# STUDY OF THE AMOUNT AND INTENSITY OF SELECTION PRACTICED IN AN INBRED LINE OF SWINE

# STUDY OF THE AMOUNT AND INTENSITY OF SELECTION PRACTICED IN AN INBRED LINE OF SWINE

By

MARTIN CLEOH SMITH

Bachelor of Science

University of Arkansas

Fayetteville, Arkansas

1947

Submitted to the Department of Animal Husbandry

Oklahoma Agricultural and Mechanical College

In Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

1948

APPROVED BY:

J. A. Whatley
Chairman, Thesis Committee

A. E. Darlow
Head of the Department

D. C. McIntosh
Dean of the Graduate School

ACKNOWLEDGEMENT

The writer wishes to express his sincere appreciation to Dr. James A. Whatley, Associate Professor of Animal Husbandry, in making the records of the Oklahoma Station of the Regional Swine Breeding Laboratory available in this study and for his counsel and many valuable suggestions in the preparation of this thesis.

TABLE OF CONTENTS

# INTRODUCTION

The effects of selection have been exerted since the beginning of time. In the evolutionary changes of the animal kingdom natural selection has been a major factor in survival. With the domestication of our present farm animals a second type of selection was introduced; that of artifical selection. Artifical selection does not displace but does supplement natural selection; differing only in the kind or degree of characteristics which are favored by the animal breeder. Also, in many cases artifical selection may be more intense, less of the decision being left to chance or to accidental circumstances. Hence, selection may be interpreted to mean differences in reproductive rates within a population whereby animals with some characteristics tend to have more offspring than animals without those characteristics. Thereby, the genes of the favored animals tend to become more abundant in the population and those of the less favored individuals less abundant.

Man in his control of the breeding of domesticated animals tends to select for traits which best suit his individual needs and fancies. However, there must be some apparent differences between animals before the livestock breeder can choose for breeding purposes those animals which more nearly approach his ideal. Thus it is variation upon which selection operates. The causes of variation are: the differences in heredity with which the animal started life; the differences in the environments, internal and external, to which it is exposed during development; and a joint effect of the above two which cannot fairly be ascribed to either one alone. As genes are the basis of all inheritance, only differences caused by genes can be transmitted from parent to offspring. Therefore it is actually genetic variation upon which selection can be effective. The degree of heritability then determines in part the effectiveness of selection for any characteristic. An additional factor affecting selection is the duplicate nature of inheritance, whereby dominance may play an important role in covering up undesirable characteristics. Also, the linkage of many genes on the same chromosome which tend to be transmitted together requires an increased number of individuals to obtain all possible variations.

In the selection of breeding animals many mistakes are caused by inaccurate measures of the value of certain traits. This is particularly true in meat animals. Environmental effects are often misinterpreted as genetic effects. Dominance and complex gene interaction commonly called "nicking" may mask the true genotype of an animal.

By application of our continuously growing knowledge of the mechanics of inheritance, it is possible to materially reduce the errors commonly encountered in selection. However, selection can never be perfect, due to the duplicate nature of inheritance, the inability to accurately determine the true genotype of an individual, the relatively long generation interval and low reproductive rate of our farm animals, the inability to eliminate and accurately measure environmental effects, and the large part played by chance in the random segregation and recombination of genes in reproduction.

Deviation from the random mating system through that of inbreeding brings out many hidden recessives which may cause an inbred population to decline in many or all characteristics unless rather rigid selection is practiced. Inbreeding in itself does not cause deterioration, and if it is not too intense and is accompanied by selection, actual improvement may be made.

This study has been conducted on a rather mildly inbred population of swine in an effort to determine how much selection has been practiced in items of productivity and individuality.

## REVIEW OF LITERATURE

### Selection in General

Man has a very limited number of ways to control the heredity of his domesticated animals. The foremost of these in regard to the length of time which it has been practiced is that of selection; the designating of which individuals shall produce offspring, which shall leave a large number and which a few. Harrison in his presentation of Roman rural history, as reviewed by Lush (1947), has shown that agricultural literature of that time contained comments on the kinds of animals to select for different purposes. Even today among many animal breeders the only method of livestock improvement is that of selection.

Among the early works Darwin's _Origin of Species_ remains as a pillar of knowledge that has weathered the pros and cons of later workers, even though it was written without the knowledge of Mendel's laws of heredity. Darwin recognized the significance of both natural and artificial selection. However, some of his conclusions, which were questionable from a genetic standpoint, have recently been corrected and brought up to date by Fisher (1930).

Man's knowledge of how the mechanism of inheritance operates has been expanded through the contributions of such men as Mendel, Galton, and Johannsen, but that knowledge has not given him the ability to interfere with the processes of reproduction and change them into the direction which he desires. All that man can do is select from among the animals available for breeding those which most nearly approach his ideals and accept the gametes which they produce. Even after the gametes are produced he still cannot select those which possess genes he desires but must let the array of gametes produced by his chosen sire unite with whatever ova the chosen dam has produced.

The animal breeder can neither change the laws of Mendelism, nor the numbers of genes, nor their linkage groups. He is unable to change the physiological interaction of genes, such as dominance, except as he can find and increase the frequency of certain genes which will produce the desired physiological effect. Thus, the genetic improvement which can be brought about by selection is the sum of the genetic gains made for several traits, particularly those of economic importance. Hence, the sum of the average (strictly additive) effects of an animal's genes for a trait may be classified as its genotype for that particular trait. Environmental factors, dominance, and epistasis may make phenotypic performance unlike the genotype for that trait; hence, animals having the highest values for an aggregate genotype cannot be recognized directly with perfect accuracy. Therefore, selection for improved breeding value must be practiced indirectly by selecting directly for a correlated variable based on the phenotypic performance of each animal for several traits, Hazel (1943).

## Methods of Selection and Selection Indexes

In order to select most efficiently the animal breeder must know the relative economic value of the trait under consideration, its heritability and the genetic and environmental correlation of each trait with the other traits. Hazel and Lush (1942) realizing that the most efficient methods of selection are those which result in the maximum genetic improvement per unit of time and effort expended classified the procedures into three rather basic methods. First, the tandem method--selection is for one trait at a time until it is improved to a certain level, then a second trait and etc.. Second, the total score method--selection for all desirable traits is practiced simultaneously, the total or index being constructed by adding into one figure the credits and penalties given each animal according to its superiority or inferiority for each trait considered. Third, the "independent culling levels" method--a certain level of merit is established for each trait, and all individuals below that level are discarded regardless of their rating in other traits.

The method of total score is the most efficient, while the tandem method is the least efficient of the three. The greatest obstacle to the total score method lies in determining how much weight to give each trait when calculating an index. However, Hazel and Lush (1942) concluded that information on the heritability and economic importance of each trait and the genetic and phenotypic correlations between the different traits are necessary in order to give each trait its proper value in a selection index.

Linkage and non-random mating (inbreeding) systems may cause correlated variations, however, their effects would be less permanent and consequently less important in selection. Repeated crossing over ultimately makes the coupling and repulsion heterozygotes equally numerous. A more important cause of correlated variation in an interbreeding population lies in the environmental circumstances peculiar to each animal, particularly for traits which develop during the same periods.

Sex-limited traits and traits such as carcass merit cannot be measured directly on all breeding animals. Sometimes selection must be practiced before each animal's performance for every trait is known. Therefore, Lush and Molln (1942) suggested as a possibility for increasing genetic progress the use of information about the average performance of close relatives such as full sisters and dams, realizing that this could be carried so far as to lower the rate of progress. The sow's own record should receive something like three times as much weight as the record of her dam or each full sister on such a "family" basis. About 50 per cent more progress could be made in selection based on the performance of three litters as compared to the progress made by use of only one litter's performance.

In a study of litter size as a selection index in swine, McPhee (1931), observed a significant correlation between size of litter produced and size of litter in which the sire was born.

## Inbreeding

Hughes (1933) in reporting the work on an inbred herd of Berkshire swine observed larger litter size in the inbreds as compared to the outcrosses up until 1923. Following that date there was a gradual decrease in the number of pigs farrowed in the inbred line, however, these litters were from sows farrowing their first litter. This coincides with Hodgson's (1935) report in which he observed a smaller litter size in inbreds as compared to non-inbreds. There was little difference between birth weight of individuals from advanced inbred generations and non-inbred generations. The inbreds and non-inbreds tended to remain about equal in rate of gain until the sixteenth week, after that the non-inbreds gained faster and reached the 200 pound weight about three weeks before the inbreds.

