THE AMOUNT AND EFFECTIVENESS OF SELECTION IN INBRED LINES OF SWINE

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By

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INTRODUCTION

Animal breeders have practiced selective mating of their animals for thousands of years. Early in the domestication of our present breeds of livestock, man recognized the power of selection and practiced some degree of it. Selection, whether artificial or natural, is a force which causes animals possessing certain characteristics to be allowed to produce more offspring than animals who do not possess those characteristics. As a result, the genes responsible for the favored characteristics become more numerous in the population upon which selection is operating.

Natural selection is not replaced by artificial selection but is supplemented by it. Man selects for those characteristics of his livestock which best fit his needs and fancy. Particularly because of the artificial environment which man is able to supply for his livestock, his selective practices may differ widely from natural selection both in direction and intensity.

There must be apparent differences between animals before the livestock breeder can choose for breeding stock those animals which most nearly conform to his ideal. Thus it is variation upon which selection operates. Differences between individuals are caused by differences in heredity, differences in environment, and the interaction of heredity and environment. Since only differences caused by genes can be passed from an animal to its offspring, it is actually the genetic variation upon which selection operates. The degree to which differences in a characteristic are caused by heredity (the heritability of a characteristic) will influence the effectiveness of selection for that characteristic. Because of the duplicate nature of inheritance we must select pairs of genes rather than single genes, and dominance may thus influence the effectiveness of selection. Linkage and epistasis further complicate selection. Many genes occur on the same chromosome in linkage groups, therefore many more individuals are required to produce all possible gene combinations and this tends to reduce variability. Complex interactions between genes may cause a given gene to produce different effects dependent upon the other genes present.

In the selection of breeding stock mistakes are caused by several factors. Accurate measures of the worth of an animal are lacking for many traits, - - this is especially true for meat-producing animals. Environmental effects are misinterpreted as gene effects. Dominance may confuse the genotype of an animal. Complex gene interactions may produce the phenomenon of "nicking", in which case again the true genotype may be masked.

The application of our ever-growing knowledge of the mechanism of inheritance can, however, materially reduce some of the errors in selection. Because of the duplicate nature of inheritance and the large part played by chance in the random assortment and recombination of genes in reproduction, selection can never be made perfect.

Inbreeding, through its power to bring into play hidden recessives which seem (in the majority of cases at least) to be largely deleterious in effect, may cause an inbred population to decline in many or all characteristics unless this inbreeding is accompanied by rather intense selection. Inbreeding in itself does not cause deterioration, and if it is not too intense and is accompanied by selection sufficiently accurate and intense enough to cull out undesired genes as they are brought to light, actual improvement may be made.

The following study of selection is made on inbred lines of swine. The inbreeding here appears to be a major factor opposing progress by selection.

REVIEW OF LITERATURE

The literature on selection dates back to the writings of the Romans over two thousand years ago. According to Harrison (1913) some of their great authors gave advice on how to select animals for desired traits.

Darwin's Origin of Species (1885) remains the classic work on selection, even though it was written without knowledge of the Mendelian laws of heredity. Darwin realized the importance and powers of both natural and artificial selection and presented a great quantity of evidence and many illustrations of its effectiveness. He pointed out the success of Bakewell and the Collings brothers in modifying "the forms and qualities of their cattle" by methodical selection. Darwin's conclusions are corrected and brought up to date with modern genetic knowledge by R. A. Fisher (1930).

The first experiments marking advance in our understanding of selection were conducted by the Danish botanist, W. L. Johannsen, during the beginning of this century. These experiments are reviewed by Sinnot and Dunn (1925). From his experiments, Johannsen distinguished hereditary from non-hereditary variation and demonstrated two fundamental principles of successful selection: first, selection must be based on hereditary variation; secondly, the factors responsible for the selected characters must be heterozygous when selection is begun.

Mass selection is a basic principle of breeding, and knowledge of its existence by ancient peoples has already been mentioned. The first experimental demonstration of the effectiveness of mass selection in opposite directions was made by F. L. Winter (1929). He summarized the Illinois work on selection of strains of corn for high and low protein, and high and low oil content. The cumulative effects of continuous selection over a period of 29 years resulted in lines which were markedly different in the selected traits.

"Student" (1934) applied statistical analysis to Winter's data on oil content of corn and speculated on the number of genes which probably conditioned that characteristic.

Gowell (1900) was probably the first modern investigator to attempt to improve egg production in poultry by means of selection. He reports (1905) an appreciable increase in egg production through selection. Little progress in the development of high producing strains had been made up to that time. Marble and Hall (1931) analyzed the results of a high production line and a low production line selection experiment carried on at Cornell University over a fifteen year period. Selection in this experiment was for other traits as well as for egg production. It is of interest to note that by careful selection body and egg weight were both increased with increased production. Line comparisons also showed obvious genetic differences between lines.

In a controlled selection experiment for high and low efficiency of food utilization in the rat, Morris et al. (1933) demonstrated evidence of heritable factors influencing the efficiency of food utilization.

H. D. Goodale (1938), working at the Mt. Hope Farm, Massachusetts, presented results of probably the first selection experiment in animal breeding in which breeding stock were selected by the progeny test. The object of his experiment was to determine the limits of change by selection when the character being selected (body weight) was not in itself a limiting factor. The albino mouse was the animal used. He concluded that genotypic selection showed a much greater efficiency than would have been shown by phenotypic selection alone.

Goodale's selection experiment was carried out in one direction only. MacArthur (1944) conducted a carefully planned and well controlled selection experiment to produce an extremely large and extremely small bodied race of house mouse. One of his primary objectives was to aid in the genetic studies of the inheritance of quantitative characters. From his studies he concluded that size genes, or modifiers, act to multiply each other's effects rather than act in a simple additive fashion. He further theorized, on the basis of his findings, that the most prized qualities of high producing livestock may be expected to improve simultaneously with proper selection. Castle and Phillips (1914) and Castle and Wright (1916) conducted selection experiments for the hooded pattern in rats. Castle's first interpretation of these experiments was in error; he later proved the multiple factor hypothesis to be the correct explanation of the inheritance of the hooded pattern.

Grimes (1941) reported results of one of the first selection experiments using large animals. A strain of swine efficient in food utilization was developed by selection for superior efficiency of gain and compared with a strain developed by selection for inferior efficiency of gain. It was found that, in spite of environmental factors, pigs from the same foundation stock could be separated by selection into high and low lines as to rate and economy of gain.

Krider et al. (1946) report results of an experiment in which swine were selected for rapid and slow growth rates. Heritability estimates of growth rate were made through the study of line differences created by selection and from the analysis of variance within lines. They concluded that heritability of weight differences increased from about five percent at birth to twenty-four percent at one hundred and eighty days.

