. The two original gilts had a slight relationship to Western Lady 2nd, foundress of the Western Lady line, and in the fall of 1937, a son of Western Lady 2nd was used on two Viola females; the 1938 crop of Violas, therefore, consisted of but two litters. Since then about 15 sows are farrowed each spring and 10 litters are put on test.

The performance record for this line is presented in table 7. The performance of the line certainly has not declined with the advance of inbreeding. This line also shows an improvement in feed costs but this may be due, at least in part, to improvements in equipment and management. Two or three boars have been used each year and the inbreeding has been advanced about 7 per cent per year.

The Black Star Line. The boar, Black Star, used at the Northwest Station, was brought to the West Central Station in the fall of 1937 and used on all the females in the herd excepting the two Violas mentioned above. The Western Lady and Black Star lines were, therefore, one and the same in 1938, as were the Violas and Western Ladys in 1937. In the fall of 1938 the Western Lady and Black Star lines were separated. A son of Black Star was used on the Black Star line, and a son of Western Lady 2nd, farrowed in 1937, was used on the Western Lady line. From this time on no interchange of breeding stock has occurred between the two lines. In the Black Stars the breeding has been back to Black Star. The line is about as closely related to Black Star as his own outcross sons and daughters, and it will remain essentially so unless an outcross is introduced. The performance for this line shows rather definite signs of improvement with the advance in inbreeding; this is true of fertility, rate of gain, and feed costs. Furthermore, the line appears to have improved considerably in body form. In 1938 and 1939 the Black Stars were criticized some for being a little long of leg and light of ham. While the pigs in this line are

Table 7. Performance of the Viola Line by Years

	1937	1938	1939	1940	1941
F_x	0	.08	.16	.29	.27
Number of pigs born alive	....	10.5	8.3	8.8	9.0
Number of pigs weaned	7.7	9.0	5.9	7.3	7.6
Weaning weight	47	29	34	33	32
112 day weight	125	91	95	102	101
180 day weight	249	207	203	225	225
Rate of gain—weaning to 200 pounds	1.57	1.44	1.36	1.50	1.52
Feed per 100 pounds gain	363	327	346	332	311

