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An Experimental Study of Inbreeding and Outbreeding Swine

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FOREWORD

The experiment from which the data reported in this bulletin were collected was conducted to find out more about how swine respond to inbreeding and how inbreeding might be employed to improve them.

Inbreeding has been used effectively in the formation of practically all of the pure breeds of livestock. It is a system of mating that is very effective in fixing type in a herd or group of animals. Since inbreeding has been used in bringing the pure breeds of livestock to their present degree of perfection, it seems logical that it should be useful in bringing about further improvement.

The pure breeds of livestock have been a great factor in livestock production throughout the world. Commercial producers early discovered the value of purebreds for improving commercial livestock. For a number of years the breeders of purebreds were kept busy furnishing animals to be used for grading up common stock; and, except in the case of some few herds, they had little time to devote to actually improving the purebreds themselves. Now that the breeders of purebreds have increased the number of their animals to the point where the demand for purebred sires for grading up common stock has been met, their attention has been turned more toward the improvement of the pure breeds. The experiment reported in this bulletin was designed to secure information which would be helpful in this work of breed improvement.

AN EXPERIMENTAL STUDY OF INBREEDING AND OUTBREEDING SWINE

O. S. Willham and W. A. Craft*

Livestock breeding is a building process in which the units are genes or character determiners and the finished products are animals. Genes may be classified for convenience in two groups: (1) Those that produce desirable characters, and (2) those that produce undesirable characters. The frequency of desirable genes can be increased by selection, but experience has shown that the increase is accomplished very slowly in a herd or population.

Genes occur in pairs. One member of a pair may be dominant and mask the appearance of the other member; or one gene of a pair may be epistatic and mask the appearance of the genes in other pairs; or a gene in one pair may act as the complement of one in another pair and bring about results commonly called "nicking" by livestock breeders. Therefore, desirable combinations of genes are as necessary as desirable gene pairs. A desired characteristic may be the result of a combination of several genes interacting together, and such combinations are relatively unstable due to independent separation of genes belonging to different pairs when reproductive or sex cells are formed. Thus culls occur among the progeny of good parents. Many undesirable genes may be hidden by dominance or epistasis and make selection against them exceedingly difficult.

Inbreeding quickly reveals the genetic nature of a stock, because inbreeding tends to fix the genes affecting the different characters or to increase the number of gene pairs for which the members are alike or homozygous. The genes which are fixed may be either desirable or undesirable; therefore stock possessing many deleterious genes does not show up favorably when inbred. If undesired genes are fixed in a line, outcrossing is the only practical way to recover the good ones which have been lost. Selection may aid within limits in controlling the genes fixed, but the intensity of selection varies inversely to the number of characters selected.

It appears that it is next to impossible to produce a herd or line possessing only genes for good. Therefore, the establishment of inbred lines with a few good characters fixed in one and a few different desirable characters fixed in another, and so on, followed by converging the lines, may be an effective procedure for obtaining the maximum in animals. There are now in progress at this and other stations experimental studies with swine which should shed light on the effectiveness of converging inbred lines.

Obviously, breeders of purebred livestock are keenly interested in these procedures, since inbreeding and outbreeding, or a combination of the two plus selection, are the only courses of action open to them. Inbreeding has been practiced, usually only for a short time, by many breeders since the time of Bakewell; and, as a rule, it has been followed for the purpose of concentrating the inheritance of a noted sire or to fix certain characters in a herd.

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* The experiment was initiated in 1923 by the junior author and was under his direction until March 1, 1936, at which time he assumed charge of swine investigations in the Bureau of Animal Industry, United States Department of Agriculture. The senior author has been in charge of the experiment since March 1, 1936.

OBJECTIVE

The experiment which has furnished the data for this report was initiated to obtain definite information relating to the effects of continuous but relatively limited inbreeding as compared with outbreeding when practiced with swine. It was believed that the experiment might answer the following questions:

Can selection successfully guide the fixation of characters in a herd of swine being inbred by half-brother×half-sister matings through several generations?

Will inbred boars produced by this system be, in general, superior as sires to outbred boars when mated to non-related sows?

REVIEW OF LITERATURE

On Inbreeding in General

A survey of the literature on inbreeding reveals that varying degrees of success have been attained in numerous species by those who have followed the practice. The reader is referred to East and Jones (1919), Wright, (1921), and Lush (1937) for an explanation of the consequences of inbreeding.

Wright (1922) developed a practical measure for determining the degree of inbreeding. The measure gives the percentage of decrease in the number of unfixed pairs of genes, or heterozygosis, that is brought about through the mating of related individuals. This measure is always relative to the foundation stock to which the pedigrees are traced.

Wright and McPhee (1925) developed an approximate method of calculating from livestock pedigrees the coefficients of inbreeding and relationship. The method has been used extensively to analyze the systems of matings used in developing the pure breeds of the present day. It is disclosed that the present rate of inbreeding in the pure breeds is very small, being generally between 0.50 and 1.0 percent per generation. Lush (1932) found in a study of the Poland China breed of swine recorded between 1885 and 1929 an increase of 0.54 percent in the inbreeding coefficient for each generation. It is clear, therefore, that inbreeding has not been practiced extensively in this breed. There are a few exceptions where the intensity of inbreeding has for short periods exceeded the usual average. For example, McPhee and Wright (1925) found that the inbreeding in the Shorthorn breed increased at the rate of about 4 percent per generation from 1790 to 1810. As another instance, Willham (1937) found that, in the Hereford breed, an increase in the inbreeding coefficient of about 2.5 percent for each generation occurred from 1920 to 1930.

The older experiments and opinions on inbreeding have been so well reviewed by East and Jones (1919), Wright (1921), and Hays (1919) that no attempt need be made to review them here. Inbreeding experiments with poultry have been well reviewed by Waters and Lambert (1936). The early work with inbreeding shows in general that it brings about a decline in vigor.

On Inbreeding of Swine

The history of the breeds of swine in America contains accounts of both success and failure with inbreeding. Gentry's success in inbreeding Berkshires is a notable example of achievement. Most of these accounts, however, are based on general observations rather than on actual trials.

Early opinions seem to be that the breeds of swine will react to inbreeding in an adverse way more quickly than will the other kinds of livestock. Two reasons seem possible for these opinions: (1) The interval between generations in swine is shorter than for other classes of livestock; and (2) the breeds of swine may be more heterozygous than the other classes of livestock.

Hays (1919) reported results obtained from a project with Berkshire swine initiated at the Delaware Station by Hayward in 1908. The study extended over a period of 10 years. Double matings were made for a time with either a Yorkshire or Chester White boar and the inbred and crossbred pigs from the same litters were compared. It is reported that the certainty of pregnancy and size of litters were reduced by inbreeding, and that mortality was greater among the inbreds than among crossbred or outbred pigs. Birth weight was apparently not affected by inbreeding, since the inbred pigs weighed slightly more at birth than did the outbreds and crossbreds. Growth rate was apparently reduced by inbreeding, however. It was concluded that intensive inbreeding in swine is followed by more disastrous results than in cattle.

Hughes (1933), working with the Berkshire breed of swine at the California station, beginning in 1922, has practiced brother×sister matings without loss in size of litter farrowed. He reports that: (1) The type of pigs in all the inbred litters has been similar; (2) changes in color or structural abnormalities were not observed; (3) no noticeable loss in size or vigor of the pigs occurred; and (4) the pigs in inbred litters were more uniform in size than those in the outbred litters.

In the fall of 1922, the U. S. Bureau of Animal Industry selected six Poland China gilts and their litter brothers to start inbred lines.* In most cases, litter mates were used to make brother×sister matings. An outbred group was maintained as a check in the trial. A decline in birth weight occurred in the first generation, but a further decline in the second generation was not observed. The mean litter size in the control group was 7.15 ± 0.19 pigs and it was 6.75 ± 0.34 for the first-generation inbred pigs. The mean litter size of the inbreds declined to 4.26 ± 0.48 pigs in the second generation. Due to an excess proportion of males in the inbred litters, the decrease in litter size, and the heavy losses up to weaning, it was impossible to carry the inbred lines any further than the second generation. A few characters appeared among the pigs in the Bureau's studies which seemed to be due to recessive genes. These included sepia color, cleft palate, hernia, and cryptorchidism.

Six inbred lines of Tamworths were started in the Bureau of Animal Industry experiments by brother×sister matings.** Only two of the lines were successful. These were carried to the fifth generation, when they were discontinued on account of lack of fecundity.

Several inbred strains of Chester Whites were also started in the Bureau of Animal Industry experiments, but only two were successful.** These were maintained by brother×sister matings to the seventh generation. The Chester Whites used in the Bureau's experiments responded more favorably to inbreeding than the other two breeds. There was, however, a decrease in the birth weights, weaning weights, and size of litters among the inbred Chester Whites. The sixth and seventh generations were less vigorous than the fifth. In general, the inbreeding resulted in a decline in number of pigs farrowed and raised, a decrease in rate of growth, and an increase in the amount of feed required to produce a unit of gain. However, some inbred litters performed well in feeding tests.

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* Reported by McPhee et al., 1931.

