A STUDY OF THE DEVELOPMENT OF AN INBRED LINE OF DUROC SWINE

By

RUTLEDGE GORDON HOLLEMAN, JR.

Bachelor of Science. 1948

Master of Science. 1950

The State College of Washington

Pullman, Washington

Submitted to the Faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in Partial Fullfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY
1953

A STUDY OF THE DEVELOPMENT OF AN INBRED LINE OF DUROC SWINE

RUTLEDGE GORDON HOLLEMAN, JR.

DOCTOR OF PHILOSOPHY

1953

THESIS AND ABSTRACT APPROVED:

James A. Whatley Jr.
Thesis Adviser

Doyle Chambers
Faculty Representative

D. C. McIntosh
Dean of the Graduate School

ACKNOWLEDGEMENT

The writer wishes to express his sincere appreciation to Dr. James A. Whatley, Jr., Professor of Animal Husbandry, for the many helpful suggestions during the present study and the preparation of this thesis.

He also wishes to acknowledge the assistance given by Professor Carl E. Marshall of the Department of Mathematics in the machine tabulation and computation in a portion of this study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

Since ancient times man has attempted to produce animals of a type most nearly suited to his needs, both economic and aesthetic. The early animal breeder began with stock resulting largely from natural selection and through the use of the three tools, selection, inbreeding and crossbreeding, began to develop breeds more suited to his needs.

Improvement of present farm animals is achieved through the use of one or more of these tools to varying degrees. Natural selection is not replaced entirely by artificial selection, but frequently man selects for traits in his livestock which would be detrimental to animals in the wild state. Intensity of inbreeding can be controlled by man by planned matings. Among wild animals, inbreeding occurs most frequently in small populations isolated by geographic barriers, while under domestication, breed or species crosses are produced between races which would seldom if ever meet in their natural habitats. Many of these hybrids have considerable economic importance.

The improvement of farm animals by selection depends on three factors: the proportion of each generation required for breeding purposes, the variability of the population for the characters in question, and the degree of heritability of these characters.

There must be apparent differences between individuals before the breeder can select those animals for breeding which most nearly conform to his ideal. This variability is the material upon which selection operates. Variation between individuals is influenced by differences in genes possessed by these individuals, differences in environment to which they are subjected and the interaction between the animal's heredity and its environment. Selection can be effective only on the genetic portion of the variation.

The degree of heritability determines in part the effectiveness of selection for any characteristic. The duplicate nature of inheritance may cause difficulty in selection, as dominant genes may cover up undesirable recessives. Furthermore, traits may be measured inaccurately, the environmental effects are often misinterpreted as genetic effects and complex gene interactions may mask the true breeding value of an individual. Because of these complications, the true genotype of an animal can never be determined accurately.

It is frequently asked if inbreeding is injurious merely by reason of the consanguinity. The answer is no. Inbreeding is a powerful force for bringing out hidden recessives. These recessives in turn may cause a decline in many or all characteristics, but inbreeding itself does not cause deterioration. This decline may occur unless inbreeding is accompanied by rather intense selection. If inbreeding is not too intense, and is accompanied by selection accurate and intense enough to cull out undesired genes as they appear in a homozygous condition, inbreeding could be beneficial.

The effectiveness of selection is dependent on sorting the more desirable genes or groups of genes from the less desirable, and maintaining the highest possible frequency of these desirable genes in the population. Inbreeding, as a tool, is used to expose these less desirable genes of recessive nature and to permit their being culled from the population.

REVIEW OF LITERATURE

Early livestock breeders noted for their establishment of the pure breeds owed a great part of their success to the judicious use of inbreeding. By inbreeding selected animals they fixed the desired type and made it prepotent within the developing breeds. Other effects such as lower fertility, decreased vigor and reduced size also became associated with inbreeding. Accordingly, inbreeding fell into disfavor.

No explanation was available for the effects attributed to inbreeding until the rediscovery of Mendel's papers in 1900. It became clear at once that hidden recessives which are present in most populations are exposed more frequently when the mating of related animals takes place. The probability of two related animals possessing the same hidden recessive genes is greater than in two unrelated animals. Frequently the desirable genes are dominant while the recessive genes are those which produce the more undesirable traits. Thus it became evident why inbreeding should be associated with undesirable characteristics.

From 1906 until 1920, an investigation on the effects of inbreeding in guinea pigs was carried on by the Bureau of Animal Industry. Wright (1922) described the results of this work. Of the 35 inbred lines started in the experiment only 23 of these were carried to the completion of the work. In all but one family, full sib matings were practiced. Parent-offspring matings were practiced in the other line. The best individuals in the litter were selected for breeding stock. A comparison of the inbred guinea pigs to the outbred control stock showed a decline in vigor in all characters measured. This decline was especially marked in fertility. The other striking result of this experiment was the differentiation of families with respect to color and other characters. This fixation of characters within families and differentiation between families is one of the well known effects of inbreeding today.

Another early inbreeding experiment was conducted by King (1918) (1919) with rats. A strain of rats was carried on with brother x sister matings for 25 generations. Vigor was maintained and the inbred strain actually surpassed the outbred control stock in both size and fertility. This maintenance of size and fertility was attributed to the intense selection practiced. In an inbreeding experiment with swine also carried on in this period, Hayes (1919) double mated Berkshire sows to related Berkshire boars and to Yorkshire boars. Thus inbred and crossbred pigs were obtained in the same litter. He found a higher mortality rate among the inbred pigs than among the crossbreds. The certainty of conception and size of litter were also reduced in the inbreds. Mortality rate among these inbred pigs may have been higher, however, than if they had been forced to compete only with other inbred pigs rather than crossbreds.

Hughes (1933) reported the results of an 11 year inbreeding study with Berkshire swine. Brother x sister matings were made consistently after initiating the experiment in 1922. Litter size at farrowing held up rather well in succeeding generations and pigs of the inbred litters were more uniform than those of the outbred litters. According to Craft (1952) litter size farrowed held up rather well until 1947 when an outcross was made. Difficulty in raising the inbred pigs made this outcross necessary.

Hodgson (1935) reported the results of inbreeding studies with Poland-China swine at the Minnesota Station. Of the seven original lines, three were carried for eight generations by full sib matings without loss of vigor. Litter size at birth was slightly smaller in the inbreds than in non-inbred stock. Individual pig weights were comparable up to 112 days of age. After that the outbreds 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 Duroc swine inbred by half-sib matings. Inbred animals also made smaller daily gains and were less efficient in feed utilization than a non-inbred control herd. Similar findings were reported by Hetzer et al. (1940) with inbred Chester White swine. In their study, differences in the inbreeding of the litter had a greater effect on litter size than did differences in the inbreeding of their sires and dams.

Baker and Reinmiller (1942) discussed the development of four one sire lines of Duroc swine over a period of nine seasons. When corrected for age of dam, the data did not indicate any definite trend in the number of pigs farrowed, the number farrowed alive, number of pigs weaned, weaning weight of litter, or the productivity index of the dam. Since the maximum inbreeding of the parents was 23 per cent and that of the litters was 30 per cent, it is possible that selection was able to counteract the adverse effects of this relatively mild inbreeding.

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

Comstock and Winters (1944) later presented a more detailed study of the same line. They determined partial regressions of litter size farrowed on inbreeding of dam and litter to be -.009 and -.028, respectively. Theoretically, this meant that each one per cent increase in inbreeding of both sow and litter would decrease litter size by .037 pigs per litter. Inbreeding had a much smaller effect on growth rate (b = -.0022). The authors concluded from their study that litter size is much more difficult to maintain than growth rate in a line being inbred. For this reason, maximum attention to selection is necessary in the development of inbred lines of swine.

Winters et al. (1947) found that neither the inbreeding of the dam nor the inbreeding of the litter had a significant effect on the survival of the pigs from birth to weaning or upon total weaning weight of the litter. It appeared that selection was effective in holding survival at a high rate.

Stewart (1945) in his study of the same herd found that litter size at farrowing increased with an increase in the age of the dam, but an increase of 10 per cent in inbreeding of the dam resulted in a decrease of about 0.6 pig per litter.

The effects of age of sow, inbreeding of sow and inbreeding of litter on sow productivity and pig performance were described by Blunn and Baker (1949). They found that age of sow was the most important factor affecting sow performance, but inbreeding of litter became increasingly important to the pig survival as the pigs grew older.

In a study of performance of inbred lines of swine by Dickerson et al. (1947) it was observed that for each 10 per cent rise in litter inbreeding, independent of age and inbreeding of dam, an average decline of 0.2 of a pig at birth, 0.5 of a pig at 56 and 154 days occurred. A decline of 3.6 pounds in pig weight 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 determined that 180 day weight of the individual pig decreased 0.76 pound for each one per cent increase in inbreeding. A later study by Laben and Whatley (1947) of one line of Duroc swine indicated a decrease in 180 day weight from 187 pounds to 153 pounds in five generations of mild inbreeding, although selected animals averaged 22 pounds heavier than the generation from which they came. A decline of 0.7 of a pig in size of litter weaned occurred in spite of the fact that breeding animals were selected from litters 1.2 pigs larger than the average.

Craft (1952) summarized the general results of inbreeding experiments with swine which have taken place in the Regional Swine Breeding Laboratory. His summary presents an excellent overall picture. The decline in pigs farrowed was estimated to be about one-third of a pig per litter, and for number weaned, about one-half pig per litter, for each increase of ten per cent in inbreeding. Strength and vigor of pigs at birth appeared to be reduced in some lines as inbreeding increased. Rate of growth declined in some lines but not in all. Economy of gain has been improved in some lines under inbreeding and selection.

Darwin's Origin of Species (1885) remains as the classic work on selection, even though it was written without the knowledge of Mendel's laws of heredity. Darwin recognized the importance of both natural and artificial selection in the development of the pure breeds. Some of Darwin's conclusions, which were questionable from a genetic standpoint have been corrected and brought up to date by Fisher (1930).

One of the early workers advancing knowledge of selection was the Danish botanist, W. L. Johannsen, whose experiments are reviewed by Sinnott and Dunn (1925). Johannsen distinguished hereditary variation from non-hereditary variation and demonstrated two fundamental principles of successful selection: selection must be based on hereditary variation, and the factors responsible for the selected characters must be heterozygous when selection is begun.

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.

One of the first selection experiments in animal breeding in which breeding stock were selected by progeny test was reported by Goodale (1938). His objective was to determine the limits of change by selection when the character being selected, body weight in the albino mouse, was not in itself a limiting factor. He concluded that genotypic selection showed a much greater efficiency than would have been shown by phenotypic selection alone. Goodale selected in one direction only.

MacArthur (1944) conducted a carefully planned and well controlled selection experiment to produce an extremely large and an extremely small bodied race of house mouse. One of his primary objectives was to study the inheritance of quantitative characters. From his studies, he concluded that size genes, or modifiers, tend to multiply each other's effects rather than to act additively. He theorized on the basis of his findings that the desirable characters in livestock may be expected to improve with proper selection.

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 5 per cent at birth to 24 per cent at 180 days.

Working with a poultry flock, Lerner and Hazel (1947) studied the effects of selection, chance, and migration on 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 that expected gains compared very favorably to actual gains. From these results they concluded that known principles of population genetics may be used to predict rates of improvement in populations subjected to artifical selection.

Possibly, more selection studies have been conducted with swine than with any other type 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 will proceed very slowly.

Hazel and Lush (1942) described three basic methods of selection. First, the tandem method, in which selection is for one trait at a time, improving each trait to the desired level before attempting to select for the second. Second, the total score method in which all traits are selected simultaneously, the total score or index being determined through adding credits or penalties given each animal according to its merit for each trait considered. Third, the independent culling levels method, where a certain acceptable level of merit is established for each trait, and all individuals falling below that level in any one trait are culled, regardless of their rating in other traits. The total score method is the most efficient, and the tandem method is the least efficient of the three. One difficulty in the use of the total score method lies in the determination of how much weight to give each trait when calculating an index. The authors (1942a) 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.

Dickerson and Hazel (1942) compared the expected rate of improvement for various method of selection for 180 day weight in swine. Progress was nearly maximum when boars were replaced annually and selection was based on the pig's own 180 day weight. Extra progress from consideration of the 180 day weights of litter mates was negligible. About 95 per cent of the total possible improvement was obtained when one-third of all boar pigs were saved in the first culling, based on individual 56 day weight and dam's productivity, and the second culling was based on the pig's 180 day weight and dam's productivity.

In a later study (1944) the same workers compared the effectiveness of different methods of selecting for improved growth rate of pigs and productivity of sows. It was determined that from eight to ten times as many boars and about three times as many gilts as are needed should be retained after weaning to obtain a reliable measure of growth rate. Yearly progress from selection for productivity was greatest when sows were culled after the first litter, the best one-third to one-half being retained for a second litter six months after the first. Having sows farrow two litters a year is definitely advantageous in that it permits the increased accuracy of selecting boars and gilts on the dams productivity on two litters rather than one.

Baker _et al_. (1943) considered the interval of growth immediately preceeding 112 days of age to offer the greatest opportunity to identify those animals possessing the heredity for rapid growth rate.

Stringham _et al_. (1950) described the formation of two inbred Poland-China lines at the Minnesota Station. Although the two lines reached levels of inbreeding of 30 and 35 per cent, the only decline was in fertility, and that very slight. Other factors have remained stable or actually improved. Improvement was noticeable in all lines in economy of gains and body score. From this study the authors concluded that inbred lines can be developed from a few individuals and maintained with about 15 to 20 sows. Of primary importance is a flexible system of mating, rigid selection and the maintenance of a short generation interval.

In a study of the effectiveness of selection for fertility in the Minnesota No. 1 and Minnesota No. 2 lines of swine, Fine (1952) compared theoretical and actual annual rates of change for numbers of pigs farrowed and numbers of pigs weaned. Large positive selection differentials had been attained for both of these traits in both lines, but selection was unable to prevent a decline in productivity due to inbreeding. In the Minnesota No. 1, actual and predicted rates of decline were in rather close agreement, but in the Minnesota No. 2 line, there was agreement only in the direction of change. "Selection appeared to accomplish most in the line where most selection was practiced."

OBJECTIVES OF THIS INVESTIGATION

This study was conducted to determine the amount and the effectiveness of selection which has been practiced in Line 3 of the inbred Duroc swine herd at the Oklahoma Agricultural Experiment Station cooperating with the Regional Swine Breeding Laboratory. The extent to which selection intensity can offset the reduction in net merit is also considered.

A study of a hereditary congenital anomaly, flexed pasterns, which is present in the line is also considered.