The most recent report of results of a selection experiment is that of Lerner and Hazel (1947). Working with a poultry flock, they analyzed the roles played by selection, chance, and migration with respect to improvement in egg production over a twelve year period. They calculated gains theoretically expected in egg production on the basis of known selection intensity, heritability, and generation interval, and found these expected gains checked closely with the actual gains. Their general conclusions are that the currently accepted principles of population genetics may be used to predict rates of improvement in populations subjected to artificial selection.

The above cited literature attests to the power of selection in animal breeding when used by man to change the characteristics or type of his domestic animals. There is a large amount of literature on the ways in which selection may be made most effective, and many studies are recorded on the complicating factors which influence the accuracy with which the individual livestock breeder makes his selection of breeding stock.

Some of the works which deal directly with selection in swine breeding will be considered. Selection indexes, their components, and the proportional weighing of their components have received a great deal of attention in all classes of farm livestock. McPhee (1934) investigated the size of litter as a selection index in swine. He concluded that although size of litter is of great economic importance the breeder has only limited control over it and selection for it among our breeds of swine will progress very slowly. Lush (1940) in one of the early studies for the Regional Swine Breeding Laboratory discussed the problem of selection of young boars and gilts, and how to weight their dams' production record and their own market score and growth rate in selection. Hazel and Lush (1942) propose an index for selection intended to weight each of several characteristics so as to make maximum genetic improvement. They calculated that mistakes in selection caused by unmeasurable environmental factors, dominance, and gene interaction made the index some thirty-eight percent as efficient as if the exact genotypes of each animal were known. Lush and Molln (1942) proposed a productivity score for sows which will be considered later. They pointed out that selection will gain materially if based on the average of all litters a sow has produced and that the inclusion of some data on performance of close relatives would make progress more rapid. The inclusion of this extra data however could be quickly carried to a point of diminishing returns. Selection indexes based on multiple regression studies were proposed and evaluated by Hazel (1943) in his consideration of the genetic basis for constructing selection indexes. Dickerson and Hazel (1944) pointed out that the factors determining the annual amount of improvement from selection are: the average genetic superiority of the selected animals over the population from which they were selected, and the average time interval between generations. They further pointed out some of the difficulties that may be encountered in following a plan of progeny testing.

In considering selection for single traits or the effect on selection of the interaction between heredity and environment, the following reports are pertinent. Comstock et al. (1942) investigated relative values of measures of growth rate for use in swine selection. They showed the importance of exploiting a pig's genotype for growth through feeding and management to get full expression of genotypic differences. That optimal rather than maximal size of litter is to be selected for in order to realize greatest economic gains was pointed out by Olbrycht (1943). He further stated that judging a sow on her first litter performance is of very appreciable advantage, that two litters increase the accuracy of the judgment, but that more are not worthy of consideration. Dickerson and Hazel (1944) compared the effectiveness of different methods of selection for improved growth rate in pigs and improved sow productivity. They found yearly progress greatest when sows were culled after their first litter; the best half or third were then kept to produce one more litter upon which further selection was based.

The extent to which the loss in vigor which ordinarily accompanies inbreeding can be offset by selection was studied by Comstock and Winters (1943). They found that fertility was a much more difficult characteristic to maintain in lines of swine being inbred than was growth rate. Since inbreeding obviously plays an important part in the present study, other works on the effect of inbreeding on swine will be considered in the interpretation of results. Among them are papers of: Hodgson (1935), Hughes (1933), McPhee et al. (1931), and Willham and Craft (1939).

OBJECTIVES OF THIS INVESTIGATION

This study was conducted to determine the amount of selection which has been practiced in 5 inbred lines of purebred Duroc swine. The measure of the amount of selection for several characteristics is the selection differential as defined by Lush (1945). Through a study of the number of pigs available for selection as compared with the number selected for breeding, the intensity of selection will be shown. The effectiveness of the selection practiced has been judged by analysing the changes in several characteristics from generation to generation.

SOURCE OF MATERIAL AND METHODS OF ANALYSIS

The records studied were from the swine breeding project of the Oklahoma Station and the Regional Swine Breeding Laboratory. Data for this investigation were taken from the records of 5 inbred lines of purebred Duroc swine. The objectives of the Swine Breeding Laboratory and the systems of selection and breeding generally practiced throughout the cooperating stations are given by Craft (1943). The primary objective of the Oklahoma Swine Breeding project is the improvement of swine through the use of a system of inbreeding, outcrossing, and selection.

The Oklahoma station started its inbreeding project in the fall of 1937, with foundation stock for four lines. Line 1 was retained from a previous inbreeding project and was the most intensely inbred line in this study. (See also Willham and Craft (1939) and Willham (1944)). Line 1 was carried up to the spring of 1945, when it was crossed with unrelated inbred stock to form a new line (line 7). Line 2 was dropped in the fall of 1941 due to low productivity. Line 4 was culled in 1943 because of the apparent fixation of undesirable factors for inverted nipples in the line. Line 5 was established in 1942. Lines 3 and 5, and the outcross product of line 1, now designated as line 7, are present in the herd at this date.

The original breeding plan in each line was to maintain a ten sow herd with two boars in service each season. This two sire program could be expected to cause an increase in inbreeding on the average of from six to seven percent per generation. Some deviations from the plan are noticeable in the data presented later.

Selection of boars and gilts for replacement within each line were based on the weight of the individual at 180 days, the body conformation of the individual, and the productivity of the dam of the individual. If the data were available, selection of breeding stock was further based on performance of sibs in such characteristics as rate of gain, economy of gain, body conformation, and carcass quality. No numerical index which combined the ratings of the individual in all selected traits was used consistently in the selection of breeding animals. The balancing of the points on each animal was left to the arbitrary decision of the project leader. More detailed information on selection practices will be given as each characteristic is studied.

This study includes only litters produced by the mating of individuals within the same line. Line crosses were not studied with the exception of the outcross on Line 1 which produced Line 7. The lines were broken down for analysis in the following manner: through study of the records, the foundation sows of each line were determined, their progeny were then designated as Generation 1. Gilts selected from Generation 1 produced litters designated as Generation 2 and so on. Because of the overlap in time of the breeding influence of boars, they have not been considered in the breakdown of the line into generations. Thus, the generations studied are actually sow generations.