Willham and Craft (1939) observed a decrease in size of litter farrowed, size of litter weaned, and percentage of survival to weaning in inbred Duroc swine. They also reported that inbred animals made smaller daily gains and were less efficient in the utilization of feed. These findings were confirmed by Hetzer and others (1940) with inbred Chester White swine. In addition, differences in the inbreeding of the litters appeared to have had a greater effect on litter size at the various ages than did differences in the inbreeding of their sires and dams. Also, less than 20 per cent of the variance in litter size at any one of the three ages (birth, 28 days, and 70 days) was found to be hereditary in nature. Season of birth, yearly changes in feeding and management, and differences in age of dam appeared to account for another 20 per cent of the variance. The remainder or about 60 per cent of the variance in litter size at the various ages was due to causes the nature of which could not be determined. Olbrycht's (1943) work coincides with this, however, his estimates of variance in rearing ability were 19 per cent ascribable to hereditable causes, 10.3 per cent due to age, and 70.7 per cent due to other factors.

Baker and Reinmiller (1942) in presenting data on four inbred lines of Duroc swine observed no marked deterioration within the lines. When corrected for age of dam, the data did not indicate any definite trend for the nine seasons studied in the number of pigs farrowed, the number farrowed alive, number of pigs weaned, weaning weight of litter, nor the productivity index of the dam. Since the maximum inbreeding attained in the lines was 30 per cent it is possible that selection was able to counteract the adverse effects of inbreeding.

Work on Poland China swine by Winters et al. (1943) indicated a slight decrease in litter size for each unit of increase in litter inbreeding. The authors conclude that it is possible to raise the coefficient of inbreeding of Poland China hogs to 28 or 33 per cent without loss of vigor. Additional work on the Minnesota No. 1 line of swine has shown that the subsquent inbreeding of superior crossbred hogs is not necessarily followed by wide segregation of type and performance. The authors suggest that rigorous selection for performance was a factor in preventing wide segregation.

In a study of performance of inbred lines of swine by Dickerson et al. (1947) it was observed that for each 10 per cent increase in litter inbreeding, independent of age and inbreeding of dam, an average decline of 0.2 pigs at birth, 0.4 pigs at 21 days and 0.5 pigs at 56 and 154 days occurred. In pig weight a decline of 3.6 pounds at 154 days was observed. All of these observed decreases were highly significant except for number of pigs at birth which was significant.

Whatley (1942) in studying factors influencing 180-day weight in Poland China swine calculated a regression coefficient which indicated a 0.76 pound decrease in 180-day weight for each one per cent increase in inbreeding. Additional work by Laben and Whatley (1947) in one line of Duroc swine presents evidence of a decrease in 180-day weight from 187 pounds to 153 pounds in five generations of mild inbreeding, although the selected animals averaged 22 pounds heavier than their generation. A decline of approximately 0.7 pig in size of litter weaned occurred in the five generations in spite of the fact that selection of breeding stock was from litters 1.2 pigs larger than the average.

## Effectiveness of Selection

Selection can create no new genes nor completely destroy any genes already present in the population. Davenport (1907) summed up the functions of selection as the alteration of the type, not the reduction of variability. The "fixing" of an intermediate type by selection does not decrease the variability because upon relaxation of selective practices the offspring of selected parents tend to regress toward the population average.

Rice (1926) in reviewing a poultry experiment on mass selection practiced at the Maine Agricultural Experiment Station from 1899 to 1908 pointed out that yearly egg production decreased steadily even though there was selection for this trait. The point to be noted is that mass selection failed to increase production in this particular experiment. However, upon changing the system of selection slightly and using for breeders only those hens and roosters whose dams were high producers the production increased steadily over the period from 1908 to 1920.

If the breeding plan is merely that of mass selection of the most desirable phenotypic individuals, progress by selection will be limited by the heritability of the selected traits. Only that fraction of the selected superiority of the parents which is heritable will appear in the next generation. If the desired characteristic is highly heritable the best method will be mass selection, but if heritability is low greater use could be made of progeny tests and selection on a family basis. Should the variation due to epistasis be high with little additive variation, considerable use of inbreeding to create new lines of distinct form should be practiced along with subsequent inter-line selection. (Lush. 1940).

Dickerson and Hazel (1944) in studying the effectiveness of selection on progeny performance as a supplement to earlier culling in livestock determined that the progeny test should be limited to certain traits. The progeny test is most efficient when the generation interval is kept at a minimum, the rate of reproduction is low, and when the basis for making first selection is relatively inaccurate. Under the later condition the progeny test allows more of the environmental variation to be discounted and consequently a greater portion of the variance among individuals is genetic. However, most of the conditions upon which the efficiency of the progeny test depends are beyond the animal breeder's control, being relatively unchangable for a particular kind of animal and trait.

Studies on the effectiveness of different methods of selecting for two specific characters in swine, growth rate of pigs and productivity of sows, have been conducted by Dickerson and Hazel (1942, 1944). In selecting for growth rate they recommend that eight to ten times as many gilts as are needed for breeding should be retained long enough after weaning (180-day age) to obtain a more reliable measure of growth rate than the weaning weight will give. Selection on weaning weight gives only about three-fifths as much improvement in 180-day weight as selection on 180-day weights directly. Having the sows farrow two litters a year results in more rapid genetic improvement in productivity. The accuracy of selecting boars and gilts can be improved by having two litters on which to evaluate the productivity of their dam instead of one. Furthermore the additional litter furnishes more pigs from which to select breeding stock without materially increasing the generation interval. Several plans of culling for productivity in swine were discussed by the authors. Yearly progress from selection was thought to be the greatest when sows are culled after the first litter and the best one-third to one-half retained for a second litter six months later. Another plan almost as effective is to delay culling, until after the second litter, and keep the best one-fifth to one-fourth of the sows for a third litter at two years of age. Progress is retarded when more than the optimum proportion of older sows are retained, because the less intense culling of sows and the longer interval between generations is only partly offset by the more severe culling of gilts and greater accuracy of sow culling.

An experiment in which swine were selected for rapid and slow growth rates was reported by Krider (1946). Heritability estimates of growth rate were made through line differences created by selection and from the analysis of variance within lines and years. Conclusions were that heritability of weight differences increased from about 5 per cent at birth to 24 per cent at 180 days.

Dickerson and Grimes (1947) reported an experiment on selecting for efficient and inefficient feed utilization in hogs. From common stock two distinct lines differing in efficiency of gain were developed by selection. Their results indicate that selection based on rate of gain from weaning to market weight would be nearly as effective in improving economy of gain as selection based directly on individual feed requirements. Also, weight at 72-days is approximately one-third as accurate for selection for economy of gain as daily gain from 72 days to a 225 pound live weight.

Working with a poultry flock Lerner and Hazel (1947) 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 their actual gains in production to correspond very closely. The general conclusions are that currently accepted principles of population genetics may be used to predict rates of improvement for populations subjected to artifical selection.

Additional work by Dempster and Lerner (1947) in the determination of the optimum age of the breeding flock reveals that greater efficiency is obtained by a more widespread use of younger birds. The optimum plan of age distribution investigated was one in which 90 per cent of the breeding flock consists of pullets and 10 per cent of two-year old hens selected on the basis of their sister's and daughter's records. Similarly, about 80 per cent of the breeding males each year should be cockerels.

Weaver and Bogart (1943) in studying some of the factors influencing efficient production of sows concluded that there was a direct relationship between the birth weight of a pig and its 56-day weaning weight. A one pound advantage at farrowing resulted in about a seven pound advantage at weaning. In these experiments it was noted that the larger the litter weaned by the sow the smaller the feed requirement per one hundred pounds of gain per pig. Also, there is a direct relationship of gain per day after weaning and weight at six months of age with the size of pig at weaning time. The heavier pigs made greater daily gains. This work has been substantiated by Winters et al. (1947) on a study of factors affecting survival from birth to weaning and total weaning weight of the litter. They observed that a one pound increase in the average birth weight increased weaning weight of the litter by approximately 16 pounds after size of litter and survival were held constant.

Another phase determining the efficiency of selection, especially the amount of actual genetic improvement brought about in a population, is the heritability of the various economically important characteristics. An extensive amount of research has been conducted along this line and has been condensed into a simple table by Phillips (1947) and appears in the 1943-1947 U.S.D.A. Yearbook. By the use of these estimates of heritability it is possible to get a more accurate evaluation of a sow's productivity. The sow's productivity being a combination of a progeny test of the sow and a measure of her direct environmental influence on the litter.

Bywaters (1937) in determining the hereditary and environmental portion of the variance in weaning weight of Poland China pigs observed that a considerable portion of the variance (42 per cent) comes from what might be called prenatal environmental and embryological accidents which affects litter mates differently. Although the data are subject to sampling errors they indicate rather clearly that the hereditary portion of variance among weaning weights of individual pigs is moderately small (18 per cent).

Additional work on the importance of heredity and environment by Baker et al. (1943) indicated that genetic variance for rate of gain for short intervals increased from 7 per cent following birth to 30 per cent at 112 days. The relative importance of environment peculiar to the individual in determining rate of gain increased from 39 per cent at birth to 61 per cent at 168 days.