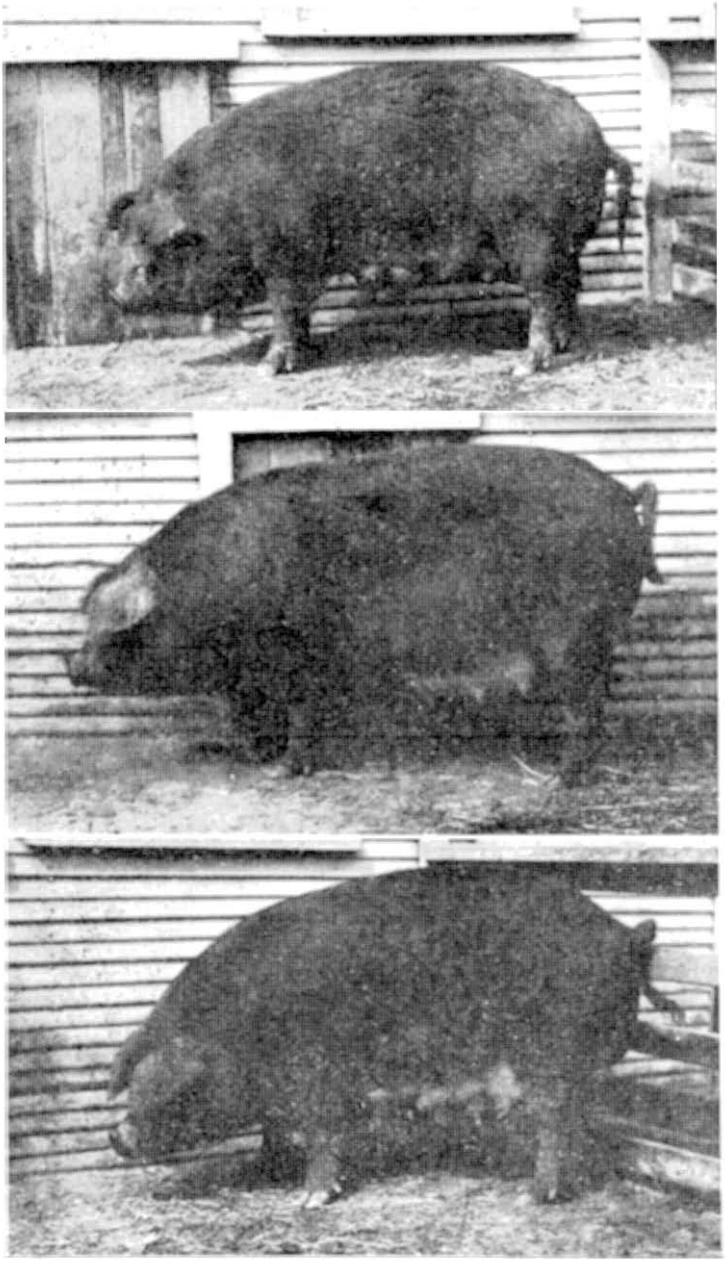
** U. S. D. A. *Annual Reports of Bureau of Animal Industry* 1934, 1936, 1937.

Hodgson (1935), working with the Poland China breed at the Southeast Experiment Station, Waseca, Minnesota, reported the results of eight generations of brother×sister matings. Certain boars refused to mate with their litter mates and thereby caused two lines to be lost. Little if any trouble was experienced in getting the sows to become pregnant when satisfactory services were obtained. The average litter size in the non-inbred group was 9.2 pigs, and for the inbreds it was 7.1 pigs. It is reported that a number of comparatively large litters were produced in the advanced inbred generations of two of the lines and that there was no significant decrease in birth weights of the inbreds. Heavy losses of pigs were reported among the inbreds. Two of the inbred lines showed very little, if any, difference from the controls in growth rate for the first 16 weeks. From 16 weeks to 200 pounds in weight, the non-inbreds gained faster and reached this weight about 3 weeks earlier than the inbreds. A third inbred line was heavier than the other two at birth but grew more slowly than the former. A few of the inbred litters were tested in the Record of Performance lots at the Minnesota Station. These lots did not do as well as the average of the pigs entered by breeders from over the state. The carcasses produced by the inbreds graded well, and seemed to average a trifle higher than the average for the other pigs in the performance tests. Little, if any, change in type occurred in the inbred strain. Some unusual colors were brought to light in one line. The pigs had spots which were pink at birth but changed to yellow and then to white at maturity. Some marked differences were noted in the temperament of the different lines. The abnormalities reported were one case of hernia and two cases of cryptorchidism. Crosses of 3 outbred sows in 1931 to a fifth-generation inbred boar and 3 other sows of the same litter to an outbred boar were made to test the pigs sired by the inbred boar. In this comparison, the pigs by the inbred boar were more uniform in gains and type, made 0.16 pounds greater daily gains, and were slightly more efficient in feed utilization than those by the outbred boar. Crosses were made between the three inbred lines in 1931, and, in comparison with non-inbred pigs, grown at the same period, the pigs from these crosses reached 200 pounds weight 4 weeks earlier than the non-inbreds.

Godbey (1932) reported a study conducted with inbred Berkshires at the South Carolina Station. The inbreeding did not seem to affect the birth weight of the pigs but did seem to reduce the weaning weight. Some excellent individuals from the show standpoint were produced, however.

At the Iowa Station, an inbred herd of Poland Chinas was started in 1930 for the purpose of studying the consequences of inbreeding swine following a closed herd plan and using 4 boars each breeding season (Lush and Culbertson, 1937). The rate of increase of inbreeding would be, therefore, approximately 3 percent per generation. The pigs in the spring of 1937 averaged 25.4 percent inbreeding relative to a base date of 1925, and the litters ranged from 3 to 37 percent in inbreeding coefficients. The highly inbred pigs in this project have tended to be smaller at weaning and to gain more slowly than pigs with less inbreeding.

Ritzoffy (1933) states that the Turopolje pig found on the Turopolje plains of Croatia has been inbred since time immemorial with no bad results. There are two types, one curly- and the other smooth-coated. They have long bodies, arched backs, sloping pelvis and a concave profile; and they are very hardy. The usual size of the litter reported is 10 pigs, and the pigs weigh around 260 to 330 pounds at 12 to 14 months of age. Breeders in this section usually save their boars and gilts from their own herds.



Three Foundation Sows. From top to bottom: Sensation Willeta Lady, 1285002; A. and M. Scissors Lady, 1252534; Miss Premier 19th, 526826A.

METHODS AND PROCEDURE

The foundation stock for this study was obtained late in 1923 from the herd of Durocs maintained by the College. Three sows were selected and mated to the boar, Peerless Sensation 5th. Inbreeding of the foundation animals was negligible, based on 5-generation pedigrees. The degree of relationship of the foundation animals is shown in Table I.

Figure 1 shows diagramatically the actual breeding program that has been followed in this investigation. It was not always possible to make half-brother×half-sister matings, and boars were not always of the same generation as the sows, which resulted in sometimes hastening and sometimes slowing down the rate of inbreeding. The progeny of Sensation Willeta Lady were designated as an A strain and the progeny of Miss Premier 19th and A. and M. Scissors Lady 3rd were designated as a B strain to facilitate keeping the half-brother×half-sister mating records. Boars from the A strain were used on the B sows and vice versa. Generations of inbreeding are designated by the small numbers following the letters suffixed to animal numbers and are determined by the generation which follows the one to which the dam belongs.

The breeding stock for the inbred and outbred group was fed and housed under identically similar conditions. The pigs were farrowed in a central barn and moved to small houses at about one week of age, in yards with green pasture (rye, oats, wheat, sudan, or rape). A creep in each lot or pen was provided with feed so that the pigs could begin eating at any time after one week of age. The pigs were weaned at 60 days of age and transferred to self-feeders supplied with shelled corn (yellow); wheat shorts; tankage (60 percent protein); and a mineral mixture consisting of: bone meal, 38 parts; calcium carbonate, 39 parts; sodium chloride, 20 parts; ferrous sulphate, 2.5 parts; copper sulphate, 0.25 parts; and potassium iodide, 0.03 parts. Each litter was lotted separately throughout the fattening period in so far as possible; and when this procedure was not possible, the inbreds were fed as one group and the outbreds as another. When green pasture was not available, alfalfa meal was supplied at the rate of 5 pounds for each 100 pounds of feed. The pigs were fed to a weight of 225 pounds.

Table I—Relationship Between Foundation Sows and Boar Relative to About 1912.*

	A. and M. Scissor Lady	Sensation Willeta Lady	Miss Premier 19th
Peerless Sensation 5th	0.2288	0.0381	0.0644
A. and M. Scissor Lady		0.0400	0.1123
Sensation Willeta Lady			0.0420

* According to Wright (1922).

The following data were taken: (1) number of pigs farrowed, (2) sex, (3) weight, (4) length from the top of the head between the ears to the base of the tail, (5) length of foreleg, (6) height of shoulder, (7) depth of chest, (8) width of chest, (9) heart girth, (10) paunch girth, and (11) circumference of the fore and hind shins. These data were taken at birth, weaning, and 60-day intervals until the pigs reached 225 pounds, when the final measurements were taken. Weights were taken at 30-day intervals following weaning.

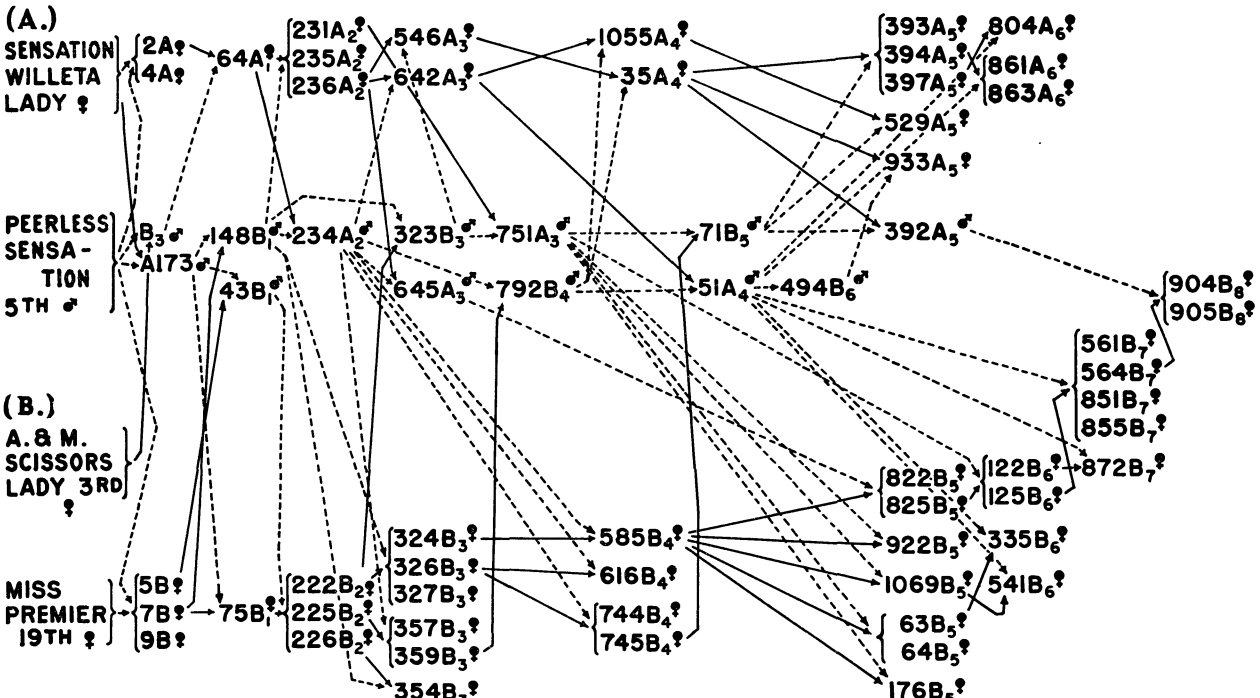
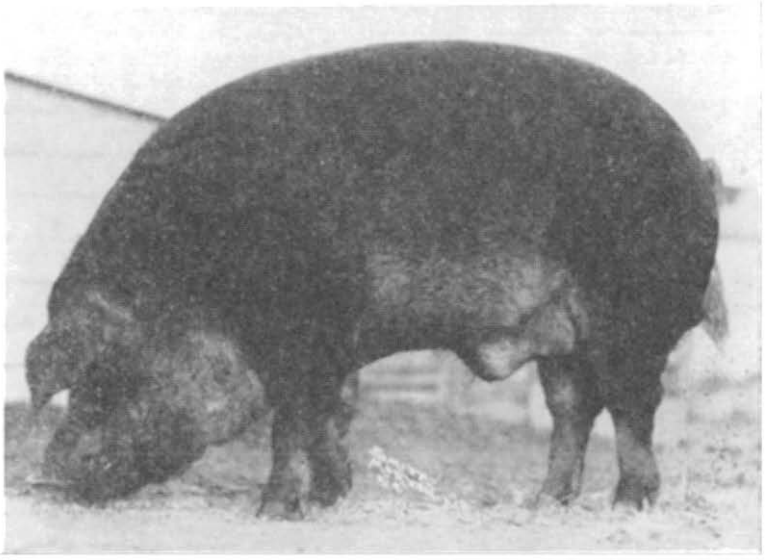