SOURCE OF MATERIAL AND COMPOSITION OF BREEDING HERD

The records from which this study was made are from Duroc Line 3 of the swine breeding project of the Oklahoma Agricultural Experiment Station cooperating with 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 the project at the Oklahoma Station is described as the improvement of Duroc swine through a system of inbreeding, selection and outcrossing.

Line 3 was started in 1938 with the sow, Marion, obtained from Joe Pudenz and Son, Carroll, Iowa, and the sow, Cameron 1, purchased from Whit Cameron, Herman, Nebraska. During the following two years, nine other sows were obtained from Whit Cameron. These foundation sows from the Cameron herd will be referred to as Cameron sows and by their respective numbers.

None of the three foundation sires, Pioneer, Pathmarker and Broadcaster Chief were actually present at the Oklahoma Station. When purchased, Marion was bred to Pathmarker, Cameron 1 was bred to Pioneer, and Cameron 9 and Cameron 10 were bred to Broadcaster Chief.

All three of the foundation sires have contributed to the present breeding herd. Six of the eleven sows have contributed. It is of interest to note that of the five non-contributor foundation sows which actually produced Line 3 litters, only one, Cameron 4, produced an individual which was selected for the breeding herd. No progeny of this daughter were then selected. The contributing foundation animals were determined early in the establishment of the line. The line has been maintained as a closed herd since 1940, when Cameron 9 and Cameron 10 were introduced.

Striking differences exist in the number of contributing progeny from each of these foundation animals. Pathmarker and Marion contributed one son and three daughters. Pioneer and Cameron 1 contributed one daughter. Cameron 8 contributed one daughter, Cameron 6 and Cameron 9 contributed two sons and one daughter each, Cameron 10 contributed two daughters, and the boar, Broadcaster Chief, contributed two sons and two daughters.

By the use of the method described by Hazel and Lush (1950), direct relationships of litters farrowed in the spring of 1951 to each of the foundation animals were computed. These relationships are shown in Table 1. Inbreeding of each litter produced in the 1951 spring farrow is also indicated.

A skeleton pedigree, Figure 1, shows the average relationship of the 1952 breeding herd to each of the foundation animals, to the progeny of these animals, and to herd sires from which all members of the breeding herd are descended. The average coefficient of relationship of the 1952 breeding herd to each individual is indicated directly under the herd number of the individual. Year of farrow of each animal is also indicated.

The original breeding plan was to maintain a ten sow herd with two boars in service each season. Some deviations from this plan are noticeable in Table 2.

Replacement gilts for the breeding herd were selected after 180 or 154 day weights were obtained, usually when the gilts weighed between 180 and 230 pounds. Prior to 1945, growth rate was measured by 180 day

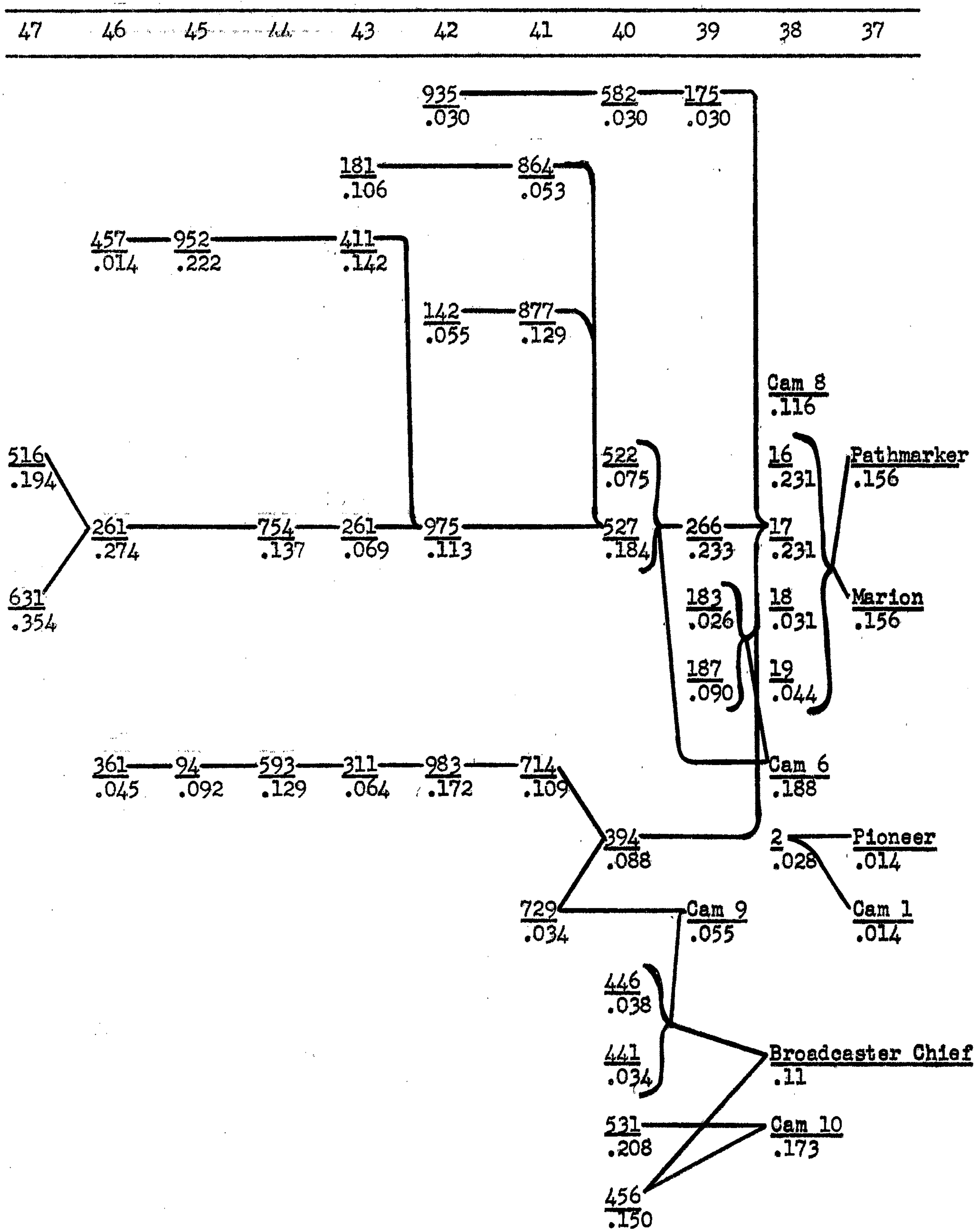
TABLE 1

INBREEDING AND DIRECT RELATIONSHIP OF LITTERS FARROWED
IN THE SPRING OF 1951 TO EACH OF THE CONTRIBUTING FOUNDATION ANIMALS

FOUNDATION ANIMAL	L710	L720	L730	L740	L750	L790	L800
PATHMARKER	.155	.170	.154	.140	.154	.154	.135
MARION	.155	.170	.154	.140	.154	.154	.135
PIONEER	.015	.013	.015	.016	.015	.012	.016
CAMERON 1	.015	.013	.015	.016	.015	.012	.016
CAMERON 6	.191	.185	.191	.191	.191	.183	.186
CAMERON 8	.113	.114	.113	.123	.113	.124	.127
BROADCASTER CHIEF	.119	.104	.119	.121	.119	.113	.123
CAMERON 9	.064	.045	.062	.057	.062	.047	.057
CAMERON 10	.164	.178	.164	.180	.164	.198	.174
INBREEDING OF LITTER	.285	.385	.289	.350	.289	.290	.351

FIGURE 1

AVERAGE DIRECT RELATIONSHIPS OF 1952 BREEDING HERD TO FOUNDATION ANIMALS THEIR PROGENY AND TO BOARS THROUGH 1947



weights, but after that date, 154 day weights were used. Initial selection of boars was made at six weeks of age, when the most desirable male pigs were saved as boars. Final selection was made when they weighed approximately 225 pounds. Selection of boars and gilts for replacement was further based on body conformation of the individual, and productivity of the dam of the individual. If data were available, selection of breeding stock was further based on performance of sibs in rate and economy of gain on a standard feeding test. No numerical selection index combining the ratings of the individual in all selection traits was used consistently in the selection of breeding animals. Evaluation and balancing of these various points was made by the project leader.

Generally, the selection of sows to remain in the breeding herd after producing litters was based on a productivity index. The productivity index, as estimate of most 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 some consideration in determining whether or not the sow would be retained for the production of additional litters.

Data were obtained on performance for the numbers of pigs farrowed and weaned and the weaning weight of the litter. Information on individual pig weaning weight, 154 day weight, and inbreeding coefficients of sow and litter was also obtained. All data on the productivity traits for older sows were adjusted to a gilt equivalent basis with the correction figures presented by Chambers (1951).

PRESENTATION OF RESULTS OF SELECTION STUDY

Line 3 was started in 1938 and the first complete records of performance were available in the spring of 1939. The number of sows farrowing each season is shown in Table 2. This table indicates a deviation from the ten sow, two sire herd. The average of 13.3 sows farrowing per season actually includes sows producing line-cross litters. Table 3, however, indicates that the average numbers of sows farrowing inbred litters each season was 8.7, and the average number of boars siring litters each season was 2.7.

Average ages of sows and boars shows no particular time trend. After 1942, however, the average age of sows producing inbred litters is greater than that of the entire sow herd with few exceptions. This indicates a general tendency to breed more gilts to produce line-cross litters. On the basis of this production record, the more productive gilts were selected to produce inbred litters.

The average inbreeding in the line has increased slowly. Average inbreeding of all sows producing inbred litters in the twelve year period was 15.9 per cent and the average inbreeding of all litters produced was 20.5 per cent.

Age of sow has a definite effect upon the litter produced. Studies by Hetzer _et al._ (1940) and Lush and Molln (1942) have presented evidence that litter size at farrowing and weaning increases with the age of the dam. The detailed study by Lush and Molln revealed that size of litter farrowed and weaned increased with age of dam up to two years of age, remained fairly constant to four and one-half years of age for pigs farrowed and three and one-half years for pigs weaned. Production then declined. Two year old sows produced the heaviest litters at weaning. Weaning weight declined for litters from sows after three or three and one-half years of age. Hetzer *et al.* found that litter size at birth increased with age of dam to an age of three and one-half years, remained constant to five and one-half years, then declined. The items of productivity, number of pigs farrowed and weaned, and litter 56-day weight were all adjusted to a gilt basis. The correction factors computed by Chambers (1951) from the Oklahoma swine herd are presented in Table 4.

Seasonal average of number of pigs farrowed and weaned, litter weaning weight, pig 56 and 154-day weight and inbreeding of sow and litter are presented in Table 5. Number of pigs farrowed and weaned and litter weaning weight are gilt corrected. The overall weighted average was 7.7 pigs farrowed, 5.3 pigs weaned with a litter weaning weight of 140.6 pounds. Figures 2 and 3 present these data graphically indicating yearly averages rather than seasonal averages. No noticeable decline occurred in any of the items over the period of the study even though the inbreeding of the litters increased from 8 to 32 per cent. In 1944 average inbreeding of sows was greater than the average inbreeding of the litters produced. This was due to the crossing of two sub-lines within Line 3.

In any program of selection, the amount of progress is influenced by the percentage of offspring which are retained as herd replacements. Table 6 shows the number of gilts and boars which were selected for the breeding herd. With the exception of one gilt, animals selected from one farrowing season produced their first litter one year later. One gilt, selected in the spring of 1938, produced her first litter in the fall of 1939. Although the percentage of gilts selected each season varied considerably, 25.7 per cent of the gilts weaned, were retained for breeding. Comparing the number of gilts retained in any given season in Table 6 to the total number of litters farrowed one year later in Table 3, it may be noted that at no time was the sow herd completely replaced by gilts. Of the 333 litters farrowed, 156 were farrowed by gilts. Over the entire period, about 47 per cent of the breeding herd was made up of gilts. According to Dickerson and Hazel (1944) this percentage of gilt replacements is too low to obtain the maximum progress in selection for productivity. They state that maximum progress from selection is made when from 1/2 to 2/3 of the sows are culled after producing one litter. This would require a replacement percentage ranging from 50 to 67 per cent.

The percentage of boars saved was, as expected, considerably smaller than the corresponding percentage of gilts saved. The percentage of the males weaned that were selected as boars and used in the line was 6.6 per cent. Rather than a ratio of one boar saved to each five gilts saved as planned originally, a ratio of one boar to 3.9 gilts was actually retained.

Improvement by selection is the most commonly used tool of the animal breeder. The breeder cannot select the desirable gametes as such, nor can he control the random segregation of genes and their recombination into zygotes. The breeder selects the most phenotypically desirable animals under the assumption that they will produce a high proportion of desirable genes in their gametes. The most useful means of measuring the intensity of selection actually practiced, is by a comparison of the average merit of the selected individuals and the average merit of the

TABLE 2

NUMBER OF SOWS AND BOARS PRODUCING LITTERS BY SEASON
AND PERCENTAGE RETAINED TO PRODUCE SUBSEQUENT LITTERS

	NUMBER SOWS FARROWING	NUMBER RETAINED	PER CENT RETAINED	NUMBER BOARS	NUMBER RETAINED	PER CENT RETAINED
1939S	14	10	71.4	2	1	50.0
1939F	11	8	72.7	1	1	100.0
1940S	12	9	75.0	4	1	25.0
1940F	11	5	45.4	2	0	0.0
1941S	12	7	58.3	2	2	100.0
1941F	15	8	53.3	4	2	50.0
1942S	12	7	58.3	4	2	50.0
1942F	15	8	53.3	4	0	0.0
1943S	16	9	56.2	5	2	40.0
1943F	15	6	40.0	3	1	33.3
1944S	8	7	87.5	4	2	50.0
1944F	14	6	42.8	2	0	0.0
1945S	17	10	58.8	2	0	0.0
1945F	15	10	66.7	2	0	0.0
1946S	18	7	38.9	3	1	33.3
1946F	16	4	25.0	2	1	50.0
1947S	10	2	20.0	3	1	33.3
1947F	8	5	62.5	2	0	0.0
1948S	11	5	45.5	2	1	50.0
1948F	10	8	80.0	2	1	50.0
1949S	23	8	34.8	2	1	50.0
1949F	11	7	63.6	0	1*	--
1950S	18	14	77.8	3	2	66.7
1950F	14	5	35.7	2	0	0.0
1951S	7	0	0.0	3	0	0.0
Average	13.3	7.0	52.6	2.7	.92	35.4

* Indicates boar retained from previous season.

