THE INFLUENCE OF HEREDITY

ON THE

MARKET SCORE OF DUROC JERSEY HOGS

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INTRODUCTION

The conformation of an individual is, to a certain extent, determined at fertilization by the inheritance received from its sire through the male gamete and the inheritance received from its dam through the female gamete. We realize from common experience and observation that the action of external factors during development also have an effect on the ultimate appearance of the individual. The extent of this environmental effect may vary with different characters. Such characters as color in animals are little effected by changing environment, whereas many economically important characters such as milk production in the dairy cow are easily effected by changing environment.

The heritability, or proportion of hereditary variability, of certain characters is of practical importance to the livestock breeder in estimating the improvement to be expected from various breeding programs. Only by the selection of hereditary differences can improvement be made in the next generation.

"Type" has been defined as an ideal or standard of perfection combining all those characters which best fit an animal for a particular use. Type of the market hog is of value to the producer only in so far as it enables him to select pigs which are capable of making the most economical gains and are in the greatest demand on the market. The cooperating stations of the Regional Swine Breeding Laboratory rate the market value of a hog by the use of a score on conformation at market weight.

It is the purpose of this paper to determine the accuracy of this method of scoring and to determine what percent of the variation in these scores is due to heredity.

REVIEW OF LITERATURE

Working with inbred strains of guinea pigs Wright (1920) made an analysis of the data recorded on the color markings of these pigs. He obtained the following correlations for random bred and inbred stock: Sire-dam (random bred) .019, (inbred) .014; average parent-offspring (random bred) .211, (inbred) .014; average litter mates (random bred) .214, (inbred) .069. The low correlation between mates indicates random mating in so far as color is concerned. He calculated ($r_{po} = \frac{1}{2}h^2$) that the variation in coat color due to heredity (h^2) was 42 percent.

Wright (1934) observed a dam-offspring correlation for the number of digits in a homozygous inbred stock of guinea pigs of .106, and a sire-offspring correlation of .261. From the average parent-offspring correlation (.18) he concluded that 18 percent of the variance in number of digits was genetic, due to sub-strain differences. Correlations between litter mates were .623 and .540 for two different stocks of inbred pigs. These figures represent the variability determined by all factors common to litter mates. Correlations of .25 and .29 were obtained for full sibs of different litters. These figures are about one-half the size of those for litter mates and therefore indicate that about 27 percent of the variation in number of digits was due to factors which act alike on all offspring from the same mating.

Wright and Chase (1936) report that 40 percent of the variation in the spotted patern of the guinea pig was due to heredity. This figure was derived from the average of a parent-offspring correlation of .19 which would give a figure of 38 percent for the hereditary portion of the variance and a determination from the standard deviations of random bred stock and an inbred strain in which the variance of the inbred strain was 59 percent of that of the random breds, leaving 41 percent of the variation due to heredity.

Gowen (1927), in a study of records from the Advanced Registry of the various dairy breed associations, observed a dam-daughter correlation coefficient for milk production of .39 for the average of three breeds. The corresponding correlation for butter fat was .42. Correlation between the potential production of the sire and his daughters for milk production was .51 and for percent of butter fat .52. The general conclusion was that most of the variance in milk production and percent of butter fat was due to inheritance.

Using records from the Scottish Milk Records Association and from the Ayrshire cattle herd book, Smith, Scott, and Fowler (1930) attempted to prove that sex-linked factors played a part in the inheritance of milk production. After correcting the records for age they secured the following correlation coefficients for milk yield: between half-sisters with the sire as the common parent .45, between dam and daughter .42, granddaughter and paternal grandsire .26, granddaughter and maternal grandsire .48, granddaughter and paternal granddam .049, and granddaughter and maternal granddam .131. These correlations are in quite close agreement with those observed by Gowen (1927). It was concluded that the results could be accounted for by other reasons than sex-linked inheritance. However, the fact that similar results were arrived at by different methods and materials confirm the impression that sex-linked factors do play a part in the inheritance of milk yield.

Copeland (1931) studied the contribution of the dam in inheritance of milk and butter fat production. He used records from the Jersey Register of merit. His correlations for yearly butter fat production were as follows: between dam and daughter .40, between dam and her sons' daughters .34, and between sister and her brothers' progeny .37. One reason given for the lower correlation coefficient between the dam and her sons' daughters was that the individuals were very seldom in the same herd whereas the individuals in the correlations between dam and daughter usually were and therefore had more nearly the same environment.

Parent-offspring correlations for milk production were observed by Heizer (1932) similar to those of previous investigators. However, the dam-daughter correlation of .78 for percent of butter fat was somewhat larger than that of other studies. Heizer's investigation was with animals all of which were in the same herd whereas previous studies had been made on Advanced Registry records and therefore included cows from many different herds. Heizer gives the following objections to Advanced Registry records for an analysis of inheritance. (1) These records usually represent selected individuals. (2) Some breeders test only their better cows. (3) Advanced Registry requirements automatically eliminate low producing individuals. (4) The records come from different herds where widely varying systems of management and feeding are practiced.

The records of 3753 Register of Merit Jersey cows were analyzed by Gowen (1934). Table 1 gives the correlation coefficients observed between various relatives. From Wright's formulas Gowen concluded that 50 to 70 percent of the variation in milk production was due to heredity and that the portion of the variance in percent of butter fat due to heredity was between 75 and 85 percent.

Table 1--Correlation Coefficients Between Relatives for Milk Production and Percent Butterfat

Relationship	Correlation Coefficient	
	Milk	Percent Butterfat
Half sisters (common sire)	.24	.25
Half sisters (common dam)	.19	.20
Full sisters	.39	.41
Dam-daughter	.30	.42
Granddaughter & Paternal Granddam	.20	.21
Granddaughter & Maternal Granddam	.14	.25

According to Plum (1935) the portion of variance in butter fat production within herds due to heredity could not be over 40 percent. He based this conclusion on an analysis of butter fat production records of cows in Iowa Cow Testing Associations. Dam-daughter correlations ranged from .32 to .40 and a correlation of .40 was obtained between different records of the same cow.

In a study on the genetic constitution of Jersey Cattle, Gowen (1933) using certain body measurements on approximately 6000 individuals worked out correlation coefficients between various relatives. From the correlations observed the conclusion was that approximately 60 percent of the variation in these measurements was due to heredity.

Lush et al (1933) found that permanent differences between sows accounted for 13 percent of the variation in litter size. A tentative estimate of one-half to two-thirds for the hereditary portion of these permanent differences in the productive ability of individual brood sows was suggested.

Investigating factors affecting the birth weights of swine, Lush, Hetzer, and Culbertson (1934) came to the conclusion that six percent of the variation in birth weight was due to genetic factors.

In his report on the genetic aspects of the Danish system of progeny testing swine, Lush (1936) observed that a little less than half of the individual variance in body length, thickness of back fat, and thickness of belly could be ascribed to the additive gene effects and that differences in rate of gain, economy of gain, and yield of export bacon were slightly less influenced by heredity.