Once broken into generations by sows, the data were recorded on each litter, on each selected gilt, and on each selected boar. Data on all litters included the dam and sire; season and year of birth; number of pigs at birth, at 21 days, at weaning, and at 180 days; the weight of the litter at each of these four ages, and the coefficient of inbreeding. Data recorded for each sow were: her individual weight at the four ages, the weaning size of the litter in which she was born, and her coefficient of inbreeding.

Because Line 3 is the largest line from the standpoint of total numbers of individuals and has been successfully maintained in a pure state since the beginning of the project, its record has been most thoroughly analysed and studied. Data previously mentioned plus notation as to sex and conformation score and the productivity rating of selected sows were compiled for each of the 1307 pigs born in Line 3. This information was entered on code sheets and punched into International Business Machine cards. Thus one card was made for each pig and it contained all the information which was available for that particular pig. Through the use of I.B.M. tabulating and calculating equipment, sums, sums of squares, and frequency distributions were readily obtained. This complete analysis of Line 3 will be discussed in detail. Data on 180 day weight and litter size for Lines 1, 2, 4, and 5 will be presented for comparison with the findings in Line 3.

PRESENTATION OF DATA

The number of pigs in each generation of line 3 are given in Table I. Of the 1307 pigs farrowed, 816 were alive and were weighed at 180 days. The figure for total number born also includes the stillborn pigs. Powell (1947), in a study of all litters in the Oklahoma inbreeding project, found that six percent of the pigs farrowed were stillborn. Weights at 21 days were missing on two litters in the first generation. These two litters were weighed at weaning and this accounts for the three pig increase from 21 days to weaning in this generation. The number of pigs at 180 days may be a slight underestimate since the number 816 includes only those individuals actually weighed. There were one or two individuals sold for breeding purposes before 180 day weights were recorded. Table I lists the numbers of individuals which are considered in the subsequent Tables on Line 3 except where otherwise indicated.

Over a period of years, and even from season to season, environmental factors acting upon an experimental livestock herd will vary regardless of attempts to hold it constant. There are several methods which could be used to overcome this difficulty, namely: 1. accurate records of environmental conditions could be kept and then studied to determine corrections to be applied to the data; 2. in certain experimental designs, analysis of variance might be used to determine an estimate of environmental differences due to season and year; 3. the experiment could be so designed that any single classification of animals has comparable data recorded over a period of several seasons. According to the third method, the environmental errors tend to cancel out insofar as they are random and occur in either direction. This last method of dealing with major environmental influences is used in this study. Table II shows the distribution by year and season of the 147 litters produced by six generations of sows. There

Table I

Number of Line 3 Pigs in Each Generation

Generation	Sex	Birth	All Individuals 21 Days	Weaning	180 Days	Selected Individuals
1	Male	118	77	79	77	8
	Fem.	114	80	81	79	17
2.	Male	160	114	108	99	10
	Fem.	156	120	115	108	20
3.	Male	142	102	96	88	9
	Fem.	148	102	98	86	15
4.	Male	117	77	76	62	3
	Fem.	126	91	88	81	17
5.	Male	96	65	64	60	0
	Fem.	92	68	68	55	6
6.	Male	23	17	16	13	0
	Fem.	15	13	10	8	0
Totals:	Male	656	452	439	399	30
	Fem.	651	474	460	417	75
	All	1307	926	899	816	105

was considerable overlap of the generations with the exception of Generation 5 which was the last sow generation in the study. Therefore only a major environmental trend would be likely to cause bias in comparing one generation with the generation immediately preceding or following it. General improvement in feeding and management practices might be expected in any study extending over a period of years. Marble and Hall (1931) believed the increase in production of a line selected for low productivity to be in part a measure of this trend. On the other hand, circumstances might exist where there would be decline rather than improvement. Should facilities for pasture be very limited in a swine experiment, parasite control would become increasingly difficult. A build up of parasite infestation might cause a general decline of the health and vigor of the herd. It is not likely that any major change in environmental conditions could be of much importance in these data since feeding and management conditions have been similar during the period covered.

Since one-half of the inheritance of any individual is attributable to the sire and one-half to the dam, consideration of but one side of the pedigree would not give all the information needed for logical interpretation of the data. Selected sows produced their effect in the next generation, since by the plan of this study all of their litters have been assigned to that generation. Due to the seasonal overlap of sow generations, however, boars may have sired litters in other than the generation immediately following the one in which they were born. Table III shows the amount of generation overlap in boar influence. The large number of Generation 1 and 2 litters sired by boars born in these same generations was due to the retention of a number of foundation and Generation 1 sows over a period of several years in the herd and the mating of these older sows to the younger boars from later generations. Some of this effect is also shown in other generations.

Table II. Seasonal Distribution of Line 3 Litters by Sow Generations

Year	1938		1939		1940		1941		1942		1943		1944		1945		1946		
Season	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	
Sow Generations																			Generation Totals
Foundation	2	0	5	5	6	5	1												24
1			4	1	5	3	7	5	4	3	2	1							35
2					1	0	3	4	7	4	5	4	3	2					33
3										2	3	1	3	2	4	7	5		27
4												1	0	1	2	3	3	12	22
5																	2	4	6
Season Totals	2	0	9	6	12	8	11	9	11	9	10	7	6	5	6	10	10	16	147

Table III

Distribution by Generation of Litters Sired by Selected Boars

Boars Selected from Generation	Number Boars Selected	Sired Litters in Generation 1	2	3	4	5	6	Total Litters
1	8	15	22	7				44
2	10	3	11	19	7	2		42
3	9		2	7	16	6		31
4	3				4	14	6	24
Total	30							141*

* Six litters in Generation 1 were sired by four Foundation Boars.

Age of the sow is important in this study for two reasons. First, it has been shown that pigs produced by gilts tend to be lighter than those produced by older sows. In considering average weights up to weaning, it is therefore pertinent to know the average age of sows producing the pigs concerned (Keith, 1930; Kuhlman and Cole, 1929; McKenzie, 1928; Carmichael and Rice, 1920). Second, the average age of parents determines the generation interval or rate at which breeding stock is being turned over. Data on age of sows is presented in Table IV. First generation sows were older since there was a tendency in the early period of the project to retain sows above average in breeding ability for several years in order to secure more offspring from them.

In the card for each pig having a 180-day weight, a weight-class code number (intervals of 10 pounds) was punched. The 816 cards were then tabulated to give frequency distributions for 180-day weights according to various classifications. Figure 1 shows the frequency distribution of 180-day weights of all pigs and of the 105 selected boars and sows. Although there is a slight skewness toward the lighter weights and somewhat of a bi-modal appearance the distribution is not evidently different from a normal distribution. Whatley (1942) found the same slight skewness in studying 180-day weights in Poland China Swine. The difference between the two means plotted in Figure 1 show the over-all selection differential for 180-day weight of 22 pounds. Figure 2 shows the changes in the means of selected individuals and the population from which they were selected in each generation. 180-day weight was only one of several characteristics being selected, therefore selected animals are to be found on either side of the mean of the population from which they are selected. Their mean, however, lies above the mean of the population. The distance above the general mean depends upon the accuracy and intensity of selection and the importance given the particular characteristic in selection (Lush, 1945, p. 146 and Hazel and Lush, 1942).