TABLE 3

AVERAGE AGE OF SOWS AND BOARS PRODUCING LITTERS BY SEASON

	TOTAL NUMBER SOWS	AVERAGE AGE OF SOWS IN YEARS	SOWS PRODUCING INBRED LITTERS	AVERAGE AGE OF SOWS IN YEARS	TOTAL NUMBER BOARS	AVERAGE AGE OF BOARS IN YEARS	AVERAGE AGE OF PARENTS OF INBRED LITTERS IN YEARS
1939S	14	1.25	9	1.17	2	1.00	1.15
1939F	11	1.77	8	1.88	1	1.50	1.84
1940S	12	1.79	12	1.79	4	1.33	1.68
1940F	11	1.95	9	1.94	2	1.25	1.81
1941S	12	1.54	10	1.25	2	1.00	1.21
1941F	15	1.33	10	1.30	4	1.12	1.25
1942S	12	1.42	12	1.42	4	1.50	1.44
1942F	15	1.47	10	1.70	4	1.50	1.64
1943S	16	1.47	12	1.62	5	1.20	1.50
1943F	15	1.50	7	1.29	3	1.33	1.30
1944S	8	1.62	6	1.58	4	1.12	1.40
1944F	14	1.57	7	2.14	2	1.50	2.00
1945S	17	1.18	6	1.50	2	1.50	1.50
1945F	15	1.47	10	1.70	2	1.50	1.67
1946S	18	1.56	10	2.00	3	1.17	1.81
1946F	16	1.31	16	1.31	2	1.25	1.30
1947S	10	1.25	10	1.25	3	1.17	1.23
1947F	8	1.12	5	1.20	2	1.25	1.21
1948S	11	1.32	11	1.32	2	1.25	1.31
1948F	10	1.40	4	1.62	2	1.50	1.58
1949S	23	1.37	8	2.06	2	1.25	1.90
1949F	11	1.36	0	--	0	--	--
1950S	18	1.36	7	1.93	3	1.67	1.85
1950F	14	1.82	5	2.40	2	2.25	2.35
1951S	7	1.71	7	1.71	3	1.67	1.70
Average	13.3	1.46*	8.7	1.77*	2.7	1.35*	1.67*

* Weighted averages, all others are arithmetic averages.

TABLE 4

CORRECTION FACTORS FOR ADJUSTING PRODUCTIVITY DATA
TO A GILT BASIS*

AGE OF SOW (Years)	SIZE OF LITTER		LITTER 56 DAY WT.
	FARROWED	WEANED	
1.0	1.000	1.000	1.000
1.5	.821	.881	.776
2.0	.760	.909	.759
2.5	.705	.875	.746

* Chambers (1951)

TABLE 5.

AVERAGES OF THE PRODUCTIVITY ITEMS*, INDIVIDUAL ITEMS, INBREEDING, AND NUMBER OF LINE LITTERS FARROWED BY SEASONS

SEASON	NUMBER LITTERS	PER CENT INBREEDING		PIGS PER LITTER		LITTER 56-DAY WEIGHT	NUMBER PIGS AT 56-DAY	PIG 56-DAY WEIGHT	NUMBER PIGS AT 154 DAYS	PIG 154-DAY WEIGHT
		SOW	LITTERS	FARROWED	WEANED					
1939S	9	1.0	8.3	7.8	5.2	128.9	49	26.0	45	120.2
1939F	8	2.8	3.1	7.4	3.7	85.6	35	25.5	35	137.8
1940S	12	4.3	12.5	7.4	5.5	146.4	71	29.8	69	153.0
1940F	9	3.0	11.8	6.1	5.2	166.2	53	36.1	53	172.6
1941S	10	7.0	13.0	8.2	7.0	179.7	69	28.8	57	134.4
1941F	10	14.5	21.7	8.1	4.9	116.9	52	25.6	44	125.9
1942S	12	14.9	22.0	6.6	5.6	150.2	74	29.9	73	123.9
1942F	10	19.1	18.0	8.2	5.1	99.4	51	22.7	43	92.3
1943S	12	18.5	25.8	7.4	4.5	101.6	60	24.8	54	104.4
1943F	7	15.8	17.8	7.4	4.8	127.0	34	27.4	34	146.0
1944S	6	20.4	21.6	8.8	7.4	212.8	49	32.7	48	160.8
1944F	7	25.6	16.0	7.7	4.3	105.2	33	29.4	29	121.1
1945S	6	18.6	19.4	5.8	5.0	130.1	34	30.6	33	114.8
1945F	10	20.8	26.0	7.7	5.7	139.9	64	28.4	53	112.6
1946S	10	15.3	20.0	7.2	6.2	150.5	69	28.8	61	133.8
1946F	16	19.0	24.5	7.0	5.2	140.6	85	29.9	80	109.2
1947S	10	15.8	22.9	8.4	5.5	139.4	58	27.7	48	105.6
1947F	5	16.7	23.7	8.8	6.4	170.8	34	28.4	32	126.2
1948S	11	22.6	26.6	8.2	5.2	135.1	62	28.6	52	92.4
1948F	4	22.2	26.3	4.9	4.3	137.1	18	34.8	18	120.9
1949S	8	21.9	36.8	8.3	6.4	198.1	63	34.8	62	135.6
1949F	0	---	---	---	---	---	---	---	---	---
1950S	7	25.9	30.0	10.0	5.4	170.0	43	36.4	41	137.5
1950F	5	26.4	28.4	9.9	2.3	70.1	13	35.9	12	140.7
1951S	7	27.7	32.0	8.3	6.0	192.0	44	35.8	42	144.9
Average	8.7**	15.9	20.5	7.7	5.3	140.6	50.7**	29.6	46.6**	127.5

* All productivity items corrected to gilt equivalent, Chambers (1951).

** Arithmetic averages. All others weighted by respective number of litters or pigs.

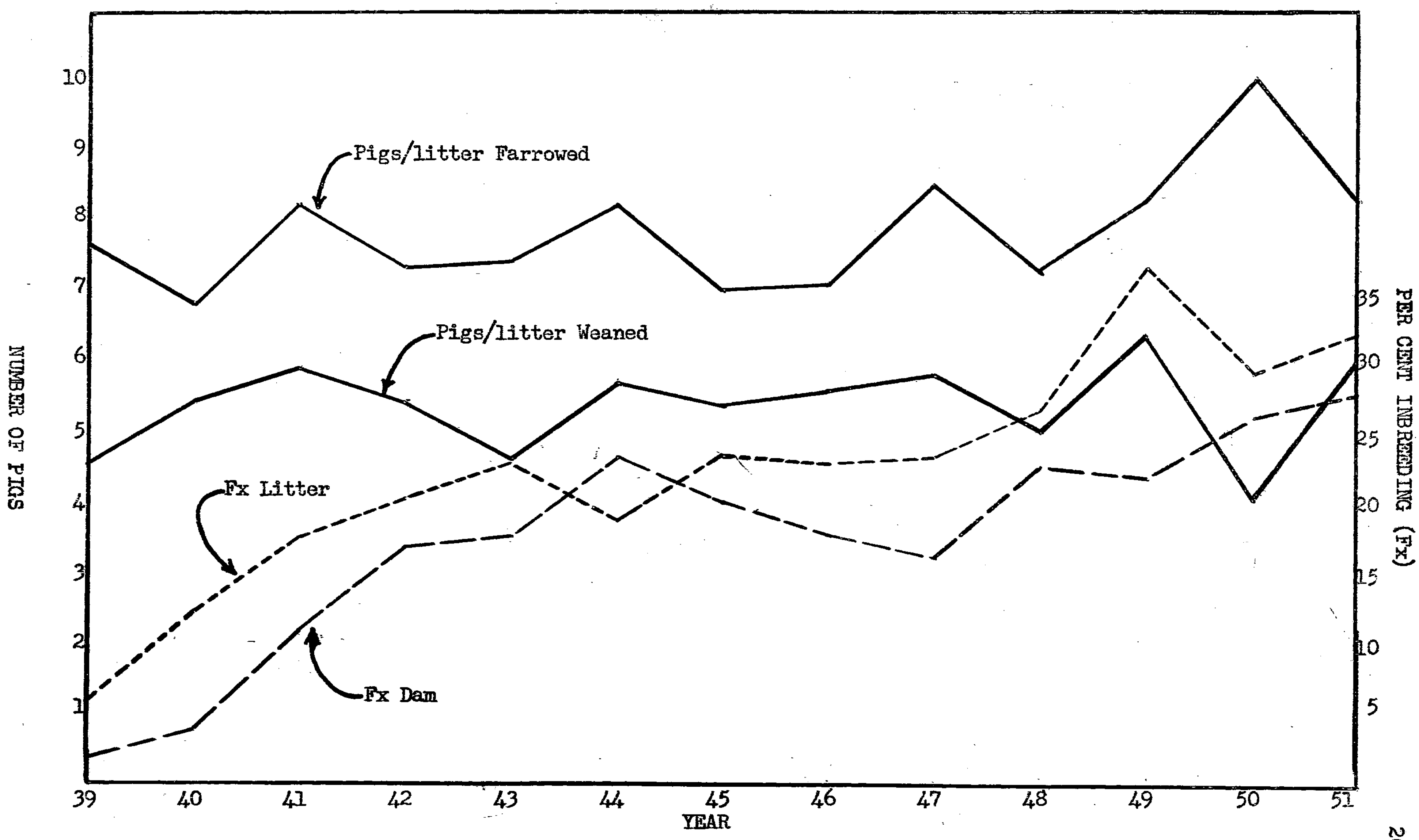


FIGURE 2. Average number of pigs farrowed and weaned per litter by years, and average inbreeding of the dams and litters by years.

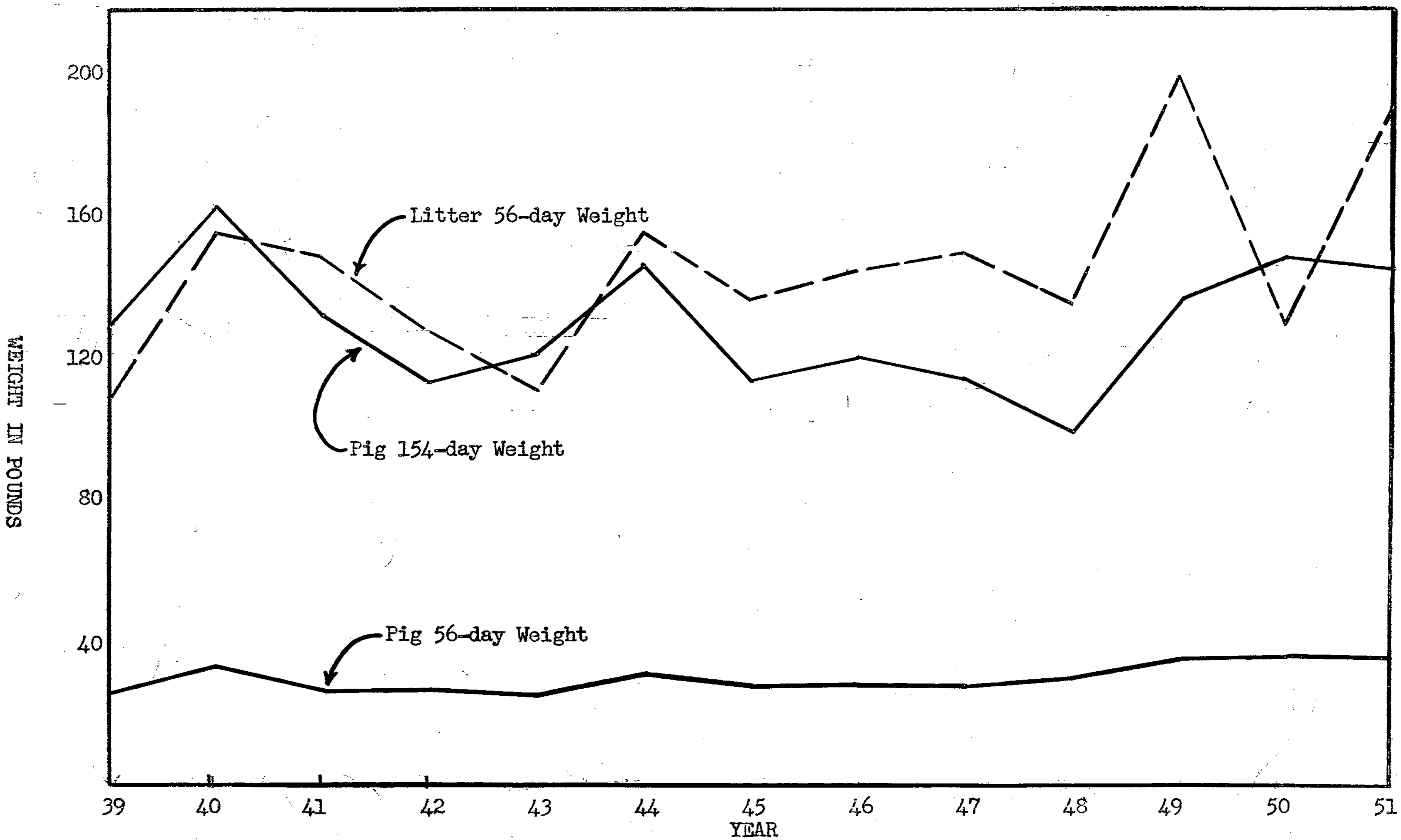


FIGURE 3. Average litter weaning weight and individual pig 56 and 154-day weights by years.

TABLE 6

NUMBER OF PIGS WEANED BY SEASON AND NUMBER RETAINED FOR BREEDING HERD

	GILTS			BOARS		
	NUMBER WEANED	NUMBER RETAINED	PER CENT RETAINED	NUMBER WEANED	NUMBER RETAINED	PER CENT RETAINED
1939S	24	4	16.7	25	2	8.0
1939F	16	2	12.5	19	1	5.3
1940S	35	7	20.0	36	2	5.6
1940F	29	8	27.6	24	3	12.5
1941S	32	4	12.5	37	1	2.7
1941F	32	8	25.0	20	3	15.0
1942S	42	8	19.0	32	3	9.4
1942F	22	6	27.3	29	1	3.4
1943S	23	2	8.7	37	3	8.1
1943F	19	7	36.8	15	2	13.3
1944S	33	11	33.3	16	2	12.5
1944F	16	5	31.2	17	1	13.3
1945F	38	9	23.7	26	1	3.8
1946S	36	6	16.7	33	2	6.1
1946F	34	6	17.6	51	2	3.9
1947S	29	6	20.7	29	1	3.4
1947F	15	5	33.3	19	1	5.3
1948S	36	15	41.6	26	1	3.8
1948F	6	3	50.0	12	2	16.7
1949S	30	9	30.0	33	0	0.0
1949F	0	0	0.0	0	0	0.0
1950S	17	2	11.8	26	1	3.8
1950F	6	0	0.0	7	0	0.0
1951S	18	15	83.3	26	3	11.5
Average			25.7			6.6

population from which they came. The difference between these two averages is referred to as the selection differential.