Lush and Molln (1937) in a report on the degree to which litter size is a constant characteristic of sows report correlations between litters from the same sow of .07 for the number of pigs farrowed, .11 for number of pigs weaned, and .12 for the weaning weight of the litter.

Bywaters (1937) made a study of the hereditary and environmental portions of the variance in weaning weights of pigs. The average inbreeding of the pigs in the study was 8.5 percent. To determine the genetic portion of the variance he used the correlation coefficients between relatives. He obtained the following correlations: litter mates .45, dam-offspring .05, maternal half-sibs .114, paternal half-sibs .017. From these correlations he concluded that approximately 18 percent of the variation in weaning weight was due to heredity.

Whatley (1939) concluded that the genetic portion of the individual variance in 180-day weight in a Poland-China herd of hogs was somewhere between 20 and 60 percent. An intra-lot regression of the variance between pairs of pigs on their genetic relationship indicated that 30 percent of the individual intra-lot variance was due to genetic factors. The intra-sire regression of the weight of the offspring from high and low mates on the weight of their dams (.233) indicated that about 41.6 percent of the variability had a hereditary basis. In this regression each set of full sibs had equal weight. When each pig was given equal weight a regression coefficient of .307 was obtained making an estimate of 61 percent for the variance due to heredity. Correlation coefficients between different relatives were: .339 between litter mates, .202 between full sibs not litter mates, .152 between dam and offspring, .150 between maternal half sibs, and .051 between paternal half sibs. The correlation between paternal half sibs indicated that about 20 percent of the variation was hereditary although it seemed likely that this was an underestimate due to the selection practiced in the herd.

SOURCE OF DATA

The data for this study came from the records on the Duroc Jersey herd of the Oklahoma Experiment Station in cooperation with the Regional Swine Breeding Laboratory. This herd is maintained for investigations on the effects of inbreeding swine and the crossing of inbred lines to produce pigs with hybrid vigor.

The Oklahoma station became a cooperating member of the Regional Swine Breeding Laboratory in the fall of 1937. The plan set up at that time was to develop four inbred lines with approximately ten sows and two boars in each line each season, selected from within each line. Under such a breeding program the inbreeding should increase about six or seven percent per generation. This is about one-half the intensity of a half-brother x half-sister mating.

The foundation stock for Line 1 were some of the inbred animals on hand from the inbreeding experiment (Adam's Project) which had been carried on by the Oklahoma Experiment Station since 1923. Some vigor was added in 1938 by a mild outcross but the general vigor of the animals in this line remained below that of the other lines. The average inbreeding coefficient of the Line I litters included in this study was .34.

Line II was developed from the outbred stock which had been used in connection with the Adam's Project conducted at this station. In addition, a boar secured from the Nebraska Agricultural Experiment Sub-Station at North Platte, Nebraska was incorporated in the line. In the spring of 1940 a second boar from the Nebraska station was used as a mild outcross in an attempt to increase the vigor of this line. An average inbreeding coefficient of .15 was observed for the Line II litters included in this study.

The foundation stock for Line III consisted of a number of gilts from the Cara Cameron and Sons herd at Herman, Nebraska and one bred gilt from the Joe Pudenz herd at Carroll, Iowa. The foundation boar for this line was a boar pig bought in dam with the Pudenz gilt. Two more gilts were added from the Cameron herd in the spring of 1940. The average inbreeding coefficient of the litters in this line from the time it was started to the fall of 1940 was eight percent.

Line IV was established from three outbred sows secured from the Adam's Project and from boars secured from the college herd of Durocs. In the fall of 1938 three bred gilts were purchased from the Texas Experiment Station and added to this line. Two more bred gilts were added in the spring of 1940 from the herd of W. A. Williams at Vega, Texas. Seven percent was the average inbreeding of all litters in this line up to the fall of 1940.

Since the beginning of the project some crosses between lines have been made to determine if any pigs with hybrid vigor could be produced.

Breeding animals were selected from within the lines on the basis of their rate of gain, performance of parents and sibs, and score at market weight. Selection of boars first occurred at about six weeks of age when the least promising ones were castrated. A second selection of boars and a first selection of gilts was made when they reached market weight usually between 200 and 225 pounds. Further selection occurred after they had produced one or more litters, selection now being based primarily on productive ability and the performance of the offspring.

Gilts usually were bred so they would farrow the first time when they reached one year of age. The breeding schedule was arranged for each sow to produce two litters a year. As a whole the management and feeding was similar to that which would be practiced by any good commercial producer.

All pigs in the project were scored at market weight which was usually between 200 and 225 pounds by three or four men. Each pig was scored on six points on a basis of zero to nine. The six items scored were health and vigor, quality, length of body, details of conformation, animal as a whole, and market grade. The six items were added to get the score for individual pigs. The scores given by different men were averaged to give the average score per pig which was used in this study.

Since the foundation animals weighed more than 225 pounds at the start of the project and other animals introduced into the herd were over this weight when brought in, the records on them are not complete. For this reason some of the data could not be used in this study due to the fact that there were no scores on some of these older individuals in the herd. The animals included in this study were from the different lines and line crosses which were farrowed between the fall season of 1937 through the fall season of 1940.

The distribution of the 1127 pigs scored during the period of study is shown in Figure 1. The curve of distribution is skewed slightly towards the higher scores. The average score (37.8) given the pigs was much higher than the midpoint (27) between zero and a perfect score of 54. If the scorers had maintained an average of 27 for the individual or an average of 4.5 for each of the six points scored, there very likely would have been a more equal distribution of scores. The standard deviation of all scores was 4.5.

That selection of the parents was at least partly based on the market score is indicated by an average score of 39.0 for the selected