Hazel et al. (1943) in conducting a study of genetic and environmental correlations between growth rates of pigs at different ages indicated that genes with persistent effects were responsible for much of the genetic variation. As a consequence of breaking the gains down into 56-day intervals the multiple correlation (0.516) based on gains in the three periods is only 4 per cent larger than that based on gain over the entire period (o.497). As a result it is suggested that growth rate from 56 to 112 days be used as a basis for selecting boar pigs, because it occurs before puberty.

The question of type in swine production has long been a point of contention. However, in the past few years some studies have been conducted on swine type as a factor in swine production. Zeller (1940) and Hetzer and Brier (1940) observed significant differences in a number of traits among small, intermediate, and large type swine. There was a difference in litter size farrowed of approximately four-fifth of a pig between types with the larger animals farrowing the larger litters. All factors considered, the intermediate type was believed to be superior.

In testing for the statistical significance of each source of variation Hetzer et al. (1944) obtained high significance for litter difference within sires, season and strain. Intra-season differences between the three type strains were very large and highly significant compared with the differences between sire progenies of the same strain and season.

## Results of Regional Swine Breeding Laboratory

In reviewing some of the accomplishments of the Swine Breeding Laboratory, Craft (1943) pointed out that repeatability of litter size weaned is about one-sixth. All sows that produce first litters above the average in number of pigs farrowed may be expected to produce about 0.31 pig more in subsequent litters than the average of the entire group of sows from which they were selected.

Accuracy of selection for number of pigs farrowed and weaned and weight at weaning can be increased materially if selection is based on more than one litter.

McPhee (1945) points out that in general some decline in fertility, survival, and growth rate accompanies inbreeding, but critical selection minimizes the decline in these traits. For growth rate, selection can offset the effect of inbreeding up to 15 per cent per generation but fertility cannot be maintained without loss if the inbreeding is more than 4 per cent per generation. Purebred hogs can withstand on the average an increase of 3 to 4 per cent inbreeding per generation until about 30 per cent is reached without much loss in productive characters provided selection is critical.

## OBJECTIVES OF THIS INVESTIGATION

This study was conducted to determine the amount of selection which has been practiced in line 5 of the inbred Duroc swine herd at the Oklahoma Experiment Station. The measure of the amount of selection for the several characteristics is the selection differential as defined by Lush (1947). The intensity of selection will be shown by the number of pigs available for selection as compared to the actual number retained for breeding purposes and by a comparison of the selection differential to the standard deviation of the population from which the selected animals were chosen.

## SOURCE OF MATERIAL AND METHOD OF PROCEDURE

The records upon which this study was made are from Duroc line 5 of the swine breeding project of the Oklahoma Station and the Regional Swine Breeding Laboratory. The objectives of the Swine Breeding Laboratory and the breeding and selection systems generally followed by the cooperating stations are presented by Craft (1943). The primary objective of this station is the improvement of Duroc swine through a system of inbreeding, selection and outcrossing.

Line 5, the subject of this study, was started in 1942 by stock purchased from Clarence Miller, Alma, Kansas; Ira Johnson, Perry, Iowa; H.D. Youngman, Baxter Springs, Kansas; and the Texas Experiment Station. A system of rather close mating was followed, which increased the inbreeding of the litters to approximately 22.6 per cent in the spring of 1945. In 1946 an outcross was made by introducing some stock from the J. Ward Stevenson herd of Graham, Missouri.

Since that time the line has been bred as a closed herd, and the average inbreeding of the litters again reached 22 per cent in the fall of 1947.

The original breeding plan was to maintain a ten sow breeding herd with two boars in service each season. However, there has been some deviation from this plan as will be noted in the data presented.

Gilts were selected to enter the breeding herd after 154-day weights, and in most cases 180-day weights, were obtained. Initial selection of boars was made at six weeks of age, at which time usually five to eight boars were saved. Final selection of boars was made at the time of scoring when they weighed approximately 225 pounds. The dam's productivity score, the individual animal's growth rate, individual's score and to a certain extent the performance records of litter mates was considered in final selection. In general, the selection of sows to remain in the breeding herd after producing litters was based upon a productivity index. The productivity index, an estimate of probable producing ability, was determined from the sow's lifetime performance records using a modified form of the formula presented by Lush and Molln (1942). The individual's age, type and conformation were given minor consideration in determining whether or not the sow would be retained for the production of additional litters.

The selection of boars and gilts and the determination of which sows to retain in the breeding herd was not made with a definite index in which each point was weighted by its relative importance. The balancing of the various points for each animal was an arbitrary decision made by the project leader.

This study primarily includes only litters produced by mating of individuals within the line. Exceptions occurred when an unrelated sire was introduced into the line in the spring of 1946 and when, in the fall of 1946, four gilts and one boar unrelated to the line were introduced.

Data were obtained on selected animals and their dams for performance in the numbers of pigs farrowed and weaned, the weaning weight of the litters, and the average weaning weight per pig per litter. For the selected animals additional information on their inbreeding coefficients, 56-day weights, 154-day weights, total scores, and the items composing the total scores were obtained for study.

The number of pigs farrowed and weaned, litter weight at weaning, and average weaning weight per pig per litter, were used in determining the sow's productivity and to compare the amount of automatic selection and actual selection on gilts. All data on the productivity traits for older sows were adjusted to a gilt basis with the correction figures presented by Lush and Molln (1942).

Intra-season standard deviations were computed for each trait in which actual measurements were used in arriving at the selection differential. Comparisons of the selection differentials and standard deviations were used to determine the selection intensity for each trait.

## PRESENTATION OF RESULTS

Line 5 was started in 1942 hence the first complete records of performance were in the spring of 1943. The average number of sows farrowing each season is shown in Table I. Although the number of sows farrowing each season deviates considerablely from the original plan of a ten sow herd the average is still about seven and one-half sows per season. The average age of sows farrowing each season corresponds to the generation interval. Initially the average age was high, however, as the project proceeded the average age decreased indicating a more severe culling of older sows and the increased use of gilts. This reduced the generation interval and speeded up the rate of turn over in the breeding herd.

The average inbreeding in the line increased until in 1946 when some outcrosses were intorduced. Following the introduction of the outside blood, the line was bred as a closed herd and the average inbreeding increased to 22 per cent in the fall of 1947 which was the same average as that previous to the outcross. The average inbreeding of all litters in the ten season period was 10.4 per cent.

The age of the sow has a definite effect upon the litter produced. Work by Hetzer et al. (1940), Lush and Molln (1942), Nordskog et al. (1944), and Stewart (1945) has advanced evidence that litter size at farrowing and weaning increases with the age of the dam. Also the litters produced by gilts were lighter than those produced by older sows. Therefore the items of productivity, number farrowed, number weaned, and 56-day weight, were all adjusted to a gilt (1 year) age basis. The correction figures as taken from Lush and Molln (1942) are:

| Age of Sow | Litter size | | Litter 56-day weight |
|---|---|---|---|
| | Farrowed | Weaned | |
| 1 year old gilts | .0 | .0 | 0 |
| 1½ year old sows | -0.5 | -0.5 | -20#, -10% of litter wt. |
| 2 year old sows | -1.5 | -1.0 | " " |
| 2½ year old sows | -1.5 | -0.5 | " " |

The average weaning weight of each individual pig per litter was obtained by a division of the adjusted litter weight at weaning by the adjusted number of pigs weaned.

The averages over the ten season period for each item aside from number of sows farrowing were arrived at by using the actual number of litters farrowed in that season. This gives a better estimate of the average performance of the sows than would be obtained by giving each season, equal weight regardless of the number of sows producing in that season.

Over a period of years, and even from season to season, environmental factors will vary regardless of attempts to hold them constant. There are several methods which could be used to allow for these environmental effects, namely, (1) accurate records of environmental conditions could be kept and studied so as to determine corrections to be applied to the data; (2) in certain experimental designs, analysis of variance might be used to calculate an estimate of environmental differences due to season and year; and (3) the experiment could be so designed that any single classification of experimental animals has comparable recorded data over a period of several seasons. According to the third method the environmental effects tend to cancel out insofar as they are random and occur in either direction. The latter method of overcoming temporary environmental effects is the one generally followed in this project.

It will be noted in Table I that there is considerable fluctuation in the seasonal averages for litter size weaned and for weaning weight of the litter, whereas for litter size farrowed the seasonal averages are somewhat constant with very little variation from the mean. These seasonal variations in average litter size weaned and average litter weaning weight could be attributed to temporary environmental conditions which affected the young pig and which existed only within the one season. Over a period of years the average would be a more true estimate of the line's producing ability than any one season's measurements. Hence, the value 8.7 pigs for litter size farrowed, 5.6 pigs for litter size weaned, and 159.3 pounds for litter weaning weight can be considered descriptive of the line 5.

In any program of selection the amount of progress is influenced by the number of offspring which have to be retained as herd replacements. Table II, shows the number of gilts and boars which were selected for the breeding herd. In every case the animals selected one season entered the breeding herd one year later; that is, selected gilts farrowed in the spring of 1943 entered the breeding herd in the spring of 1944 with their first litters.