The selection differential for a particular characteristic depends primarily on the number of traits being considered in selection, the amount of variation in each, the relative emphasis placed on each, the correlations among them and the proportion of animals needed for breeding.

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 7. These calculations were made on data adjusted to a gilt age basis by the method previously presented. This and succeeding formulas for determining selection differentials are presented by Dickerson (1950).

A selection differential on dams (ΔD) was determined each season by the formula:

$$\Delta D = \frac{\frac{N_1 D_1}{2} + N_2 \cdot 2D_2 + N_3 \cdot 2D_3}{N_1 + N_2 + N_3}$$

Where

N_1 = Number of gilt litters farrowed this season.

N_2 = Number of line litters farrowed this season by older sows with inbred litter performance six months before.

N_3 = Number of line litters farrowed this season by older sows with line-cross litter performance six months before.

D_1 = Average for dams of the gilts farrowing (weighted according to the number of gilts from each sow), less the average for all sows farrowing one year earlier when the gilts were born.

D_2 = Average performance last season of selected older sows farrowing this season, less the average performance of all sows farrowing last season.

D_3 = Average line-cross performance last season of selected older sows, farrowing line litters this season, less average production of all sows farrowing line-cross litters last season.

The quantity D_1 is actually the difference between the dams of the selected gilts and the average of the sow herd during the season in which the gilts were produced. Since this figure is obtained from the dam's performance, an estimate of the gilts producing ability is obtained by dividing this figure by two.

The quantities D_2 and D_3 are based on the differences between older sows producing inbred litters this season and the averages of their respective groups last season. Since this selection is over a six month period only, it is multiplied by two to place D_1, D_2 and D_3 on an equal basis of one year. Thus, the selection differential, although computed for each season, is really on an annual basis. By multiplying each quantity by the number of litters farrowed within the respective group, and dividing by the total number of litters produced, the difference is on an annual basis per individual, per season.

The sires selection for sow productivity was determined by the formula:

$$\Delta S = \frac{\frac{N_1 S_1}{2} + N_2 S_2 + N_3 S_3}{N_1 + N_2 + N_3}$$

Where:

N_1 = Number of pigs weaned by one year old sires.

N_2 = Number of pigs weaned by 1-1/2 year old sires.

N_3 = Number of pigs weaned by 2 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 1-1/2 year old 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 sire). Dams records are all in the season when boars were born.

S_3 = Average of dams of 2 year old sires (weighted by number of pigs weaned by each sire) less the average for dams of all sires of same age group in use in season before (weighted by number of pigs weaned by each sire). Dams 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 is divided by two. For older sires, the quantities S_2 and S_3 are multiplied by two to place them on an annual basis, then divided by two, as only one half of the boar's inheritance is received from his dam, hence the quantity N_2 S_2.

From the data in Table 7, it can be seen that equal emphasis was placed on both boar and sow selection for number of pigs farrowed. The data indicate that much more emphasis was placed on sow selection for number of pigs weaned per litter and litter weaning weight. This occurred in spite of the fact that four times as many sows as boars were retained for the breeding herd.

The average annual selection differential is a weighted average. The selection differential for each season is weighted by the number of pigs weaned in that season. These figures indicate that selection on the dams as compared to selection on the boars was about equal for pigs per litter farrowed, nearly twice as great for pigs per litter weaned and one and one-half times as great for litter weaning weight.

The total selection for any season is the arithmetic average of the two selection differentials. The total average annual selection shown in Table 7 was determined by the formula:

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

These annual selection differentials indicate that an average of 0.56 pig per year increase was sought in size of litter farrowed and an average of 0.88 pig per year in size of litter weaned. There was a 27 pound increase selected for annually in litter weaning weight. Actually, the amount of this selection advantage which could be transmitted is determined by the heritability of each trait. As inbreeding increases, heritability decreases by the quantity 1-F, F being the average increase in coefficient of inbreeding. Thus, as inbreeding increases, theoretically a greater selection differential must be attained to hold levels of production constant.

Intraseason standard deviations for each of the traits under consideration, as presented in Table 7, were computed to determined the intensity of selection. The larger the selection differential in relation to the standard deviation, the more intense the selection. The selection differential for size of litter farrowed was approximately 23 per cent of a standard deviation. According to Lush (1947) this selection differential represents a selection intensity the equivalent of culling the poorest 12 per cent of the population on the basis of size of litter farrowed. Actually, as may be determined from Table 2, 47 per cent of the total number of sows and 65 per cent of the boars were culled after producing litters. Of the three items of productivity, selection for pigs per litter farrowed is weakest in intensity. The

TABLE 7

SELECTION DIFFERENTIALS OF PRODUCTIVITY ITEMS IN LINE 3

	PIGS PER LITTER				LITTER WEANING WEIGHT (Pounds)	
	FARROWED		WEANED			
	Δ D	Δ S	Δ D	Δ S	Δ D	Δ S
1939S	.38	.75	.62	1.25	8.12	16.25
1939F	2.90	0	1.67	0	42.78	0
1940S	1.01	.28	3.39	.24	74.24	14.49
1940F	.29	.26	2.06	1.54	45.74	22.74
1941S	.83	.05	.34	.48	.57	5.06
1941F	2.14	1.32	.44	1.30	1.66	23.89
1942S	.78	.16	1.29	.31	32.88	47.67
1942F	.71	.72	.88	.13	15.65	1.47
1943S	1.39	.53	.38	.29	10.07	9.50
1943F	.54	.42	.80	.53	22.19	25.42
1944S	2.95	.52	2.60	.45	91.62	13.83
1944F	.16	1.34	.16	.11	2.83	11.58
1945S	.34	.32	1.86	1.15	42.92	29.06
1945F	.37	1.27	.73	.09	12.73	1.16
1946S	.94	1.24	1.59	1.20	43.96	34.81
1946F	1.11	1.45	1.29	1.25	35.34	18.17
1947S	1.31	.23	1.88	.38	72.26	7.38
1947F	1.27	.02	2.05	.24	29.70	2.56
1948S	.24	.41	.65	1.07	38.29	49.58
1948F	.45	.61	1.69	.43	69.00	2.01
1949S	.14	.27	.02	.14	11.21	9.03
1949F	—	—	—	—	—	—
1950S	.38	.27	1.38	1.35	70.30	45.36
1950F	1.16	.46	.34	.52	15.74	7.07
1951S	.35	5.55	.45	4.32	36.06	114.13
Average Annual Selection	.56	.55	1.13	.64	33.94	21.29
Total Ave. Annual Selection	.56		.88		27.62	
Standard Deviation	2.41		2.35		61.81	

selection differentials for size of litter weaned and weights of litter weaned are 33 per cent and 44 per cent respectively of their standard deviations.

In selecting for productivity some automatic selection will probably take place 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 actual selection of these gilts to determine if the actual selection was more effective than automatic selection. This automatic selection is the difference between the average of the dams of the selected gilts (weighted by the number of gilts weaned per litter) and the average of the dams of all gilts in the season in which the gilts were farrowed (weighted by the number of litters farrowed). In computing actual selection differentials, the dam's records must be used since the gilts have not produced a litter, therefore:

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

This automatic selection may be compared to the quantity D_1 in the formula for calculating the actual selection differential. This quantity is the actual selection on the gilts. 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. Comparison of automatic and actual selection in the three traits of sow productivity is presented in Table 8. The weighted average for the entire period is obtained by weighting each season by the number of gilts farrowing that season. Deliberate selection is obtained by

TABLE 8

COMPARISON OF AUTOMATIC AND ACTUAL SELECTION IN THREE TRAITS OF SOW PRODUCTIVITY. GILTS ONLY.

	NO. GILTS LITTERS FARROWED	SIZE OF LITTER FARROWED			SIZE OF LITTER WEANED			WEIGHT OF LITTER WEANED		
		Actual Selection	Automatic Selection	Deliberate Selection	Actual Selection	Automatic Selection	Deliberate Selection	Actual Selection	Automatic Selection	Deliberate Selection
1939S										
1939F										
1940S	2	3.58	1.52	2.06	2.27	0.63	1.64	47.41	12.34	35.07
1940F	2	0.94	0.09	0.85	3.04	2.19	0.85	63.23	48.00	15.23
1941S	7	-0.66	0.53	-1.19	0.28	0.83	-0.55	22.30	14.71	7.59
1941F	6	1.06	1.62	0.56	-1.15	2.43	1.28	38.40	43.64	- 5.24
1942S	4	-0.33	0.14	-0.47	0.61	0.43	0.18	22.46	8.07	14.39
1942F	3	-1.40	0.08	-1.48	-0.10	0.41	-0.51	10.73	10.38	-21.11
1943S	4	1.19	1.11	0.08	1.02	1.16	-0.14	23.07	27.86	- 4.79
1943F	6	-0.14	0.30	-0.44	1.29	1.21	0.08	27.58	14.68	12.90
1944S	1	2.43	1.08	1.35	0.71	1.21	-0.50	26.69	26.02	0.67
1944F										
1945S										
1945F										
1946S										
1946F	9	0.65	0.44	0.21	0.83	0.56	0.27	20.01	10.64	9.37
1947S	6	-0.55	0.76	-1.31	0.56	1.00	0.44	41.54	17.91	23.63
1947F	3	1.42	0.83	0.59	1.53	0.93	0.60	50.84	25.61	25.23
1948S	6	0.34	-0.04	0.38	0.98	0.44	0.54	63.92	15.82	48.10
1948F	2	0.73	0.27	0.46	0.96	0.47	0.49	44.91	8.36	36.55
1949S										
1949F										
1950S										
1950F										
1951S	2	-0.07	0.06	-0.13	0.02	0.17	-0.15	1.56	3.67	- 2.11
Weighted Average		.345	.575	- .229	.911	.950	- .039	31.88	18.63	13.25
½ Weighted Average		.172	.288		.456	.475		15.940	9.315	
Automatic Selection / Actual Selection			1.67			1.04			.58	

subtracting the amount of automatic selection from actual selection. This deliberate selection is the increase in the amount of selection obtained over purely random selection of gilts who reached weaning age. Positive figures for deliberate selection indicate how much actual selection surpassed automatic selection. No gilts were selected for several seasons, therefore, those seasons are omitted in Table 8.

Selection differentials were also computed for individual items on both sires and dams. Since the individual's own record plays an important part in selection, a study of individual performance as to 56-day and 154-day weights and inbreeding were computed and tabulated in Table 9. In each case a seasonal selection differential was computed separately for sows and boars. The measurements used were actually tabulated for the animal. No dam corrections were made, the individuals were merely grouped within sex as to respective ages. The calculations of the selection differential on dams in each season on an annual basis and for each individual item was determined by using the formula:

$$\Delta D = \frac{N_1 D_1 + N_2 (2D_2) + N_3 (2D_3) + \ldots\ldots}{N_1 + N_2 + N_3 + \ldots\ldots}$$

Where:

N_1 = the number of progeny weaned by gilts.

N_2 = the number of progeny weaned by one and one-half year old sows.

N_3 = the number of progeny weaned by two year old sows, etc.

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

TABLE 9

SELECTION DIFFERENTIALS FOR INDIVIDUAL ITEMS IN LINE 3

	INBREEDING		INDIVIDUAL 56-DAY WEIGHT		INDIVIDUAL 154-DAY WEIGHT	
	Δ D	Δ S	Δ D	Δ S	Δ D	Δ S
1939S	—	—	—		—	
1939F	—	—	—		—	
1940S	-0.33	-3.78	-4.23	4.73	6.63	9.34
1940F	0	18.99	- .42	-4.08	- 1.25	- 2.20
1941S	-2.67	3.47	6.56	9.43	14.84	20.12
1941F	1.71	5.95	.84	3.44	8.23	7.40
1942S	-0.94	-5.42	4.40	3.29	10.86	8.48
1942F	-3.56	1.97	1.75	3.94	- 0.77	7.76
1943S	-8.65	3.55	3.54	2.44	15.12	21.76
1943F	1.33	-12.52	4.92	6.77	25.34	26.42
1944S	5.93	-5.93	.22	2.30	5.22	10.35
1944F	5.08	3.99	-2.20	-3.80	-20.31	- 9.36
1945S	-1.05	2.18	2.10	3.19	20.18	17.74
1945F	-1.08	3.24	3.22	4.01	1.60	3.01
1946S	-3.54	3.84	.08	.97	-15.83	-11.46
1946F	-3.27	2.60	.77	-2.15	16.06	13.11
1947S	-5.72	-8.59	4.81	8.26	24.82	34.90
1947F	-4.57	- .03	.24	8.15	7.10	27.58
1948S	3.50	-3.08	8.48	2.63	53.79	26.27
1948F	3.40	0.18	-1.78	-3.06	12.79	13.06
1949S	1.66	- .61	.25	2.88	4.05	17.82
1949F	—	—	—	—	—	—
1950S	-0.27	.61	.55	6.62	5.23	32.73
1950F	.46	- .37	.24	-1.38	- 1.03	- 2.77
1951S	.19	- .82	1.32	1.89	6.46	4.45
Average Annual Selection	-1.05	.58	2.17	2.95	10.17	12.71
Total Ave. Annual Selection	-.24		2.56		11.44	
Standard Deviation	15.71		10.48		30.00	

D_2 = the average weight or inbreeding coefficient of sows farrowing this season as one and one-half year olds (weighted according to the number of progeny weaned by each) less the average of all sows which farrowed the season before as one year olds (weighted according to the number of progeny weaned by each last year.)

D_3 = the 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. D_2 and D_3 represent the selection practiced on sows over a six month period. D_2 and D_3 therefore must be multiplied by two in order to place them on the same one year basis as D_1. Calculation of the selection differentials for the sires for each of these individual items on an annual basis were computed by the use of the formula:

$$\Delta S = \frac{N_1 S_1 + N_2 (2S_2) + N_3 (2S_3) + \ldots\ldots}{N_1 + N_2 + N_3 + \ldots\ldots}$$

Where:

N_1 = the number of progeny weaned by one year old sires.

N_2 = the number of progeny weaned by one and one-half year old sires.

N_3 = the number of progeny weaned by two year old sires, etc.

S_1 = average weight or inbreeding coefficient 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 = the average weight or inbreeding coefficient 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 old boars the season before (weighted according to the number of progeny weaned by each).