Table IV

Average Age in Years of Sows Producing
Each Generation

	Generation 1	2	3	4	5	6
Age of Dams of All Pigs	1.8	1.6	1.4	1.6	1.5	1.3
Age of Dams of Selected Pigs	1.6	1.9	1.5	1.5	1.5	—
Difference	+0.2	-0.3	-0.1	+0.1	0.0	—

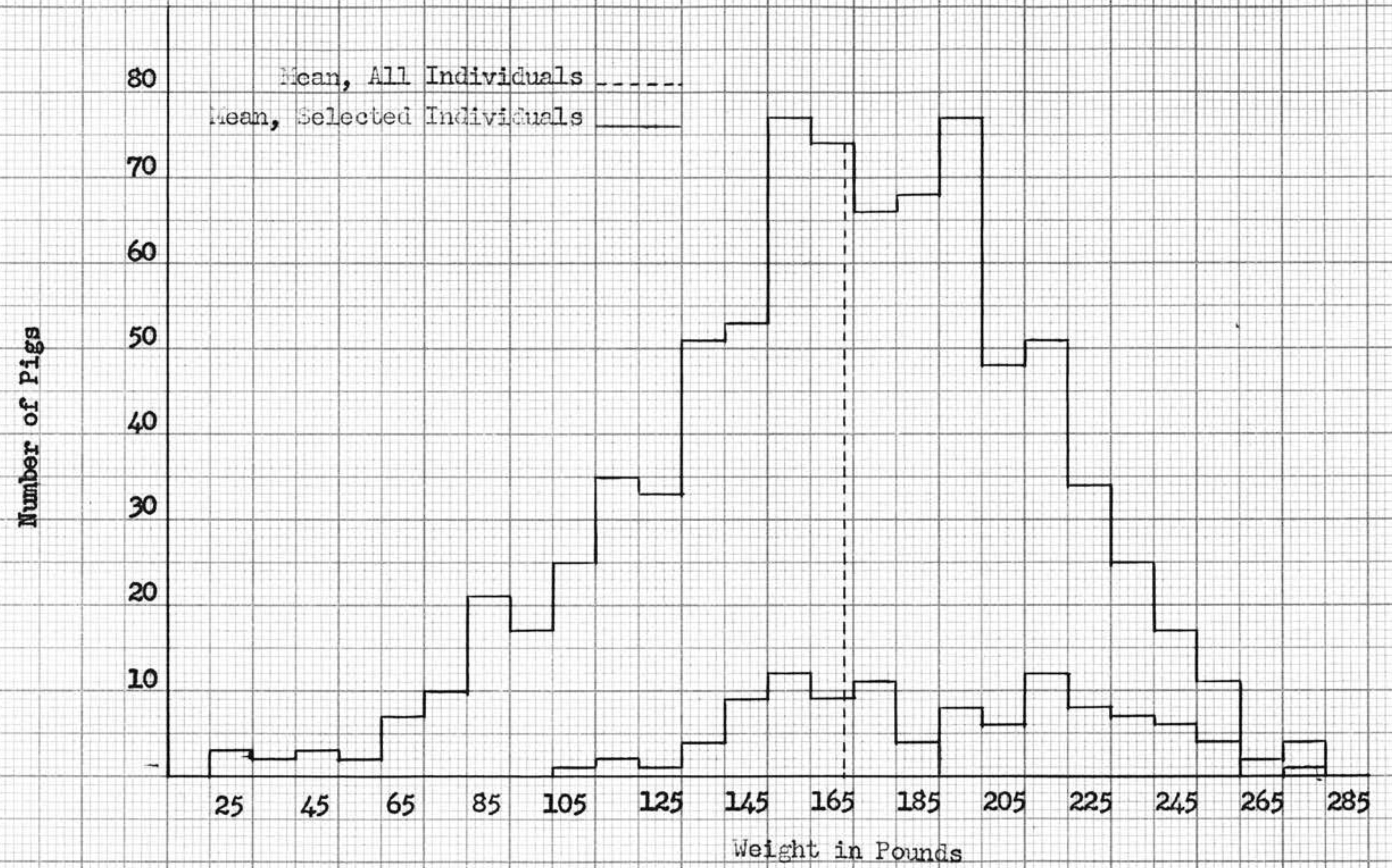

Figure 1. Frequency Distribution of 180 Day Weights of 816 Pigs and 105 Selected Breeding Animals.