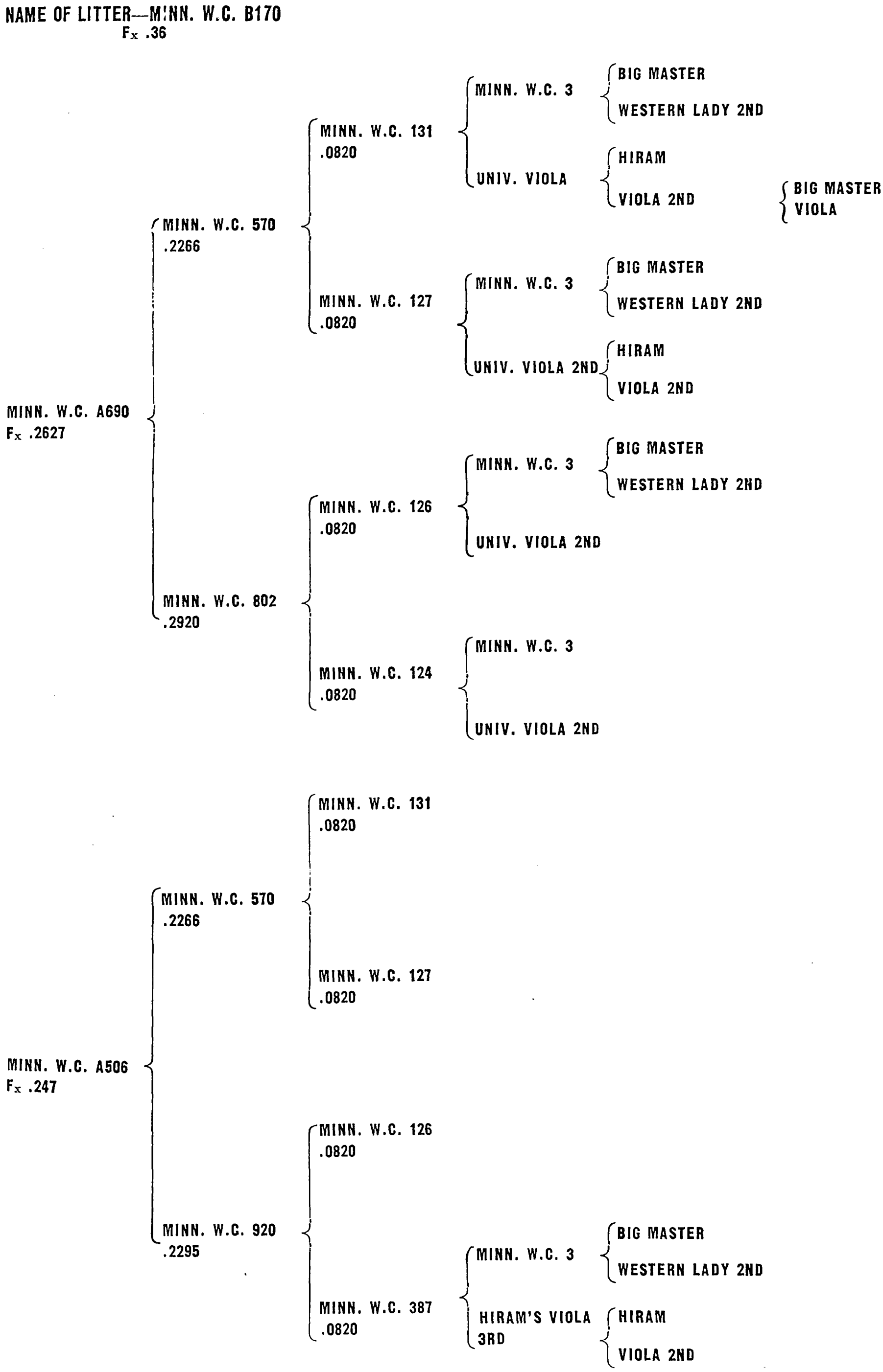


FIG. 9. A Viola pedigree.

NAME OF LITTER—MINN. W.C. B290
F_x .34

- MINN. W.C. A400 F_x .237
  - MINN. W.C. 751 .2031
    - MINN. W.C. 521 .1464
      - MINN. W.C. 24 .0078
        - BLACK STAR
          - BLACKSTONE
          - BRILLIANT QUEEN
        - MINN. W.C. 37-50
          - BIG MASTER
          - WESTERN LADY 2ND
      - MINN. W.C. 180 .0195
        - BLACK STAR
        - H. VIOLA 4TH
          - HIRAM
          - VIOLA 2ND
    - MINN. W.C. 22 .0078
      - BLACK STAR
      - MINN. W.C. 37-50
        - BIG MASTER
        - WESTERN LADY 2ND
  - MINN. W.C. 474 .1914
    - MINN. W.C. 24 .0078
    - MINN. W.C. 64 .0078
      - BLACK STAR
      - MINN. W.C. 37-62
        - BIG MASTER
        - WESTERN LADY 2ND

- MINN. W.C. A486 F_x .233
  - MINN. W.C. 751 .2031
  - MINN. W.C. 974 .2578
    - MINN. W.C. 494 .1679
      - MINN. W.C. 24 .0078
        - BLACK STAR
        - MINN. W.C. 37-50
      - MINN. W.C. 51 .0078
        - BLACK STAR
        - VIOLA 3RD
          - BIG MASTER
          - VIOLA
    - MINN. W.C. 470 .1914
      - MINN. W.C. 24 .0078
      - MINN. W.C. 64 .0078
        - BLACK STAR
        - MINN. W.C. 37-62
          - BIG MASTER
          - WESTERN LADY 2ND

FIG. 10. The pedigree of a Black Star litter at the West Central Station.

Table 8. Performance of the Black Star Line (West Central Station) by Years

	1938	1939	1940	1941
F_x	.01	.18	.23	.25
Number of pigs born alive	7.5	7.6	7.9	8.9
Number of pigs weaned	6.5	4.4	6.9	7.4
Weaning weight	34	33	38	33
112 day weight	92	95	110	104
180 day weight	209	208	240	230
Rate of gain—weaning to 200 pounds	1.38	1.38	1.56	1.54
Feed per 100 pounds gain	347	357	329	324

still slightly longer of leg than the Violas and Western Ladys, criticisms of their type have largely disappeared.

The North Central Station. The line at this station, known as the Minn. No. 1 line, rests on a crossbred foundation of the Tamworth and Danish Landrace breeds. For 1937 farrow, three Tamworth gilts were secured from Western Canada and three from Iowa. A Danish Landrace boar was used on the six gilts.

In the fall of 1937 two more Tamworth gilts were added to the herd and mated to a new Landrace boar. Four Landrace gilts were added to the herd and mated to crossbred Landrace-Tamworth boars. These additions were made in order to broaden the genetic base for the line. This precaution apparently made little if any effective contribution to the line because the present stock traces almost entirely to three of the 1937 litters.

In the fall of 1937, two F_1 boars were used on 13 of their half-sister F_1 gilts. The 1938 crop consisted of F_1, F_2, backcross Landrace, and backcross Tamworth pigs. In the fall of 1938 all purebred Tamworth and Landrace animals were sold and breeding stock was selected entirely on the basis of performance records. That has been the policy ever since, although an attempt has been made to develop gradually a colored stock. One white boar was used in 1938, but none since. Another departure from selecting strictly on performance was made in 1939. Several of the 1939 litters gained rapidly but were long-legged and light-hammed. These litters were culled entirely. The policy has since been not to save animals for breeding that are light of ham or very defective in feet or legs.

Starting with 1938, four or five boars have been used each year. An attempt is being made to advance the inbreeding very slowly, but when a certain family in the line exhibits a superior performance, the inbreeding advances more rapidly than is to be expected on the basis of the number of sires used.