S_3 = average weight or inbreeding coefficient for two year old sires (weighted according to the number of progeny weaned by each) less the average for all sires with litters as one and one-half year olds in the season before (weighted according to the number of progeny weaned by each).

The values obtained for the one year old sires are over a one year period. The values obtained for older sires, however, are obtained over a six months period and are multiplied by two to place them on an annual basis.

In the formulas for ΔD and ΔS the selection differential in each age group for sires or dams is weighted by the number of progeny weaned by each selected sire or selected dam. Total selection practiced in each season is obtained by the formula:

$$\text{Total Selection} = \frac{\Delta D + \Delta S}{2}$$

The average annual selection for individual 56 and 154-day weights and coefficient of inbreeding were computed. Average annual selection for 56-day weight was 2.56 pounds. Selection for 154-day weight was 11.44 pounds and selection for inbreeding was -.24 per cent. On the average, individuals selected for the breeding herd were less inbred than the population from which they were selected.

The standard deviation is an estimate of the variability of the population and here again can be used to determine the intensity of selection. Selection differentials for pig 56-day weight and pig 154-day weight were respectively 24 per cent and 38 per cent of a standard deviation. Selection pressure for inbreeding was slightly negative.

When selection is based on individuality alone the expected change in merit annually depends on:

1. The amount by which inbreeding is increased.
2. The average change in phenotypic merit that would result per unit increase in inbreeding in the absence of selection.
3. The extent to which phenotypic differences are heritable.
4. The average amount by which phenotypic merit of breeding animals excels the mean phenotypic merit of the group from which they are selected. This may be expressed by the formula:

$$y = bI + sH$$

Where:

y = the expected change per year.

I = the annual increase in inbreeding.

s = the annual selection differential.

H = heritability.

b = the average change in phenotypic merit of offspring per unit of inbreeding when either s or H equals 0.

sH is the change in merit resulting from selection since only the heritable portion of the selection differential may be transmitted from parent to offspring. bI is the change in merit due to inbreeding since b is the change per unit of inbreeding and I the number of units by which inbreeding changes. When y equals 0, selection is just sufficient to offset the effects of inbreeding.

To determine the effects of inbreeding of sow and inbreeding of litter on the five traits under study, total and intraseason simple regression coefficients were computed. The results of this study are presented in Table 10. Since inbreeding of sow and inbreeding of litter both increased at similar rates throughout the course of the study, it was not considered that the two regression coefficients for one trait were completely unrelated. A more precise measure of the independent effects of inbreeding of sow and inbreeding of litter on each item was desired.

Standard partial regression coefficients were believed to provide a more nearly exact means of measurement of the separate effects of inbreeding of sow and inbreeding of litter. The standard partial regression coefficients as presented in Table 11 are the result of this study. In this table, regressions of litter size at birth, litter size at weaning, litter weaning weight, individual pig weaning weight and individual pig 154-day weight on inbreeding of dam, holding inbreeding of litter constant, and on inbreeding of litter holding inbreeding of sow constant are tabulated. Due to the considerable variation between seasons, the intraseason regression coefficients are believed to be the best estimate of the effects of inbreeding of dam and inbreeding of litter on the traits under consideration.

Actual average annual gains were computed for each of the five traits studied. Average yearly increases in inbreeding of sow and litter were also determined. These averages were computed by subtracting the average performance for one season from the average performance in that trait one year earlier. In this manner, an arithmetic average for yearly gain in each characteristic was computed.

TABLE 10

TOTAL AND INTRASEASON SIMPLE REGRESSIONS OF LITTER SIZE AT BIRTH (N_o), LITTER SIZE AT WEANING (N_{56}), LITTER WEIGHT AT WEANING (T_{56}), PIG WEIGHT AT WEANING (W_{56}) AND PIG WEIGHT AT 154-DAYS (W_{154}) ON INBREEDING OF DAM (I_d) AND INBREEDING OF LITTER (I_l).

	N_oI_d	N_oI_l	$N_{56}I_d$	$N_{56}I_l$	$T_{56}I_d$	$T_{56}I_l$	$W_{56}I_d$	$W_{56}I_l$	$W_{154}I_d$	$W_{154}I_l$
TOTAL	.024	.007	-.028	.011	.053	-.838	.020	.024	-.630	-1.108
INTRASEASON	.011	-.022	-.041	.053	.037	-.487	-.131	-.085	-.654	-1.302

TABLE 11

TOTAL AND INTRASEASON STANDARD PARTIAL REGRESSIONS OF LITTER SIZE AT BIRTH (N_o), LITTER SIZE AT WEANING (N_{56}), LITTER WEIGHT AT WEANING (T_{56}), PIG WEIGHT AT WEANING (W_{56}) AND PIG WEIGHT AT 154 DAYS (W_{154}) ON INBREEDING OF DAM HOLDING INBREEDING OF LITTER CONSTANT (d·l) AND ON INBREEDING OF LITTER HOLDING INBREEDING OF DAM CONSTANT (l·d)

	N_o		N_{56}		T_{56}		W_{56}		W_{154}	
	d·l	l·d	d·l	l·d	d·l	l·d	d·l	l·d	d·l	l·d
TOTAL	.034	-.019	-.049	.038	.090	-1.266	.007	.019	.097	- .996
INTRASEASON	.022	-.029	-.071	.072	.260	- .576	-.111	-.044	-.048	-1.284

Due to the limited nature of the data, it was not possible to compute a reliable estimate of heritability for any of these traits. Since heritability will decrease as inbreeding increases, it can be assumed that heritability will decrease approximately in proportion to the quantity, 1-F, where F is the average inbreeding coefficient of the parental generation. From Table 5, the average inbreeding of sows producing inbred litters was 16 per cent. This would indicate an average decline in heritability of 16 per cent from heritability of the outbred foundation animals. For this reason, it was decided to select conservative estimates of heritability from the literature.

Lush and Molln (1942) in their study of experiment station and college herds in eight states, and herds maintained by the Bureau of Animal Industry determined heritability for size of litter farrowed, size of litter weaned and litter weaning weight to be 17, 17 and 18 per cent, respectively. Baker et al. (1943) in their study of six inbred Duroc lines at the Nebraska station found that 15 per cent of the individual pig weight at 56 days was heritable. Comstock et al. (1942) and Nordskog et al. (1944) found heritability of pig 56-day weight to be zero. An estimate of the heritability of pig 154-day weight was not obtainable directly. Whatley (1942) found that at least 30 per cent of the individual variance in 180-day weight in Poland-China swine at the Iowa Station was due to hereditary differences. More recent studies indicate that this estimate of heritability may be too high.

To determine the expected average annual change in merit the following equation was used:

$$y = sH + b_{y\,1.2}\, I_d + b_{y\,2.1}\, I_1$$

Where:

y = the expected change in merit per year.

s = the average annual selection differential.

H = heritability.

$b_{y\ 1\cdot 2}$ = the average change in phenotypic merit per unit of inbreeding of the dam holding inbreeding of litter constant.

$b_{y\ 2\cdot 1}$ = the average change in phenotypic merit per unit of inbreeding of litter holding inbreeding of dam constant.

I_d = the average annual increase in inbreeding of dam.

I_l = the average annual increase in inbreeding of litter.

Results of the study are presented in Table 12. The difference between actual yearly gain and expected yearly gain is presented in the last line of the table. Standard errors for expected gain are also entered. The difference between actual gain and expected gain is larger than the computed standard error in the case of size of litter farrowed and pig 56- day weight. In the other three items under study, the differences are well within the range of the standard error, indicating that these differences could be zero.

TABLE 12

EFFECTIVENESS OF SELECTION IN DUROC LINE 3

	SIZE OF LITTER FARROWED	SIZE OF LITTER WEANED	WEIGHT OF LITTER WEANED	PIG 56-DAY WEIGHT	PIG 154-DAY WEIGHT
Ave. Perform. 1 yr. Later	7.639	5.510	148.053	30.064	127.043
Ave. Perform. This Year	7.735	5.447	142.597	29.160	126.671
ACTUAL GAIN	- .096	.063	5.456	.904	.375
Ave. Ann. Sel. Diff	.56	.88	27.62	2.56	11.44
Heritability	.17*	.17*	.18*	.15*	.30**
GENETIC SELECTION	+ .095	+ .150	+4.972	+ .384	+3.432
Ave. Ann. Incr. in Fx Litter	2.227	2.227	2.227	2.227	2.227
Correction/Unit Incr. in Fx	- .029	.072	- .576	- .044	-1.284
CORRECTION FOR Fx LITTER	- .065	+ .171	-1.283	- .098	-2.859
Ave. Ann. Incr. in Fx Sow	2.195	2.195	2.195	2.195	2.195
Correction/Unit Incr. in Fx	.022	- .071	.260	- .111	- .048
CORRECTION FOR Fx SOW	+ .048	- .156	+ .571	- .244	- .105
Expected Gain	+ .078 ± .143†	+ .165 ± .125	+4.260 ± 3.828	+ .042 ± .463	+ .468 ± 3.888
Actual Gain	- .096	+ .063	+5.456	+ .904	+ .372
Expected Gain	+ .078	+ .165	+4.260	+ .042	+ .468
DIFFERENCE	- .174	- .102	+1.196	+ .862	- .096

* Lush and Molln (1942)
** Baker *et al*. (1943)
*** Whatley (1942)
† Standard Error. G. W. Snedecor. Statistical Methods, 4th Ed. (Ames, Iowa: 1946), p. 366.

DISCUSSION

As originally planned, the swine breeding program at the Oklahoma Agricultural Experiment Station called for the improvement of Duroc swine through a system of inbreeding, selection and outcrossing, when it was believed that outcrossing would be advantageous to the herd. Line 3 started in 1938 and has been maintained as a closed line to date (1952). Although inbreeding has risen to fairly high levels, production has remained fairly constant. No considerable decline has been noted in number of pigs farrowed per litter, number of pigs weaned per litter, litter weaning weight, pig 56-day weight or pig 154-day weight. Since data collected and records maintained over this period were quite complete, it was thought that some explanation of these high levels of production might be found.

It should be emphasized that this line is a selected line, in that it is only one of the four lines which have been retained in the herd. It is likely that one of the reasons for retaining this line is the continued good performance even under a long period of inbreeding. A similar study of all of the lines might not necessarily give the same results.

Progress which can be made in any livestock breeding program where selection is the chief tool, is determined to a large extent by the number of individuals which must be retained as replacements for the breeding herd, the average age of the parents (or generation interval) and the accuracy of selection. In this study, it was determined that approximately 26 per cent of the gilts weaned were retained for replacements for the breeding herd, while 53 per cent of the sows farrowing were retained to produce subsequent litters. These actual figures deviate somewhat from the suggestions of Dickerson and Hazel (1944). Greater selection intensity was practiced on the gilts than they recommended. Average age of sows producing litters was 1.46 years, however, rather than their estimated optimum age of 1.16 to 1.25 years. Although it is difficult to compare these figures directly, it appears that a balance between the two factors, actual selection intensity for gilts and actual age of sows may approach the optimum figures for maximum progress by selection.

The average age of sows producing inbred litters exceeds that of the entire sow herd by 0.31 years. This indicates that, particularly during the latter half of the period included in the study, older sows have produced most of the inbred litters. This is not without exception, however, as may be noted from the number of inbred litters produced by gilts in Table 8.

The average age of the entire sow herd has shown no particular tendency to decline, ranging from 1.12 years to 1.95 years.

The effect of inbreeding, both in 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 is reached without much loss in productive characters if selection is critical. This situation applies very closely to Line 3. The line is approximately 10 sow generations old and inbreeding is slightly greater than 30 per cent. Intensity of selection for productivity items measured as a percentage of the standard deviation, ranges from 23 per cent of a standard deviation for number of pigs farrowed, to 45 per cent of a standard deviation for litter weaning weight. Selection has been quite critical for production in the line.

From Table 5 and Figures 2 and 3, pigs per litter farrowed and weaned do not appear to decline during the period of the study, nor does litter weaning weight decline. The latter will be discussed in more detail later.

Actual average annual changes in the number of pigs farrowed and weaned per litter were computed.

The average size of litter farrowed decreased by -.096 pig per year as size of litter weaned increased by + .063 pig per litter per year. It was desired to determine to what extent inbreeding of sow and of litter affected these characteristics. To avoid the effects of seasonal variation, intraseason partial regression coefficients were computed, and were believed to present the best measure of the effects of inbreeding. These partial regressions were computed to determined the separate effects of inbreeding of sow and of litter. These regression coefficients are presented in Table 11.

These corresponding partial regression coefficients for size of litter farrowed were .022, and -.029. Theoretically, an increase of one per cent in the inbreeding of both sow and litter would cause a decline of .007 of a pig. Actual annual increases in inbreeding were larger and the theoretical decline in size of litter size farrowed due to inbreeding was determined to be .017 of a pig per year. This leaves an additional amount of decline in litter size of .079 of a pig not accounted for. The average annual selection differential was + 0.56 pig. If any part of the variation in litter size is heritable, then some part of the decline due to inbreeding could be compensated for. One possible explanation may be offered. If the heritability estimate used in this study had been lower, for example, 10 per cent, the difference between actual and expected gain would have been .039 with a standard error of ± .143. This is a quite real possibility. If heritability had been low originally, and decreased with inbreeding as could be expected, the estimate of 17 per cent as the maximum estimate of Lush and Molln (1942) may be too high. Selection intensity was not high enough to offset the decline caused by inbreeding.

Partial regressions for size of litter weaned were -.071 and .072. These regressions indicate that with no selection, and approximately equal increases in the inbreeding of sow and litter, that production could be held constant. With some positive selection pressure, production could be increased. This corresponds to the actual annual gain of .063. Again, the expected gain was greater than the actual gain, but the difference between the two fell well within the range of the standard error.

Inbreeding of dam and litter caused a net decline in the weight of litter weaned. Selection intensity for this trait was much greater than that for size of litter farrowed, and actual gain and expected gain corresponded rather closely. There was an increase in litter weight with an increase in inbreeding of the sow, but this was more than offset by a decrease in litter weight with an increase in inbreeding of the litter itself. Selection pressure alone therefore seems responsible for the increase in litter weight at weaning.

Pig 56-day and 154-day weights will be considered together. Selection intensities for both traits were appreciable. Inbreeding of both dam and pig was responsible for a decline in merit, but a positive actual gain was achieved through selection. The difference between actual gain and expected gain in pig 56-day weight exceeds the standard error but again this could be accounted for by the use of an estimate of heritability which was too large to actually describe this population.

It was desired to determine how much of the selection of gilts for productivity was deliberate and how much would have taken place if selection of gilts among those available for selection had been purely random. These results were presented in Table 8.