Although the percentage of gilts selected each season varied considerablely, 18 per cent of the gilts weaned were saved for

Table I. Averages of the Productivity items, inbreeding, generation interval, and number of sows farrowing by seasons.

| Season | No. sows farrowing | Av. Age of sows per season | Av. $F_x$ of all pigs weaned | Adjusted Averages * | | | |
|---|---|---|---|---|---|---|---|
| | | | | Number farrowed | Number weaned | 56-day wt. of litter | Av. 56-day wt. of pig |
| 1943-S | 7 | 2.14 | .000 | 8.3 | 5.1 | 158.4 | 30.8 |
| 1943-F | 10 | 2.10 | .013 | 10.2 | 5.3 | 155.4 | 29.3 |
| 1944-S | 6 | 2.08 | .175 | 8.5 | 4.5 | 143.0 | 31.8 |
| 1944-F | 7 | 1.14 | .144 | 7.9 | 2.6 | 71.3 | 27.4 |
| 1945-S | 5 | 1.00 | .226 | 7.6 | 4.3 | 102.3 | 19.2 |
| 1945-F | 7 | 1.07 | .089 | 8.5 | 6.1 | 155.1 | 25.6 |
| 1946-S | 5 | 1.50 | .028 | 7.7 | 5.1 | 131.2 | 25.7 |
| 1946-F | 11 | 1.40 | .065 | 9.5 | 7.6 | 232.0 | 30.4 |
| 1947-S | 10 | 1.35 | .154 | 9.0 | 7.3 | 206.2 | 28.4 |
| 1947-F | 6 | 1.33 | .222 | 8.4 | 5.7 | 150.3 | 26.5 |
| Average | ** 7.4 | 1.53 | .104 | 8.7 | 5.6 | 159.3 | 28.0 |

*Adjusted to a gilt basis as per data by Lush and Molln (1942).

**Number of sows farrowing is a straight mathematical average. The other averages were determined by weighting the seasonal average by number of sows farrowing that season.

Table II. Percentages of Pigs Weaned Which Were Retained for Breeding Purposes

| Season | Gilts | | | Boars | | |
|---|---|---|---|---|---|---|
| | No. weaned | No. Saved | Per cent | No. weaned | No.Saved | Per Cent |
| 1943 Spring | 20 | 2 | 10.0 | 21 | 2 | 9.5 |
| Fall | 28 | 5 | 17.9 | 28 | 2 | 7.1 |
| 1944 Spring | 16 | 5 | 31.3 | 13 | 1 | 7.6 |
| Fall | 9 | 6 | 66.7 | 11 | 1 | 9.1 |
| 1945 Spring | 10 | 0 | 0.0 | 10 | 0* | 0.0 |
| Fall | 21 | 4** | 19.0 | 22 | 0*** | 0.0 |
| 1946 Spring | 14 | 5 | 35.7 | 14 | 1 | 7.1 |
| Fall | 45 | 3 | 6.7 | 42 | 1 | 2.4 |
| Total | 163 | 30 | 18.4 | 161 | 8 | 5.0 |

*Selected an unrelated boar, RL52.

**Selected in addition four gilts; RL178, RL182, RL171, and RL 195 unrelated to the line.

***Selected boar, RL172, unrelated to the line.

breeding. Comparing the number of gilts saved each season (Table II) to the number of sows farrowing one year later (Table I) it will be noted that the gilt replacement percentage varied from zero in the spring of 1946 to 100 per cent in the spring of 1945. The overall average replacement percentage was about 60 per cent. According to Dickerson and Hazel (1944) this percentage of gilt replacements is too low to obtain the maximum progress in selection for productivity.

The percentage of boars saved was generally smaller than the corresponding percentage of gilts saved, but this is to be expected under a breeding plan of one boar for each five sows. Five per cent of the boars weaned were selected and used in the line. In addition to the boars produced within the line two boars unrelated to the line were introduced into the line in 1945. This percentage of boars saved for breeding is somewhat larger than the figure given by Lush (1947, p, 147) as the average replacement requirement for boars. Although the percentage of boars saved was larger in this project than would have been necessary in a larger line, this large a retention percentage is to be expected in this line in which the breeding plan was to use one boar for each five sows.

The system of improvement by selection is perhaps the one most universally used, however, the breeder cannot select the gametes he desires nor can he interfere with the random gene segregation nd recombination in the formation of zygotes. Consequently, the eeder has very little choice other than the selection of some enotypically desirable individuals and acceptance of their offing. The most useful means of measuring the intensity of selection actually practiced is by a comparison of the average of the selected animals and the average of the population from which they came. This difference is commonly referred to as the selection differential.

In this study a selection differential for each item of productivity was calculated each season on the dams and on the sires as shown in Table III. The calculations were made on data adjusted to a gilt age basis by the method previously presented.

The tabulation starts with the spring of 1944 due to the fact that a performance record one year earlier than this date is required in the calculation of selection differentials on gilts farrowing their first litter.

A selection differential on dams was determined each season by the formula;

$$\Delta D = \frac{\frac{M_1 D_1}{2} + M_2' \cdot 2 \cdot D_2'}{M_1 + M_2'} .$$

The various letters have the following designation:

- $M_1$ = Number of gilt litters farrowed this season.
- $M_2'$ = Number of litters farrowed this season by older sows with a litter performance six months before.
- $D_1$ = Average for dams of the gilts (weighted according to the number of gilts from each sow) farrowing this season, less the average for all sows farrowing all during the farrowing season one year earlier.
- $D_2'$ = Average performance last season of selected older sows farrowing this season, less the average performance of all sows farrowing last season.

The quantity, $D_1$, is actually the difference between the dams f selected gilts and the average of the sow herd during the rrowing season when the gilts were produced. Since this figure

Table III. Selection Differentials of Productivity (four items) in Inbred Line 5.

| Season | Av. $F_x$ of all pigs weaned | No. of pigs weaned | No. Farrowed (pigs/litter) | | No. Weaned (pigs/litter) | | Litter Weaning Wt. (pounds) | | Av. Weaning Wt. per pig (pounds) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | △D | △S | △D | △S | △D | △S | △D | △S |
| 1944-S | .175 | 29 | +1.02 | +0.84 | +1.73 | +0.51 | +40.4 | +23.4 | -1.72 | +1.20 |
| 1944-F | .144 | 20 | -0.19 | -2.33 | +0.49 | -0.12 | +14.4 | -11.2 | -0.06 | -1.03 |
| 1945-S | .226 | 21 | +0.05 | -0.73 | +0.95 | +0.49 | +31.0 | + 0.3 | +0.13 | -1.69 |
| 1945-F | .089 | 43 | -0.14 | +1.51 | +1.11 | +0.54 | +30.3 | - 2.1 | -0.04 | -2.55 |
| 1946-S | .028 | 28 | +0.20 | +1.24 | +1.06 | +2.04 | +14.5 | +21.0 | -1.90 | +1.88 |
| 1946-F | .065 | 87 | +0.09 | -0.20 | +1.44 | +0.57 | +49.9 | +16.8 | +1.98 | +1.73 |
| 1947-S | .154 | 75 | +2.00 | +0.23 | +2.46 | +0.43 | +87.5 | + 9.7 | +1.71 | -0.16 |
| 1947-F | .222 | 36 | +1.45 | +0.05 | +2.51 | +0.13 | +44.5 | + 5.0 | -2.87 | +0.11 |
| Av. Annual Selection * | | | +0.70 | +0.26 | +1.64 | +0.56 | +43.4 | + 9.8 | +0.28 | +0.19 |
| Av. Annual Selection | | | +0.48 | | +1.10 | | +26.6 | | +0.23 | |
| Standard deviation ** | | | 2.6 | | 2.4 | | 73.0 | | --- | |

* Weighted by number of pigs weaned per season.

** Calculated as an intra-season standard deviation of all litters produced within line 5 is obtained from the dam's performance; an estimate of the gilt's probable performance ability is obtained by dividing this figure by two.

The quantity, $D_2^1$, is the difference between the performance of the selected old sows and the average of all sows based on their performance record last season. Since this selection is over a six months period only, it is multiplied by two to place both quantities, $D_1$ and $D_2^1$, over an equal time period of one year. Thus the selection differential figured for each season is really on a year basis. By multiplying each quantity by the number of litters farrowed and dividing by the total number of litters produced, the difference is on an annual basis per individual per season.

The sire's selection for sow productivity was determined by the formula:

$$\triangle S = \frac{\frac{N_1 S_1}{2} + N_2 S_2}{N_1 + N_2},$$

in which each symbol has the following designation:

$N_1$ = Number of pigs weaned from one year old sires.

$N_2$ = Number of pigs weaned from one and one-half year old sires.

$S_1$ = Average for dams of one year old sires (weighted by number of pigs weaned per sire) less average for all sows farrowing during season when one year old sires were born.