Table 9. Performance of the Minn. No. 1 Line by Years

	1937	1938	1939	1940	1941
F_x	0	.07	.14	.19	.22
Number of pigs born alive	9.2	9.5	8.8	9.3	8.6
Number of pigs weaned	8.0	7.7	7.1	7.0	6.8
Weaning weight	44	34	30	29	35
112 day weight	115	102	102	110	110
180 day weight	239	225	229	248	229
Rate of gain—weaning to 200 pounds	1.53	1.51	1.57	1.67	1.50
Feed per 100 pounds gain	308	358	315	302	307

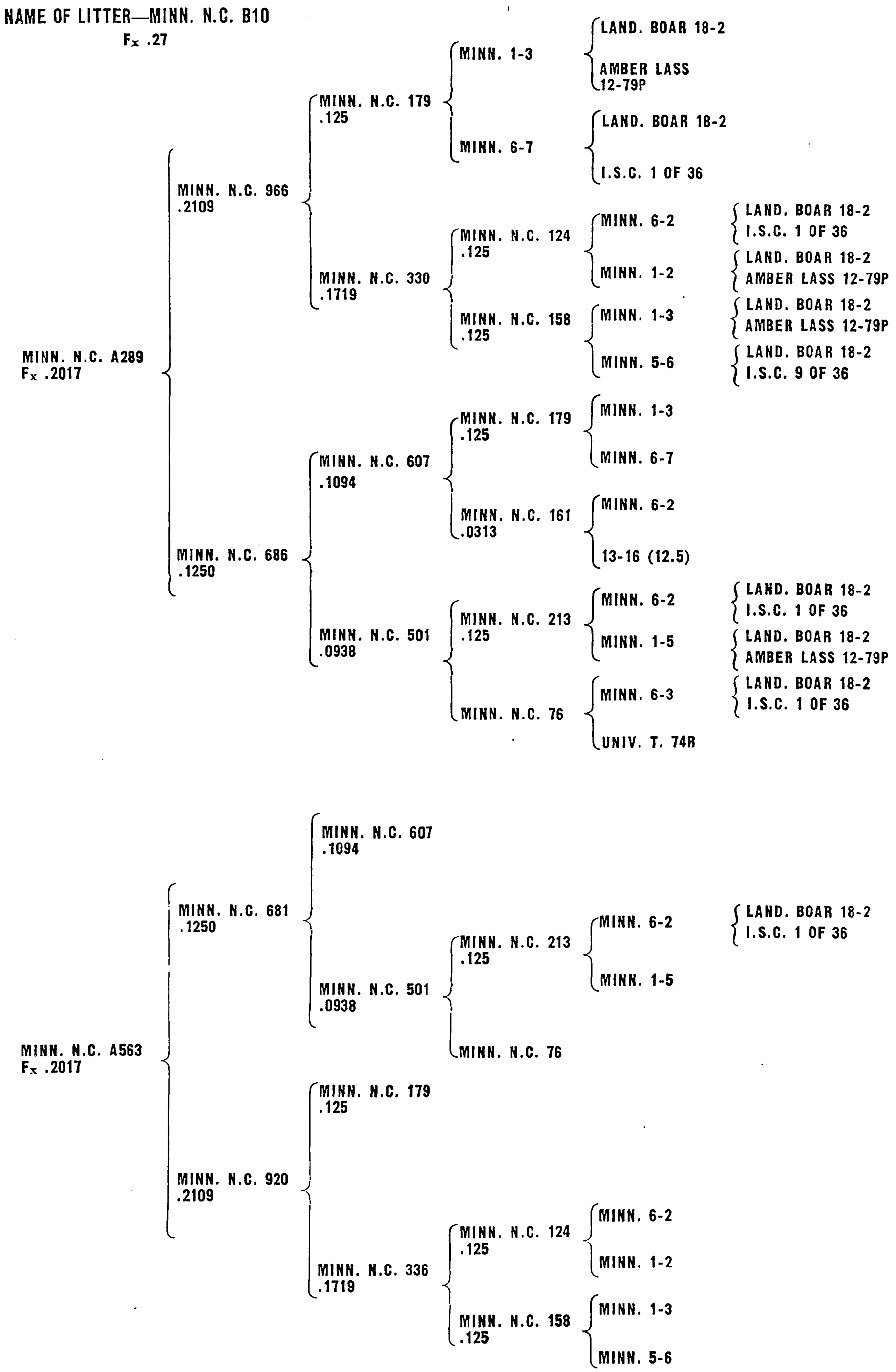


FIG. 11. A Minn. No. 1 pedigree.

Some segregation in body type and performance was apparent in the 1938 and 1939 crops. At no time, however, has segregation been the cause of any particular economic loss; all the hogs have sold at top market price when properly finished.

The comparison of the 1941 record with that of 1940 might be taken as an indication that the line was deteriorating. However, single year to year comparisons as to the effects of breeding are quite meaningless because of the many complicating environmental factors. In 1941 nearly one half of the pigs had a touch of hog cholera while still nursing. This affected both the number weaned and the rate of gain. Furthermore, the 1940 crop likely gained more rapidly than is to be expected normally. Taken as a whole, the line has shown no particular change in performance through the five years. The high feed requirements in 1938 are to be explained on the basis of the dry season and the resultant bare pastures.