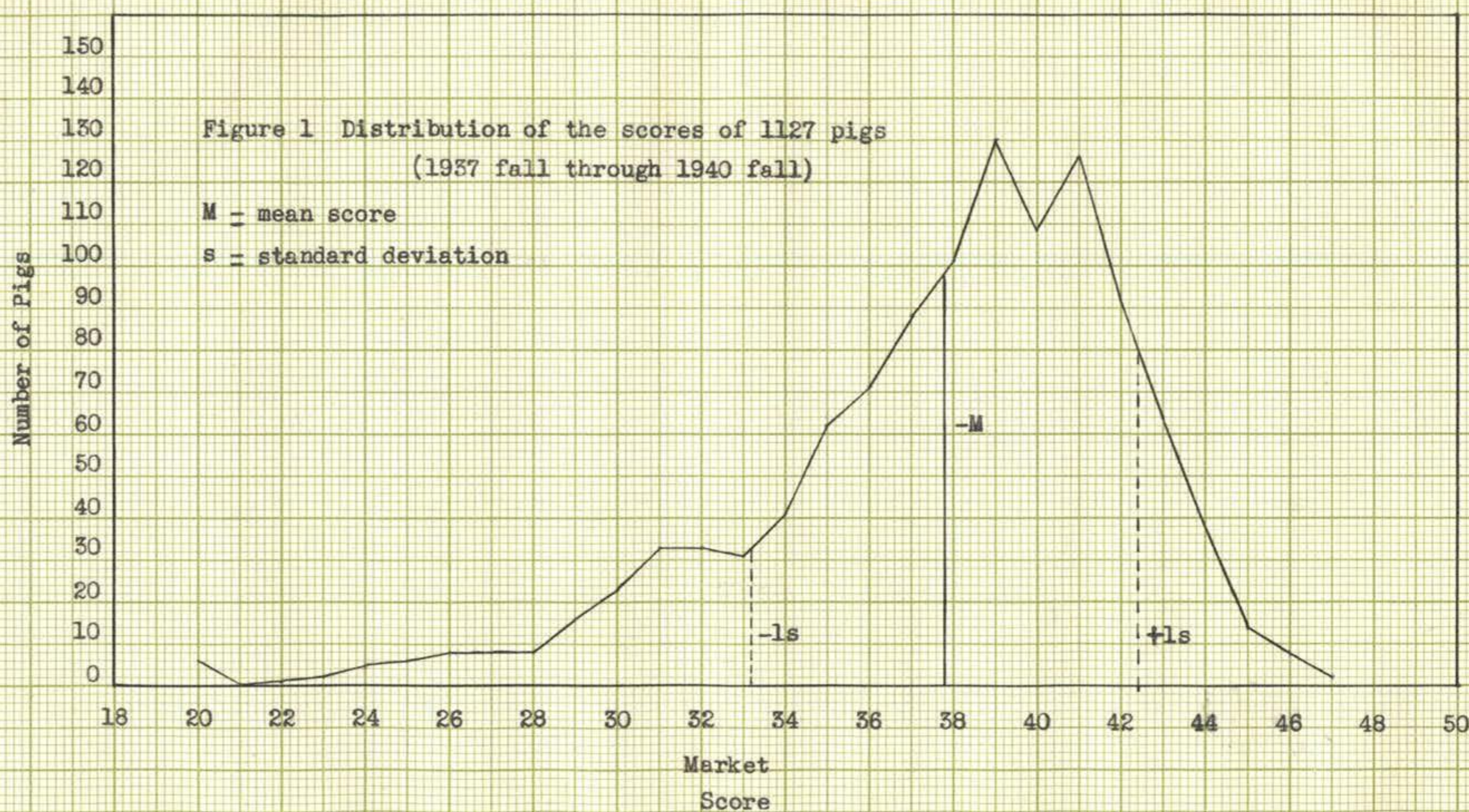

Figure 1 Distribution of the scores of 1127 pigs
(1937 fall through 1940 fall)

parents as compared to an average score of 37.3 for all pigs of the generations from which the parents were selected. Furthermore, the standard deviation of 3.7 for the parents was smaller than the standard deviation of 4.6 for the herd as a whole.

Table 2 gives the average market score and percent of inbreeding in each line for each season. It clearly brings out the differences between the four lines in average score and percent of inbreeding. The seasonal trend of scores for the combined four lines was distinctly upward, starting at 32.8 in 1937 and reaching 39.7 in the fall of 1940 with an average for all seasons of 38.7. The inclusion of pigs from line crosses in the general average in the last column of the table did not greatly change the average from that of the four lines. It is difficult to determine whether the rather uniform seasonal increase in scores was due to the increased individual merit of the pigs resulting from selection or whether the increase was due to improved environmental conditions.

With the exception of the low score for the small number of litters farrowed in the fall of 1937, the most noticeable increase occurred in 1940. Certain changes in feeding and management of the herd at this time probably account for at least part of this increase. At this time the protein supplement of 50 parts meat scraps, 25 parts cottonseed meal, and 25 parts alfalfa leaf meal was altered to include fish meal as a substitute for 20 parts of the meat scraps. This ration change seemed to produce more rapid growth resulting in pigs of apparently more vigor at 225 pounds. Previous to this time large groups of sows and litters were run together until weaning and the sows were hand fed. In 1940 all of the sows were self fed and most of the sows and litters were placed in individual lots although at times two sows with small litters were

Table 2

The Average Market Score and Percent Inbreeding by Seasons

Season	Line I		Line II		Line III		Line IV		Av. of Four Lines		Av. Score of All Pigs*
	Score	% Inbred	Score	% Inbred	Score	% Inbred	Score	% Inbred	Score	% Inbred	
1937 Fall	33.7	--	32.0	--	----	--	----	--	32.8	--	34.3
1938 Spring	32.1	45	37.7	0	36.9	0	----	--	36.0	16	36.9
1938 Fall	35.7	26	36.7	9	----	--	----	--	36.2	18	38.1
1939 Spring	34.6	41	37.8	18	38.9	8	37.1	11	37.8	19	38.2
1939 Fall	33.4	29	36.5	19	38.5	3	38.9	12	37.3	15	37.7
1940 Spring	35.8	38	39.6	22	40.6	12	40.5	8	39.6	18	39.5
1940 Fall	34.6	40	39.4	11	41.4	10	40.6	3	39.7	12	39.9
Av. All Seasons	34.6	34	37.5	15	39.8	8	39.9	7	38.7	17	38.1

*Pigs from line crosses were also included in this average placed together. As a result of this change in management pigs weaned at heavier weights and gained faster after weaning.

The average inbreeding of all four lines did not materially change during the years from which the study was taken. The range was from 12 to 19 percent with an average for all seasons of 17 percent. This is only about two-thirds as much inbreeding as one generation of brother x sister mating would produce.

An analysis of variance of the scores of the four lines was made (Table 3) to determine if there were significant differences between lines and between seasons within lines. The mean square for the between line variance was highly significant indicating that there was a distinct difference in the average score of the four lines.

A highly significant difference in the average scores of different seasons within lines was also observed. This further proves the fact that there were significant seasonal differences in the scores.

Table 3

Analysis of Variance of Market Scores of the Four

Lines of Hogs at 225 Pounds of Weight

Source of Variance	D/f	Sum of Squares	Mean Square
Total	714	16285	23.1
Between Lines	3	2816	938.6**
Within Lines	711	13469	18.9
Between Seasons Within Lines	19	1500	78.9**
Within Seasons Within Lines	692	11969	17.3

** Highly significant (Snedecor's F Test)

ANALYSIS OF DATA

The Reliability of the Method of Scoring Used

Fifteen pigs weighing between 200 and 225 pounds were scored by four men on three different days to check the accuracy of the scoring method used.

The object of this study was to determine if these scores brought out differences between pigs; if different men score enough alike to make the scores by different men comparable; and if a man scores near enough the same level on different days to make the scores of different days comparable.

Intervals of several days were left between each scoring so there would be little tendency of the men to remember how much they had scored the same pig the time before. The second and third time the pigs were scored their numbers were not read until after the scoring was completed so as to help eliminate the possibility of remembering certain pigs.

An analysis of variance of these scores is shown in Table 4. In the column labeled "interpretation" the amount of variance due to different sources is given. The last column gives the percent of the total variance attributable to each of the sources.

The mean square between pigs was highly significant and the interpretation column shows that the variance between pigs ($P = 3.376$) was larger than for any other single item. "P" represents the amount of variance between pairs of scores of different pigs in excess of the variance between pairs of scores of the same pig. In this case P was 47.8 percent of the total variance.