(A.)
SENSATION WILLETA LADY ♀
2A♀
4A♀
64A♀
231A2♀
235A2♀
236A2♀
546A3♀
642A3♀
1055A4♀
35A4♀
393A5♀
394A5♀
397A5♀
804A6♀
861A6♀
863A6♀
529A5♀
933A5♀
PEERLESS SENSATION 5TH ♂
B3♂
A173♂
148B♂
43B♂
234A2♂
323B3♂
751A3♂
645A3♂
792B4♂
71B5♂
51A4♂
494B6♂
392A5♂
904B8♀
905B8♀
561B7♀
564B7♀
851B7♀
855B7♀
872B7♀
(B.)
A. & M. SCISSORS LADY 3RD ♀
822B5♀
825B5♀
122B6♀
125B6♀
324B3♀
326B3♀
327B3♀
585B4♀
616B4♀
922B5♀
335B6♀
1069B5♀
541B6♀
MISS PREMIER 19TH ♀
5B♀
7B♀
9B♀
75B1♀
222B2♀
225B2♀
226B2♀
357B3♀
359B3♀
354B3♀
744B4♀
745B4♀
63B5♀
64B5♀
176B5♀

Figure 1.

In 1932, digestion trials, with representative pigs from each group, were introduced to determine if differences in the ability of the pigs to digest the feed consumed might be one of the factors affecting economy of gains. The pigs were paired for each trial and after a preliminary period of 3 days in the cages, collections of the excreta were made daily for 3 days and the coefficeints of digestion determined based on aliquot samples*. A total of 39 pairs of pigs were tested. The feed used in the digestion trials was ground corn, wheat shorts, tankage, alfalfa meal and mineral mixture, carefully mixed and fed twice daily. Water was supplied **ad libitum.** Coefficients of digestion were determined for protein, ash, fat, fiber, and nitrogen-free extract. Nitrogen utilization coefficients were calculated also.



Foundation Boar. Peerless Sensation 5th, 423899.

In the fall of 1934, representative inbred and outbred pigs were selected and fed individually for a period of 30 days. This was done to more accurately measure the economy of gains in the two strains and to secure an idea of the variation between individual pigs in economy of gains. This procedure was repeated with other samples of pigs until a total of 29 inbred and 31 outbred pigs had been tested.

A rather detailed study was made of the hemoglobin content of the blood of the two groups of pigs at varying intervals.** Samples were taken at birth, at 1, 2, 3, 4, 6, 8, 12, 16 and 20 weeks after birth, and again at 180 days of age. This study was made to determine whether the usual drop in hemoglobin level following birth tended to persist longer in the inbred than in the outbred pigs.

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* The chemical analyses were made by Dr. V. G. Heller, Department of Agricultural Chemistry Research, Oklahoma Agricultural Experiment Station.

** Dr. L. H. Moe of the Veterinary and Bacteriology Department of the Oklahoma Agricultural Experiment Station assisted in this study.

RESULTS

Number of Pigs Farrowed

There was a significant decrease in the number of pigs farrowed per litter in the inbred group. However, the decline occurred largely in the first two generations of inbreeding. Table II shows the average number of pigs farrowed per litter for each generation of inbreeding. The outbred litters have been grouped so as to approximately compare with the different generations of inbreeding. In addition to the total pigs farrowed per litter, the average number of pigs per litter which were born alive has been included in the table.

An analysis of variance of these data indicates that differences in number of pigs per litter are significant for the different generations of inbreeding.* Table II shows the decrease in average size of litters. Changes in the average number of pigs farrowed per litter in the outbred strain during the course of the experiment are not significant. The outbred sows farrowed an average of 9.3 pigs per litter whereas the inbred sows farrowed an average of 6.6 pigs per litter during the entire period. The difference, 2.7 ± 0.34 pigs** per litter in favor of the outbred group, is significant. The inbreds averaged 0.8 stillborn pigs per litter while the outbreds averaged 0.9.

Table II—The Average Size of Litters Farrowed.

Generation of inbreeding*	INBRED LINE			OUTBRED LINE		
	Number of litters	Total pigs	Live pigs	Number of litters	Total pigs	Live pigs
1	12	8.9	7.8	10	9.4	8.3
2	4	7.5	6.8	10	9.2	8.7
3	15	7.1	5.9	10	8.5	8.1
4	28	7.1	6.3	10	9.1	8.4
5	21	6.4	5.7	10	8.9	7.1
6	26	5.5	4.7	10	10.4	8.4
7	13	6.0	5.6	10	9.6	9.1
8	7	5.3	5.1	5	10.0	9.4
Average		6.6	5.8		9.3	8.4

* The generations of inbreeding and years did not coincide, so that the pigs in one generation were raised in several different years. This helped to lessen the variation between generations which was caused by environment.

The differences between the size of litters in the spring and fall were not statistically significant in either strain, January and July being the dividing lines for spring and fall pigs.

In the inbred strain, the first litters averaged 1.18 pigs smaller than the second litters produced by the same sows. There was no difference, however, between the size of the first and second litters produced by the outbred sows. The latter is not in accordance with expectation, since second litters usually average approximately one more pig than first litters.

* The statistical significance of differences used throughout this paper were determined by analysis of variance, according to Snedecor (1934).

** Standard errors were used throughout this study.

The difference between the size of litters produced by different sows in the inbred group is significant. About 56 percent of the variance in size of litters was accounted for by the sows when the size of the gilt litters was adjusted by adding one pig and only sows which produced two or more litters were used. This indicates that size of litter may be a characteristic varying among sows according to their inheritance of genes affecting fertility. There was not a significant difference between the size of litters sired by different boars. The data on the outbred group do not disclose a significant difference between the sows or boars for size of litters, which is not as expected for the sows.

The Birth Weight of Pigs*

There was a decrease in the birth weight of the inbred pigs, most of which came in the first and fourth generations of inbreeding. The average birth weights of the liveborn pigs for each generation of inbreeding are given in Table III. Data on outbreds are included for comparison. The liveborn pigs instead of total farrowed were used, since it was often impossible to obtain an accurate birth weight of the stillborn pigs.

Table III—Average Birth Weight of Liveborn Pigs for Each Generation of Inbreeding.

	INBRED LINE		OUTBRED LINE
Generation of inbreeding	Average Percent inbreeding	Average birth weight (lbs.)	Average birth weight (lbs.)
1	15.6	2.28	2.59
2	20.5	2.36	2.75
3	31.2	2.26	2.55
4	34.6	2.06	2.54
5	39.3	2.13	2.31
6	42.4	1.89	2.21
7	42.4	2.04	2.62
8	45.6	2.25	2.27
Average		2.13	2.47

The outbred pigs averaged 0.34 ± 0.03 pounds heavier at birth than the inbreds, which difference is highly significant. The difference in birth weights between generations of inbreeding is satistically significant also, but the decline actually occurred in the fourth generation. Furthermore, the difference in the average birth weights of pigs produced by different sows is significant. Litter and sow differences among the outbreds with respect to birth weights of pigs were significant also. The data indicate a tendency for sows from both groups to produce pigs all of which tend to average relatively large or small.

The average birth weight of 1.89 pounds for the sixth-generation inbreds is low and difficult to explain; but, since the outbreds raised about the same time also have low birth weights, this decrease in birth weight might be due in part to environmental factors.

* Progress Report. W. A. Craft: "The Influence of Birth Weight Upon Subsequent Development of Pigs." *Am. Soc. of An. Prod.* 1929:128-130.

Average coefficients of inbreeding for each generation are shown in the second column of table III. These were computed by adding the coefficient of inbreeding for each litter in a generation and dividing the sum by the number of litters. Wright's method of calculating the coefficient of inbreeding was used and the pedgrees were traced to about 1912. The percentage of inbreeding was higher in the first generation than would be expected for the matings used, due to the relationship that existed among the foundation animals. Theoretically, if the inbreeding gained at the beginning is disregarded, there has been on the average a loss of 5.7 percent of the remaining heterozygosis per generation, which is the equivalent of using two boars each breeding season in a closed herd of approximately 20 sows. The inbreeding from one generation to the next did not increase uniformly, since certain inbred boars were used extensively over a period of years and a few parent×offspring and brother×sister matings were made.

Number of Pigs Weaned and Their Weaning Weights

The number and weight of the pigs weaned by a sow was used as a criterion of her performance. Table IV shows the number of pigs weaned each generation, their average weaning weight, and the average number weaned per litter. The average number of pigs weaned per litter and their weaning weight are shown for the outbreds at the bottom of the table. The percentage of the pigs surviving to weaning age (60 days) is also shown in table IV.

Table IV—The Number and Weight of Pigs Weaned During Each Generation of Inbreeding.