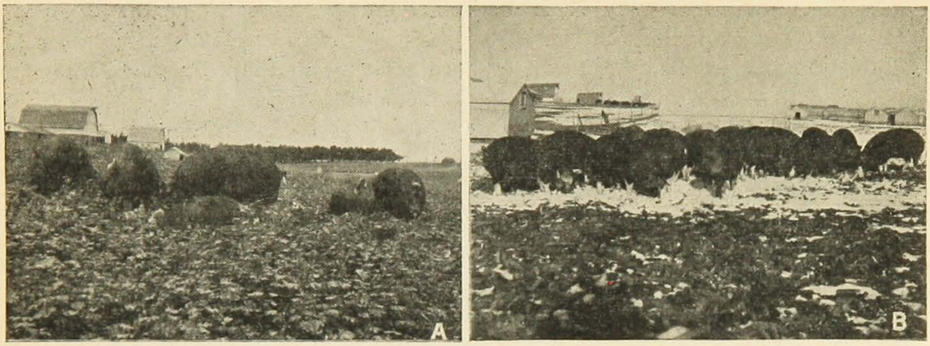
Several boars from this line have been placed with farmers for experimental crossing on sows of other breeds. The general reaction from the farmers who have made the cross has been favorable. A comment from nearly everyone who has used this stock in a cross is to the effect that the little pigs possess considerably more life and vigor than is common in pigs of the same age. It, therefore, appears that this line possesses some genes, at least, that are not common to the more popular American breeds of swine.

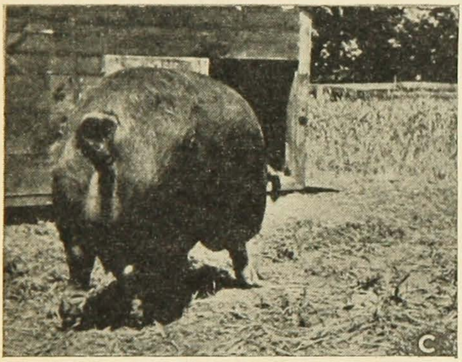
The 1942 Crop. The inbreeding has been advanced for all the lines in the 1942 farrow. The M line at the Southeast Station has an F_x of nearly 70 per cent and the two lines at the Northwest Station and the three at the West Central Station all have an F_x of 28 per cent or better. An average F_x of 30 per cent necessitates that about half of the pigs have F_x's above 30 per cent. All lines excepting the C.2 at the Central Station give indications of performing as well or better than during previous years. The average number of pigs born alive by lines is presented in table 10. In this table and all previous tables the number born alive is calculated on the basis of all sows saved for farrow, so that the average may include some sows that failed to farrow any pigs.

Line Differences. To those working intimately with the project it appears that the lines are manifesting some differences in conformation, type, and manner of growth; yet these differences, if they do exist, are far too small to allow separation of the Poland China lines by any means other than the individual identifications of their ear notches.

Table 10. 1942 Farrowing Record by Lines

Station	Line	Number of Sows	F_x, per cent	Average No. Born Alive
Southeast	M	32	70	6.6
Central	C.2	21	28	4.6
Northwest	M.L.	15	32	7.3
Northwest	B.S.	20	33	7.2
West Central	W.L.	18	28	7.5
West Central	V.	19	31	7.5
West Central	B.S.	16	31	8.2
North Central	Minn. No. 1	43	24	8.9





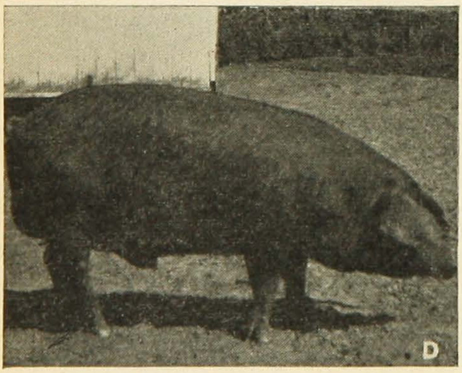


FIG. 12. Types of animals being developed in the experimental herds.

A. Herd boars (Viola, Western Lady, and Black Star) at the West Central Station.

B. Breeding gilts (Black Star and Market Lady) at the Northwest Station.

C. An M sow (F_x, .65) at the Southeast Station.

D. Minn. No. 1 herd boar at the North Central Station.

Differences in body measurements for the 1941 pigs are presented in table 11. A study of the table shows clearly that the Poland China lines do not differ markedly from one another in body measurements. Small differences in measurements between stations cannot be taken too seriously because different men took the measurements, and Fenske *(1)* found that measurements of the same animals differed significantly when taken by different men.