For number of pigs farrowed and number of pigs weaned, automatic selection was greater than the actual selection achieved. This indicates that deliberate selection actually decreased the selection differentials which would have been attained had random selection been practiced. No explanation is made for this other than the fact that more emphasis may have been placed on the growthier pigs from smaller litters which probably have a more desirable pre-weaning environment. This is borne out by selection intensity achieved for individual pig weights at 56-days and 154-days.

Deliberate selection for litter weaning weight nearly doubled the selection differential which would have been attained if selection had been random. This may further indicate that more attention was given to the heavier pigs from moderate sized litters than to smaller pigs from extremely large litters.

The average selection differential for amount of inbreeding indicated that although gilts selected were less inbred than the population from which they were selected, boars were selected on the average from the more highly inbred pigs. The total average annual selection differential, however, was -.24 per cent. Compared to its standard deviation of 15.7, negative selection intensity was extremely low.

A set of nomographs are presented in Figures 4, 5, 6, 7, and 8. Each of these represents the equation for expected gain as described on page 44, for one of the five characters under study. The heritability estimates and partial regression coefficients are held constant as in Table 12, and the selection differentials, increase in inbreeding of sow and increase in inbreeding of litter are permitted to vary. The nomographs are designed so that any combination of three points, falling in a straight line will cause y, the expected gain, to equal zero. The equation for each of the nomographs is presented also. The purpose of these graphs is to illustrate how large a selection differential is required to exactly offset increases in inbreeding of both sow and litter. If a larger selection differential is obtained than this figure obtained from the nomograph, and increases in inbreeding remain constant, then theoretically an increase in that item may be expected.

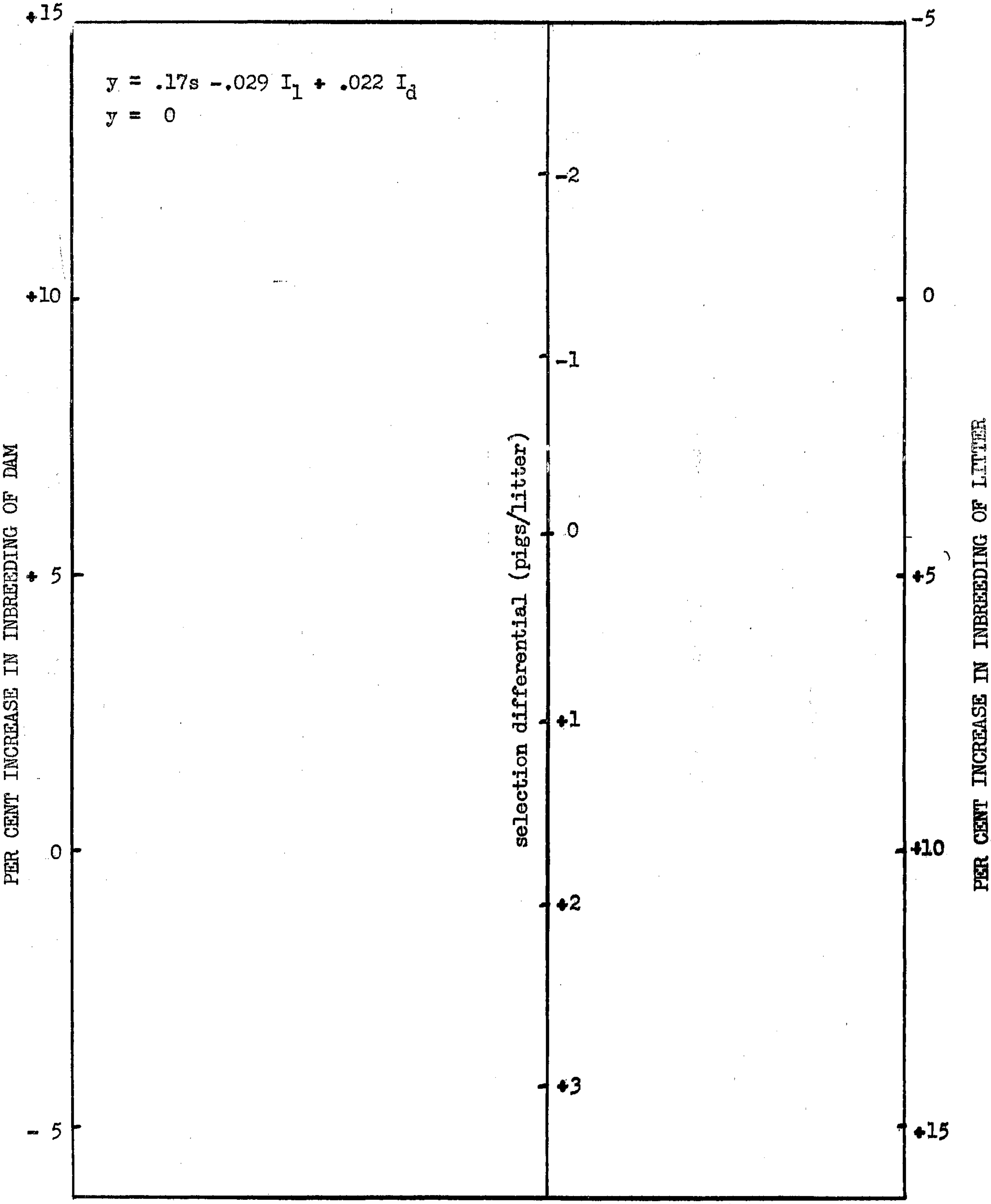


FIGURE 4. Nomograph for litter size at birth. Any combination of three points in a straight line will cause y (expected gain) to equal zero.

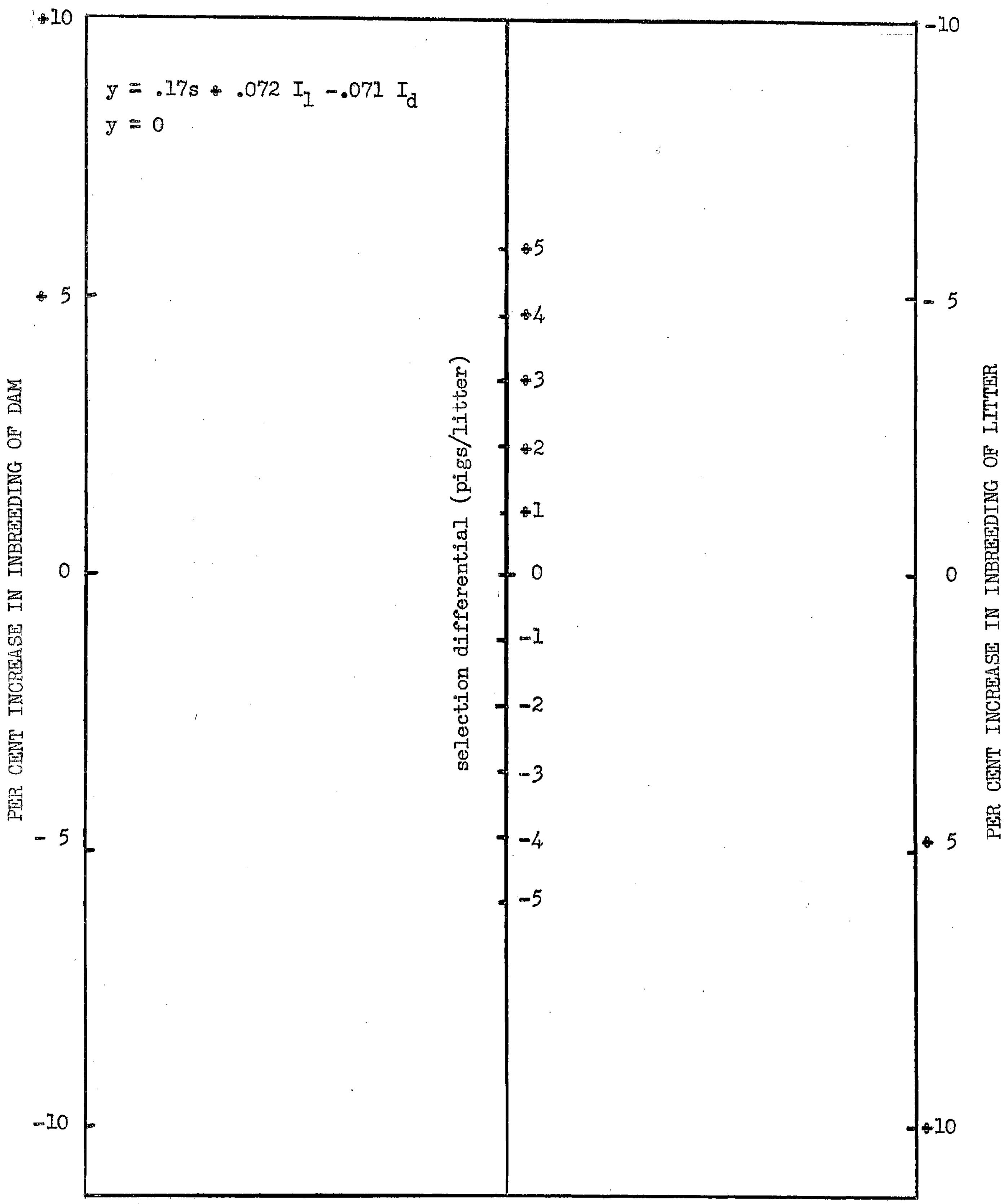


FIGURE 5. Nomograph for litter size at weaning. Any combination of three points in a straight line will cause y (expected gain) to equal zero.

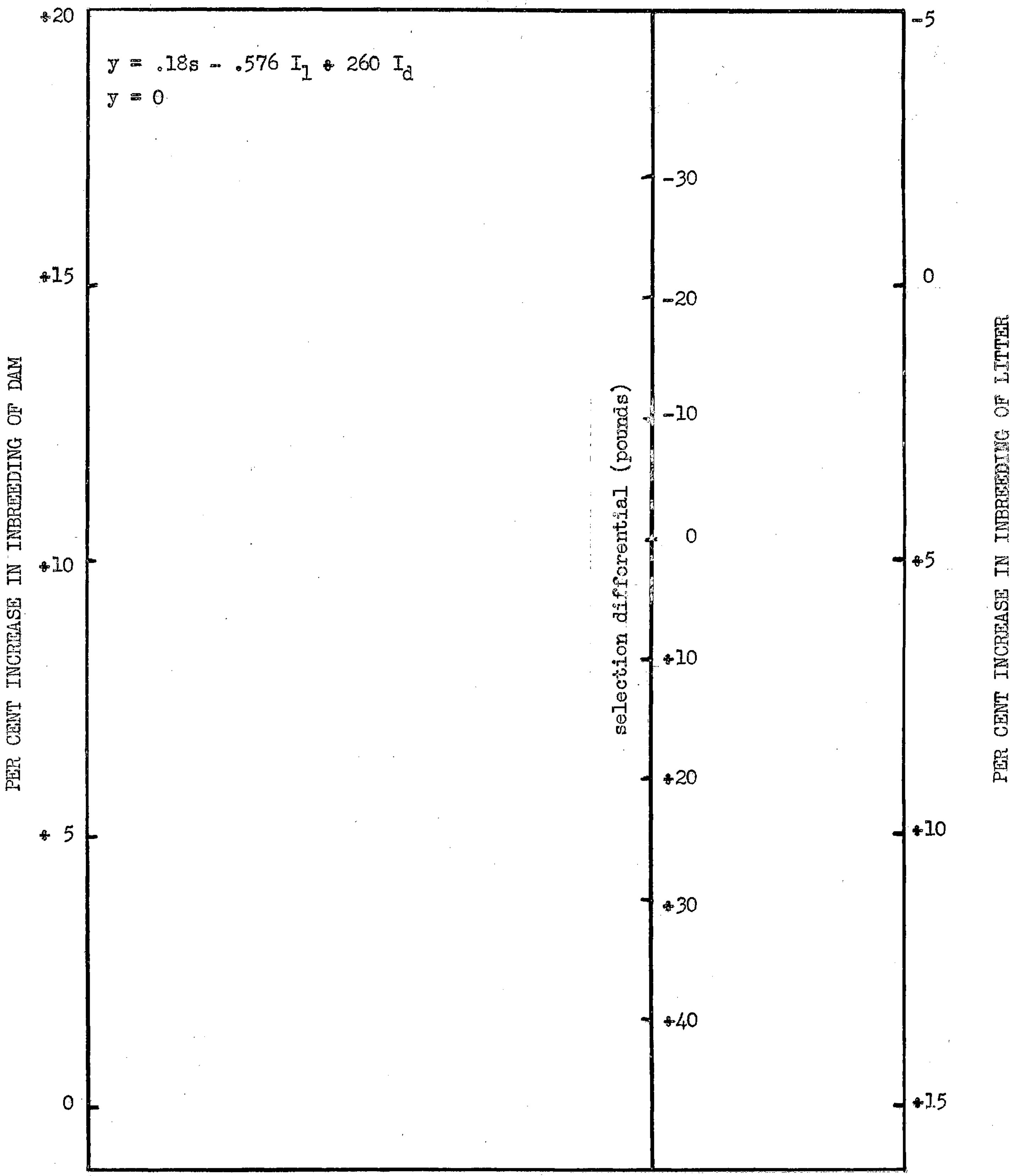


FIGURE 6. Nomograph for litter weaning weight. Any combination of three points will cause y (expected gain) to equal zero.