Generation of inbreeding	Number of pigs	Average number per litter	Average weaning weight	Percentage of pigs surviving to weaning
1	71	5.9	26.1	76.3
2	17	4.3	25.0	63.0
3	44	2.9	24.4	50.0
4	97	3.5	21.2	56.4
5	56	2.8	23.8	49.1
6	59	2.3	25.3	52.2
7	38	2.2	24.4	45.8
8	16	2.3	24.3	44.4
Average for inbreds*	398	3.1	23.8	54.8
Average for outbreds	404	5.4	26.7	64.2

* Based on total of 129 litters.

The average number of pigs weaned per litter gradually decreased as the inbreeding became more intense. The percentage of the pigs raised to weaning also declined during the course of inbreeding. Outbred sows weaned 11 percent more pigs than the inbred sows. Although the decrease in weaning weights of the inbred pigs was small, the difference between the weaning weights for different generations of inbreeding is significant. The low weaning-weight of the fourth-generation pigs had a marked influence on the average for the entire eight generations. In the inbred group, the spring pigs averaged 24.8 pounds each at weaning time, while the fall pigs averaged 22.9 pounds each when weaned.

Rate of Growth of the Pigs*

Rate of gain is used as a measure for growth rate in this study. Table V shows the average daily gains for each of the first three 60-day periods for each generation. Average daily gains for the outbreds are included at the bottom of the table for comparison.

The decline in rate of gain from birth to weaning is not significant, the fourth generation being the only one which is below the average. Although there is considerable variation among the averages between different generations of inbreeding for rate of gain from 61 to 120 days, the trend is not certain. Furthermore, the same conditions prevail for the average daily gains during the next period, 121 to 180 days. The influence of environmental factors during these periods may have interfered with the establishment of trends. It appepars also that certain factors favorable for rapid growth may have been lost in the early generations of inbreeding. The difference between the average daily gains for the inbred and outbred pigs during the first 60 days was only 0.04 pounds. For the second 60 days, the difference was 0.09 pounds; and for the third 60-day period, it was 0.31 pounds in favor of the outbreds. The latter is interpreted to indicate that the inbreds tended to grow a little more slowly than the outbreds as age increased, up to about 180 days, then they gained proportionately faster than the outbreds.

Table V—The Average Daily Gains for Specific Periods for Each Generation of Inbreeding.

	BIRTH TO 60 DAYS		61 TO 120 DAYS		121 TO 180 DAYS	
Generation of inbreeding	Number of pigs	Average daily gain (lbs.)	Number of pigs	Average daily gain (lbs.)	Number of pigs	Average daily gain (lbs.)
1	71	0.40	29	0.55	26	0.70
2	17	0.38	14	0.28	13	0.48
3	44	0.37	31	0.34	26	0.60
4	97	0.31	69	0.39	63	0.64
5	56	0.36	53	0.45	43	0.84
6	54	0.38	47	0.43	39	0.83
7	30	0.38	22	0.45	20	0.77
8	12	0.32	11	0.38	9	0.85
Average for inbreds	381	0.36	271	0.45	235	0.72
Average for outbreds	404	0.40	338	0.54	317	1.05

Inspection of table V shows that there were relatively heavy losses between weaning and 180 days. These are believed to be due in part to parasitic infestation and necrotic enteritis, which was exceedingly difficult to control under the crowded conditions prevailing throughout the course of this study. Table VI has been compiled to show the average daily gains of only those pigs which finally reached 225 pounds. It also shows in addition the rate of daily gain from 181 days to 225 pounds in weight.

* Progress Report. W. A. Craft: "The Effect of Inbreeding on Rate of Growth and Resistance to Disease in Swine." *Proc. So. Agri. Workers.* 1934.

A comparison of the data in tables V and VI reveals that the pigs which died following weaning were apparently gaining just about as fast as those which survived to 225 pounds of weight. The inbred pigs increased their daily gains faster proportionately than the outbreds during the period from 181 days of age to 225 pounds in weight, and thereby reduced the difference to 0.12 pounds.

Number of Litters Produced per Sow

Forty-four inbred sows used in this study averaged 470 days of age when their first litters were farrowed, whereas 32 outbred sows averaged 457 days of age when their first litters were farrowed. Table VII shows the average length of the intervals between litters in the two groups.

The intervals between inbred litters were shorter than those between outbred litters. Some of the intervals of the outbreds may have been lengthened by having to wait for an outbred boar. The results indicate that the inbred sows were just as regular breeders as the outbreds. Inbred sows were kept in service slightly longer than the outbreds, averaging 900 days of age when their last litters were farrowed, whereas the outbred sows averaged 855 days of age when farrowing their last litters. The inbred sows

Table VI—Average Rate of Daily Gain for Inbred Pigs Which Survived to 225 Pounds Weight.

Generation of inbreeding	No. of pigs to 225 lbs.	DAILY GAINS (LBS.) Birth to 60 days	61 to 120 days	121 to 180 days	181 days to 225 lbs.	Birth to 225 lbs. weight
1	24	0.44	0.63	0.86	1.36	0.84
2	13	0.40	0.28	0.48	1.04	0.68
3	24	0.41	0.36	0.58	1.02	0.68
4	55	0.35	0.41	0.65	1.14	0.71
5	43	0.37	0.50	0.86	1.14	0.76
6	39	0.42	0.47	0.85	1.27	0.81
7	19	0.40	0.50	0.80	1.23	0.78
8	9	0.37	0.45	0.85	1.02	0.74
Average for inbreds	226	0.39	0.45	0.71	1.15	0.77
Average for outbreds	304	0.43	0.53	1.04	1.27	0.85

Table VII—Average Interval Between Litters Expressed in Days.

Interval between litters	INBREDS Number of intervals	INBREDS Days	OUTBREDS Number of intervals	OUTBREDS Days
1st and 2nd	38	214	23	227
2nd and 3rd	31	197	16	208
3rd and 4th	16	231	9	235
4th and 5th	4	168	2	188
5th and 6th	1	175	1	183
6th and 7th	1	198		
Average	91	209	51	218

averaged 3.03 litters, while the outbreds averaged 2.81 litters each. There was a tendency to keep the inbred sows to an older age, especially if they were good, so that more progeny could be obtained. However, the inbred sows were not as heavy as the outbred sows at maturity.

Selection of Breeding Stock

Selection was practiced when possible throughout the course of the study. There were times, however, when opportunity for selection did not exist due to losses and other factors. In table VIII, a summary is presented showing the selection of breeding stock from the standpoint of size of litter and birth weight of pigs.

Two gilts saved from the first generation of inbreeding came from smaller than average litters and were smaller than average in birth weight. There was no regularity of the trends in the different generations on these points. At the bottom of the table the average for the entire 47 sows selected as breeders shows that this group came from litters which had 1.2 pigs per litter more and that they weighed about 0.1 pounds per pig more at birth than average. The sows were selected from significantly larger litters than the average, but they were not significantly heavier at birth. The 17 boars selected as breeding animals came from litters which were only 0.8 of a pig larger, but they were 0.9 pounds heavier than the average at birth.

Table VIII—The Selection of Breeding Stock on Size of Litter and Birth Weight of Pigs.

Generation of inbreeding	Number of sows selected	AVERAGE SIZE OF LITTER*		AVERAGE BIRTH WEIGHT (LBS.)	
		All litters	Litters from which sows were selected	All pigs in generation	Pigs selected
1	**2**	**7.8**	**5.0**	**2.3**	**2.1**
2	**6**	**6.8**	**9.0**	**2.4**	**1.9**
3	7	5.9	7.4	2.3	2.5
4	6	6.3	6.8	2.1	2.4
5	12	5.7	8.5	2.1	2.3
6	7	4.7	5.6	1.9	1.8
7	5	5.6	5.7	2.0	2.4
8	2	5.3	5.0	2.2	2.7
Average for sows	47	5.8	7.0	2.1	2.2
Average for boars	17	5.8	6.6	2.1	2.9
Effective breeding sows	26	5.8	7.4	2.1	2.1
Outbred sows	22	8.4	9.5	2.6	2.9

* Counting liveborn pigs only.

The effective breeding sows include only those sows which have actually raised pigs from which breeding animals have been selected. Apparently these sows have come from slightly larger litters but have been just average in birth weight. The records show that the selection on size of litter

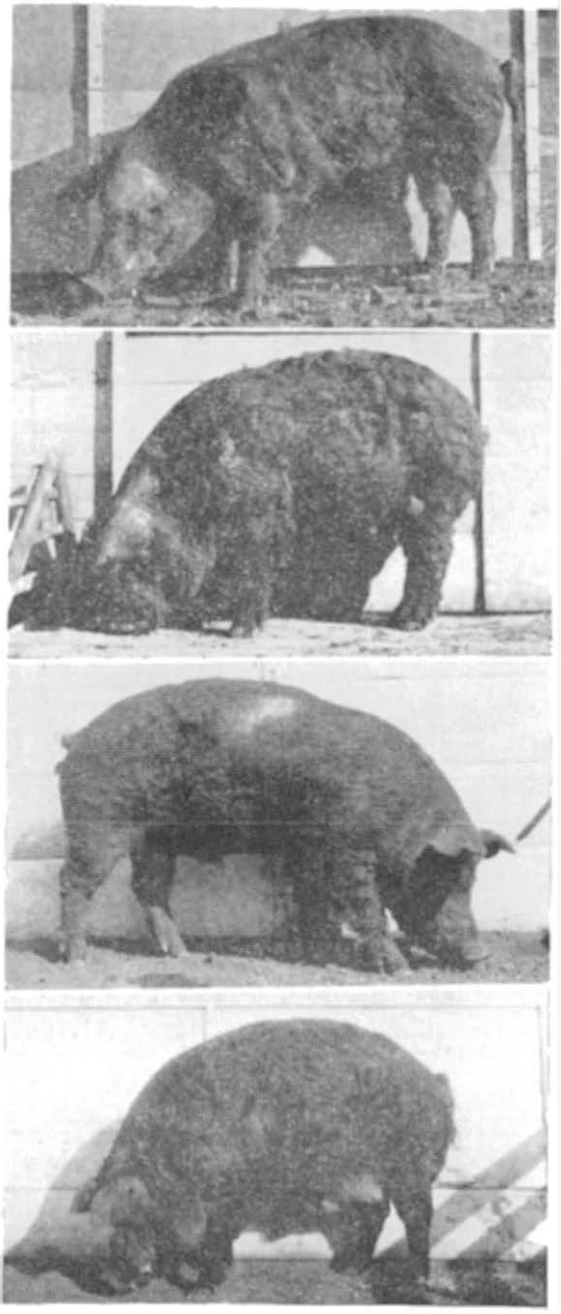
from which the breeding animals were chosen was approximately the same intensity in the outbred as in the inbred group.