Effects of Inbreeding. In practically every carefully conducted study of its effects, inbreeding has been found to be accompanied by a reduction in the various items constituting vigor. The data gathered in this project show that, with no change in the inbreeding of the sows, the average number of pigs born alive per litter decreased at the rate of 0.017 pigs per 1 per cent of inbreeding in the pigs. The decrease is not statistically significant. With no change in the inbreeding of the litter, however, each additional 1 per cent increase of inbreeding in the sows was accompanied by an average decrease of 0.058 pigs born alive per litter. This decrease is highly significant. These data indicate that if no other measures are taken to offset the effects of the inbreeding, a 10 per cent increase in inbreeding of

Table 11. Body Measurements (in inches) by Lines (1941) Corrected to 205 lb. Weight

Station	Line	Length of Body	Width of Body	Depth of Body	Length of Foreleg
Southeast	M	40.66	11.66	14.91	12.28
Central	C.1	39.67	10.46	14.08	13.18
Central	C.2	39.75	10.40	14.08	12.73
West Central	V.	40.07	10.67	15.11	13.10
West Central	W.L.	39.71	10.69	14.94	13.31
West Central	B.S.	40.41	10.70	14.94	13.54
Northwest	M.L.	40.01	10.10	14.40	11.34
Northwest	B.S.	40.45	9.97	14.35	12.04
North Central	Minn. No. 1	42.05	10.97	14.13	11.87

brood sows may result in a loss of about ½ pig per litter and a 30 per cent increase, of about 1½ pigs.

Rate of gain between weaning and the 200-pound weight decreased at an average of 0.0035 pounds daily for males and 0.0029 for females per 1 per cent increase in inbreeding. Both decreases are statistically significant. The correlation between inbreeding and rate of gain is —.17 for males and females alike. Interpreted in more general terms, this means that if the increase in inbreeding is not accompanied by any counteractive measure a 10 per cent increase in inbreeding may be expected to have been accompanied by a decrease of 4.34 pounds in 180-day weight for males and 3.60 for females. A 30 per cent increase in inbreeding would result in decreased 180-day weights of about 13 pounds for males and 11 for females. No significant relationship was found between inbreeding and the variation in rate of gain.

Effectiveness of Selection. The foregoing pages have described the methods of selecting breeding stock. The question that then arises is how effective these methods have been; and, furthermore, are those animals which make the greatest contributions to the later generations actually superior in performance to the average of those saved as breeders? A summary of the data bearing on these points is presented in table 12. Due to several environmental upsets and to an expansion of the M line almost regardless of individual merit, data from the Central and Southeast Stations are unsuited for a study of this kind; hence they are omitted. The table reveals that the animals selected for breeders were superior in performance to the average raised and that those which later contributed to the herd as ancestors were superior in performance to the average of those selected. The table also indicates that, when selecting for improved perform-

Table 12. The Performance Records of the Animals Produced, Those Saved as Breeders, and Those that Became Ancestors

	No. born alive	No. weaned	Weaning weight, lb.	180 day weight, lb.	Rate of gain lb., weaning to 200 lb.	Feed per 100 lb. gain
Average of animals produced	8.40	6.50	33.62	214.2	1.434	333.5
Average of animals retained as breeders	8.97	7.67	34.96	228.7	1.522	329.7
Average of those contributing as ancestors	9.24	7.95	35.49	232.2	1.532	327.9

ance in several items, the amount selected for in any one item will of necessity be only slightly above the average for the entire population. The table further indicates that the improvement of a line as the direct result of selection will be relatively slow. At the same time a study of this table and tables 1 to 10, in connection with the statements made above regarding the effects of inbreeding, makes it clear that the selection as practiced in this project has been sufficiently rigorous not only to offset the retrogressive effects of inbreeding but to allow for some improvement in performance.

Changes in Body Proportions. During the five years of this project the measurements—length, width, and depth of body and length of foreleg—have been taken at the time the pigs came off the feeding tests. These measurements, when corrected to a constant weight, give a slight indication that the pigs have become shorter of leg through the years. This holds true for each of the three stations—Northwest, West Central, and North Central—when taken independently. The data from the Central and Southeast stations are not satisfactory for inclusion in this study.

Sheep Experiment

OBJECT

An inbreeding project with Shropshire sheep was initiated in 1936. The object of the experiment was to increase the genetic purity of a Shropshire flock of sheep for economic factors by intensive selection for performance accompanied by mild inbreeding.

PLAN OF THE EXPERIMENT

The purebred flock of about 50 ewes at the North Central Experiment Station was used for the study. The flock was essentially closed to outside breeding. Since that time two ewes from the outside have been added and a few ewes were bred to a ram from outside, but he was a ram that was closely related to the original flock ram. Neither of these outside infusions of breeding has resulted in any material change in the genetic constitution of the flock. The two purchased ewes and all their progeny have since been culled because of poor performance. It is noteworthy that they were introduced in the flock for the very purpose of improving its genetic constitution. They were selected from what is generally considered the best of breeding in the nation and by men with many years' experience in selecting sheep by the usual standards. Selection of breeding stock within the project has been made on the basis of performance. The factors considered are: (1) lambing record, twinning receiving a preference, (2) rate of gain, (3) market quality of lamb, (4) weight of fleece, and (5) grade of fleece.

The stud ram at the time the flock was closed was not related to the ewe flock. He was used in the flock for four years, but he was used on only a few of his daughters. Sons and grandsons of the original ram have been used since they became available. The number of rams used each year varies somewhat, dependent largely on how many rams it is thought should be tested in the flock. About three rams have been used each year since sons and grandsons of the original stud ram have been available.