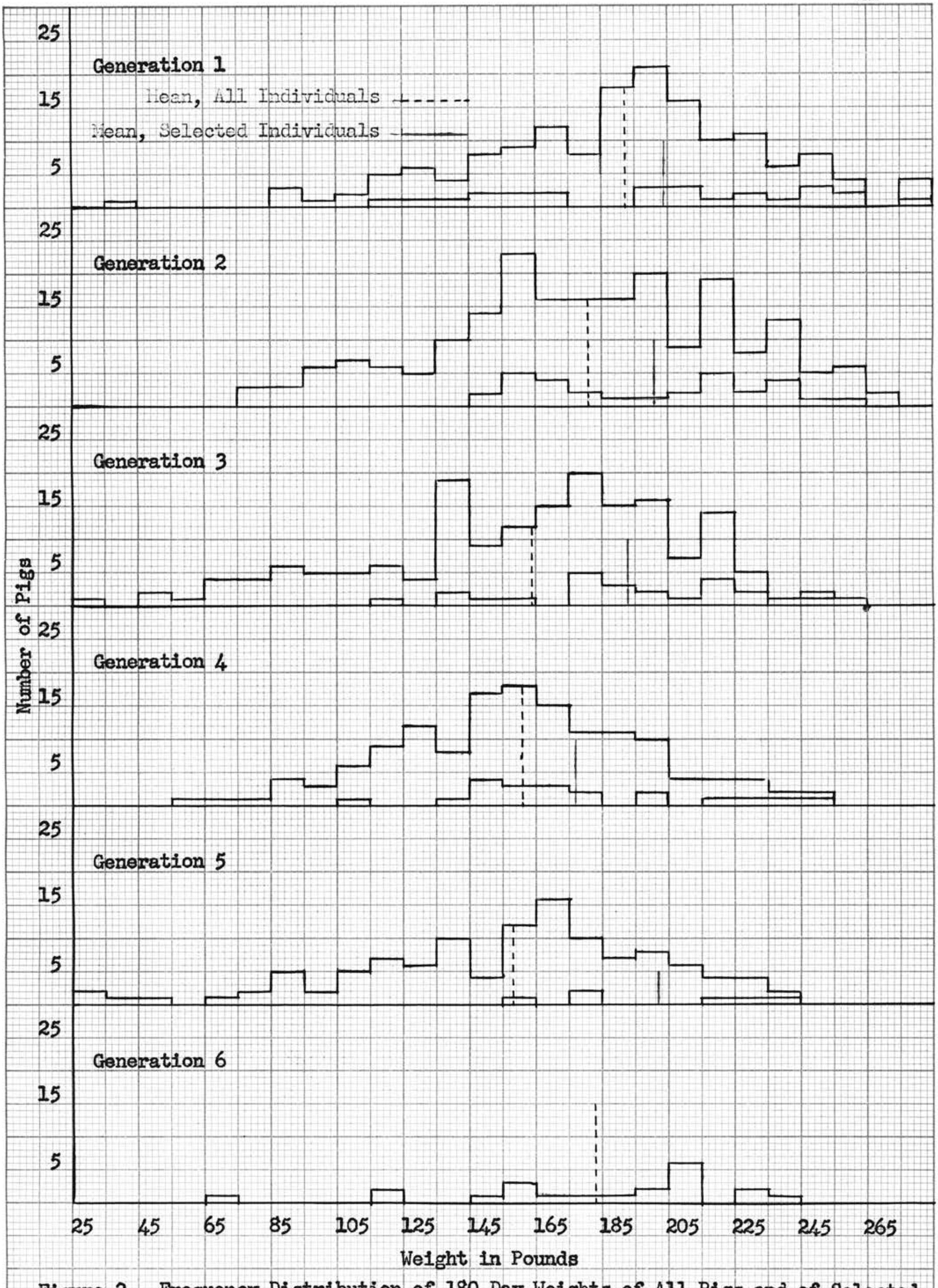

Figure 2. Frequency Distribution of 180 Day Weights of All Pigs and of Selected Individuals by Generation.

Figures 1 and 2 indicate a decline in 180-day weight, in spite of selecting for breeding stock those individuals who averaged superior to the population from which they were selected. The standard deviation of the population mean is 45 pounds, the selection differential for 180-day weight for all breeding animals is 22 pounds. This gives a selection differential which in terms of standard deviation is about .5. This corresponds in intensity to saving 70 percent of the population (Lush, 1945 page 148). This rather low intensity of selection for 180-day weight could still slowly increase the population mean. The explanation of the fact that it did not is probably that inbreeding was being practiced.

In Table V are given the average inbreeding coefficients of pigs alive at 180 days. This is the age at which most of the selection took place. An exception to this is the tendency to select boars, initially at least, when near six weeks of age. Inbreeding increased up to the fourth generation at approximately a rate of five percent per generation. In the last two generations the average fell five percent from its peak in the fourth generation. The variability of the coefficient of inbreeding as indicated by the standard deviation did not decrease appreciably except in the last generation. The average given for all pigs, because of the different numbers of individuals in the generations, is not the simple arithmetic average of the generation figures given. This holds true as well for Tables VI through XII.

The average birth weights of all pigs was 2.6 pounds with a standard deviation of 0.7 pounds. (Table VI). There was no significant change in birth weights as the generations progressed. The average birth weights and their standard deviations are nearly identical with those found by Lush et al. (1934). Examination of the data shows that the boars tended to be a little heavier than gilts. The selected boars and selected gilts averaged .5 and .3 of a pound more respect-

Table V

Selection Differentials for Coefficient of Inbreeding

	All Pigs at 180 Days		Selection Differentails	
Generation	Average Fx.	Standard Deviation	Boars	Sows
1	.04	.06	-.02	.00
2	.14	.09	+.04	+.03
3	.22	.11	+.03	+.04
4	.24	.10	-.06	-.02
5	.18	.09	——	-.08
6	.19	.01	——	——
Average	.16	.11	-.01	.00

Table VI

Selection Differentials for Birth Weight
(in pounds)

Generation	All Individuals		Selection Differentials	
	Average Weight	Standard Deviation	Boars	Sows
1	2.8	0.7	+0.3	+0.1
2	2.6	0.7	+0.5	+0.3
3	2.5	0.6	+0.7	+0.3
4	2.6	0.7	+0.8	+0.2
5	2.7	0.7	——	+0.2
6	2.8	0.7	——	——
Average*	2.6	0.7	+.55	+0.28

* The average is weighted according to the number of individuals in each generation.

ively, at birth than the average of all individuals.

In Table VII are presented the average 21-day weights and standard deviations of all pigs. Neither the weight nor its variability changed much over the period of this study.

The average weight of all boars was superior to that of the gilts (not shown in the Table), and the selected boars prove to have been quite definitely superior to the generation average and to the weights of selected gilts.

The average weaning weight of all pigs was 28.5 pounds with a standard deviation of 8.1 pounds. In table VIII averages and standard deviations with the amount of superiority shown by selected boars and gilts are given for each of the six generations. There was no noticeable difference between the average weights of all males and females at weaning. Of the 899 pigs weaned, the average weight of males was 28.6 pounds; and the females was 28.5 pounds. The slight advantave in weight in favor of males found at birth and at 21 days had disappeared at weaning. The average selection differentials, + 6.2 pounds for boars and + 3.6 pounds for gilts, are both highly significant statistically. No decrease in mean weaning weight from the first to sixth generation was found.

At 180 days (Table IX) it was found that the average weight had decreased from a high of 187 pounds in the first generation to a low of 153 pounds in the fifth generation. The sixth generation shows some evidence of an increase in mean 180-day weight; however, relatively few individuals were included in this generation (Table I). Variability in 180-day weights as indicated by the standard deviations shows little change. Selection differentials for boars were lower than for sows except in the third generation where the eight selected boars averaged 193 pounds, which is 34 pounds more than the mean of the population from which they were selected. The selection differentials for sows were found to fluctuate less from generation to generation except for the six sows selected from Generation 5 which show almost twice the average selection differential.