The mean square between days was not significant. A slightly negative figure was obtained for the extra variance between pairs of scores on the different days ($D = -0.001$) over the variance between pairs of

Table 4

Analysis of Variance of Market Scores on 15 Pigs

Source of Variance	D/f	Sum of Squares	Mean Square	Interpretation	Percent of Total
Total	179	1224.64	6.84		
Between pigs	14	650.14	46.44**	E + 4G + 3F + 12P ; P = 3.376	47.8%
Between days	2	15.51	7.76	E + 4G + 15A + 60D; D = -0.001	0.0%
Between men	3	14.24	4.75	E + 3F + 15A + 45M; M = -0.119	-1.7%
Pigs x Days	28	84.99	3.04	E + 4G ; G = 0.181	2.6%
Pigs x Men	42	222.92	5.31**	E + 3F ; F = 0.999	14.1%
Days x Men	6	42.62	7.10**	E + 15A ; A = 0.319	4.5%
Remainder— Men x Pigs x Days	84	194.21	2.31	E ; E = 2.312	32.7%

** Highly significant (according to Snedecor's F test)

E = remainder of the variance including the error in scores.
P = variance in the average differences between pigs.
D = variance in the average score made on different days.
M = variance in the average score made by four men.
A = variance due to interaction between men and days.
F = variance due to interaction between men and pigs.
G = variance due to interaction between pigs and days.

scores on the same day. Due to the small number of degrees of freedom this negative figure may have been due to sampling errors.

The variance between scores given by different men was a negative figure (M = -0.119) and was derived from a mean square which was not significant. Random pairs of scores by the same man showed greater variance than random pairs of scores by different men, although the difference was not statistically significant.

The mean square of the pigs x days interaction was not significant but those for the pigs x men and days x men were highly significant. The pigs x men interaction contributed more (F = 0.999) to the variance than the other two double interactions combined. The pigs x men interaction may be spoken of as the failure of different men to score different pigs in the same order.

The triple interaction of men x pigs x days contributed the second largest amount (E = 2.312) to the total variance. This complex interaction might also be called the remainder or the error term since it includes all of the variance not explained by pig to pig, day to day, men to man differences or the interaction of any two of these.

This study quite clearly indicates that all of the variance in scores was not due to actual pig differences. However, because of the fact that quite a large figure was obtained for the variance in pig to pig differences, this method of scoring should serve its purpose quite well. Since the day to day and man to man variance was so small, it would appear that scores made on different days are comparable as would be the scores between different men. Probably one reason for the small amount of variance in scores by different men was that these four men had been scoring pigs together for some time and were therefore very likely using the same level of scoring. This was made possible by occasional comparisons and discussions of scores after the animals had been scored, but never before. However, it should be remembered here that no such comparisons or discussions were made at any time in this particular phase of the study in checking the scoring technique.

Regression of the Offspring Score on the Parent's Score

Many livestock breeders observe that the offspring of their selected animals show a regression towards the herd average for the things being selected for. This regression is quite noticeable but usually does not drop as far back as the average of the generation from which the parents were selected. The reason for this regression is that the parents were selected on their outward appearance or phenotype, and therefore, part of the selection was based on differences due to environmental factors as well as differences in genotypes. Since only the hereditary differences would be transmitted to the offspring, the average of all the offspring cannot be expected to be as high as that of their selected parents, although they should average higher than the parental generation. Two other factors which complicate the picture are dominance and epistasis or "nicking." These two factors reduce the effectiveness of selection in much the same way as environmental factors by causing an individual to breed differently than his phenotype would indicate.

The amount the offspring will regress towards the herd average depends in part on the intensity of the selection. In animal breeding there usually is selection for so many different things that being too critical for any one characteristic will cut down the range of selection for others. However, the more intense the selection the greater the increase in merit of the offspring for that particular characteristic. In addition to selection intensity, the heritability of the character (or the extent to which it is influenced by genes which are not dominant and do not interact together in a complex way) will also have a bearing on the effectiveness of selection.

If the parents are divided into two groups, the high scoring individuals making up one group and the low scoring ones the other, the environmental effects on the two groups of offspring will tend to cancel out if raised under similar conditions, thus leaving the remainder of the variance in their scores due to the influence of genetic factors. Comparing this difference between the offspring of selected parents with the difference between the average of the two parental groups should give the regression coefficient from which the proportion of the total variance which is inherited can be calculated.

In this study this method was first used to show the regression of the offspring scores on the dam's score. The sows were divided according to their score at market weight. All sows with a score of 40 or over made up the high dam group and all of those with a score of less than 39 made up the low dam group. They were divided so there would be approximately the same number of sows and pigs in each group. To determine if there had been any tendency to mate high scoring sows to high scoring boars, and vice versa, the scores of the boars mated to each group of sows were averaged. The boars mated to the high sows averaged 38.4 and the boars mated to low sows averaged 37.9. This did not include all of the boars mated to these sows since some of the boars had never been scored. However, the number of unscored boars mated to each group of sows was approximately the same and there is little reason to believe that the merits of these boars mated to these groups were much different. The figures given above indicate a slight tendency to mate the high sows to slightly higher scoring boars. However, the difference (.5) is so small that the variance in the scores of the two groups of pigs due to sire differences were negligible.

Included in this study were 312 pigs from 54 litters in the high group and 303 pigs from 63 litters in the low group.

Figure 2 is a diagram of the results obtained. The average score for the high dams was 42.1, and for the low dams, 35.6. The offspring of the high group averaged 38.6 and the offspring of the low group averaged 37.7. The difference in the average score between the two groups of dams was 6.5 while the difference between the offspring was 0.9.

The average score of the selected dams (38.9) was 1.6 points above the average score of 37.3 for the generation from which they were selected, and the average score of the offspring (38.1) of these parents was .8 of a point above the average of the parental generation (37.3) or exactly half of the selection differential. The selection of sows used in the breeding herd is illustrated by the fact that the average score of the high sows was 4.8 points above the average of their generation whereas the average of the low sows was only 1.7 points below the parental generation average. This indicates that most of the low scoring gilts were culled from the herd without permitting them to produce a litter.