$S_2$ = Average for dams of older sires (weighted by number of pigs weaned by each sire) less the average for dams of all sires of same age group in use the season before (weighted by number of pigs weaned by each season). Dam's records are all in the season when boars were born.

The boar's selection is based on his dam's record, therefore the average difference must be divided by two, as the boar receives only one-half of his inheritance from his dam. For the older sires the quantity, $S_2$, must also be divided by two, since sire selection is on his dam's record. However, the selection of the older sires is the additional selection after the selection practiced six months earlier, thus must be multiplied by two to place it on an annual basis equivalent to that of one year old sires. Consequently $\frac{2 N_2 S_2}{2}$ can be written in the simpler form of $N_2 S_2$.

It will be noted in Table III that the selection differentials for both dams and sires fluctuated considerably from season to season for numbers of pigs farrowed and for the average weaning weight per pig per litter. The seasonal selection differentials on the number of pigs weaned and the litter weight at weaning were almost consistently positive indicating that perhaps more attention was given to these points than to litter size farrowed or average weaning weight per pig per litter in selecting the breeding animals.

The average annual selection for the boars and sows is a weighted average of the seasonal selection differentials. These figures indicate that the selection on the dams was at all times from about two to almost five times as intense as the corresponding selection on sires.

The total selection for any one season is an arithmatical average of the dam's selection differential and sire's selection differential. The total selection being shown is that of the average annual selection which was arrived at by the formula;

$$\text{total selection} = \frac{\triangle D + \triangle S}{2}.$$

The annual selection differential indicates that on the average approximately 0.5 pig per year increase was reached for in litter size farrowed and 1.1 pig per year on size of litter weaned. There was approximately a 25 pound increase selected for annually in total litter weaning weight, while the annual selection differential for average weaning weight per pig in the litter was 0.23 pounds. The amount of this selected advantage which would be transmitted is determined by the heritability of each trait.

An unselected population possesses a certain amount of variation among the various individuals. The range between the highest and lowest individual is in a sense a measure of variation, but not a very reliable one since it depends on only two individuals. A more reliable measure of variability is the standard deviation. Hence, the intra-season standard deviation was calculated using the original measurements. The intra-season standard deviation was used because the selection of breeding animals was among individuals born within the same season or producing litters in the same season. Aside from measuring the variability of the population, the standard deviation can be used to determine the relative intensity of the selection differential. The larger the selection differential in relation to the standard deviation the more intense the selection. For example, the selection differential for litter weight at weaning was approximately 37 per cent of the standard deviation. Using this percentage value and the table presented by Lush (1947, p. 148) it will be noted that this selection differential represents a selection intensity the equivalent of culling the poorest 20 per cent of the population on the basis of litter weight at weaning. Were this the only trait on which selection was practiced the selection differential could be considered small, but as a number of items were selected for simultaneously, a reduced amount of selection could be practiced for each individual trait.

In productivity items there is likely to be some automatic selection in favor of gilts from the more productive sows merely because of the larger number of gilts available for selection. It is of interest to compare the automatic selection of gilts with the net or actual selection of these gilts to determine if the actual selection was more effective than automatic selection. This automatic selection is the difference in the average of selected gilts farrowing less the average of all gilts the season they were farrowed. Due to the fact that gilts have not produced a litter on which to obtain a performance record, the dam's records must be used. Hence,

Automatic selection = average litter size of dam one year earlier (weighted by number of pigs weaned per litter) less the average litter size of dam one year earlier (weighted by number of litters farrowed).

A basis of comparison for the automatic selection would be the actual selection on the gilts which is the quantity, $D_1$, as presented in the formula for determining sow productivity. The actual or net selection is the average litter size of dam per gilt saved and producing a litter less the average litter size of dam per litter farrowed in all litters one year before.

The values per season as determined by the above outlined method are tabulated in Table IV for each season. The weighted average for the entire period is arrived at by multiplying each seasonal performance by the number of gilts farrowing that season. The difference column is net selection minus automatic selection, or the increase in amount of actual selection as compared to the random selection of gilts from those raised to weaning age. In those cases where the actual or net selection is larger than the automatic selection the figures for net selection include those for automatic selection. Therefore the positive difference values indicate how much the actual selection surpassed automatic selection.

There were no gilts selectedin the spring of 1945, hence the blank record for the spring of 1946.

Under any program of livestock improvement by selection, the

Table IV. Comparison of Automatic and Actual Selection in Three Traits of Sow Productivity in Inbred Line 5. Gilts Only.

| Season | No. of gilt litters | No. farrowed (pigs) | | | No. Weaned (pigs) | | | Weaning Weight (pounds) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Net (Actual) Selection | Automatic Selection | Difference | Net (Actual Selection | Automatic Selection | Difference | Net (Actual) Selection | Automatic Selection | Difference |
| 1944-S | 2 | +0.75 | +1.02 | -0.27 | +1.86 | +1.02 | +0.84 | +55.57 | +31.08 | +24.49 |
| 1944-F | 6 | +0.21 | +0.04 | +0.17 | +1.11 | +0.65 | +0.46 | +38.27 | +12.60 | +25.67 |
| 1945-S | 5 | +0.10 | +0.48 | -0.38 | +1.90 | +1.48 | +0.42 | +62.00 | +45.62 | +16.38 |
| 1945-F | 6 | +0.07 | +0.62 | -0.55 | +2.76 | +3.43 | -0.67 | +67.72 | +78.82 | -11.10 |
| 1946-S | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1946-F | 8 | +0.56 | +0.01 | +0.55 | +0.37 | +0.23 | +0.14 | +33.48 | + 4.67 | +28.81 |
| 1947-S | 5 | +2.40 | +1.01 | +1.39 | +2.80 | +1.83 | +0.97 | +72.60 | +46.48 | +26.12 |
| 1947-F | 3 | 0.0 | +0.32 | -0.32 | +1.03 | +0.79 | +0.24 | +32.33 | +27.86 | +4.47 |
| Average* | | +0.58 | +0.41 | +0.17 | +1.61 | +1.35 | +0.26 | +51.00 | +34.06 | +16.94 |

* Weighted by number of gilts litters farrowed each season.

individuality of the animal under consideration is the major point considered. True enough the progeny test and the animal's pedigree can be used to supplement individual selection. However, with the use of each additional aid, emphasis on individual selection must be reduced. Therefore, with the fact in mind that the individual's own record plays the most important part in selection, a study of the individual's performance as to 56-day and 154-day weight, total score and items composing total score, as well as inbreeding were studied and tabulated in Table V. In each case a seasonal selection differential was determined separately for sows and boars. Within seasons the individuals were broken down into groups on the basis of age as the selection differential is a measure of the difference between an individual and its contemporaries. In each case the measurements used were those actually tabulated for the animal; no age corrections being made other than the grouping of individuals within sex as to respective ages.

The calculation of the selection differential on dams in each season on a year basis and for each individual item was simplified by using the formula;

$$\Delta D = \frac{M_1 D_1 + M_2(2D_2) + M_3\ (2D_3) + ----}{M_1 + M_2 + M_3 + \ ----} .$$

$M_1$ = Number of progeny weaned by gilts.

$M_2$ = Number of progeny weaned by one and one-half year old sows.

$M_3$ = Number of progeny weaned by two year old sows, etc.

$D_1$ = Average weight or score of gilts farrowing (weighted according to the number of pigs weaned by each), less the average of all gilts from the same farrowing season.

$D_2$ = Average weight or score of sows farrowing this season as one and one-half year old (weighted according to the number of progeny weaned by each), less the average of all sows which

Table V. Average Selection Differential on Each Individual Trait per Season On A Year Basis.

| Season | No. of pigs weaned | 56-day weight (pounds) | 154-day weight (pounds) | Total Score (points) | Items Composing Total Score | | | | | | Inbreeding (per cent) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Vigor & Health (points) | Quality (points) | Length of body (points) | Details of conformation (points) | Animal as a whole (points) | Grade (points) | |
| 1944-S | 29 | +0.15 | +12.29 | +1.29 | +0.28 | +0.18 | -0.32 | +0.21 | +0.50 | +0.41 | 0.0 |
| 1944-F | 20 | +4.05 | -11.20 | +0.77 | +0.63 | -0.25 | -0.01 | +0.21 | +0.02 | +0.15 | -0.13 |
| 1945-S | 21 | +4.15 | +13.70 | +3.24 | +0.55 | +0.83 | +0.44 | +0.46 | +0.47 | +0.47 | +1.42 |
| 1945-F | 43 | +0.95 | + 4.35 | +3.73 | +0.59 | +0.41 | +1.63 | +0.38 | +0.41 | +0.29 | -5.87 |
| 1946-S | 28 | +6.93 | +25.25 | +6.17 | +1.42 | +0.88 | +0.51 | +1.20 | +1.03 | +1.10 | +0.67 |
| 1946-F | 87 | +4.90 | +25.20 | +4.79 | -- | -- | -- | -- | -- | -- | -5.19 |
| 1947-S | 75 | +0.50 | + 5.75 | -- | -- | -- | -- | -- | -- | -- | +0.04 |
| 1947-F | 36 | +3.05 | +11.95 | -- | -- | -- | -- | -- | -- | -- | +0.53 |
| Average Annual Selection * | | +2.89 | +12.95 | +3.81 | +0.69 | +0.42 | +0.59 | +0.49 | +0.45 | +0.49 | -1.88 |
| Standard deviation ** | | 7.4 | 35.4 | 7.3 | 2.2 | 2.0 | 1.9 | 1.3 | 1.8 | 1.7 | 6.4 |
| Selection differential / Standard Deviation | | .4 | .4 | .5 | .3 | .2 | .3 | .4 | .2 | .3 | .3 |

* Weighted by the number of pigs weaned per season.
** Calculated as an intra-season standard deviation of all pigs produced within line 5.

farrowed the season before as one year olds (weighted according to the number of progeny weaned by each last season).