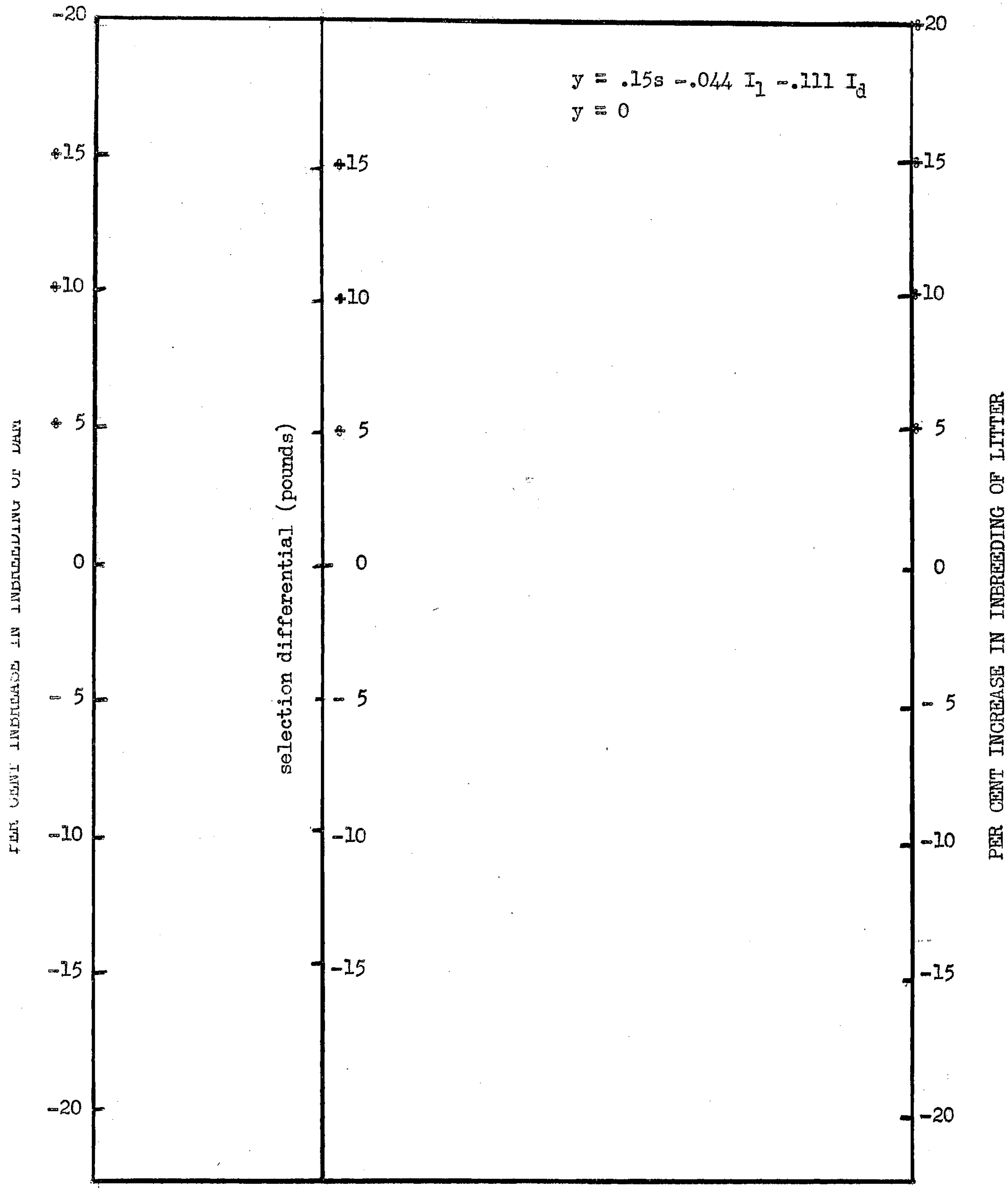


FIGURE 7. Nomograph for pig 56-day weight. Any combination of three points in a straight line will cause y (expected gain) to equal zero.

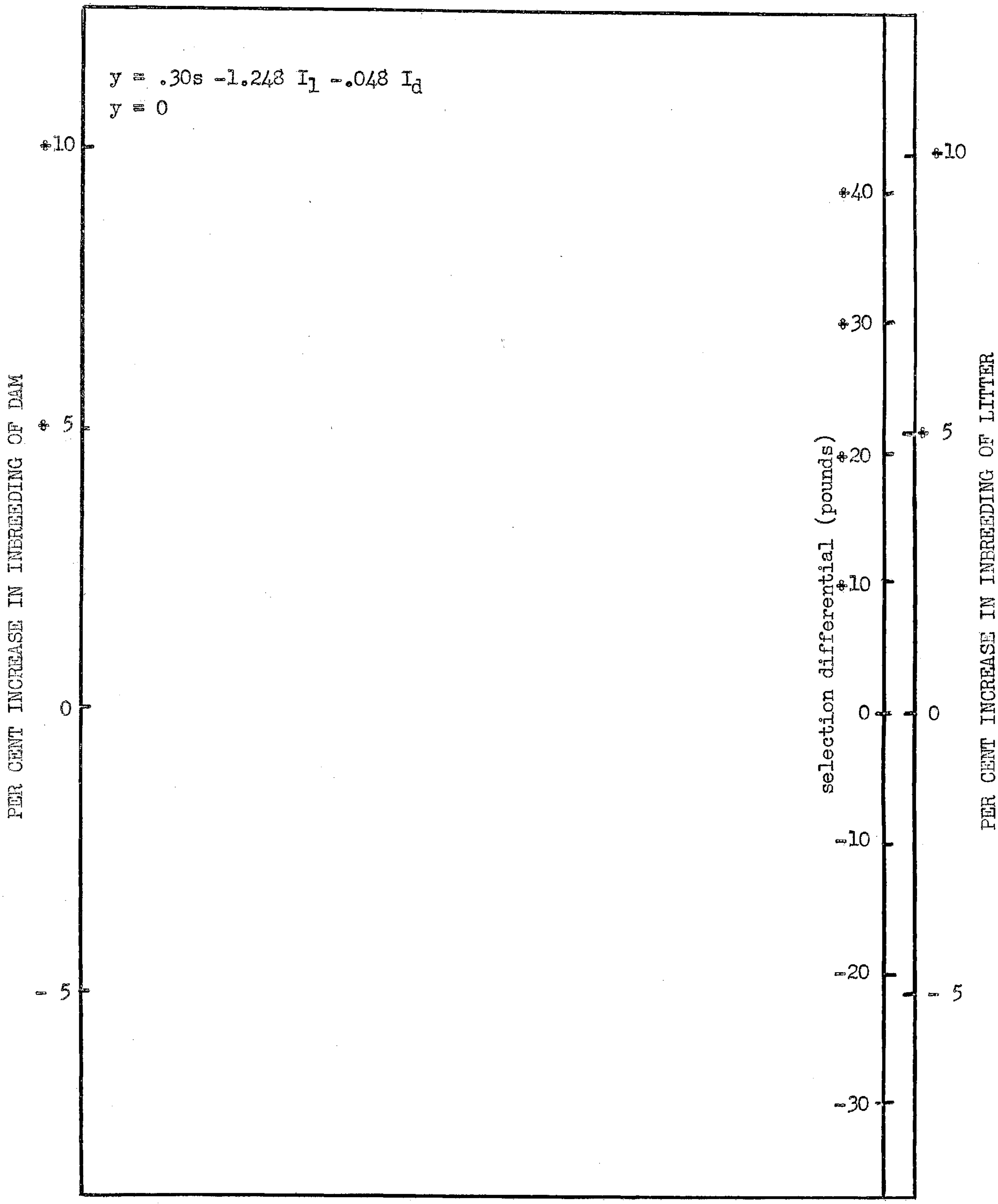


FIGURE 8. Nomograph for pig 154-day weight. Any combination of three points in a straight line will cause y (expected gain) to equal zero.

A STUDY OF THE FLEXED PASTERN CONDITION IN LINE 3

One of the most striking effects of inbreeding is the bringing to light of undesirable hereditary recessive physical defects. The decline in vigor associated with inbreeding is usually slow unless extremely close matings are made. The interaction between genotype and environment may mask true genetic changes in productivity until a long time study has been made. The appearance, in an inbred animal, of a hereditary congenital anomaly, however, is immediately noticed. Such a condition existed in Line 3.

In the spring and fall farrows of 1946, a condition of flexed pasterns appeared. A typical example of a pig affected with this abnormality appears in the photographs in Figure 9.

This anomaly is present at birth, persists for four or five days and gradually disappears. Severity of the defect is quite variable. Mildly affected pigs appear to walk on their toes. In the most severe cases, the extreme flexion may cause the hooves to turn under, causing the pig to walk on the knuckle of the pastern joint. Most frequently, the condition appears in the front legs only, but occasionally, all four feet may be affected.

Frequently, but not invariably, the flexed pastern condition is accompanied by extreme weakness and spraddling of the hind legs. Pigs manifesting this defect are able to nurse normally if given the opportunity, but walk only with great difficulty.

A similar defect was noted by Mead et al. (1943) in the Jersey herd at the University of California. In the inbred calves possessing the

FIGURE 9. Photographs showing a typical pig affected with the flexed pastern condition.

characteristic, the abnormality was present at birth, always affecting the forelegs and infrequently the hind legs also. Degree of severity varied from animal to animal and although bilateral, the defect was not always expressed identically on each side. Affected calves always recovered within six to eight weeks, the milder cases recovering more rapidly. Affected calves showed no higher mortality than normal calves. The workers interpreted the abnormality as being conditioned by a single autosomal recessive gene.

Table 13 summarizes the incidence of the flexed pastern condition since it was first noted. Generally, rate of incidence of the condition is increasing both in the proportion of affected litters farrowed, and in the proportion of the pigs per litter. That this anomaly is of considerable economic importance may be seen by comparing the survival rate of normal pigs and affected pigs. Approximately 37 per cent of the affected pigs have survived to weaning as compared to 67 per cent of the normal pigs. The majority of the baby pig losses occur during the first few days after farrowing before the affected pigs have recovered. Inability of these pigs to walk properly causes most of those lost to be laid on by the sow.

A comparison was made of the pedigrees of those five individuals, one boar and four sows, which produced the first four litters recorded in 1946 as having affected pigs. Assuming that only one foundation animal contributed the condition to the line, only those foundation animals common to the pedigrees of all five animals should be suspected of contributing the gene or genes responsible for the flexed pastern condition. Three such animals were found. The boar Pathmarker and the sows Marion and Cameron 8 were related to the five carrier individuals.

TABLE 13

SUMMARY OF PIGS AND LITTERS AFFECTED BY FLEXED PASTERNS

						PER CENT SURVIVAL TO WEANING	
SEASON	NUMBER LITTERS FARROWED	NUMBER LITTERS AFFECTED	NUMBER PIGS FARROWED	NUMBER PIGS AFFECTED	PER CENT PIGS AFFECTED	NON-AFFECTED PIGS	AFFECTED PIGS
1946S	10	1	95	1	1.1	72.6	0.0
1946F	16	3	124	5	4.0	70.6	60.0
1947S	10	1	92	3	3.3	65.2	0.0
1947F	5	3	47	5	10.6	76.2	40.0
1948S	11	3	100	5	5.0	62.1	60.0
1948F	4	2	22	2	9.1	80.0	100.0
1949S	8	6	88	24	27.3	65.6	66.7
1949F	0	0	0	0	0	0	0
1950S	7	4	94	27	28.7	56.7	14.8
1950F	5	5	58	41	70.7	35.3	11.1
1951S	8	6	70	24	34.3	87.0	16.7
Average	8.4	3.4	79.0	14.0	19.4	67.1	36.9

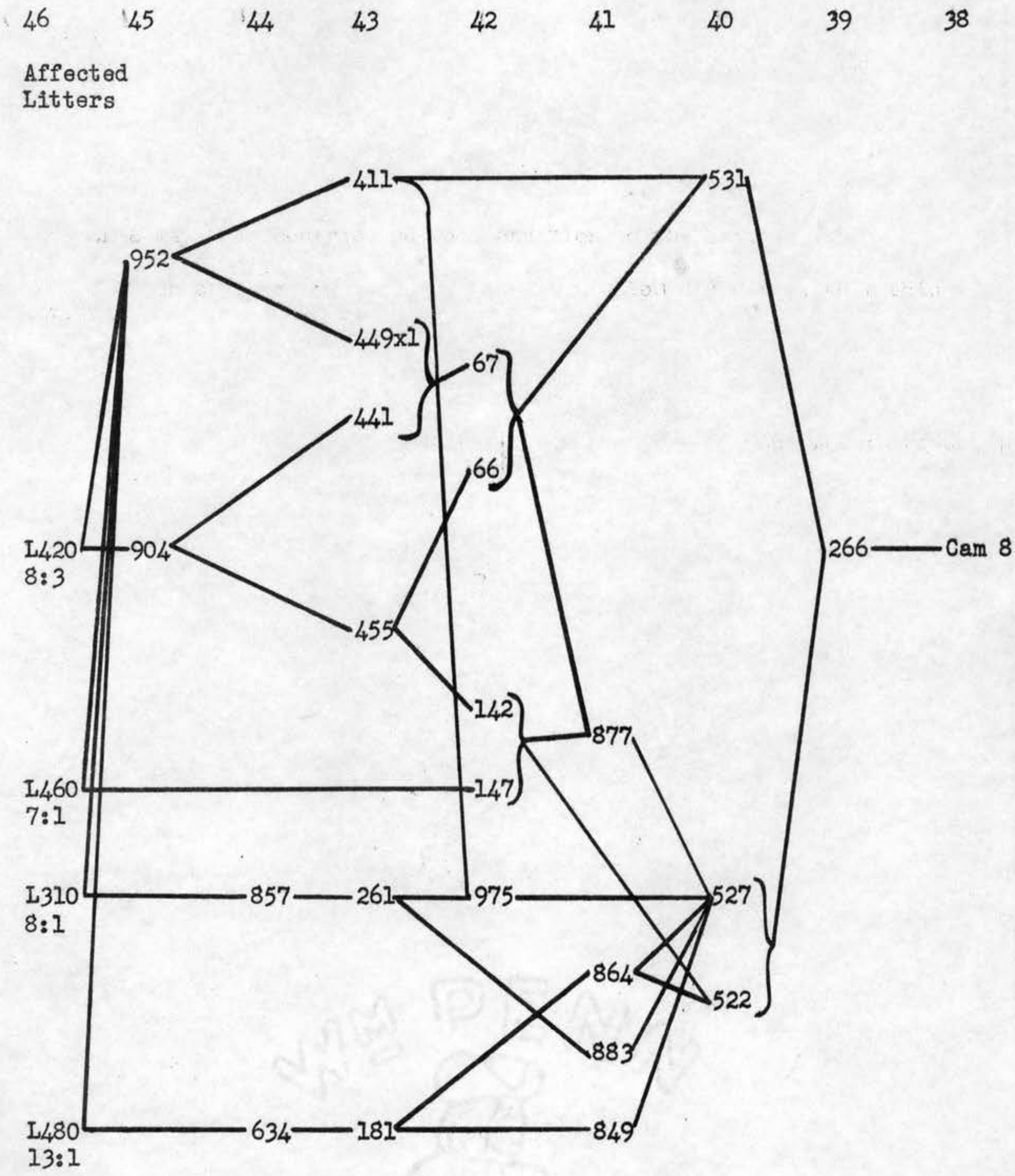
It appears unlikely that either Marion or Pathmarker introduced the condition to Line 3. When purchased, Marion was bred to Pathmarker. Two boar and four gilts were selected from her first litter for the breeding herd. During the following several seasons, descendants of Marion and Pathmarker were mated and total relationship to these two foundation animals increased rather rapidly. Yet, the flexed pastern condition was not recorded in noticeable numbers until 1946. It is possible that this condition occurred earlier and was not recognized. It appears quite possible that Cameron 8 may have contributed the condition to the line.