In 1939 the Shropshire flock at the Northwest Experiment Station was added to the project. This is a flock of about 50 ewes. At this time rams from the North Central Experiment Station had been used for two years on this flock. The Northwest Station flock was closed to outside breeding in 1939. Two or three rams have been used each year since the flock was closed; hence the degree of inbreeding has been low. The degree of inbreeding likely will continue to be low unless an unusually productive family is discovered in the flock.

RESULTS

An inbreeding experiment with sheep proceeds much slower than one with swine. There are several reasons for this. One reason is that swine are much more prolific—swine reach sexual maturity at an earlier age, have more young at birth, breed twice a year, and breeding swine are not kept to as great an age. A second and more complicating factor is that it is much more difficult to standardize practices of feeding and management and yet maintain environmental conditions that are in keeping with practical sheep production. Sheep naturally are grazing animals; what is more, it is as grazers that they fit into the economic picture. Grazing conditions cannot be standardized from year to year with anything like the degree of uniformity possible with the rations of growing pigs. Thus the results obtained from year to year in an experiment such as this cannot be regarded as nearly so indicative of the effects of the breeding program as those obtained in the swine project. With all the standardization that has been carried out in the swine experiment, it is apparent that seasonal factors still cause considerable yearly variation in performance. A further complicating factor in standardizing and recording performance in sheep is that the breeds differ so greatly in weight. (Recently several breeds have been included in this project although only results from the Shropshires are reported herein.) It was well recognized at the beginning of the project that the objective was the efficient production of lambs and wool of high quality. But what was not clear was how to proceed in recording the data bearing on these items. By trial and error a method has been evolved which appears to be quite satisfactory. Figure 13 shows what data are recorded and how. Since sheep differ so greatly in size, adjustments are made later so that production is based on a function of ewe weight.

Because of the above-mentioned complicating factors in recording and interpreting data, it is not at all certain how much of the data gathered thus far on performance in the sheep project can be interpreted as being the result of the methods followed in selection and breeding. It does appear that both flocks have improved in lambing percentage. The fleece yields and growth rates of the lambs have shown so much yearly variation that more time will be required before positive statements can be made as to the trends in these characters. Those who have worked with the flocks from the beginning of the project are quite certain that both flocks

Breed ____________________ **FLOCK PERFORMANCE RECORD** Station ____________________

Ram No. ____________________ Year ____________________

Ewe	Wt.[1]	Dates Bred	Wool		Lamb Record										Remarks
			Wt.	Grade	Date Lambed	Sex	Lamb No.	Brand	Birth Wt.	15 weeks[2]		Final[3]		Grade[4]	
										Date	Wt.	Date	Wt.		

[1] Ewe weight taken between November 1 and 15.
[2] Every lamb to be weighed when 15 weeks old.
[3] Final weight and grade to be taken when (whichever occurs first) the lamb weighs 95 pounds or when 23 weeks old.
[4] Grades: 1 (Choice), 2 (Good), 3 (Medium), 4 (Common), 5 (Cull).

Shearing dates ____________________

FIG. 13. Illustrating the type of form used in gathering data on performance in sheep.

have improved in appearance as commercial sheep.

A very important result obtained is that the work thus far conducted has made it clear that a flock of sheep can be closed to outside breeding for a number of years without materially raising the level of inbreeding. The North Central flock has been essentially closed to outside breeding since 1936; yet in 1941 the F_x of the ewe flock had been raised only 4 per cent and that of the lambs 9 per cent as a result of the inbreeding practiced. The Northwest flock was closed in 1939, and in 1941 the F_x of the ewe flock was unchanged while that of the lamb crop had been raised one half of 1 per cent.

Discussion

INBREEDING automatically increases the number of homozygous gene pairs; or, in other words, it promotes genetic purity. In the process of inbreeding, a line becomes purified for many undesirable, or at least less desirable, genes. This is because, by and large, genes which promote vigor have been found to be dominant, and dominant genes cover up the action of recessive genes. Hence inbreeding brings these undesirable, and previously unrecognized, traits to light. Inbreeding without rigorous selection for vigor, therefore, is almost certain to result in a loss of vigor. The degree of loss will vary considerably, dependent upon the rate of inbreeding and upon the genetic constitution of the stock at the start. The purpose of an inbreeding program obviously is to enable the breeder to purify lines for the more desirable genes.

Rigorous Selection Desirable. Selection, on the other hand, is the tool available to the breeder to offset the reduction in vigor resulting from inbreeding. This is the reason that a rigorous program of selection was incorporated in this inbreeding program.

Only one of the lines of hogs reported on herein is highly inbred (the M line with an F_x of 70 per cent) and even it is not highly inbred by the standards of corn breeders. Five Poland China lines have been developed with average F_x's ranging from 28 to 33 per cent (1942 crop of pigs) as the result of the inbreeding in this project. F_x's of around 30 per cent may be interpreted as indicating that about one third of the genetic variability existing in the original stock has been eliminated by the inbreeding.