$D_3$ = Same for two year old sows farrowing this season compared with the performance of all sows farrowing as one and one-half year old sows last season.

The quantity, $D_1$, is the selection differential on gilts that were farrowed one year earlier (selection over a one year period). $D_2$ and $D_3$ represent the selection practiced on sows over a six month period; i.e., it is the selection advantage gained by culling the sows that produced litters in the herd six months earlier. $D_2$ and $D_3$ are thus independent of the $D_1$'s of previous seasons. However, $D_2$ and $D_3$ must be multiplied by two in order to place them on an equivalent time basis (one year) as $D_1$.

On the sires, calculation of the selection differentials for each individual item on a year basis was facilitated by use of the formula;

$$\Delta S = \frac{N_1 S_1 + N_2 (2S_2) + \text{----}}{N_1 + N_2 + \text{----}}$$

$N_1$ = Number of progeny weaned from one year old sires.

$N_2$ = Number of progeny weaned from one and one-half year old sires.

$S_1$ = Average weight or score of one year old sires (weighted according to the number of progeny weaned by each), less the average for all boar pigs from the same farrowing season.

$S_2$ = Average weight or score of one and one-half year old sires (weighted according to the number of progeny weaned by each), less the average for all sires with litters as one year olds the season before (weighted according to the number of progeny weaned by each last season).

The values obtained for the one and one-half year old sires are over a six months period, therefore to place them on the same time basis as the one year old sires they are multiplied by two.

In the formulas for $\Delta D$ and $\Delta S$ the selection differentials on each age group of sires or dams are weighted in proportion to the number of progeny weaned by each selected sire or selected dam.

The amount of total selection practiced in each season is a straight average of the dam's and sire's selection differentials obtained by substituting in the formula;

$$\text{total selection} = \frac{\Delta D + \Delta S}{2}.$$

These total selections are the values tabulated for the various season in the main body of Table V.

The practice of scoring for items composing the total score was abandoned in the fall of 1946 and the practice of scoring was abandoned in the spring of 1947, hence the blank spaces in the body of the table.

To obtain an idea of the average amount of selection practiced each season a weighted average annual selection was determined for each item. The procedure used was the same as discussed earlier in which the selection differential for each season was weighted by the number of pigs weaned. The average annual selection differential for 56-day weight and 154-day weight was about 3 pounds and 13 pounds, respectively. There was a positive selection differential for all items with the exception of percentage of inbreeding. The negative selection for percentage of inbreeding indicated that throughout the experiment there was a tendency to choose the less inbred individuals for breeding stock.

The standard deviation is an estimate of the variability of the population and can be used to determine the intensity with which selection was practiced. The fraction, selection differential over the standard deviation, (TableV) shows equal selection intensity for

56 and 154 day weights and that the intensity of selection for total score was somewhat higher than for the weights. There was also a tendency to select breeding animals that were about one-third of a standard deviation below the average inbreeding of the line.

## DISCUSSION

The swine breeding program as originally set up at the Oklahoma Experiment Station for the improvement of Duroc swine was not for the specific purpose of studying selection. The program called for improvement through a system of inbreeding and selection and outcrossing when it was thought that outcrossing would be advantagous to the herd. However, the data collected and the records maintained over the period of years lend themselves to a detailed study of the intensity with which selection has been practiced on the various items of productivity and individuality.

The largest portion of variation in any one of the characteristics studied is probably due to environmental conditions both permenent and/or temporary. Therefore, it would be advisable to consider the somewhat incomplete notations on environmental conditions that existed throughtout the period covered by this study. In the spring of 1943 a few cases of swine pox appeared in the herd. The swine herdsman relates that during the year 1944 quite a bit of trouble with navel ill and enlarged joints occurred in the herd, particularly within some of the foundation stock of line 5. In the spring of 1945, difficulty with damp corn that had been heating was encountered. In the fall of 1945 an outbreak of hog cholera caused the loss of about forty-five pigs and adversely affected the growth rate of the 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. The fall of 1946 and spring of 1947 notations show that a heavy worm infestation did exist within the swine herd although a three year pasture rotation plan was in practice. It would be difficult to make any corrections for these season to season environmental conditions, but it should be borne in mind that these temporary environmental changes and probably many others of unknown origin did have some effect on the data. The seasonal environmental fluctuations would have a definite effect upon averages such as those presented in Table I, but their effects on the selection differentials would be unimportant. The selection differentials are calculated on an intra-season basis. Hence, any variation between seasons would not introduce any consistent bias in the selection differentials.

The progress which can be made in a livestock breeding program, where selection is the chief tool, is determined by the number of individuals which must be retained as replacements for the breeding herd, the average age of the dams producing offspring, and the accuracy of selection for economically important traits. The average age of parents producing offspring and the number of individuals required for replacements tend to work or pull against each other. Hence, a somewhat delicate balance must be established, and as suggested by Dickerson and Hazel (1944) the maximum yearly progress in productivity by selection is obtained in a swine breeding herd which consists of about one-third to one-half older sows and the remainder first litter gilts. Under this system the average generation interval, the average age of all dam's farrowing during one season, would range between 1.16 and 1.25 years.

Throughout this project an effort has been made to reduce the average age of the sows in line 5 and thus shorten the generation interval. From Table I it will be noted that as the project progressed the average age of sows farrowing decreased and then leveled off at an average of about 1.35, which is relatively close to the herd average suggested by Dickerson and Hazel (1944) for maximum progress by selection. By observing Table II for number of gilts saved and comparing these numbers to the actual number of sows farrowing per season one year later, one can readily determine that the gilt portion of farrowing sows was on the average around 60 per cent, which may be considered approaching the average for maximum improvement through selection for productivity, provided the older sows do not exceed one and one-half years in age.

The effect of inbreeding both in the parents and in the litters has been studied at several stations and the general conclusion as presented by McPhee (1945) is that purebred hogs can be inbred 3 to 4 per cent per generation until about 30 per cent inbreeding is reached without much loss in productive characters if selection is critical. In line 5, inbreeding has been mild with the maximum of 22.7 per cent being reached in the spring of 1945, however, the following year a mild outcross was made thus reducing the litter inbreeding to about 3 per cent. Since that time the line has been bred as a closed herd, and at the close of this study the average inbreeding of the litters was approximately 22 per cent. The average inbreeding per litter for the period of this project was 10.4 per cent. Therefore, in these analyses of data the influence of litter inbreeding has not been considered a major factor in limiting the effectiveness of selection.

The seasonal averages for the items of productivity are interesting. Throughout the period covered by this study the seasonal averages for numbers of pigs farrowed and average weaning weight per pig per litter do not appear to change. Whereas, the average number of pigs weaned and the litter weaning weight appear to increase.

In an effort to determine whether these apparent changes did occur, the data were further analyzed under the assumptions of linear relationships between seasons and the items studied. The effects of inbreeding were disregarded. For number of pigs farrowed, it was found that there was a decrease of 0.02 pigs per litter per season, or a decrease of 0.04 pigs per litter per year. The simple linear regression coefficient for average weaning weight per pig per litter was -o.2; indicating a decrease in average pig weight per litter at weaning of 0.2 of a pound per season. However, in studying the number of pigs weaned and litter weaning weight positive linear regression values were obtained in both cases - for number of pigs weaned, +0.30 pigs; and for litter weaning weight, +6.7 pounds. The positive regression coefficients indicatethat on the average litter size at weaning increased 0.3 pigs per season and litter weaning weight increased 6.7 pounds per season.

Upon studying the records of the other lines in the herd it was noted that an unusually low performance for number of pigs weaned per litter occurred in the fall of 1944. Consequently there was a lower litter weaning weight. This coincides with line 5 records, therefore it might be assumed that the lowered performance records for the fall of 1944 were largely due to some unusual environmental effects. It will be noted that the performance records of line 5 in the fall of 1946 and the spring of 1947 were relatively high, but notations indicated that environmental conditions in these seasons were, if anything, below average. Although a round worm infestation of young pigs was noted in these seasons, the litter size and litter weaning weights in line 5 were well above average.