Further study of the descendants of Cameron 8 indicate that this could possibly be the case. Her only contributing progeny, the boar L266, was used in the line in 1940. All lines of descent from Cameron 8 and L266 to the four affected litters are presented in the pedigree in Figure 10. The ratio of normal to affected pigs is shown under each litter number. Several litters produced by matings between descendants of Cameron 8 were farrowed during the years 1941, 1942 and 1943. Had the flexed pastern condition been conditioned by one pair of genes, it appears quite likely that the anomaly would have appeared during those years. A further study of this pedigree indicates a real possibility that two or more recessive genes may have been accumulating, or increasing in frequency, so that by 1946, the first homozygous recessive individuals were produced. This evidence supports the theory that although the condition is generally recessive in nature, it is not a simple recessive condition governed by one pair of genes.

Prior to the 1951 spring farrow, the anomaly had been noted in four line-cross litters. In two of the litters, Line 3 boars were bred to Duroc Line 5 sows. That ratio of normal to affected pigs was 14 to 5.

FIGURE 10

LINES OF DESCENT FROM CAMERON 8 TO THE FIRST LITTERS AFFECTED
BY THE FLEXED PASTERN CONDITION



The other two litters were produced by Line 3 sows bred to Duroc Line 7 boars. The normal to affected pig ratio in these two litters was 16 to 6. These additional data support the theory that the condition is recessive in nature, since all parents of these litters were presumably not affected at birth.

The exact nature of inheritance is unknown. In a study of the 1950 farrow, all five inbred litters were affected. Rate of incidence varied between litters from 40 per cent to 100 per cent with an average of 71 per cent.

In the spring farrow of 1950, a litter of eight normal pigs sired by L802 was farrowed by the sow L873. In the fall farrow of the same year, from the same mating, three normal and ten affected pigs were farrowed. The boar L802 was himself affected at birth. Postulating that the boar was homozygous recessive for two pairs of genes, and the sow was heterozygous for one pair and homozygous recessive for the other pair of genes, the total ratio of 11 normal to 10 affected pigs is very close to the expected 1:1 ratio. However, the probability of the eight normal pigs in the first litter receiving the one dominant gene from their dam is only 1/256. These few numbers are not sufficient to fully establish a true ratio, but further indicate that more than one pair of genes controls the condition.

In the fall of 1950, two matings were made between an affected boar and two affected littermates. Had the condition been simple recessive this critical test should have produced only affected progeny. Two of the four progeny in one litter were not affected at birth but the other two were affected in both the fore and hind legs. The other mating between this boar and another littermate produced only one live pig, but it was completely normal and vigorous. Here, it was demonstrated that the condition is not simple recessive in nature.

DISCUSSION

These examples may serve to illustrate the difficulty of analysis. It seems quite likely that the abnormality is conditioned by at least two pairs of genes and probably more. Although of a general recessive nature, the anomaly is not controlled by simple recessive genes. Expressivity is variable, both in degree and extent of flexion. If presence of the condition is determined by degree of penetrance, modifying genes or environmental conditions may play an important part in controlling incidence of the anomaly. Climatic conditions during gestation may provide one source of variation. Since the first recorded affected litter in 1946 spring, approximately 17 per cent of the inbred pigs farrowed in the spring have been affected as compared to 24 per cent of the fall farrowed pigs.

Nothing is known definitely of the physiological basis of the condition. Sow and pig rations have been adequate in all respects for other lines of breeding, as the condition has been noted only in Line 3, in any appreciable numbers.

A possible clue may be taken from the work of Ensminger _et al_. (1947). Sows fed rations deficient in thiamine and choline produced pigs possessing various abnormalities of the feed and legs. Thiamine deficient sows lost their appetites and farrowed prematurely. Pigs were generally characterized by a weak-legged condition, including spraddled hind legs and cocked rear pasterns. Choline deficient sows farrowed fairly good litters at the end of a normal gestation period. Pigs, however, showed an extremely weak legged condition and provided a striking resemblance to Line 3 pigs affected with flexed pasterns and spraddled hind legs.

Possibly the nutritional deficiency type of flexed pasterns and the genetic type may be related to some extent. If the dominant alleles of the genes causing the abnormality were actually those concerned with the metabolism of certain specific nutrient materials, then the absence of these dominant genes could actually produce a deficiency of these materials in the parent with the resulting abnormal offspring. Ensminger reports that the choline deficient sows failed to lose their appetites and farrowed normally in all respects. Line 3 sows producing litters affected by the characteristic have a normal gestation period and farrow normally. The further resemblance of litters farrowed by both Line 3 sows and choline deficient sows indicates the although the condition is genetic in nature, that flexed pastern condition may be of nutritional significance.

SUMMARY AND CONCLUSIONS

1. A detailed study of the amount of selection practiced in inbred Line 3 of Duroc swine of the Oklahoma Agricultural Experiment Station in cooperation with the Regional Swine Breeding Laboratory is presented. The data include records of 1950 pigs from 211 inbred litters and 994 pigs from 120 linecross litters farrowed by Line 3 sows. The data cover a period of 14 years and consider the following traits: size of litter farrowed, size of litter weaned, litter weaning weight, individual pig 56-day weight, individual pig 154-day weight and coefficients of inbreeding of sires, dams and litters.
2. Eleven sows and three boars were used as foundation animals for the line. Six of the sows and all three of the boars have contributed to the present breeding herd. Relationship of the pigs farrowed in the spring of 1951 to these contributing foundation animals range from 1.4 to 18.8 per cent.
3. An average of 52.6 per cent of the sows and 35.4 per cent of the boars producing litters were retained to produce subsequent litters.
4. The average age of the entire sow herd was 1.46 years while the average age of the sows producing inbred litters was 1.77 years. The average age of all boars used was 1.35 years.
5. An average of 25.7 per cent of all gilts weaned were retained for the breeding herd, while 6.6 per cent of the males weaned were used as boars in the line.
6. The seasonal average size of litter farrowed, size of litter weaned and litter weaning weight did not change appreciably during this study when data were corrected to gilt equivalent.

7. Selection differentials of .56 pig for size of litter farrowed, .88 pig for size of litter weaned and 27.62 pounds for litter weaning weight were achieved, with corresponding standard deviations of 2.41, 2.35 and 61.81. Selection intensity for litter size farrowed was weakest, and for litter weaning weight was strongest among the items of productivity.
8. Boar selection was from 56 to 98 per cent as intense as sow selection for productivity in spite of the smaller numbers saved.
9. A comparison of actual selection and automatic selection indicates that selection for litter size farrowed and litter size weaned was actually reduced through deliberate selection. Greater selection differentials could have been attained through random selection alone. Deliberate selection for litter weight weaned actually increased actual selection over that which would occur under random selection.
10. Selection differentials for individual 56-day weight and individual 154-day weight were 2.56 pounds and 11.44 pounds respectively. Selection intensity was greater for 154-day weight.
11. Generally, breeding stock selected was .24 per cent less inbred than the population from which they were selected.
12. Inbreeding of the sows had reached a level of 27.7 per cent in the spring of 1951 while the litters they farrowed were 32 per cent inbred.
13. Standard partial regressions on inbreeding of dam and inbreeding of litter are computed. These regressions indicate that inbreeding of the dam, ignoring inbreeding of the litter has a depressing effect on size of litter weaned, and individual 56-day and 154-day weights. The more highly inbred sows farrowed larger litters and weaned heavier litters.

14. Inbreeding of the litter, holding inbreeding of the dam constant, increased the size of litter weaned, but depressed all four other traits.

15. The only one of the five characters studied which actually declined was size of litter farrowed. This is attributed to the weakness of intensity of selection and low heritability of this trait.

16. The difference between the expected annual gain and actual annual gain was of no significance for size of litter weaned, weight of litter weaned, and individual 154-day weight. This same difference for size of litter farrowed and individual 56-day weight fell outside the range of the standard error. The estimates of heritability selected from the literature may be larger than actual average heritability for Line 3. If so, these two differences would be of no significance.

17. A study was made of the flexed pastern condition occurring in Line 3. It was determined that the condition is of a general recessive nature, although not simple recessive and is controlled by two or more pairs of genes. Expressivity is quite variable, and unless an extremely large number of genes control the condition, the concept of penetrance may be required to explain the condition. Physiological basis for the malformation is not known, but genes causing the condition may be recessive alleles of those genes required for the proper metabolism of some nutrient substance.

LITERATURE CITED

Baker, M. L., L. N. Hazel and C. F. Reinmiller. 1943. The Relative Importance of Heredity and Environment in the Growth of Pigs at Different Ages. Jour. Ani. Sci. 2:3-13.

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

Blunn, C. T. and M. L. Baker. 1949. Heritability Estimates of Sow Productivity and Litter Performance. Jour. Ani. Sci. 8:89-97.

Chambers, Doyle and J. A. Whatley, Jr. 1951. Heterosis of Crosses of Inbred Lines of Duroc Swine. Jour. Ani. Sci. 10:505-515.

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

Comstock, R. E., P. S. Jordan and O. M. Kiser. 1942. Measure of Growth Rate for Use in Swine Selection. Jour. Agric. Res. 65:379-389.

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

Craft, W. A. 1952. Swine Breeding Research in the Regional Swine Breeding Laboratory. Unpublished.

Darwin, Charles. 1885. The Origin of Species. D. Appleton and Co. New York.

Dickerson, G. E. 1950. Record of Proceedings of Conference of Collaborators, Regional Swine Breeding Laboratory. Lincoln, Nebraska. p. 18.

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

Dickerson, G. E. and L. N. Hazel. 1944. Selection for Growth Rate of Pigs and Productivity of Sows. Jour. Ani. Sci. 3:201-212.

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

Ensminger, M. E., J. P. Bowland and T. J. Cunha. 1947. Observations on the Thiamine, Riboflavin, and Choline Needs of Sows for Reproduction. Jour. Ani. Sci. 6:409-423.

Fine, N. E. and L. M. Winters. 1952. Selection for Fertility in Two Inbred Lines of Swine. Jour. Ani. Sci. 11:301-312.

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

Goodale, H. D. 1938. A Study of the Inheritance of Body Weight in the Albino Mouse by Selection. Jour. Hered. 29:101-112.

Hays, F. A. 1919. Inbreeding Animals. Delaware Agr. Exp. Sta. Bul. 123.

Hazel, L. N. and J. L. Lush. 1942. The Efficiency of Three Methods of Selection. Jour. Hered. 33:393-399.

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

------ and ------. 1950. Computing Inbreeding and Relationship Coefficients from Punched Cards. Jour. Hered. 41:301-306.

Hetzer, H. O., W. V. Lambert, and J. H. Zeller. 1940. Influence of Inbreeding and Other Factors on Litter Size of Chester White Swine. U. S. Dept. of Agri. Circ. No. 570.

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

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

King, H. D. 1918. Studies on Inbreeding. I. The Effects of Inbreeding on the Growth and Variability in the Body Weight of the Albino Rat. Jour. of Exp. Zool. 26:1-54.

------. 1918. Studies on Inbreeding. II. The Effects of Inbreeding on the Fertility and on the Constitutional Vigor of the Albino Rat. Jour. of Exp. Zool. 26:335-378.

------. 1919. Studies on Inbreeding. IV. A Further Study of the Effects of Inbreeding on the Growth and Variability in the Body Weight of the Albino Rat. Jour. of Exp. Zool. 29:71-112.

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

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

Lerner, I. M. and L. N. Hazel. 1947. Population Genetics of a Poultry Flock under Artificial Selection. Genetics. 32:325-339.

Lush, J. L. 1945. Animal Breeding Plans. 3rd Ed. The Iowa State College Press. Ames. Iowa.

Lush, J. L. and A. E. Molln. 1942. Litter Size and Weight as Permanent Characteristics of Sows. U. S. Dept. of Agri. Tech. Bul. No. 836.

MacArthur, J. W. 1944. Genetics of Body Size and Related Characters. American Naturalist. 78:142-157 and 224-237.

Mead, S. W., P. W. Gregory and W. M. Reagan. 1943. Hereditary Congenital Flexed Pasterns in Jersey Cattle. Jour. Hered. 34:367-372.

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

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

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

Sinnott, E. W. and L. C. Dunn. 1925. Principles of Genetics. McGraw-Hill Book Co., New York.

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

Stringham, E. W., L. M. Winters and P. S. Jordan. 1950. The Geneology of an Inbred Poland China Herd of Swine. Minn. Agri. Exp. Sta. Tech. Bul. 191.

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

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

Winter, F. L. 1929. The Mean and Variability as Affected by Continuous Selection for Composition in Corn. Jour. Agri. Res. 39:451-476.

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

Winters, L. M., J. N. Cummings, and H. A. Stewart. 1947. A Study of Factors Affecting Survival from Birth to Weaning and Total Weaning Weight of the Litter in Swine. <u>Jour. Ani. Sci</u>. 6:288-306.

Wright, Sewall. 1922. The Effects of Inbreeding and Crossbreeding on Guinea Pigs. <u>U. S. Dept. of Agri. Bul. 1090</u>.

-------. 1922. The Effects of Inbreeding and Crossbreeding on Guinea Pigs. <u>U. S. Dept. of Agri. Bul. 1121</u>.

VITA

Rutledge Gordon Holleman, Jr.
candidate for the degree of
Doctor of Philosophy

Thesis: A STUDY OF THE DEVELOPMENT OF AN INBRED LINE OF DUROC SWINE

Major: Animal Breeding

Biographical and Other Items:
Born: December 23, 1924 at Little Rock, Arkansas
Undergraduate Study: California State Polytechnic College, 1946-1947; The State College of Washington, 1947-1948.
Graduate Study: The State College of Washington, 1949-1950; O.A.M.C., 1950-1952.
Experiences: Army, 100th Infantry Division in France and Germany, 1943-1946; Research Biologist, General Electric Company, 1948-1949.

Associate Member of The Society of Sigma Xi.

Date of Final Examination: September , 1952.

THESIS TITLE: A STUDY OF THE DEVELOPMENT OF AN INBRED LINE OF DUROC SWINE

AUTHOR: Rutledge Gordon Holleman, Jr.

THESIS ADVISER: Doctor J. A. Whatley, Jr.

The content and form have been checked and approved by the author and thesis adviser. Changes or corrections in the thesis are not made by the Graduate School office or by any committee. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

TYPIST: Mrs. Belva B. Holleman