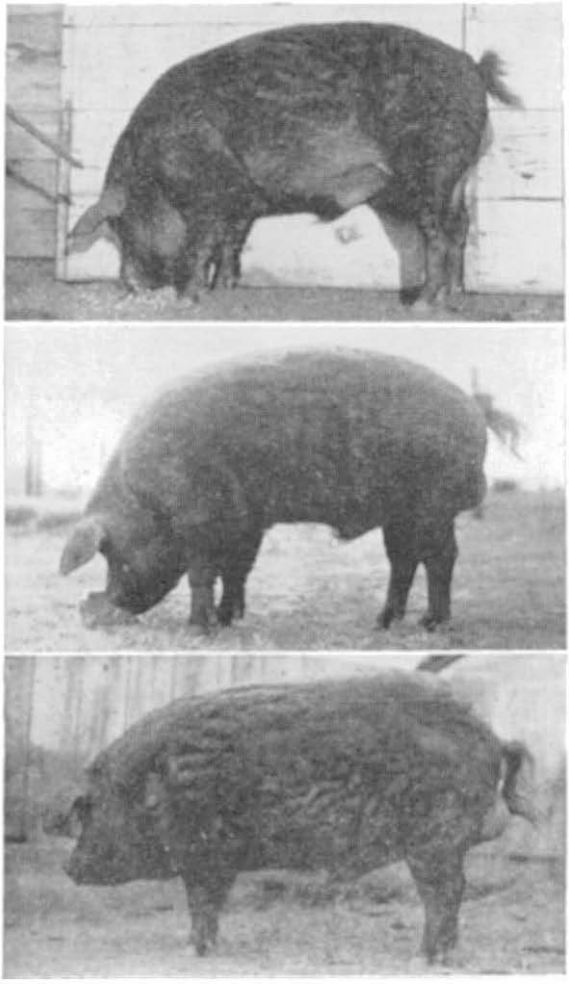
Table IX shows the average number of pigs weaned per litter, the average number weaned per litter in litters from which breeding stock was selected, the average weaning weight for all pigs, and the average weaning weights of those pigs selected as breeders for each generation of inbreeding. The table also presents the average for inbred sows selected as breeders, for inbred boars selected as breeders, for outbred sows selected as breeders, and for the effective inbred sows.

The data reveal that gilts were selected from litters in which more than the average number of pigs were weaned, and that these gilts were also slightly larger than average at weaning time. The boars selected for breeders were from litters in which fewer pigs were weaned than were weaned in the litters from which gilts were chosen. The selected boars averaged heavier than the selected gilts at weaning, but further study of these data failed to disclose any sex difference in the weaning weights of the inbred group as a whole. Boars were selected at the time the pigs were castrated, which was usually when they were 6 to 8 weeks of age. Gilts were not generally selected until nearer the finished weight of 225 pounds. The intensity of selection for size and weight of litter at weaning time was approximately the same for each group.

Table IX—The Selection of Breeding Stock on the Size and Weight of Litters Weaned.

		AVERAGE NUMBER OF PIGS WEANED PER LITTER		AVERAGE WEANING WEIGHT (LBS.)	
Generation of inbreeding	Number of breeders selected	All pigs	Of litters from which breeders were selected	All pigs	Pigs selected as breeders
1	2	5.9	3.5	26	32
2	6	4.3	7.5	25	25
3	7	2.9	6.2	24	27
4	6	3.5	4.2	21	23
5	12	2.8	5.2	24	26
6	7	2.3	5.0	25	26
7	5	2.2	4.7	24	28
8	2	1.0	3.0	24	26
Average for sows	47	3.1	5.3	24	26
Average for boars	17	3.1	3.4	24	31
Effective breeding sows	26	3.1	5.2	24	26
Outbred sows	22	5.4	7.0	27	29





Inbred Boars. On opposite page, from top to bottom, they represent the first, second, third, and fourth generations; above, the fifth, sixth, and eighth generations.

Table X shows by generations of inbreeding the average rate of daily gain for the first three 60-day periods for the inbreds, for the litters from which breeding animals were selected, and for the actual animals selected as breeders.

The selection differentials in rates of daily gain have not been large; the largest occurred in the first generation of inbreeding and on the rate of daily gains for the third 60 days. The average selection differential for the 47 sows was 0.04, 0.05, and 0.09 pounds respectively for the first, second, and third 60-day periods. The selection differentials for the 17 boars saved for breeding were 0.11, 0.03, and 0.30 pounds respectively for the 60-day periods. The selection differential for the effective sows was slightly lower than the average for the 47 sows. Selection differentials for the outbreds during the first 60-day period were about the same as for the inbreds; sows selected for breeders in the outbred group had a smaller rate of daily gain during the second and third 60-day periods than the average of the entire group of outbreds. This analysis might indicate that more emphasis was given to rapid gains when selecting stock in the inbred than in the outbred group; but, if so, it was purely accidental.

The inbred sows selected as breeders averaged 280 days of age when they reached 225 pounds, and the boars selected as breeders averaged 263 days of age. All of the inbred pigs raised in the project averaged 297 days of age and the outbreds 260 days of age when they reached the market weight of 225 pounds.

Feed Required to Produce 100 Pounds of Gain*

The amount of feed required to produce 100 pounds gain by the inbred and outbred pigs is shown in table XI. The pigs were fed by litters or in groups; in general, there was a spring and a fall group from each strain. Since there was no difference in economy of gains between the spring and fall groups, they were combined.

The data disclose that more feed has been required to produce 100 pounds gain during some years than others. A study of the records and notes in connection with the project indicates that some of the large variations in efficiency may have been caused by severe attacks of necrotic enteritis. The inbreds have required on the average 21 pounds more feed than the outbreds to make 100 pounds of gain.

The outbred pigs were more efficient in economy of gains than the inbreds up to 1933. During the feeding periods of 1933, 1934, and 1936, the inbred pigs required less feed to put on 100 pounds gain than the outbreds. Since the pigs were fed in groups and it was impossible to measure the individual variations in economy of gains, it is not possible to determine whether these differences were large enough to be significant. The slower gains made by the inbred pigs may be in part responsible for the lower economy. On the other hand, it may be that less efficient utilization of feed has been responsible for the poorer gains of the inbreds.

* Progress Report. W. A. Craft: "Further Observations on Inbred and Outbred Pigs in the Feed Yards." *Proc. Am. Soc. An. Prod.* 1931:265-268. See also: Progress Report. W. A. Craft: "Utilization of Feed by Inbred and Outbred Pigs." *Ass'n. So. Agri. Workers.* Feb. 1936. S. A. W. 1936

Table X—Selection of Breeding Stock on Average Rate of Daily Gain (in pounds) for Each of the First Three 60-Day Periods.

Generation of inbreeding	Number of sows	1ST SIXTY DAYS			2ND SIXTY DAYS			3RD SIXTY DAYS		
		Average of all inbreds	Litter from which selections were made	Pigs selected	Average of all inbreds	Litter from which selections were made	Pigs selected	Average of all inbreds	Litter from which selections were made	Pigs selected
1	2	0.40	0.50	0.50	0.54	0.56	0.78	0.70	1.10	1.23
2	6	0.38	0.36	0.39	0.28	0.25	0.24	0.48	0.53	0.52
3	7	0.37	0.36	0.40	0.34	0.35	0.35	0.60	0.49	0.61
4	6	0.32	0.35	0.34	0.40	0.47	0.50	0.64	0.50	0.58
5	12	0.36	0.39	0.40	0.45	0.48	0.61	0.84	0.91	1.03
6	7	0.42	0.36	0.39	0.42	0.33	0.47	0.83	0.82	0.91
7	5	0.38	0.43	0.43	0.45	0.56	0.67	0.77	0.89	1.05
8	2	0.36	0.35	0.39	0.44	0.57	0.72	0.78	0.59	0.49
Average all sows	47	0.36	0.39	0.40	0.45	0.44	0.50	0.72	0.76	0.81
Average all boars	17	0.36	0.43	0.47	0.45	0.46	0.48	0.72	0.93	1.02
Effective sows	26	0.36	0.38	0.39	0.45	0.43	0.48	0.72	0.72	0.78
Average outbreds	22	0.40	0.43	0.44	0.54	0.47	0.51	1.03	0.91	1.00

Table XI—Amount of Feed (in pounds) Required to Produce 100 Pounds Gain by Inbreds and Outbreds.

Year	No. pigs finished	Average inbreeding	INBREDS — Per 100 Pounds Gain			
			Corn	Shorts	Tankage	Total
1925	18	0.1464	246.8	149.8	20.9	417.5
1926	5	0.1430	240.3	164.1	27.4	431.9
1927	6	0.1854	289.9	155.9	29.8	475.6
1928	16	0.2549	299.1	160.6	24.7	484.4
1929	5	0.3098	296.9	154.8	31.9	483.6
1930	38	0.3464	292.2	133.1	24.4	449.7
1931	22	0.3484	283.8	132.3	24.3	440.4
1932	12	0.3974	293.1	132.6	26.3	452.0
1933	30	0.3963	261.3	100.1	19.4	380.8
1934	14	0.4006	240.3	80.1	21.7	342.1
1935	28	0.4057	344.4	71.8	17.9	434.1
1936	24	0.4206	295.8	109.0	26.1	430.9
Average	218		286.5	119.8	23.1	429.4

Table XI—(Continued.)

Year	No. pigs finished	OUTBREDS — Per 100 Pounds Gain			
		Corn	Shorts	Tankage	Total
1925		No Record			
1926	16				412.4
1927	16				414.9
1928	29				469.0
1929	7	304.3	130.5	18.3	453.1
1930	7	211.9	141.7	24.9	378.5
1931	41	260.9	112.4	18.0	391.3
1932	48	306.1	96.3	21.9	424.3
1933	43	269.4	94.4	19.9	383.7
1934	18	255.6	85.1	21.3	362.0
1935	27	304.6	61.9	15.1	381.6
1936	18	300.8	108.1	26.1	435.0
Average*	209	281.5	97.3	20.1	398.9
	270**				408.2**

* Average of feed per 100 pounds gain from 1929 to 1936 inclusive.