It is significant that the five lines mentioned above on which careful records of production have been maintained since the beginning of the project have evinced no recognizable loss of vigor. It is assumed that this result is due to genetic superiority of the original stock and to the rigorous selection that has accompanied the inbreeding.

It is also significant that the highly inbred M line while not performing as well as the above-mentioned lines appears to possess more inherent capacity for performance than many outbred purebred herds. The performance of this line is superior to that of each of the seven lines culled early in this project. It is of much importance that every one of the seven lines eliminated rested on what was considered the very best of breeding. The lines that have survived also rest on what was considered superior breeding; but on the basis of the available information regarding the animals at the time they were secured, it is not likely that anyone could have foretold the fate of the various lines.

Superior Foundation Stock Essential. A reason frequently advanced for utilizing inbreeding in livestock improvement is that the inbreeding process will uncover undesirable recessives, some of which would be lethal or at least sublethal. The inbred stock would thereby be rid of at least some of its undesirable genes and the implication is that the stock would thereby be improved. This experiment has not provided an adequate test for this theory, but, on the other hand, the results to date give no encouragement to the thought sometimes expressed that a superior line can be evolved from a mediocre foundation through inbreeding and rigorous selection. It was recognized early that the C.1 line did not possess a satisfactory genetic constitution. The line was continued largely to test whether inbreeding and rigorous selection would produce a few superior segregates which might provide a satisfactory foundation for improvement. During the last three years of the trial the average F_x for this line remained around 20 per cent although each year a number of litters were produced which had F_x's of around 30 per cent. If the line had been continued for another year the F_x would not have been much above 20 per cent. Each year the litters possessed a rather wide spread in degree of inbreeding, and each year the poor-performing individuals came from the more highly inbred litters; hence in selecting for performance the F_x of the line remained about the same. Possibly if the line had been carried for a longer period some advance in inbreeding and a visible degree of improvement would have been made. However, it is perfectly clear that neither inbreeding nor selection nor both can change the composition of any given gene. It therefore follows that if certain desirable genes are absent when the line is closed, neither selection nor inbreeding is going to put the absent genes into the stock. Selecting for genes that are not present is analogous to searching for red kernels of corn in a basket containing only white kernels. The only way to obtain red kernels is to secure them from some other basket. In like manner, if certain genes that are absent from a line are really needed, the only method of getting them in is by going outside.

The C.1 line was crossed with the Western Lady line to provide the foundation for the C.2. The C.2 is an improvement over the C.1 but it gives no indication of proving as valuable as the Western Lady. When the cross was made, valuable genes from the Western Lady were undoubtedly added to the C.1 genes but there is no indication that the genes in the C.1 line contributed anything to the improvement of the Western Lady; in fact, some desirability appears to have been lost.

In the practical problem of developing more highly purified lines of farm animals that will prove useful to the industry, the results to date of this experiment give no indication that it is worth-while continuing to work with a line that is obviously inferior in genetic constitution. It appears that the efforts at purification will be more productive if expended on what at least appears to be superior stock.

Crossbreds Do Not Run Out. It has been rather generally believed that the intermating of a crossbred population would result in wide segregation and the production of a population that is on the whole quite undesirable. This has not been borne out in the results on the Minn. No. 1 line. There has been some segregation in type, color, and performance, but in no year has the segregation been sufficiently great to make the crop commercially undesirable. The performance of this line by years has been very satisfactory (table 9). The results obtained with this line indicate at least that the crossing of two superior strains furnishes a promising foundation for developing a superior inbred line.

It is noteworthy that the average F_x for the Minn. No. 1 line has been raised to 22 per cent in less than four generations following the original cross. It is less than four generations because some animals are retained in the breeding herd for a second or even a third year. This is from two to five times as high as the F_x in any of the pure breeds thus far reported on by Lush *(6)* with the exception of Shorthorn cattle in Great Britain. Most of the popular pure breeds of today have herd book records of from 60 to 70 years' standing. Yet in that time the inbreeding has been advanced only about one half as much as has been done with this line in four years from the original cross. Height of a strain's F_x is not a measure of the strain's desirability, but in the pure breeds a high degree of homozygosity is desirable and the degree of homozygosity is closely associated with the strain's F_x.

All the coefficients of inbreeding reported on in these experiments are calculated from a beginning base of 0. Through the years all breeds have been inbred to some extent. Lush and Anderson *(7)* in a study of the Poland China breed found that from 1886 to 1929 the coefficient of inbreeding rose from a base of 0 to 9.8 per cent. It may therefore be assumed that the foundation stock for the Poland China lines had coefficients of inbreeding of about 10 per cent at the beginning of this experiment. This means that as the result of the inbreeding, both before and during the experiment, it is to be expected that on the average the Poland China lines with F_x's of about 30 per cent will be genetically pure for about 70 per cent of their hereditary factors. There is no way of estimating what effect selection may have had on increased genetic purity.