The regression of the scores of the offspring on the scores of their dams was .9/6.5 or .138. Since the effect of the sires was eliminated by the mating of each group of sows to representative groups of boars, the differences between the progeny of the high sows and low sows must have been the result of hereditary differences in their dams. Environmental differences between the pigs should have been equally balanced within the two groups of pigs. The differences between the two groups of dams, on the other hand, includes both environmental and hereditary differences. To obtain the influence of heredity on the score the regression coefficient is doubled since the dam can only contribute half of her

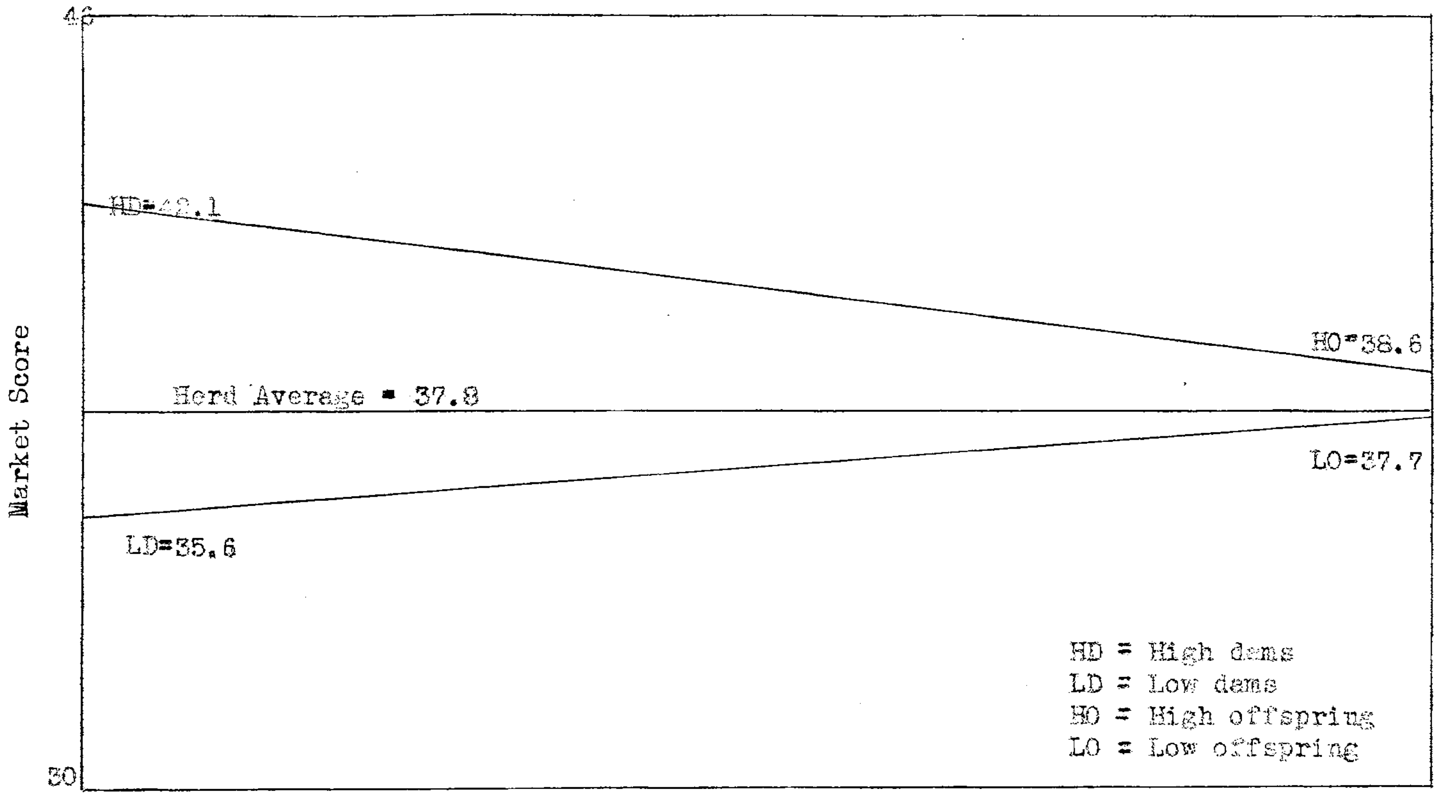

Figure 2. Regression of the Scores of the Offspring of High Sows and Low Sows Towards the Herd Average

inheritance to her offspring. This gives a figure of 28 percent for the portion of variance in market score due to heredity.

The existence of a correlation between the environments of dam and offspring, which would tend to increase the resemblance between the score of the dam and her offspring over that of individuals chosen at random within the herd, would tend to make the regression of offspring on the dam higher than if environmental effects were uniform or were at least random. In these data the scores in the last year were distinctly higher than in earlier years. Part of this change was very likely due to improved environmental conditions.

If there was a tendency for sows born in low scoring seasons to produce pigs only in a similar low scoring season, whereas those sows born in a high scoring season, produced pigs in a similar high scoring season there would be an environmental correlation between dam and offspring. The seasonal distribution of pigs from sows born in different years is shown in Table 5. Most of the earlier sows were retained in the herd throughout the period of study and produced almost an equal number of pigs in all seasons. This distribution of sows of different ages in all farrowing seasons would indicate only a slight environmental correlation between sow and offspring. Furthermore, a study of pigs farrowed in 1940 (the year of the highest level of scoring) shows that for the most part these pigs came from sows equally distributed as to year of birth.

The same general method was followed in determining the regression of the offspring scores on the sire's score as was used in the determination of the offspring regression on the dam. All boars with a score of 40 or over were sorted into the high group and those with a score of less than 38 made up the low group. The division was made at these scores

Table 5

Relation of the Birth Year of Offspring to the Birth Year of Their Dam

Offspring	Season in which Dam was Born: 1937 Fall	1938 Spring	1938 Fall	1939 Spring	1939 Fall	Average Score of Offspring
1938 Fall						36.2
1939 Spring	3 Litters 20 Pigs	15 Litters 58 Pigs				37.8
1939 Fall	2 Litters 9 Pigs	17 Litters 92 Pigs	7 Litters 35 Pigs			37.3
1940 Spring	3 Litters 18 Pigs	13 Litters 75 Pigs	4 Litters 17 Pigs	4 Litters 25 Pigs		39.6
1940 Fall	1 Litter 2 Pigs	8 Litters 58 Pigs	3 Litters 21 Pigs	4 Litters 25 Pigs	6 Litters 40 Pigs	39.7
Av. Score of Dams	33.1	38.7	41.1	42.3	41.2	

so there would be approximately equal numbers of offspring from high boars and low boars. Because it was necessary to leave some of the boars out of the study to make this equal division, boars scoring between 38 and 40 were eliminated. This should not effect the results since the average individual does not have much effect on a regression coefficient. This left 195 pigs from 32 litters in the high group and 177 pigs from 33 litters in the low group.

From Figure 3 it will be observed that the average score (41.8) of the high scoring boars was 7.8 points above the low sire score of 34. The high boars were 4.5 points above the parental generation average and the low boars were 3.3 points below this average. The fact that the low boars average was quite far below the parental generation (3.3 points as compared to 1.7 points for sows) indicates that there was not as large a selection differential for the boars as there was for the sows. The progeny of the high boars had an average score of 40.3 which was three points above the low group average. When a comparison was made of the sows mated to each group of boars it was found that the average scores of the two groups of sows were identical. Therefore, since there was no assortative mating, all of the variance between the groups must be accounted for by differences inherited from the sire and environmental effects.