Table VII

Selection Differentials for 21 Day Weight
(in pounds)

	All Individuals		Selection Differentials	
Generation	Average Weight	Standard Deviation	Boars	Sows
1	10.0	3.1	+2.5	+1.6
2	10.5	2.7	+1.8	+1.1
3	9.7	2.9	+2.5	+0.9
4	10.6	2.6	+3.0	-0.1
5	10.8	2.9	—	+0.1
6	10.3	2.9	—	—
Average*	10.3	2.9	+2.2	+0.8

* The average is wieghted according to the number of individuals in each generation.

Table VIII

Selection Differentials for Weaning Weight
(in pounds)

	All Individuals		Selection Differentials	
Generation	Average Weight	Standard Deviation	Boars	Sows
1	28.4	8.5	+6.6	+4.5
2	29.6	8.2	+5.6	+4.2
3	26.9	8.3	+8.7	+4.0
4	26.5	6.9	+3.5	+3.4
5	30.7	8.1	----	+2.6
6	33.4	5.8	----	----
Average*	28.5	8.1	+6.2	+3.6

* The average is weighted according to the number of individuals in each generation.

Table IX

Selection Differentials for 180 Day Weights
(in pounds)

Generation	All Individuals		Selection Differentials	
	Average Weight	Standard Deviation	Boars	Sows
1	187	44	+ 7	+14
2	176	44	+13	+23
3	159	46	+34	+27
4	156	38	- 2	+20
5	153	45	—	+44
6	178	43	—	—
Average*	168	45	+20	+23

* The average is weighted according to the number of individuals in each generation.

On the average, boars and barrows weighed slightly less than gilts at 180 days.

The tendency to select breeding animals from the larger sized litters is illustrated in Table X. The selection differentials for boars and sows are based on averages obtained by considering the size of litter from which each selected pig came. On the average, boars were selected from slightly larger litters than gilts, though the difference is only 0.2 of a pig in favor of the boars. Over the entire period there was very little fluctuation in the variation in litter sizes, but there was a slight decline in the average litter size.

Table XI shows the results of selection for conformation score of the pig at market weight. The pigs were scored on six different items: health and vigor, quality, length of body, details of conformation, animal as a whole, and market grade. Each item had a maximum value of 9, thus permitting a perfect score of 54. The individual score was an average of scores given by two or three experienced judges when the pigs were near a weight of 225 pounds. Stonaker and Lush (1942) give a more complete description and evaluation of this scoring system. The number of individuals scored is not identical with the number weighed as given in Table I. The numbers of individuals scored in generations 4, 5, and 6 were low or lacking because of a new score card used in 1946, which was not comparable with the one used in previous years. Consequently, the pigs scored by the new card were not included in this study. The mean score of all individuals was 40.4 points with a standard deviation of 4.5 points. Selected individuals were consistently higher in score than their generation average, and selected sows showed a consistently higher score than did selected boars. The variances of the scores for the separate generations showed no indication of increasing uniformity nor was there any noticeable change in the average score.

The production indexes of the 70 selected females shown in Table I were studied and the results are presented in Table XII. Production indexes were

Table X

Selection Differentials for Litter Size at Weaning as Indicated by the Average Superiority in Size of Litters From Which Breeding Animals Were Selected

	All Litters			Selection Differentials	
Generation	Number	Average Size	Standard Deviation	Boars	Sows
1	24	6.7	2.6	+1.5	+1.4
2	35	6.4	2.0	+0.7	+0.4
3	33	5.9	2.3	+1.4	+1.6
4	27	6.1	2.4	+0.6	+0.3
5	22	6.0	2.4	—	+2.0
6	6	4.3	2.4	—	—
Total or Average	147	6.1	2.3	+1.3	+1.1

Table XI

Selection Differentials For Score

Generation	Number	Average Score	Standard Deviation	Boars	Sows
	All Litters			Selection Differentials	
1	155	40.1	3.8	+1.1	+2.6
2	205	40.4	4.7	+1.2	+2.2
3	169	40.5	5.8	+2.9	+2.0
4	107	40.2	6.2	+3.5	+3.9
5	39	41.4	5.5	——	+3.1
6	——	——	——	——	——
Total or Average	675	40.4	4.5	+1.9	+2.7

calculated by a formula proposed by Lush and Molln (1942) whereby the real or most probable producing ability of a sow was estimated from her lifetime production record. The performance of the sow was determined by the number of pigs at birth, 21 days, and 56 days, and litter weight at 21 and 56 days. Appropriate age corrections were made for each of the items. Each of the indexes studied was based on all litters which a sow had produced. Therefore, they are of somewhat varying reliability as more confidence would be placed in the production index figure for a sow that had farrowed four litters than a gilt that had farrowed only one litter. This discrepancy is in part corrected in the calculation of the index by regressing the productivity toward the population average. To make comparisons logical, the indexes were all weighted according to the number of pigs each sow produced. For analysis the actual indexes were coded in order to eliminate the negative figures on sows of below average productivity. The mean production indexes of the sows in each generation showed no decided trend up or down. In the selection differentials shown in Table XII, no distinction was made between the dams of selected boars or selected gilts. This gave a number of 32 sows which were the dams of all the pigs selected for breeding. A more detailed study of the records than is shown in Table XII reveals that boars selected from Generations 2 and 3 came from dams having no greater mean productivity indexes than did the dams of gilts selected from these generations. This indicates that in spite of the opportunity for more intense selection of the boars, they were not from dams averaging any higher in productivity than were the larger numbers of selected gilts. However, the three boars selected from Generation 4 had dams averaging 55.7 points, and were from three different dams, while the seventeen selected gilts were from ten different dams averaging only 43.9 points.

The "effective" dams listed in Table XII are those which have contributed

Table XII

Selection Differentials for Productivity Index of Sows

Generation	Production Index of Dams of All Pigs (Average)*	Selection Differentials**	
		Dams of Selected Pigs	Effective Dams of Selected Pigs
1	—	—	—
2	45.1	+0.3	+1.0
3	47.1	+3.7	+4.5
4	42.8	+2.8	+6.1
5	47.8	+10.5	+13.0
6	42.2	—	—
Average	45.5	+2.5	+4.1

* Weighted by the number of pigs each sow raised.
** Weighted by the number of pigs selected from each sow.

to the inheritance of the individuals that are in the herd today. They were determined by the construction of a complete herd pedigree from the present individuals to the foundation animals. It was found that about one-half the selected sows from generations 1, 2, 3, and 5 and one-third the selected sows from generation 4 were ancestors of the present animals in line 3. These 34 "effective" sows averaged only 0.3 pounds heavier at weaning and 5 pounds heavier at 180 days, were no higher in score and were from no larger litters than the 75 selected sows. They did, however, average 4.1 points above all selected sows in productivity index. In terms of the litter size and litter weight at weaning this is the equivalent of two extra pigs and 60 pounds additional weight.