Inbreeding Speeds Improvement. Here is an important point in connection with the foregoing: With the usual development of the breed it took 44 years to advance the breed's F_x 10 per cent, while in these experiments the F_x's for five of the Poland China lines were advanced about 30 per cent in four or five years. These experimental results indicate, at least, that more definite inbreeding might be used to advantage in improving the breeds.

In the swine experiment one objective has been to advance the F_x as rapidly as possible and yet attempt some improvement in performance. In the sheep experiment no special attempt has been made toward a rapid advance in the flock's F_x. By the closed flock system the F_x on the one flock in five years was advanced only 9 per cent. No estimate on the F_x for the Shropshire breed as a whole is available but it is not likely that it differs appreciably from those of the several breeds reported by Lush *(6)* of which only the Shorthorn had an F_x of over 10 per cent. In the five years that this flock has been closed to outside breeding, it appears that as much increased genetic purity has been developed in the flock as the direct result of inbreeding as has been developed in the breed since the establishment of a flock book.

On the basis of the experience with swine, laboratory animals, and corn it is not likely that the 9 per cent increase in F_x has had any noticeable effect on the breeding behavior of the flock. The F_x on a herd of cattle will advance even more slowly than in a flock of sheep. It is quite clear, therefore, that a fair sized flock of sheep or herd of cattle might be bred from within for many years before the herd's F_x would be raised to the level of the lines of swine developed during the five years of this project.

Inbreeding Aids Disease Control. Transmissible disease provides cause for considerable consternation to owners of valuable herds. Many diseases are introduced in clean herds by the addition of new animals. The closed herd offers possibilities of avoiding considerable danger of infection from the outside. When it is taken into account that sheep and cattle reproduce so much more slowly than swine, it appears that many owners of superior flocks and herds might avail themselves for several years at least of the closed herd system without raising the level of inbreeding to the point where it is likely to have deleterious effects on performance. At the same time a beginning would be made in the process of purifying the stock.

A further advantage of the closed herd system is that the breeder saves for use sires which he knows much more about than sires secured from outside herds. It has been demonstrated many times in good dairy herds that, even with careful selection of sires from the outside, for every bull that raises the herd average, there will be another which will lower it. The point cannot be demonstrated quite so clearly in meat animals, but there is every reason to believe that it is equally true in all classes of stock.

Summary and Conclusions

INBREEDING projects with swine and sheep have been under way for five years.

An attempt was made at the outset to secure superior foundation animals.

A rather low percentage of the original selections has made a contribution to the present stock on hand. The culling of individuals and lines has been on the basis of performance.

With no change in the inbreeding of the litter, each additional 1 per cent increase of inbreeding in the sows was accompanied by a decrease of 0.058 pigs born alive per litter.

Rate of gain between weaning and the 200-pound weight decreased at an average of 0.0035 pounds daily for males and 0.0029 for females per 1 per cent increase in inbreeding.

The performance of the animals selected as breeders was superior in fertility, rate of gain, and economy of gain to the average of the pigs produced.

The performance of the animals that contributed to the herds as ancestors was superior in fertility, rate of gain, and economy of gain to the average performance of those saved as breeders.

The results of this experiment show clearly that there is a definite tendency for the offspring of each generation to revert to a performance lower than that of the parents and toward the population's mean. This tendency retards progress by selection.

It has been demonstrated that it is possible to raise the coefficient of inbreeding of Poland China hogs 28 to 33 per cent without loss of vigor for the line. It is the authors' opinion that several of the lines have been improved during the inbreeding process. That, however, is a point on which conclusive evidence is lacking, for even though treatment is standardized, year-to-year differences in environment exist and it is possible that little improvements have been made in care and management.

It is the authors' opinion that the rigorous methods of selection for performance made possible the improvement cited, yet this point cannot be substantiated statistically because of yearly environmental differences.

It has been shown that the subsequent inbreeding of superior crossbred hogs is not necessarily followed by wide segregation of type and performance. It is believed that the rigorous selection for performance was a factor in preventing wide segregation.

In this experiment the crossbred foundation provided an excellent foundation for developing an inbred line.

A flock of sheep can be bred from within for a number of years without appreciably changing its F_x.

It appears that many owners of purebred herds—hogs, sheep, and cattle—might close their herds to outside breeding solely as a precaution against introducing disease.

Coefficients of inbreeding of around 30 per cent are not high in comparison to those obtained by corn breeders, but they are 30 per cent higher than the average of their breed. They are high enough to warrant expectation that on the average about one third of the genetic variability of the foundation stock has been eliminated.

These results show it is possible for breeders with herds of 20 sows or more to improve the stock by moderate inbreeding and rigorous selection.

Herds can be inbred to raise their F_x's about 30 per cent which should reduce their present genetic variability about one third. Several such herds in a breed could furnish seed stock that might advance the merit of the breed perceptibly. This procedure should bring improvement much faster than present methods of breeding.

Breeders who are not willing to check the performance of their stock should not expect to advance the merit of the breed in utility characters.

In general, the experiments reported herein represent but a first step in this experimental program. The second phase of the project will deal with hybridizing the inbred lines. Preliminary trials indicate possibilities for increasing vigor and performance of stock within as well as between breeds through the crossing of the inbred lines.

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