** Average total feed per 100 pounds gain from 1926 to 1936 inclusive.

The nutritive ratio for the ration, consumed free choice, averaged throughout the duration of the study about 1:5.7 for the inbred pigs and 1:6 for the outbreds.

Digestion Trials*

The average coefficients of digestibility and nitrogen utilization for the two groups are given in table XII. The outbred pigs had higher coefficients of digestibility for each nutrient than the inbred pigs. It is of particular interest that the average of the coefficient for protein was 2.35 percent, and that for nitrogen-free extract (determined by calculation), 1.36 percent in favor of the outbred pigs. These differences are statistically significant. The differences for ash, fat, and fiber were not significant.

In order to ascertain whether there was a significant difference in the coefficients of digestibility between the pigs from different dams, the pairing was disregarded and only those sows having 3 or more pigs in the trial were included. This procedure gave 33 inbred pigs from 4 sows and 38 outbreds from 6 sows. An analysis of variance disclosed a significant difference between the coefficients for protein and ash between the pigs from dlifferent inbred dams. The differences between pigs from different outbred dams were not significant, however.

Table XII—Comparison of the Average Coefficients of Digestibility for the Inbred and Outbred Pigs.

		COEFFICIENTS OF DIGESTIBILITY					
Group	No. of pigs	PERCENTAGE OF					
		Protein	Ash	Fat	Fiber	N. F. E.	C. of N. U.
Outbreds	39	74.28	44.04	58.81	41.94	87.64	41.59
Inbreds	39	71.93	40.42	55.13	38.49	86.28	45.20
Differences		2.35 ± 1.08	3.62 ± 2.53	3.68 ± 2.04	3.45 ± 2.11	1.36 ± 0.66	3.61 ± 1.76

The data were again grouped as above except for sires instead of dams. Only those boars which had sired both inbred and outbred pigs in the trial were used. This provided a group of 35 inbreds and 30 outbreds. The differences between the coefficients for protein and nitrogen-free extract for the two groups sired by 792B_1 and for the digestion of fat for the two groups sired by O_{13} were statistically significant, but the differences between the coefficients of those sired by 751A_3 were not significant. A further analysis of the data by variance revealed that pigs sired by the three boars differed significantly in their ability to digest protein.

The data were grouped according to litters including only litters in which three or more pigs were tested, which provided five litters in each group. This analysis differed from the analysis by dams in that the former

* Progress Report. W. A. Craft and O. S. Willham: "The Role of Nutrition in Genetic Research. Digestion Trials with Inbred and Outbred Pigs." *Proc. Am. Soc. An. Prod.* 1936:260-263.

in several instances included two or more litters. The differences between litters for the digestion of protein, ash, and fat were significant for the inbreds but not for the outbreds.

Some correlations between litter mates were deduced from the variance of the coefficients of digestion for both groups of pigs. These correlations are shown in table XIII.

If the results obtained in these trials are a reliable index of the digestive function of the pigs used and the sample is adequate for the two populations, the results account in part for the greater amount of feed required by the inbred pigs than by the outbreds to make a unit of gain.

Table XIII—Correlation Between Litter Mates for Digestion Coefficients.

COEFFICIENT OF DIGESTIBILITY FOR:	CORRELATION BETWEEN LITTER MATES	
	Inbreds	Outbreds
Protein	0.3507	—0.0432
Ash	0.4542	0.2013
Fat	0.2378	0.1840
Fiber	0.0257	—0.1034
Nitrogen-free extract	—0.0444	—0.1298
Nitrogen utilization	—0.0156	0.1144

NOTE: The correlation coefficients were deduced from the analysis by subtracting the mean square within groups from the total mean square and then dividing by the total mean square. The more uniform the pigs are within groups, the higher the correlation will be, whereas more variation within groups will make for a low correlation between the animals within the groups. The correlation coefficients indicate that the inbred pigs were more uniform in their abilities to digest protein, ash, and fat than were the outbred pigs.

The significant differences between litters from different inbred dams and differences that were not significant between litters from different outbred dams for the digestion of protein and fat are interpreted to support the view that differences in the function of digestion are probably genetic, and that inheritance has become more fixed in certain of the inbred sows than in others or in the outbreds. The differences which were obtained between pigs sired by the three different boars, as well as the correlations between litter mates, appear also to support this view. It is also conceivable that decreased efficiency in digestion of these nutrients might after a time affect vigor and indirectly result in a decrease in resistance to disease and parasitic infestation, which is apparently characteristic of the inbred pigs produced in this study.

Individual Feeding*

The average initial weight, gain, and feed required per 100 pounds gain for the inbred and outbred pigs fed individually are given in table XIV.

The inbred pigs required on the average 451 pounds of feed to make 100 pounds of gain, while the outbreds required only 446.5 pounds. This difference of 4.5 pounds, although in favor of the outbred pigs, is not large enough to be statistically significant. The standard error of the mean difference was about 29 pounds. The coefficient of variability for the feed required for 100 pounds of gain was 30.6 percent in the outbred group and 18.2 percent in the inbred group.

* Progress Report. W. A. Craft: "Influence of Individuality on Feed Consumption by Inbred and Outbred Pigs." *Ass'n. of So. Agri. Workers; Proc. of 34th, 35th and 36th Annual Conventions.* 1935:491.

Table XIV—Gains and Economy of Gains of Pigs on Individual Feed.

Group	No. of Pigs	Average initial weight	Average gain	Average amount of feed per 100 lbs. gain
Outbreds	31	83.7±5.35*	41.1±2.27*	446.5±24.48*
Inbreds	29	80.9±4.46*	36.4±1.90*	450.9±15.25*
Differences		2.8±7.01*	4.7±2.98*	4.4±29.35*

* Standard deviations.

It was thought that the differences in initial weights of the pigs might be responsible for the large variation within groups. There was no correlation between initial weight and feed required per 100 pounds gain in either group. However, a positive correlation was found between initial weight and gain. This correlation was +0.7377 for the inbred pigs and +0.5203 for the outbreds. The correlation was negative between gains and feed required per 100 pounds gain, the magnitude being −0.6849 for the inbreds and −0.6543 for the outbreds. These coefficients indicate that the larger pigs gained faster and that the faster gaining pigs used less feed for 100 pounds gain, which is in accordance with expectancy.

An attempt was made to measure the correlation between the feed required for 100 pounds gain during the 30-day individual feeding period with the feed required for 100 pounds gain during the entire fattening period. This necessitated some estimations of the feed consumed by the individuals, since they were fed in groups except during the 30-day trial. A positive correlation of +0.556 between the feed required for 100 pounds gain during the two periods was found. The data were combined for the inbred and outbred groups to compute this correlation.

A positive correlation of 0.36 was found between the daily gains from weaning to market weight and the daily gains for the 30-day period. It was not necessary in the case of this correlation to do any estimating, since the daily gains were recorded individually. It is very doubtful whether the gains during the 30-day periods could be used to any advantage in measuring the gains from weaning to market weight, since only 13 percent of the variance in daily gains from weaning to market weight was accounted for by the daily gains during the 30 days.

If the samples of pigs used from the two groups in the individual feeding trials were representative of the two groups, and if the 30-day period is long enough to be an accurate measure of the pigs' performance from weaning weight to market weight, then it would seem that there was no difference in the amount of feed required for 100 pounds gain in the two groups. But it appears doubtful whether the 30-day trials are long enough to furnish a good measure of the entire period from weaning to market weight.

The data in table XI show that the inbred pigs were more economical than the outbreds during only three out of the twelve years they compared, and these differences were small.

The large variation in the amount of feed required for 100 pounds of gain in both the inbred and outbred groups indicates that differences in the amount of feed required for 100 pounds gain must be large in order to be significant.

Comparison of Inbred and Outbred Boars*

From time to time outbred sows were mated to inbred boars to produce a litter of pigs. These pigs were placed in the outbred group. These crosses were on the order of diallel crosses and, since there would be at least one litter from each boar from the same sow, made it possible to compare the performance of certain inbred and certain outbred boars. Comparisons were made on the number of pigs farrowed per litter, the average birth weight of pigs, the number of pigs weaned per litter and the average weaning weight of the pigs, the daily gains during each of the first three 60-day periods, and the number of days to reach 225 pounds in weight. There were 13 sows used and 44 litters of pigs produced. Twenty-nine of the litters were sired by inbred boars and 15 by outbred boars. The outbred boars were superior, in general, to the inbred boars, for they were among the best phenotypically that could be found in the breed at that time. This fact should be considered in these comparisons.

Table XV shows the results according to the various sows. At the bottom of the table the average results are presented for the litters by the inbred and outbred boars. There is practically no difference in the size of litters or birth weight of pigs, as would be expected. It is generally conceded that the physiology of the sow determines the size of the litter and for the most part the birth weight of pigs. The pigs from the outbred boars may have been a trifle more vigorous than those from inbred boars, since the size of litter weaned for outbred boars was 0.8 pigs larger. The litters from outbred boars were also slightly heavier than those by inbred boars. The pigs sired by inbred boars gained practically as fast during the first 60-day period as those sired by outbred boars; but during the second and third 60-day periods those by outbred boars gained faster than those by inbred boars. The pigs from inbred boars required 43 days longer to reach 225 pounds in weight than those from outbred boars.

* Progress Report. W. A. Craft: "The Performance of Inbred Sires." Mimeograph Report. Okla. Exp. Sta. April 13, 1935.

Table XV—Performance of Inbred and Outbred Boars.