Figure 3 illustrates that the progeny of the high boars did not regress as much toward the herd average as the progeny of the low boars. This can partially be accounted for by the fact that most of the high scoring boars were of recent years and therefore they and their offspring had the advantage of improved environment. For instance, Table 6 shows that almost two-thirds of the pigs born in the fall of 1940 were sired by young boars born in the fall of 1939. This correlation between the

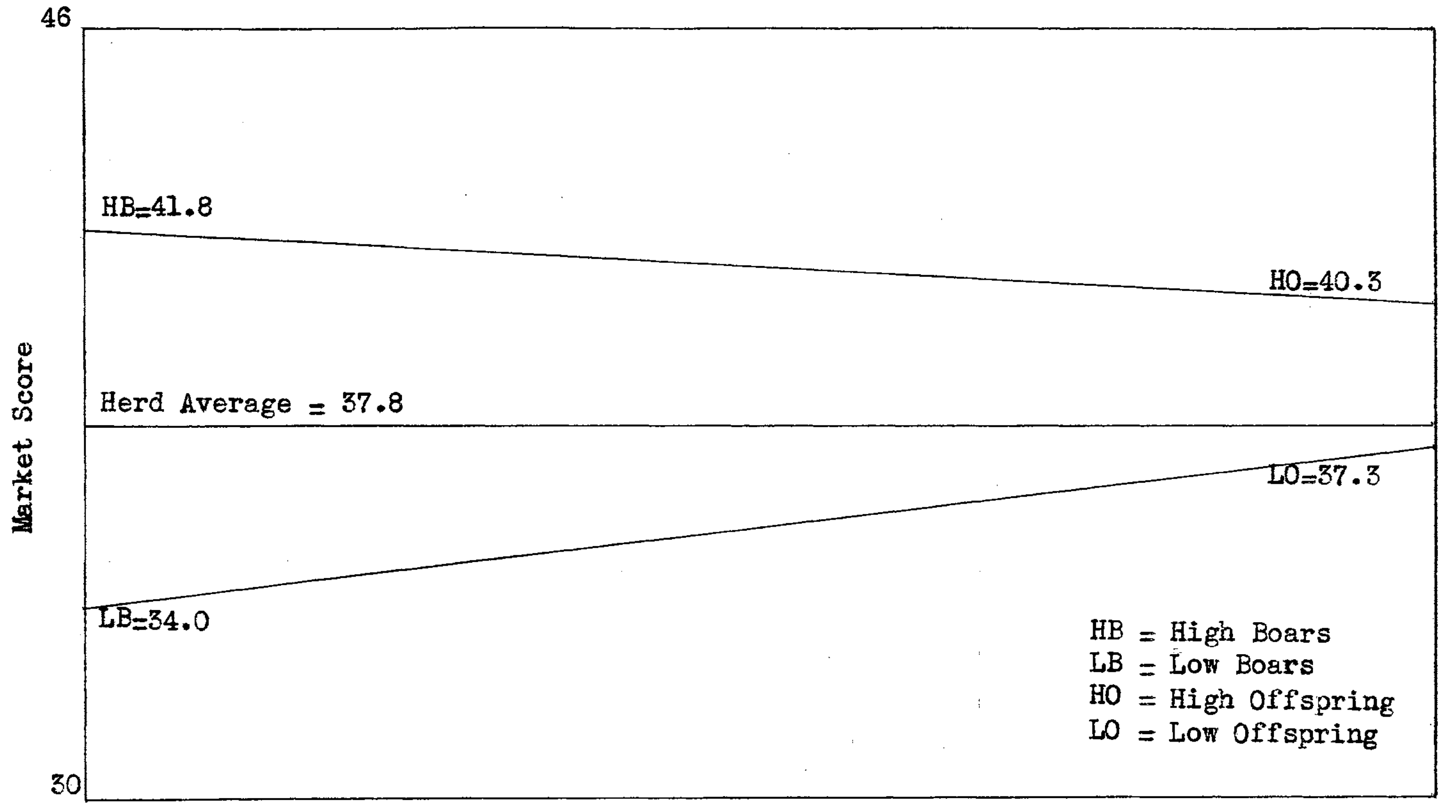

Figure 3.

Regression of Scores of the Offspring of High Boars and Low Boars Towards the Herd Average

Table 6

Relation of Birth Year of Offspring to the Birth Year of Their Sire

Offspring	Season in Which Sire was Born					Av. Score of Offspring
	1937 Fall	1938 Spring	1938 Fall	1939 Spring	1939 Fall	
1938 Fall	3 Litters 10 Pigs					36.2
1939 Spring	2 Litters 10 Pigs	16 Litters 68 Pigs				37.8
1939 Fall	1 Litter 6 Pigs	25 Litters 130 Pigs				37.3
1940 Spring		9 Litters 57 Pigs		15 Litters 78 Pigs		39.6
1940 Fall		1 Litter 6 Pigs		6 Litters 39 Pigs	15 Litters 101 Pigs	39.7
Av. Score of Sires	32.5	38.3		37.8	41.0	

environments of sire and offspring could do much to increase the size of the offspring-sire regression coefficient. This possibly explains why this regression coefficient of 3/7.8 or .38 is much higher than a similar regression of the offspring on the dam. Doubling this regression coefficient gives 76 percent as the amount of variance in score due to the genetic constitution of the individual. This figure, however, is quite likely an overestimate because of the environmental correlation between sire and offspring.

Parent-Offspring Correlation and Regression

Since Wright (1921) determined the biometric relations between various relatives, several workers have used the correlation between parent and offspring to estimate the importance of heredity for certain characteristics. The correlation coefficient, in the manner used in studies of this type, is a measure of the average variance of a certain characteristic between parent and offspring. A high correlation would indicate close resemblance between the scores of the offspring and those of their parents, and a low correlation would indicate only a slight resemblance between the scores of offspring and their parents. However, if the independent variable (the parents) were selected, the correlation coefficient would be smaller than in an unselected population. It has been demonstrated earlier that the parents in these data were selected. The lower scoring gilts and boars were culled and never allowed to produce offspring. For this reason, an estimate of heritability from a parent-offspring correlation in these data would be an underestimate.

On the other hand, the regression coefficient, which is similar to the correlation coefficient in so far as they both deal with the relationship existing between two variables, is the amount of increase or decrease of the dependent variable (offspring) for each unit increase or decrease of the independent variable (parents). The regression coefficient is a more reliable figure to use than the correlation coefficient in determining the influence of heredity in a study of this type because there is no reason why selection should tend to either consistently raise or lower the coefficient from that obtained in a population in which there is no selection.

The regression coefficients, which were computed in the previous section by an approximate method, should be similar to those computed by the usual statistical methods in this section of study.

To eliminate the effect of the sire on the score of the offspring, dam-offspring correlation and regression coefficients were computed on the mates and offspring of 11 different boars which were mated to six or more sows. In this calculation of the intra-sire dam-offspring correlation and regression coefficients 412 pigs from 83 litters were included. Table 7 gives the dam-offspring correlation and regression coefficients for each sire group. As is to be expected, when dealing with small groups in which sampling errors may be large, there was quite a wide range in the regression coefficients from the different sire groups (-.321 to +.628). Allowing each group to have equal weight the average regression coefficient was .124. Since the method and data were basically the same as that used for regression of the offspring score on the dam's score in a preceding section, the regression coefficient obtained here is similar in size. Doubling this figure gives 25 percent as the hereditary portion of the variance in score at market weight. The correlation was not used because of the selection of the breeding animals.