The total number of pigs and the numbers of selected individuals in lines 1, 2, 4, and 5 are presented in Table XIII. The number of generations during which each line was bred is also indicated. Seasonal distributions of litters within generations of these lines are very comparable with the seasonal distributions of Line 3 litters as presented in Table II. For the appropriate numbers found in Table XIII, Table XIV shows the line averages and selection differentials for size of litter at weaning, for 180-day weight, and for coefficient of inbreeding.

Table XIII

Number of Individuals at 180 Days in Lines 1, 2, 4, and 5.

		Number of:			
Line	Generations	Litters	Pigs	Selected Boars	Selected Sows
1	7	95	451	14	31
2	3	55	280	6	21
4	4	71	405	10	17
5	5	61	331	10	26
Totals		282	1467	40	95

Table XIV

Weaning Size of Litters, 180-Day Weights and Their Selection Differentials for Lines 1, 2, 4, and 5.

	Weaning Size of Litters			180-Day Weights		
Line	Average No. Pigs Per Litter	Selection Boars	Differential Sows	Average Weights in Pounds	Selection Boars	Differential Sows
1	6.0	+0.3	+0.2	128	+10	+42
2	5.8	+1.2	+1.4	150	+ 1	+10
4	6.4	+1.9	+1.4	162	+21	+29
5	6.2	+0.2	+0.2	157	+46	+23

DISCUSSION

The largest portion of the variation in any of the characteristics studied is probably due to permanent and temporary environmental effects. It is of importance, then, to consider the scattered and incomplete notations on environmental factors which may have influenced the performance of individuals in these data. Recorded observations show that 1941 seasons were unusually wet and that difficulty with roundworm infestation was encountered. In the fall of 1942 there was an outbreak of swine pox followed by mange which had an adverse effect on the fifty litters raised. A few cases of swine pox appeared in the spring of 1943. During 1944, feed was above average in quality and conditions were conducive to good gains. In the spring of 1945, difficulty with damp corn that had been heating was encountered. Since heated corn is especially unpalatable to young pigs, it caused a decrease in grain consumption and rate of gain. In the fall of 1945 an outbreak of hog cholera caused the loss of 44 pigs and adversely affected the growth rates of pigs that recovered. In the spring of 1946 a notation was made that pre-weaning mortality rates were lower than in previous years, but that there was a high rate of influenza during the month of May. It would be difficult to make any corrections or allowances for these season to season environmental differences, but it should be borne in mind that these temporary environmental changes and probably many others of unknown origin and effect, did exist in the data. It has been pointed out that the seasonal overlap of generations should tend to reduce the effects of these temporary environmental influences.

All reported estimates of heritability of birth and 21-day weights are very low. Certainly selection for growth rate based on birth weight or 21 day weight is not practical, since later weights give a more reliable index of the inherent growth ability of the individual. It is of interest, however, to note that the selected pigs were consistently somewhat larger than their generation average. This is the natural result of selecting the growthier pigs for breeding and the tendency for larger pigs at birth to continue so throughout life (Kuhlman and Cole, 1929). The average selection differentials for birth and 21 day weights shown in Tables VI and VII are statistically significant.

Weaning weight is somewhat more highly heritable than birth and 21 day weight. Estimates of from 0 to 18 percent have been made. In these data the initial selection for growth rate of boar pigs was made at six weeks of age and the remaining boar pigs were castrated. About two or three times as many boars as could ultimately be used for breeding were selected at this age near weaning. They were chosen according to productivity of their dams, growth rate and size of the litter, and individual weight and conformation. Detailed study of Line 3 data revealed that selected boars were 6 pounds heavier than the average of all the boars and barrows at weaning, and nearly 3 pounds heavier than selected females. However, the males at weaning did not average any heavier than the females. The advantage in selection differential shown in Table VIII was due primarily to the more intense selection of boars. For all generations, about 7 percent of the boars were selected and 18 percent of the gilts were saved for breeding.

The study of 180 day weights in line 3 shows a trend downward in spite of a significantly large mean selection differential both for gilts and boars. Three boars which show a negative 180 day weight selection differential in Generation 4 sired 24 litters: 14 of these were in Generation 5, 2 in the spring and 12 in the fall of 1946. While this may not account for all of the low weight in Generation 5, it is certain that selection for boars at least could have had little chance to increase 180 day weight. The sows that produced Generation 5 were 20 pounds superior in 180 day weight to the population from which they had been selected, but none of this superiority was shown in their offspring. The 44 pound selection differential for sows selected from Generation 5 may be responsible in part for the increase in weight shown in Generation 6 even though this generation was sired by the boars showing the slight negative differential. It appears that the intensity of selection has not been quite enough to maintain 180 day weight at its original level. The apparent force working against an increase in weight is the increase in inbreeding, which although mild, very likely had some effect in reducing weight at 180 days as the experiment progressed. Inbreeding increased up to the fourth generation and has since decreased about 5 percent due to the introduction of a subline which had been bred separately for several generations.

The data for litter size at weaning in Line 3 show that both boars and sows came from litters which were superior to the average by about one pig. Since it was necessary to save fewer boars than gilts it was possible to select boars from larger litters. Boars actually were selected from litters which averaged 0.2 pig larger than litters from which gilts were selected (Table X). This is in contrast to the findings of Willham and Craft (1939). In their study boars were from litters which were slightly smaller at weaning than those from which the sows were selected. The average sire of litter at weaning did decrease slightly in this study. Table X shows the average size of litter in the first generation to be 6.7 pigs, the sixth generation average is 4.3 pigs per litter. The low figure for Generation 6 is based on less than one-third the number of litters of other generations, it therefore may not be a reliable indication of a sharp decrease in litter size. Additional litters in this generation and another generation will give a more reliable estimate of the success in maintaining litter size in Line 3.

With regard to the conformation score the data on Line 3 seem to indicate that there has been no decline in the net desirability of the animals as to conformation or type. Such a conclusion, however might well contain considerable error. There is the possibility that the judges scored the pigs in each season relative to the same numerical average. If this were true, only drastic changes in conformation would be detectable over a period of time. Within any particular season the scores are a good indication of the superiority of the selected animals. When the scores of several judges are averaged (as was done in these data), more confidence may be placed in the score as an actual measure of the animal's body type and conformation. In this study, scores of selected boars averaged nearly a point less than did scores of selected gilts. Boars reach sexual maturity at a weight well below the 225 pound mark which is set as the time for scoring. The ranting and increased activity which accompanies sexual maturity in boars causes them to be lighter in weight and more rough in appearance than gilts and barrows at scoring time. The score card then, especially in alloting 9 points to quality and 9 points to market grade, may have unjustly penalized boars. Further study would be necessary to show why the more intensely selected boars averaged slightly lower in score than the gilts. The average selection differentials in Line 3 are statistically significant, and consistent superiority in score of selected animals is shown. Whatley (1942) found that the 180 day weights of Poland China males were 7 pounds less than females. Winters et al. (1942), in comparing growth rates of boars and barrows found that the presence of testes accelerates growth rate but that at puberty some other factor enters in and has a depressing effect.