INBRED BOARS

Litter	No. Sows	Av. No. pigs per litter	Av. birth wt. (lbs.)	Av. No. pigs weaned	Av. weaning wt. (lbs.)	Av. Daily Gain 1st 60 days	Av. Daily Gain 2nd 60 days	Av. Daily Gain 3rd 60 days	Av. No. days to 225 lbs.
916	2	12.0	1.90	3.5	17.0	0.25	0.54	1.03	243
24	3	7.0	1.97	3.7	29.6	0.44	0.50	0.72	315
117	3	12.7	2.52	6.3	34.4	0.53	0.52	1.02	247
911	1	9.0	2.12	5.0	17.8	0.25	0.19		
983	1	13.0	2.24	6.0	22.0	0.32	0.37	0.54	337
314	3	9.3	2.86	6.7	28.4	0.43	0.62	1.13	251
60	1	11.0	2.71	4.0	36.8	0.57	0.67	0.57	288
365	1	11.0	2.23	9.0	17.1	0.25	0.36	0.51	314
506	3	11.3	2.72	9.3	28.5	0.43	0.47	1.02	261
599	2	6.0	2.82	5.5	23.8	0.35	0.42	1.09	278
498	2	15.0	2.00	4.5	27.7	0.43	0.59	1.16	254
493	2	9.5	2.34	4.5	32.0	0.49	0.61	1.16	256
802	5	6.4	1.97	4.4	22.6	0.34	0.46	1.10	263
Av.	29	10.2	2.34	5.7	26.0	0.39	0.49	0.92	276

Table XV—(Continued.)

OUTBRED BOARS									
						Av. Daily Gain			
Sows	No. litter	Av. No. pigs per litter	Av. birth wt. (lbs.)	Av. No. pigs weaned	Av. weaning wt. (lbs.)	1st 60 days	2nd 60 days	3rd 60 days	Av. No. days to 225 lbs.
916	1	8.0	1.83	7.0	26.7	0.37	0.61	1.20	235
24	1	7.0	1.74	2.0	16.5	0.24	0.20	1.08	---
117	1	13.0	2.43	9.0	30.6	0.46	0.66	1.58	212
911	1	12.0	2.26	10.0	25.3	0.38	0.70	1.35	224
983	2	12.0	1.83	6.5	22.8	0.35	0.74	1.37	231
314	1	11.0	2.28	5.0	30.6	0.46	0.71	1.73	
$6C_1$	2	10.0	2.74	7.5	23.6	0.35	0.41	0.73	271
365	1	13.0	2.63	7.0	31.7	0.54	0.52	1.47	221
506	1	9.0	3.01	8.0	25.0	0.37	0.60	1.25	237
599	1	9.0	2.42	8.0	18.3	0.26	0.58	1.13	254
498	1	10.0	2.05	8.0	26.0	0.40	0.67	1.46	232
493	1	2.0	2.40	2.0	40.0	0.63	0.77	1.53	213
802	1	11.0	2.60	5.0	34.0	0.52	0.57	1.41	224
Av.	15	9.8	2.32	6.5	27.0	0.41	0.60	1.33	232

Table XVI shows a comparison of three important boars of each group. The three inbred boars shown in this table have been key boars in the inbred herd in recent years.

The inbred boar, $751A_3$, gave the poorest results as far as daily gains were concerned. There were fewer of his pigs living at weaning time and they were smaller than the corresponding pigs sired by the outbred boar, Miracle King. In all of the comparisons in the table, the gains of the pigs sired by outbred boars have been more rapid during the last two 60-day periods than the gains in the same periods of the pigs sired by inbred boars. These results indicate that some of the genes affecting rapid rate of growth had been lost from the inbred boars and were not adequately compensated for by the sows to which the inbreds were mated.

Type Changes*

A number of measurements were taken of the pigs at birth and at 60-day intervals until they reached 225 pounds in weight. These measurements were taken for the purpose of determining changes in type which might take place in either group of pigs during the experiment. The measurements recorded are described under "Methods and Procedure," (page 12).

* Progress Report. W. A. Craft: "Type Changes in an Inbred Stock of Swine." *Am. Soc. An. Prod. Proc.* 27:110-111. (1934).

Table XVI—Comparison of Inbred and Outbred Boars When Mated to the Same Outbred Sows.

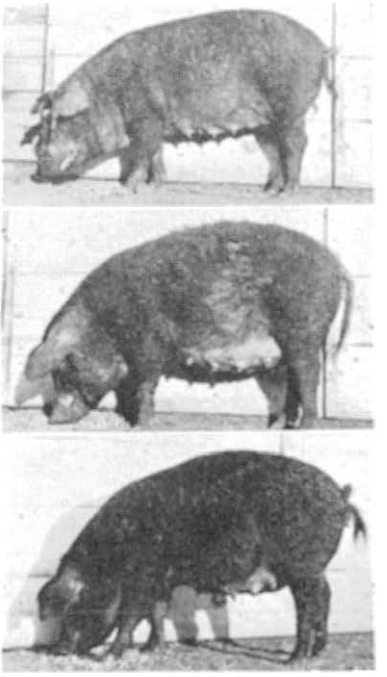
Boars compared	Sows	Litters	Average No. pigs farrowed per litter	Average birth wt. (Lbs.)	Average No. weaned per litter	Average weaning wt. (lbs.)	AVERAGE DAILY GAIN (LBS.)			Average No. days to 225 Lbs.
							1st 60 days	2nd 60 days	3rd 60 days	
$51A_4$	4	8	10.0	2.32	5.0	26.4	0.38	0.44	0.76	300
Miracle King	4	4	11.2	2.17	5.2	28.2	0.39	0.49	1.35	224
$751A_3$	1	2	11.0	1.83	3.5	18.7	0.28	0.28	0.83	306
Miracle King	1	1	11.0	2.60	5.0	34.0	0.52	0.57	1.41	224
$792B_4$	1	2	10.5	1.94	5.5	27.7	0.42	0.60	1.27	246
Miracle King	1	1	11.0	2.60	5.0	34.0	0.52	0.57	1.41	224
$51A_4$	4	5	10.8	2.47	5.6	24.9	0.33	0.49	0.81	276
Wavemaster Stilts	4	4	10.2	2.19	7.5	25.9	0.39	0.71	1.42	229
$792B_4$	3	4	7.3	2.56	6.5	25.6	0.39	0.55	1.17	256
Helendale Lad	3	3	9.3	2.48	8.0	23.1	0.34	0.62	1.28	241

The pigs varied in weight at all but one of the times when the measurements were made. In order to take care of the weight differences, the ratio of each measurement to the cube root of the weight was employed as used by Lush (1928).

Table XVII shows the weight-measurement ratios for the inbred pigs at 60 days and at 225 pounds in weight. The pigs are divided according to the generation of inbreeding to which they belonged. The averages for the inbreds and outbreds are given at the bottom of the table. Only the measurements for length, width, depth, and foreshin are shown in the table.

The differences in the weight-measurement ratios are small and the variation within the groups is also small, and therefore a number of the differences noted in the table are significant. The ratios indicate that the inbred pigs have apparently increased in length in proportion to weight at weaning age during the eight generations of inbreeding. This increase has been small, however. An analysis of the variance disclosed a significant difference between generations as far as the 60-day length ratios were concerned, but the changes were not always in the same direction.

There has been some fluctuation in the width ratios, but on the whole there has been no significant trend. All of the pigs have tended to be wider in proportion to their weight at 225 pounds than they were at weaning time. The inbred pigs have been significantly wider at both periods than the outbreds. This difference was also apparent from observations.



Three Inbred Sows. From top to bottom they represent the fifth, sixth and seventh generations of inbreeding.

There are no trends in the chest-depth ratios at either the 60-day period or at market weight. Some variation has occurred between generations, but not always in the same direction. There was no difference in the chest-depth ratios between the inbreds and outbreds, but the inbreds were slightly deeper at 225 pounds weight.

The foreshin ratios tended to decrease from weaning to market weight, while the other three ratios increased slightly. There are no trends in these ratios according to the generation of inbreeding. The inbred pigs have apparently had a little larger bone both at weaning and market weights than the outbreds.

The weight-measurement ratios were arranged in groups in which the pigs were produced by the same sow and boar and the variance analyzed.

Table XVII—Weight-Measurement Ratios for Inbred and Outbred Pigs.

Generation of inbreeding	RATIOS							
	LENGTH[1]		WIDTH[2]		DEPTH[3]		FORESHIN[4]	
	60 days	225 lbs.	60 days	225 lbs.	60 days	225 lbs.	60 days	225 lbs.
1	17.7	19.5	4.3	4.6	5.2	6.1	3.1	2.7
2	17.7	19.8	4.2	4.7	5.3	6.1	2.9	2.6
3	17.2	19.8	4.4	4.7	5.2	6.2	3.1	2.8
4	18.5	19.4	4.6	4.9	5.3	6.3	3.2	2.7
5	19.0	19.6	4.4	4.8	5.0	6.1	3.2	2.7
6	18.7	19.5	4.2	4.7	4.8	6.1	3.1	2.6
7	19.1	19.2	4.4	4.7	5.1	6.0	3.1	2.6
8	18.5	19.3	4.6	4.8	4.9	6.2	3.1	2.6
Average for inbreds	18.3	19.4	4.4	4.7	5.1	6.2	3.2	2.7
Average for outbreds	19.0	19.9	4.3	4.6	5.1	6.1	3.1	2.6

[1] Length from between the ears to the base of the tail in centimeters, divided by the cube root of the weight.

[2] Chest width in centimeters divided by the cube root of the weight.

[3] Chest depth in centimeters divided by the cube root of the weight.

[4] Circumference of the foreshin in centimeters divided by the cube root of the weight.

Differences between the groups of pigs which are full brothers and sisters were significant for foreshin, length of body, chest width, and chest depth ratios, for both 60 days of age and 225 pounds weight. These differences between groups of full brothers and sisters were more pronounced in the outbreds.

Various correlation coefficients between full brothers and sisters from these data are shown in table XVIII. The data suggest, on the whole, that the outbred pigs were slightly more uniform for the four weight-measurement ratios and weaning weight than the inbreds, and therefore had a more uniform growth rate.

Table XVIII—The Coefficients of Correlation Between Full Brothers or Sisters Deduced From the Analysis of Variance.*

	Foreshin 60-day	Chest Depth 60-day	Width 60-day	Length 60-day	Weaning weight
Inbreds	0.2540	0.4077	0.3433	0.2769	0.2485
Outbreds	0.3576	0.4870	0.4377	0.6427	0.3268

* The correlation coefficients were deduced by the same method as those in table XIII.

Hemoglobin Studies*

There is a tendency for the hemoglobin level in the blood of pigs to decrease sharply following birth, and it has been demonstrated that recovery of the normal level is aided by supplying the pigs with the proper mineral supplements. It was thought that there might be some difference between the inbred and outbred pigs with respect to the decline or recovery of hemoglobin following birth. A study was made to determine this point. The hemoglobin determinations were made at weekly intervals from birth up to eight weeks of age. The data are shown in table XIX. In the second to the bottom line of the table, an average is given which includes only those inbred pigs which reached 8 weeks of age. It was thought that the pigs having an unusually low hemoglobin level probably died before 8 weeks of age and that the pigs which lived throughout the 8 weeks might average somewhere near the outbred pigs. The comparison does not bear out this suggestion, however.