Intra-dam sire-offspring correlation and regression coefficients were also determined on 13 dams which had 3 or more litters by different boars. The figures for the 13 intra-dam groups are presented in Table 8. There were 279 pigs from 42 litters included in this data, with the litters being well distributed among the 13 sows. The regression coefficients between intra-dam groups ranged from -.291 to +.891. This wide range was to be expected in dealing with small numbers. The variance due to sow differences was eliminated by the intra-dam grouping thus making it necessary to double the regression coefficient obtained

Table 7

Intra-sire Dam-offspring Correlation
and
Regression Coefficients

Sire	No. of Litters	No. of Pigs	Correlation Coefficient	Regression Coefficient
646	13	67	-.209	-.277
L 17	7	30	.136	.145
Thom. II	8	43	.366	.574
543	8	50	.391	.452
553	8	41	-.187	-.252
714	6	32	.255	.658
375	6	27	-.221	-.321
811	8	27	-.053	-.097
Sup. Ace	7	33	.233	.309
961	6	28	.185	.299
Adv. Guard	6	34	-.251	-.126
Average			.059	.124

Table 8

Intra-dam Sire-offspring Correlation
and
Regression Coefficients

Dam	No. of Litters	No. of Pigs	Correlation Coefficient	Regression Coefficient
845	3	19	.496	.739
361	3	13	.385	.768
573	4	28	.206	.316
Cam. I	3	27	.179	.324
L 2	4	26	-.151	-.291
L 16	4	20	.047	.079
Cam. V	3	25	.280	.270
712	3	26	.487	.891
855	3	20	.197	.207
687	3	15	.198	.678
376	3	19	.207	.480
Tex. II	3	23	-.14	-.165
L 18	3	18	-.115	-.128
Average			.175	.321

(.321) in order to determine the influence of heredity on the variability of scores. This gave 64 percent as the portion of variance due to the genetic constitution of the individual. As mentioned in connection with the previous sire offspring regression, the figure of 64 percent is likely an overestimate because of the common environment of sire and offspring.

Regression of the Score of the Offspring on the Score of the Mid-parent

Reference to the use of the correlation between the offspring and the parental average in determining the influence of heredity on different characters was not found in any of the literature reviewed. There probably were several reasons for this, but very likely the chief reason was that most of these studies were concerned with characters which could be only directly measured in one parent. Milk and butterfat production in dairy cattle and litter size in swine are examples of this kind. In this study the regression of the score of the offspring on the average score of its parents is used in determining the influence of heredity.

The correlation between the offspring and one of its parents should not be over .5 even for characters which are completely hereditary. Squaring this correlation gives .25 as the degree of determination of the offspring by one of its parents. The other parent determines another fraction of .25 while the remaining fraction of .5 is determined by chance at mendelian segregation. Even if it were possible to know the actual genotypes of the parents of an individual there would still be some question as to what an offspring inherits from its parents because they would be heterozygous for many factors. The parent-offspring correlation is doubled to determine the heritability of a character because with complete hereditability the parent-offspring correlation cannot be over one-half.

Since the inheritance of the individual is 25 percent determined by each parent, the two parents determine 50 percent of the inheritance of the offspring. The square root of .5 gives .707 as the correlation between the parental average and the offspring for completely hereditary traits. Consequently the correlation between the offspring and the mid-parent would be multiplied by 1.0/.707 or 1.42 in place of 1.0/.5 or 2 for the correlation between the offspring and one of its parents.

To determine the regression of the offspring score on the mid-parent score the parents were divided into two groups. One group consisted of the high scoring sows mated to high scoring boars and the other group of low scoring sows mated to low scoring boars. By this method of grouping, many sows and boars were left out since there were matings of high sows to low boars and low sows to high boars which could not be included. However, these types of matings gave mid-parent scores which were about the average of the high and low groups. Since averages have little effect on the regression coefficient their omission from the study should not have had much effect on the results obtained. All mates that scored 39 or over went into the high group, which consisted of 90 pigs from 14 litters, and those under that score went into the low group, made up of 131 pigs from 29 litters. This was as equal a division as it was possible to make. Figure 4 shows the regression of the offspring towards the herd average. The average score of the high mates was 41.7 and of their offspring, 40.6. The low mates average score was 35.7 and their offspring average was 37.9. This gives a difference of six points between the scores of the two groups of parents, and 2.7 points between their offspring. The regression coefficient (.45) derived from these figures, when multiplied by the factor (1.42) suggested above, gives 64 percent as that portion of the variance in scores which may be accounted for by heredity.