With these notations in mind the records were reanalysed omitting the data for the fall of 1944 as it was assumed that adverse environmental conditions played a major role in producing the unusually low performance. By omitting these values it was anticipated that the slope of the regression line would be somewhat reduced should this one season be of major importance. Upon recalculating the regression coefficient for number of pigs weaned, the value dropped from +0.30 to +0.27 which is not a very large decrease. Therefore, the figure +0.27 might be considered as largely genetic in nature, indicating that as a result of selection about 0.27 pig increase per season in size of litter weaned has been brought about. In like manner, the recalculated regression coefficient for litter weaning weight showed a drop from +6.7 to +5.7, which is only about a15 per cent decrease. For the reasons stated above it seems likely that selection resulted in an increase of almost six (5.7) pounds per season in litter weaning weight. The significance of these regression values shall be further brought out in the discussion of the selection differentials for items of productivity.

The most useful measure of the superiority of individuals is the selection differential. The size of the selection differential being determined by the number of individuals which must be saved for replacements. Consequently, it would be expected that the selection on boars should be more intense. Upon a study of the data it was found that the boar pigs selected to enter the breeding herd came from litters which were of average size or a little above. As a result, the majority of the seasonal selection differentials for boars are smaller than the corresponding differentials for sows on items of productivity as recorded in Table III. These smaller selection differentials for boars could be interpreted to mean that conformation of the individual animal played a major part in boar selection. Evidence of this will be presented in the discussion of selection for individual items of which boar selection constituted the greater portion of the average selection differential. In the selection of gilts greater emphasis was placed on the dam's performance record, hence the majority of the selection differentials for items of productivity on dams are positive, and average from two to about five times as large as comparable averages for boars.

The average annual selection differential does not mean that an increase of the amount selected for will occur in the following year, rather the selection differential is a measure of how much was reached for. Only that fraction which is genetic in nature can be expected to appear in the offspring of these selected parents. Studies on heritability as presented by Phillips (1947) indicate that only a small fraction of observed differences between individuals are hereditary; litter size farrowed averaging about 19 per cent heritable; size of litter weaned, about 20 per cent; and litter 56-day weaning weight about 14 per cent. Using these heritability estimates it can be expected that on the average the litter size farrowed will increase about 0.1 of a pig per year and the number of pigs weaned will increase around 0.2 of a pig per litter per year, provided the present selection intensity is maintained. On litter weaning weight, an increase of approximately 3.7 pounds per year could be expected under the same provision as mentioned above. By a regression study of litter size weaned and litter weaning weight, it was found that an increase of approximately 0.27 pigs per litter size farrowed and an increase in litter weaning weight of 5.7 pounds were obtained. These regression values are on a season basis, therefore on a year basis the increase observed would be 0.54 pigs per litter size farrowed and 11.4 pounds for litter weaning weight. From the differences in the theoretical gains expected and the actual gains observed it would appear that the environmental conditions were such that the regression slope was increased.

The varibility of a population is measured in terms of the standard deviation. Also, the intensity of the selection differential can be determined by the same measure. The standard deviations for number of pigs farrowed per litter, number of pigs weaned per litter, and the litter weaning weight are 2.6 pigs, 2.4 pigs, and 73.0 pounds respectively. It is realized that these intra-season standard deviations calculated with only 73 degrees of freedom would not be as reliable as were they calculated from a muzh larger population, but it is felt that they are sufficiently accurate for studies of these data. Comparisons of the selection differentials with the corresponding standard deviations afford a measure of the relative intensity of selection for the various productivity items. The selection differential for litter size farrowed was 18 per cent of the standard deviation; litter size weaned, 46 per cent; and litter weaning weight, 37 per cent. These intensities indicate that at least twice as much emphasis in selection for productivity was given to the number of pigs weaned per litter and the litter weaning weight as to the number of pigs farrowed per litter.

In most seasons the actual or net selection differentials were larger than the automatic selection differentials for the corresponding period, indicating that some additional actual selective advantage was obtained over automatic selection. As a matter of fact, automatic selection accounted for the greater portion of the actual selection. On number of pigs farrowed, automatic selection makes up about 71 per cent of the actual superiority selected for; on number weaned, 84 per cent; and on the litter weaning weight only 66 per cent. These values can also be interpreted to mean that actual selection resulted in an increase in the selection differential of 29 per cent in number of pigs farrowed per litter, 16 per cent in number of pigs weaned per litter, and 34 per cent in the litter weaning weight over what would have occurred under random selection of gilts from selected parents.

The basic material upon which selection works is the individuality of the animal under consideration. It is realized that individual selection is not perfectly accurate due to the lack of quantative measures of the environmental effects, the inability to determine the actual genotype of an individual, and the inability to measure the results of gene interactions and gene-environment interactions which most surely exist. Still, it is the individual's phenotypic conformation upon which a selection decision must be made. Progress in the improvement of the breeding value of an animal must be made indirectly by selecting directly for some correlated variable based upon the phenotypic performance of each animal for several traits.

Study of the several individual characteristics as presented in Table V indicates that on the average a positive amount was reached for in each trait with the exception of inbreeding. Upon checking the records it was noted that, on the average, animals selected to enter the breeding herd were heavier at 56-days and 154-days than the average of the pupulation from which they came. The unusually large average selection differential for all items in the 1946 spring season is a result of the introduction of an unrelated boar, RL52, into the line in the spring of 1945; the RL52 boar siring the greater portion of the pigs weaned in the spring of 1946. Likewise, in the fall of 1945 four gilts and one additional boar (Table II), unrelated to the line, were selected to enter the breeding herd in the fall of 1946, consequently their superiority is reflected in the selection differential for the 1946 fall season.

A comparison of the selection differentials on the individual items for boars and sows is of interest. For the most part selection was more intense on the boars than on the sows as contrasted to the selection for productivity in which sow selection was the greatest. The selection differentials on boars and sows were about equal for 56-day weight and 154-day weight. However, there is a striking difference when comparing the differentials on the scores. The boars contributed 58 to 98 per cent of the selection differentials on the items making up the total score.

Since fewer boars are needed for replacements a greater selection differential is to be expected on the boars. The study would appear to indicate that relatively too much emphasis in selection of boars was placed on the conformation score and not enough emphasis was placed on the productivity of their dams. Perhaps this could be corrected by deferring most of the boar selection until 112 days of age as suggested by other workers (Hazel et al. 1943) and consciously placing more emphasis on the dam's productivity.

Throughout the project emphasis in selection was placed upon total score, 56-day weight, details of conformation, and 154-day weight in that order. By comparison of the selection differentials for the above four items with the intra-season standard deviations it was found they existed in the following intensities; total score, 52 per cent of the standard deviation; 56-day weight, 39 per cent; details of conformation, 38 per cent; and 154-day weight, 36.5 per cent. The remaining items composing the total score varied from 31 per cent for vigor and health down to 21 per cent for quality, the other points falling between these values.

The inbreeding of the entire swine herd varied from zero per cent to 27.8 per cent with the greatest number of individuals (164) falling at zero per cent and the next largest group (53) at 25 per cent; the overall average inbreeding percentage was 10.4. Consequently the distribution curve is skewed to the left, with a high peak at the extreme right resulting in the standard deviation, calculated as for a normally distributed population, to be somewhat larger than would be true in a normally distributed population.

The seasonal selection differentials on inbreeding indicate a tendency to select for breeding purposes those individuals slightly below the average of their contemporaries. Throughout the project boar selection tended toward the least inbred animals, the weighted average inbreeding selection differential being almost twice as large as for sows, consequently the large negative average total selection of -1.88. This negative value can be accounted for in part because; first, that in the spring of 1945 all the highly inbred sows were culled, the lowest inbred individual being retained to produce a litter six months later; and second, that in the spring and fall seasons of 1945 some unrelated stock was introduced into the herd (Table II).

This negative selection for inbreeding is anticipated if inbreeding has a somewhat degrading effect upon the phenotypic performance of the animal, especially in those cases where individuality plays the major role in determining which animals shall enter the breeding herd.

# SUMMARY AND CONCLUSIONS

1. A study of the selection intensity practiced on inbred line 5 of the Oklahoma Experiment Station of the Regional Swine Breeding Laboratory is presented. The data includes records on 435 pigs farrowed in 74 litters over the period from the spring of 1943 through the fall of 1947.
2. An average of 18.4 per cent of all gilts weaned and 5.0 per cent of all boars weaned were retained for replacements.
3. The average age of all sows farrowing decreased from 2.14 years at the start of the project to 1.33 years for the last season included in this study; the overall average age (generation interval) was 1.53 years.
4. The seasonal average size of litter farrowed and average weaning weight per pig per litter did not change appreciably throughout the project. However, a linear regression study conducted upon the two items litter size weaned and litter weaning weight as affected by season, disregarding inbreeding, yielded a positive regression coefficient of 0.27 pigs for size of litter weaned and a +5.7 pound for litter weaning weight.
5. Selection differentials of +1.10 for litter size weaned and +26.60 for litter weaning weight as compared to intra-season standard deviations of 2.4 and 73.0 in respective order were obtained. The selection for litter size weaned and litter weaning weight was the strongest among the items of productivity.
6. Throughout the project boar selection for items of productivity was only about 18 per cent to 40 per cent as intense as selection among the sows for corresponding items.