Differences in hemoglobin level between the inbreds and outbreds at birth and at 1 week were not significant, but the difference at 2, 4, and 8 weeks were highly significant. The data reveal that the inbreds failed to regain their hemoglobin level as rapidly as the outbred pigs. This failure

* Progress Report. W. A. Craft and L. H. Moe: "The Hemoglobin Level in Pigs at Various Ages." *Amer. Soc. An. Prod.* 1933. 137-141. (Newcomer Method). See also Progress Report. W. A. Craft and L. H. Moe: "Statistical Observations Involving Weights, Hemoglobin and the Proportion of White Blood Cells in Pigs." *Jour. Amer. Vet. Med. Ass'n.* 81:N. S. 34. 3. 405-407. Sept. 1932.

Table XIX—Average Hemoglobin Content of Blood* of Inbred Pigs by Generations at Birth, One, Two, Four, and Eight Weeks. (Average for Outbred Group Shown at Bottom of Table.)

Generation of inbreeding	BIRTH		ONE WEEK		TWO WEEKS		FOUR WEEKS		EIGHT WEEKS	
	Number of pigs	Average Hemo. Cont.	Number of pigs	Average Hemo. Cont.	Number of pigs	Average Hemo. Cont.	Number of pigs	Average Hemo. Cont.	Number of pigs	Average Hemo. Cont.
4	23	10.20	16	7.43	13	7.21	12	8.36	12	10.47
5	60	9.91	52	8.12	44	8.25	37	8.66	30	9.63
6	66	9.97	63	7.36	62	7.54	56	8.12	50	9.43
7	34	9.31	27	6.61	26	7.06	26	8.33	22	9.85
8	15	9.51	5	6.69	4	6.87	3	8.92	3	8.47
Average for inbreds	198	9.81	163	7.47	149	7.62	134	8.28	117	9.64
Inbreds which reached eight weeks	117	9.85	117	7.39	117	7.67	117	8.49	117	9.64
Average for outbreds	228	10.03	184	7.25	168	8.12	161	9.45	146	10.30

* Determinations made by the Newcomer Method.

of the inbred pigs to regain a normal hemoglobin level early is believed to be associated with their lower vigor in comparison with the outbred group. Further comparison between the hemoglobin level of the inbred and outbred pigs was made at 12, 16, and 20 weeks, 180 days of age, and at 225 pounds weight. There were no differences between the two strains at any of these periods save at 225 pounds weight. In the latter, there was a statistically significant difference between the two strains, but the numbers were small and it is uncertain as to the real importance of the difference. The inbred pigs reached their normal hemoglobin level sometime between the eighth and twelfth week of age, assuming the hemoglobin level at birth as normal. It may be of interest that the young pigs while in the farrowing pens had access to clean soil with which iron sulphate and copper sulphate had been mixed and that the mineral mixture fed the sows also contained sulphates of iron and copper.

The data indicate that the pigs which died prior to 8 weeks of age were, in general, those failing to show some recovery of their hemoglobin level by the second to fourth week of age.

Data were grouped so as to determine the variance of hemoglobin level of the pigs according to sows in each group. Correlation coefficients similar to the ones deduced from the weight-measurement ratios were calculated and are presented in table XX.

Throughout the period of these observations, the pigs produced by inbred sows appeared to be less variable in their hemoglobin content than those produced by outbred sows. It is suggested that some factors adversely affecting the hemoglobin content of the blood have been fixed in the inbred strain. It was thought that the heavier pigs at one week of age might be more anemic than the lighter pigs, but the data do not bear out this suggestion.

Table XX—Correlation Between Hemoglobin Levels of Pigs Produced by the Same Sows.*

Age of pigs	Pigs from inbred sows	Pigs from outbred sows
Birth	0.4354	0.3370
1 Week	0.3270	0.4160
2 Weeks	0.2897	0.0166
4 Weeks	0.2491	0.0493
8 Weeks	0.0267	0.1716
12 Weeks	0.2075	0.1421
16 Weeks	0.4031	0.0553
20 Weeks	0.4387	0.1607
180 Days	0.4586	0.0192

* The correlation coefficients were deduced by the same method as those in table XIII.

Sex Ratio

The sex ratio of the pigs produced in this study was 51.9 percent males for the inbreds and 53.8 percent males for the outbreds. The difference (1.9 percent) probably has little, if any, significance. There was some variation in the sex ratio from one generation of inbreeding to another, but these do not indicate a definite trend and the differences were no larger than could be expected from normal variation between random samples from the same population.

Length of Gestation Period

The average gestation period for the inbred sows was 115.5 days and for the outbred sows 114.4 days. The inbred litters averaged 13.63 pounds per litter at birth while the outbred litters averaged 22.25 pounds per litter. Size or weight of litter may have been the factor responsible for the difference in mean length of the gestation period for the two groups of sows.

Vigor

The rate of daily gain and the percentage of pigs surviving have been used as criteria for growth and vigor. Tabe XXI shows the percentage of pigs alive at each 30-day interval from birth to the market weight of 225 pounds. The litters are arranged by generation of inbreeding. Inbreeding apparently has had no effect on the percentage of pigs farrowed alive. But the percentage of pigs surviving to weaning has decreased as the inbreeding has become more intense.

Table XXI—Percentage of Pigs Alive at Each 30-Day Interval From Birth to Market Weight by Generations of Inbreeding.*

Generation of inbreeding	Birth	60 Days	90 Days	120 Days	150 Days	180 Days	210 Days	225 Lbs.
1	87	76	37	34	31	31	28	26
2	90	63	52	52	48	48	48	48
3	83	50	40	39	35	31	27	27
4	88	56	44	41	38	37	37	32
5	88	49	47	47	42	40	39	38
6	78	52	49	42	40	39	38	36
7	92	46	41	34	29	27	27	25
8	97	44	44	42	36	36	36	36
Average for inbreds	87	55	44	40	37	35	34	32
Average for outbreds	88	64	57	54	51	51	49	43

* "Birth" column shows percentage of live pigs to total farrowed; other columns show percentage of pigs alive to total farrowed alive.

SUMMARY

1. The object of this experiment was to study comparatively the effects of continuous but relatively mild inbreeding and outbreeding when practiced in swine. The Duroc Jersey breed was used.

2. Approximately half-brother×half-sister matings were practiced for 8 generations of dams. An outbred strain was maintained for comparison with the inbreds.

3. The inbred litters decreased from 8.9 pigs the first generation to 5.3 pigs in the eighth generation. There was no decrease in the size of the outbred litters during the experiment, the outbred litters averaging 9.3 pigs per litter.

4. There was no difference in the percentage of stillborn pigs in each group.

5. The greatest decrease in birth weight occurred in the first generation of inbreeding. The inbred pigs averaged 2.13 pounds and the outbreds 2.47 pounds at birth.

6. The eighth-generation inbreds had an average coefficient of inbreeding of 45.6 percent. Theoretically, this means that 45.6 percent of the unfixed gene pairs in the foundation stock have become fixed.

7. The inbred sows weaned on the average 2.3 fewer pigs per litter than the outbred sows, and the inbred pigs averaged 2.9 pounds lighter than the outbred pigs at weaning time.

8. The percentage of pigs surviving to weaning age decreased as the percentage of inbreeding increased. In the first generation of inbreeding, 76 percent of the pigs reached weaning age; in the eighth generation, only 44 percent of the pigs lived to weaning weight.

9. The inbred gilts weaned slightly larger litters than the inbred sows, but the pigs were smaller in size.

10. The inbred pigs made smaller daily gains than the outbreds throughout the period from birth to market weight were 0.04, 0.09, 0.33, and 0.12 pounds respectively between the two groups for each of the first three 60-day periods and from 181 days of age to 225 pounds in weight were 0.04, 0.09, 0.33, and 0.12 pounds respectively in favor of the outbreds.

11. The pigs that died following weaning time, both inbred and outbred, were apparently gaining, up to the time of their death, just as fast as the average pigs.

12. The inbred sows bred just as regularly as the outbred sows. The inbred boars mated readily with the inbred sows.

13. The heavy losses of pigs made selection of breeding stock in this experiment very difficult.

14. The inbred pigs required on the average 21 pounds more feed than the outbred pigs to put on 100 pounds of gain. The inbred pigs were more uniform in the amount of feed required for 100 pounds gain than the outbred pigs.

15. The inbred pigs, in comparison with the outbred pigs, had significantly lower coefficients of digestibility for protein and nitrogen-free extract.

16. The inbred boars which were compared with outbred boars in diallel crosses did not seem to produce any more uniform pigs than did the outbred boars. Pigs sired by the inbred boars and out of outbred sows had smaller daily gains than the outbred pigs during the latter part of the feeding period. The outbred boars were somewhat superior in phenotypic merit to the inbreds.

17. Inbred pigs became slightly shorter and thicker than the outbreds at maturity, but there was no decrease in size of bone.

18. The inbred pigs did not recover their normal hemoglobin level following the first week of age as quickly as did the outbreds.

19. Death losses throughout the growing and fattening period were greater in the inbred than in the outbred group.

20. The percentage of males was 51.9 percent in the inbred and 53.8 percent in the outbred pigs.

21. The gestation period averaged 115.5 days for the inbred sows and 114.4 days for the outbred sows.

22. On the whole, the records suggest either that certain genes, favorably affecting rate of growth particularly, were lost, or that combinations of genes producing slow growth were fixed. This occurred in the first and second generations of inbreeding.

23. The results indicate that the weight of pigs at weaning age is probably less a reliable indication of the subsequent rate of growth for inbreds than it is for outbred pigs.

24. Certain characters, such as curly hair, dark and light coat-color, coarse hair, type, shape of head and ears, and probably slow rate of growth, became fixed in some individuals among the inbreds.

25. Abnormalities which occurred in the inbred herd included: foetal resorption, blind teats, sexual infantilism, blood warts, hernia, and flexed or kinked tails. Data available do not permit genetic analysis of any of these traits, however. The same abnormalities occurred in the outbred herd, but with less frequency than in the inbred herd.

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