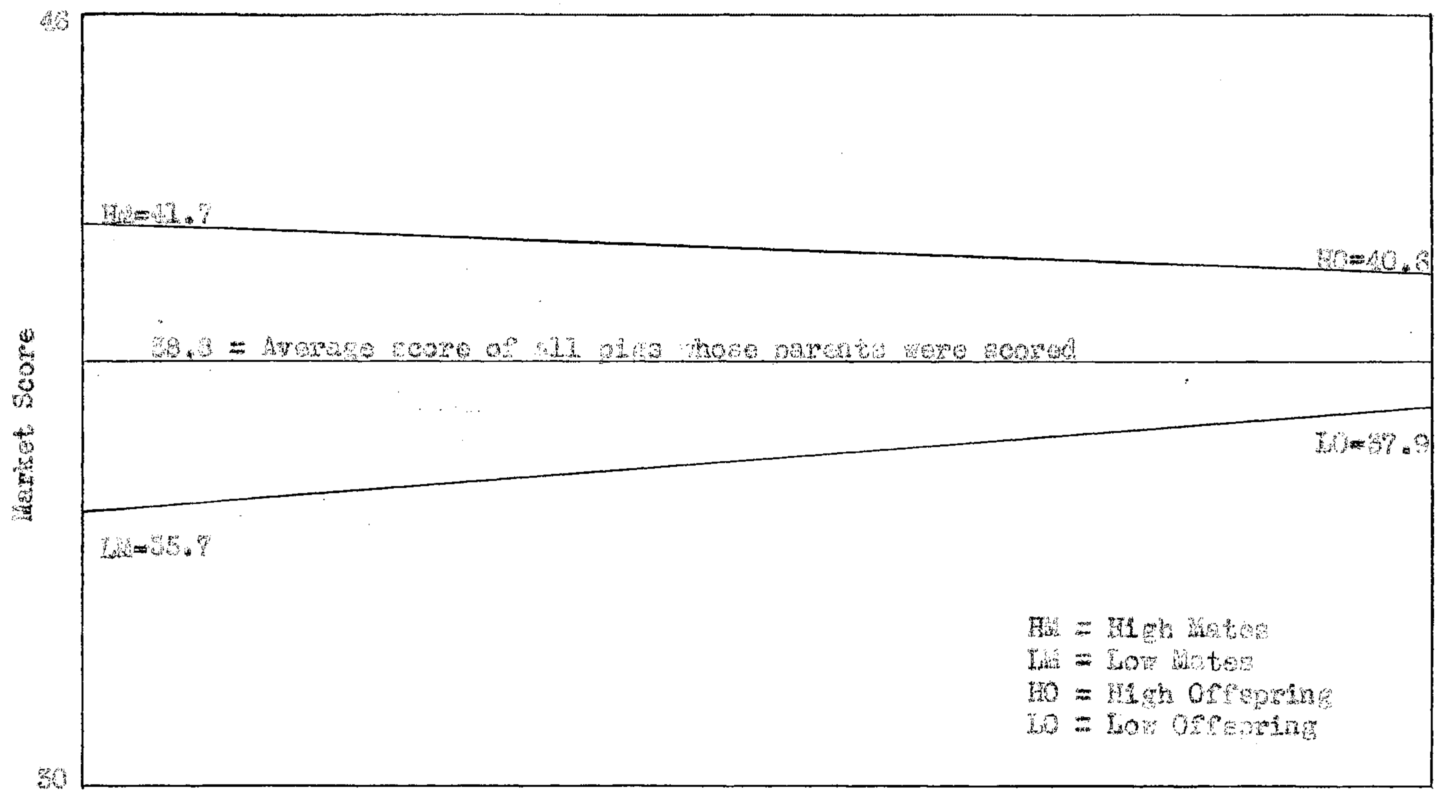

Figure 4.

Regression of the Scores of Offspring of High Mates and Low Mates towards the herd average

To check on the accuracy of the above figures, since they were based on rather small numbers, all matings were thrown together and mid-parent-offspring correlation and regression coefficients determined. Whereas the other analysis only included a total of 221 pigs, this analysis included a total of 505 pigs. A regression coefficient of .456 was obtained, which was almost identical with that (.45) derived by the other method.

As a result of the lower scores during the first years of the project it was only natural that most of the low scoring pairs should come from that period, whereas, the high scoring pairs came from later years. There was also a tendency for a large number of the offspring of these low scoring mates to be born in low scoring years. This would give rise to a correlation between the environments of the offspring and their parents as compared to that between random pairs of pigs in the herd. Correspondingly, the regression of the offspring score on the average of its parents' scores would be higher due to the common environment between parent and offspring, and gives a figure which would be an overestimate for the influence of heredity.

DISCUSSION

A comparison of the estimates obtained in this study for the influence of heredity on the market score to those of other studies for other characters was quite interesting. The parent-offspring correlations obtained in other studies with which comparisons were made are listed below:

Color markings of guinea pigs-(Wright-1920)------.21

Number of digits in guinea pigs-(Wright-1934)---.18

Spotted pattern in guinea pigs-(Wright and Chase-1936)------------.19

Milk production-(Gowen-1927)---------------------.39

Percent butterfat-(Gowen-1927)-------------------.42

Percent butterfat-(Heizer-1932)------------------.78

Milk production-(Gowen-1934)---------------------.30

Percent butterfat-(Gowen-1934)-------------------.42

Butterfat production-(Plum-1935)-----------------.36

Weaning weights of pigs-(Bywaters-1937)----------.05

180-day weights of pigs (Whatley-1939)-----------.13

These correlation coefficients ranged from .05 to .78. It must be remembered that these are figures for different characteristics in different species of animals, however, even for a certain characteristic within a species, for example, butterfat production in dairy cows, there was a range from .36 to .78 in results obtained by different investigators. Very likely one of the reasons for this wide range was the source of the data used. Some of these correlations were based on records of individual herds which, due to selection, were probably more homozygous for this characteristic than random bred stock and others were calculated from Advanced Registry records which came from a large number of herds scattered throughout the country. With such varying sources of data it is quite natural that there should be a wide range in the results obtained.

To derive a single figure for the influence of heredity on the market score the estimates obtained by each of the different methods were totaled and averaged which gave 54 percent for the heritability of the market score. Since it was not known how much each of the different methods used was an over or underestimate this average is not a very accurate figure. In this study estimates ranged between 25 and 76 percent for the portion of variance due to the genetic constitution of the animal. This may seem like a very wide range but when consideration is given to the fact that sampling errors can have quite an effect on such a small amount of data and to the inaccuracies of the method of scoring it is surprising that the estimates obtained fell within this range.

There is no doubt that the offspring-sire and offspring-mid-parent regressions gave overestimates. The environmental correlations between sire and offspring and mid-parent and offspring were so evident that it is very likely that the overestimate was quite large. On the other hand, the offspring-dam regression coefficient was believed to be smaller than would be obtained with either random or uniform environmental conditions. This would result in an underestimate for the influence of heredity, but probably not to the same extent that the others were overestimates. For these reasons it is quite likely that between 30 and 50 percent of the variation in market score in the herd studied was due to the additive effect of genes.

This study indicates that the hog breeder should be able to permanently fix certain characteristics in his hogs by various methods of breeding. However, he should remember that he will not be able to make his herd completely uniform since at least one-half of the variation in conformation, as based on the market score, is due to environmental effect.

SUMMARY AND CONCLUSIONS

1. A study was made of the influence of heredity on the market score in a herd of Duroc Jersey swine composed of four moderately inbred lines. The average inbreeding of the litters included in this study was 10 percent. The average market score of the 1127 pigs in these data was 37.8 with a standard deviation of 4.6. The distribution of the pigs was skewed slightly towards the higher scores.

2. The selection differential between the average of the animals selected and the generation average from which they came was 1.7 points. The standard deviation was 3.7 for the parents as compared to 4.6 for the herd as a whole.

3. A distinct seasonal trend in scores was observed, increasing from an average of 34.3 in 1937 to an average of 39.9 in the fall of 1940. Part of this increase was very likely due to improvement in feeding and management.

4. An analysis of variance indicated that there was a highly significant difference in the scores between different lines. However, the different lines and line crosses were analyzed together in order to secure a larger volume of data.

5. The method of scoring was that used by the cooperating members of the Regional Swine Breeding Laboratory, in which each pig is scored on six points by a committee of three or four men. A study of the reliability of this method of scoring showed that it brought out quite well the differences between pigs. It also indicated that the scores of different men were comparable and so were the scores given by the same man on different days.

6. The regression coefficients of the scores of the offspring on the scores of the dams were .138 and .124, which gave an estimate for the influence of heredity of about 25 percent.

7. Regression coefficients of the scores of the offspring on the scores of their sires were .32 and .38 indicating that between 64 and 76 percent of the variance in scores was due to heredity. It was concluded, however, that this was an overestimate due to the correlation between the environments of the offspring and their sire.

8. The regression of the offspring score on the mid-parent score was .45, giving an estimate of about 64 percent for the influence of heredity. This was also believed to be an overestimate since most of the matings of high scoring boars to high scoring sows came in the later years of the project whereas the mating of low scoring boars with low scoring sows came during the first years when the average score was lower due to poorer environmental conditions.

9. Correlation coefficients observed between parent and offspring were as follows: dam-offspring .06, sire-offspring .175, and mid-parent-offspring .25. These correlations were not used as a means of determining the influence of heredity since they would tend to give underestimates due to the selection of breeding animals on the basis of the market score.

10. The general conclusion was that between 25 and 76 percent of the variation in scores in the herd studied was due to hereditary differences between pigs.

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