7. Comparison of actual selection and automatic selection of gilts indicate that the amount of actual selection reached for was greater than would have occurred under random selection of pigs raised to weaning. Actual selection was on the average 29 per cent more intense than automatic selection on litter size farrowed, 16 per cent on litter size weaned, and 34 per cent on litter weaning weight.
8. A great deal of attention was placed on individuality in the selecting of breeding stock. The greatest amount of emphasis being placed on total score as exemplified by a comparison of the annual selection differential of 43.8 points to the standard deviation of 7.3 points.
9. More intense culling on individuality was practiced on the boars than on the gilts; the average annual selection differentials for boars was at all times larger than the corresponding selection differentials on sows.
10. The inbreeding of individual pigs ranged from 0 to 27.8 per cent; the mean of the entire pig population was 10.4 per cent with a standard deviation of 6.44. The inbreeding in the line was not considered to be high enough to seriously limit progress by selection.
11. Throughout the project there was a tendency to select the less inbred animals for breeding stock.
12. As line 5 was started in 1942 a relatively small number of pigs were available for study. Also, due to the short period of time included in this study general conclusions cannot be made. The findings presented in this report are merely a study of data on a selected group of swine and are to be used only in

combination with much more extensive studies, if definite conclusions regarding selection intensity within swine are to be made.

## REFERENCES

Baker, M.L. and C. F. Reinmiller.
A Study of Certain Trends in Inbred Lines of Swine. (Abstract) Jour. An. Sci. 1:69. 1942.

_________, L.N. Hazel, and C.F. Reinmiller.
The Relative Importance of Heredity and Environment in the Growth of Pigs at Different Ages. Jour. An. Sci. 2:1-13. 1943.

Bywaters, J.H.
The Heriditary and Environmental Portions of the Variance in Weaning Weights of Poland China Pigs. Genetics 22:457-468. 1937.

Comstock, R.E. and L.M. Winters.
A Comparison of the Effects of Inbreeding and Selection on Performance in Swine. Jour. An. Sci. 3:380-389. 1944.

Craft, W. A.
Swine Breeding Research at the Regional Swine Breeding Laboratory. U.S.D.A. Misc. Pub. 523:1-14. 1943.

Davenport, E.
Principles of Breeding. Boston. Ginn and Co. 1907.

Dempster, E. R. and I.M. Lerner.
The Optimum Structure of Breeding Flocks. I. Rate of Genetic Improvement Under Different Breeding Plans. Genetics 32:555-566. 1947.

Dickerson, G. E. and L.N. Hazel.
Selection for Growth Rate and Productivity in Closed Herds of Swine. (Abstract) Journ. An. Sci. 1:342. 1942.

_________ and __________.
Effect of Progeny Testing on Progress from Selection Within Closed Herds. (Abstract) Jour. An. Sci. 1:342. 1942.

_________ and __________.
Effectiveness of Selection of Progeny Performance as a Supplement to Earlier Culling in Livestock. Jour. Agri. Res. 69:459-476. 1944.

__________ and J.C. Grimes.
Effectiveness of Selection for Efficiency of Gain in Duroc Swine. Jour. An. Sci. 6:265-287. 1947.

__________, J.L. Lush, M.L. Baker, J.A. Whatley, Jr., and L.M. Winters.
Performance of Inbred Lines and Line Crosses in Swine. (Abstract). Jour. An. Sci. 6:477. 1947.

Fisher, R. A.
The Genetical Theory of Natural Selection. Oxford, Clarendon Press. 1930.

Hazel, L.N.
The Genetic Basis for Constructing Selection Indexes. Genetics 28:476-490. 1943.

________ and J.L. Lush.
The Efficiency of Three Methods of Selection. Jour. of Heredity 33:393-399. 1942.

________ and __________.
Constructing Selection Indexes to Make Maximum Progress (Abstract) Jour. An. Sci. 1:69-70. 1942.

________, M.L. Baker, and C. F. Reinmiller.
Genetic and Environmental Correlations Between the Growth Rates of Pigs at Different Ages. Jour. An. Sci. 2:118-128. 1943.

Hetzer, H.O., W. V. Lambert, and J.H. Zeller.
Influence of Inbreeding and Other Factors on Litter Size in Chester White Swine. U.S.D.A. Cir. 570. 1940.

__________ and G.W. Brier.
Extent to Which Type Differences Among Swine Affect Litter Size. Amer. Soc. An. Prod. 1940: 135-138. 1940.

__________, G. E. Dickerson, and J.H. Zeller.
Heritability of Type in Poland China Swine as Evaluated By Scoring.
Jour. An. Sci. 3:390-398. 1944.

Hodgson, R. E.
An Eight Generation Experiment in Inbreeding Swine. Jour. of Heredity 26:209-217. 1935

Hughes, E. H.
Inbreeding Berkshire Swine. Jour. of Heredity 24:199-203. 1933.

Krider, J.L., B. W. Fairbanks, W. E. Carroll, and E. Roberts.
Effectiveness of Selecting for Rapid and For Slow Growth Rate in Hampshire Swine. Jour. An. Sci. 5:3-15. 1946.

Laben, R. C.
The Amount and Effectiveness of Selection in Inbred Lines of Swine.
Thesis. Oklahoma A. and M. College Library. 1947.

Labeng R. C. and J.A. Whatley, Jr..
Selection in an Inbred Line of Duroc Swine. (Abstract) Jour. An. Sci. 6:478. 1947.

Lerner, I.M. and L.N. Hazel.
Population Genetics of a Poultry Flock Under Artifical Selection. Genetics 32:325-329. 1947.

Lush, J.L.
Intra-sire Correlations or Regressions of Offspring on Dam as a Method of Estimating Heritability of Characteristics. Amer. Soc. An. Prod. 1940:293-301. 1940.

__________ Animal Breeding Plans. Ames, Iowa. Iowa State College Press. 1947.

__________ and A.E. Molln.
Litter Size and Weight as Permanent Characteristics of Sows. U.S.D.A. Tech. Bul. 836, 1942.

McPhee, H.C..
Size of Litter as Selection Index in Swine. Proc. Amer. Soc. An. Prod. 1931: 262-265. 1931.

__________ Accomplishments of the Regional Animal Research Laboratories. (Abstract) Jour. An. Sci. 4:96-97. 1945.

Nordskog, A. W., R. E. Comstock, and L.M. Winters.
Hereditary and Environmental Factors Affecting Growth Rate in Swine. Jour. An. Sci. 3:257-272. 1944.

Olbrycht, T. M.
The Statistical Basis of Selection in Animal Husbandry. Parts I and II. Jour. Agri. Sci. 33:28-43, 74-84. 1943.

Phillips, W. R..
Breeding Better Livestock. U.S.D.A. Yearbook 1943-1947:33-60. U.S. Printing Office, Washington. 1947.

Rice, V. A..
Breeding and Improvement of Farm Animals. New York. McGraw-Hill Book Co., Inc. 1926.

Sinnott, E. W. and L.C. Dunn.
Principles of Genetics. New York. McGraw-Hill Book Company. 1939.

Snedecor, G. W.
Statistical Methods. Ames, Iowa. Iowa State College Press. 1946.

Stewart, H.A.
An Appraisal of Factors Affecting Prolificacy in Swine. Jour. An. Sci. 4:250-260. 1945.

__________ The Inheritance of Prolificacy in Swine. Jour. An. Sci. 4:359-366. 1945.

Weaver, L. A. and R. Bogart.
Some Factors Influencing Efficient Production of Sows. Mo. Agri. Expt. Sta. Bul. 461. 1943.

Whatley, Jr., J.A.
Influence of Heredity and Other Factors on 180-day Weight in Poland China Swine. Jour. Agri. Res. 65:249-264. 1942.

Willham, O. S. and W.A. Craft.
An Experimental Study of Inbreeding and Outbreeding Swine. Okla. Agri. Expt. Sta. Tech. Bul. 7. 1939.

Winters, L.M., R. E. Comstock, R. E. Hodgson, O.M. Kiser, P.S. Jordan, and D. L. Dailey.
Experiments with Inbreeding Swine and Sheep. Minn. Agri. Expt. Sta. Bul. 364. 1943.

____________, J.N. Cummings, and H.A. Stewart.
A Study of Factors Affecting Survival From Birth to Weaning and Total Weaning Weight of the Litter in Swine. Jour. An. Sci. 6:288-296. 1947.

Zeller, J.H.
Swine Type as a Factor in Pork Production. Amer. Soc. An. Prod. 1940;279-283. 1940.

Typist: Mrs. Paul K. Sloan