The productivity index analysis in Table XII indicates about the same trends as are shown in litter size and weaning weights. The low point in productivity of dams of all pigs in Generation 4 coincides with the highest point reached in the inbreeding. The index of dams of Generation 6 falls markedly despite their having come from individuals highly selected for production. Only six sows are considered in the sixth generation so that another generation and more data on these sows will give a better indication of whether or not productivity is actually decreasing.

In Lines 1, 2, 4, and 5 detailed study of the data compiled revealed the birth and 21 day weights followed the same trends as were indicated in Line 3. The selection differentials for these two weights were of about the same magnitude and the boars tended to be heaiver. At weaning the same tendency to select the heavier boars is found in Lines 4 and 5, however this tendency is not as evident in Lines 1 and 2. Comstock et al. (1942) point out that weaning weight is not likely to correspond closely with differences in genotype for growth since post-weaning nutrition is not optimal nor equal between pigs. A later weight is much more valuable than weaning weight because a pig's own genotype will have had a better chance to express itself. Dickerson and Hazel (1944) conclude that if culling at weaning is not to reduce efficiency of selection some eight to ten times the number of boars and three times the number of gilts should be reserved at weaning and a later, more reliable weight secured on them.

The findings for 180 day weights in the other four lines varied:

Line 1 shows a great deal of fluctuation in the average 180 day weight from generation to generation but a slight decline is apparent.

Line 2 increased in 180 day weight over the short period of three generations.

Line 4 declined steadily in mean 180 day weight from an average of 176 pounds in the first generation to 128 pounds in the fourth, in spite of consistently large selection differentials for 180 day weight.

Line 5 showed considerable fluctuation but there was an evident increase in this characteristic. The average weights and selection differentials for these four lines are given in Table XIV.

The findings as to the size of litter at weaning in these other four lines vary from line to line. In Line 1 the average size of litter at weaning increased from 5.2 pigs per litter in the first generation to 6.0 pigs per litter in the seventh generation with an average of 6.0 for all generations. This is an increase of nearly one pig. The outcross of this line may have increased litter size. However, the increase was very evident before the outcross was made. The coefficient of inbreeding had risen in this line from .24 in the first generation to .47 in the fifth generation previous to outcrossing the line. It fell to .05 in the outcross generation and rose to .22 in the last generation. The average for all generations was .28, the highest coefficient of inbreeding of any line studied. The average selection differentials for Line 1 are shown in Table XIV, they are much lower than those for size of litter at weaning found for Line 3. Line 2 showed a sharp decline in litter size at weaning, falling steadily in the three generations of the line from a mean size of 7.3 pigs per litter in the first generation to 4.2 pigs in the third generation. Selection differentials for this characteristic averaged over 1 pig in size (Table XIV). The mean coefficient of inbreeding was .11, increasing from .04 to .14 in the three generations. Litter size at weaning evidently declined slightly in Line 4 selection differentials for litter size were the highest of any line. The mean coefficient of inbreeding was .10 for the line, increasing from .06 in the first generation to .20 in the fourth generation. Line 5 has shown a slight decline in litter size at weaning, and a very low selection differential for the characteristic (Table XIV). Inbreeding was lowest for this line: it changed but little from the average of .06. From these data it appears that size of litter is but little influenced by selection.

With moderate inbreeding and rather large selection differentials in Line 3, litter size has declined slightly. However, in Line 1 inbreeding was more intense, selection differentials were lower, and litter size increased somewhat. Lines 2 and 4 showed declines in litter size concurrent with a rather large amount of selection for the characteristic and very moderate inbreeding. In reported studies of performance of inbred swine both decreases and slight increases in size of litter are found. Willham and Craft (1939) report a slight decline; Winters et al. (1943) report that some inbred lines were slightly superior to their foundation stock in this characteristic.

SUMMARY AND CONCLUSIONS

1. A detailed study of the selection practiced in one inbred line (Line 3) of Duroc swine in the Oklahoma project of the Regional Swine Breeding Laboratory is presented. The data compiled on this line include records of 1307 pigs from 147 litters and covering a period of 9 years and 6 sow generations. The following traits were studied: birth, 21 day, 56 day and 180 day weights, body conformation score, litter size at weaning and productivity of sows. Coefficients of inbreeding of all individuals were also studied.

2. Studies were also made on the selection for weights at the four above mentioned ages and for litter size at weaning in four other inbred lines. Inbreeding coefficients were studied as well. Only 180 day weight and litter size findings are presented in tabular form on these lines.

3. In Line 3, at all ages studied, the mean weight of selected individuals was above that of the generation from which they were selected. They had a higher conformation score and were selected from litters which were larger than the average at weaning. The dams of the selected pigs were above average in productivity but the significance of the difference was not tested statistically.

4. By the construction and study of a complete pedigree of Line 3 the sows "effective" in producing the present animals in the line were determined. These "effective" sows were superior to all selected sows in productivity index. The amount of the superiority, in terms of litter size and weight at weaning, amounted to 2 extra pigs and 60 pounds additional weight.

5. In spite of the positive selection differentials there appears to have been a decline in 180 day weight as the inbreeding increased. No large declines in the other selected traits were noticeable with the increase in inbreeding.

6. The selective practices appear to have been successful in preventing any great decreases in net merit in this relatively mild inbreeding program.

7. The differences in productivity in favor of the "effective" sows indicate rather intense selection on the basis of productivity. They are also probably an indication of a greater opportunity to select offspring from the more productive sows.

8. Trends in 180 day weight fluctuate from line to line but were, in general, downward.

9. Fluctuations from line to line in the increase or decrease in litter size at weaning lead to the conclusion that selection is rather ineffective in improving size of litter. Evidently forces other than the additive effects of genes play the greatest part in determing litter size.

10. It appears that if progress by selection is to be made against the generally deleterious effects of even rather mild inbreeding, selection will have to be made more accurate. Possibly by increasing the accuracy of measurements such as scores or indexes of performance and production, and by better methods of distinguishing between the influences of heredity and environment in evaluating individual breeding animals, improvement could be more consistently made in inbred lines of swine.

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