THE EFFECTS OF SIRE AND OF INBREEDING OF THE DAM AND OF THE LITTER ON PREWEANING TRAITS IN A CLOSED BREED OF SWINE

by

Keith Michael Krotch

AN ABSTRACT OF A THESIS

Submitted to
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ABSTRACT

The Effects of Sire and of Inbreeding of the Dam and of the Litter on Preweaning Traits in a Closed Breed of Swine.

by Keith Michael Krotch

This study was to examine the effect of the sire, the effect of inbreeding of the dam, and the effect of inbreeding of the litter on various preweaning traits. The traits studied were: total number of pigs born, number of pigs born alive, number of pigs at three weeks of age, individual birth weight, and individual three week weight.

A total of 530 gilt litters, sired by 197 boars, supplied the data for this study. The data were collected from two separate lines of swine of the Managra breed over a period of six generations.

A nested classification was used to analyze the variance in all five preweaning traits for effect of sire. The effects of inbreeding of the dam and of the litter on these same traits were expressed by the changes in each trait for each ten percent increase in inbreeding. Estimates of heritability for each of the traits were obtained from paternal half-sib correlation.

A significant effect of sire on individual three week weight of offspring ($p < .05$) was found for one of

the two lines of swine studied. In all other analyses, no effect of sire was evident.

Generally, the preweaning traits showed a negative response as inbreeding of the dam and of the litter increased. The inbreeding of the litter had a greater effect upon litter size and individual pig weight at three weeks than it did at birth.

Estimates of heritability of litter size obtained for each of the two groups were: $-0.03 \pm .02$ and $0.05 \pm .03$ for the total number of pigs born, $-0.01 \pm .02$ and $0.03 \pm .03$ for the number of pigs born alive, and $0.04 \pm .04$ and $0.09 \pm .02$ for the number of pigs at three weeks of age. Estimates of heritability of individual birth weight for each group were $0.04 \pm .15$ and $0.11 \pm .15$, and for individual three week weight, the corresponding estimates of heritability for each group were $-0.16 \pm .14$ and $0.25 \pm .17$.

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INTRODUCTION

The economic importance of preweaning traits in swine has long been recognized by swine breeders and commercial swine producers. However, selection for improved reproductive performance has been relatively unsuccessful due to the low heritability of most reproductive traits.

Litter size is of major concern to swine breeders as the number of pigs born has a direct effect upon the intensity of selection that can be applied. Total litter weight is also influenced by litter size to a large extent. Individual pig weight and average individual pig weight at birth and at three weeks of age have also become increasingly important as producers attempt to reduce the number of days to weaning. Despite the large role these traits play in the swine industry, apparently little can be done to improve them by selection, as the proportion of additive genetic variance associated with these traits is rather low.

Research reports of factors affecting preweaning traits have been variable in their conclusions, with disagreement as to the degree to which certain factors exert their effect, and as to the magnitude and significance of the genetic parameters estimated.

This study was undertaken to examine the effect of sire, the effect of inbreeding of the dam, and the effect of inbreeding of the litter on litter size and on individual birth and three week weights in the Managra breed of swine.

REVIEW OF LITERATURE

Effect of Sire on Preweaning Traits

There are conflicting reports concerning the effect of sire on various preweaning traits in swine and other species. Rahnefeld and Swierstra (1970) found that the boar had a significant effect upon the total number of pigs born, the number of pigs born alive and the number of pigs weaned at 56 days of age. Differences in semen quality of the boars was suggested as a possible cause of the differences between sires with respect to litter size. A significant effect of sire was also observed by Minkema (1967) on total number of pigs born per gilt litter, but not on the number of pigs born alive. Schilling et al. (1968) observed a significant effect of sire on litter size in mice, which they attributed to possible differences in semen quality or hormonal activity among the sires. Hancock (1949) as cited by Schilling et al. (1968), found that bull spermatozoa may have a composition that could cause a fertilized ovum to split. Monozygotic twinning produced by certain bulls at higher levels than could be attributed to chance alone, served as the basis for Hancock's proposition. An increase in the number of multiple births in sheep by selection of males was reported by Turner et al. (1962). The authors felt that perhaps the estimates of heritability for the incidence of multiple births had previously been too low. They suggest that selection for this trait may be successful.

Wilson et al. (1962), on the other hand, were not able to detect a significant sire effect upon the number of pigs farrowed, the number of pigs weaned, the litter weight at farrowing, and the litter weight at weaning (56 days). Dzaparidze, (1935), Krallinger et al. (1934), and Musson (1946) as cited by Rahnefeld and Swierstra (1970), all reported little or no effect of sire on litter size in swine.

Inbreeding and Preweaning Traits

The effects of level of inbreeding on preweaning traits as well as on mortality have been extensively studied in swine. Bereskin et al. (1968) reviewed the literature in this area and reported that, in general, as the inbreeding of the dam and the inbreeding of the litter increased, a corresponding decrease in litter size occurred, as well as an increase in pig mortality and slower growth rates. In their study, the inbreeding of the litter was reported as having no effect on litter size at farrowing, but a generally significant depressing effect on average birth weight per pig farrowed. The inbreeding of the dam was found to have a significant effect in depressing litter size and the average birth weight per pig farrowed. At weaning, the inbreeding of the litter had an effect on litter size, and an increased significant effect on the average weight per pig compared to the effect at farrowing. The inbreeding of the dam had no effect on the number of pigs weaned, but did have a direct influence on average pig weight at weaning. These researchers also performed a study on the effect of inbreeding of the sire on the number of pigs born and the number of pigs born alive. No significant effects were reported, and it was suggested that the inbreeding of the boar did not affect his reproductive capacity such that the size of his litters would be affected. The effect of inbreeding of the sire was omitted from subsequent analyses. The relatively small number of records available and the wide diversity of the genetic material studied were two reasons given for the large variation in results seen in this study.

Similar results to those above were reported by Bereskin et al. (1970) for the effects of inbreeding of the dam and inbreeding of the litter on traits at farrowing, for the effects of inbreeding of the litter on traits at weaning, and for the effects of inbreeding of the dam on litter size at weaning. A generally depressing, but non-significant effect of inbreeding of the dam on the average weight per pig at weaning was reported. Path diagrams from this research indicated that the inbreeding of the dam exerts its greatest effect at or before birth, and this shows up in the traits at farrowing. The inbreeding of the litter, however, becomes more important after farrowing, exerting a stronger influence on later preweaning and weaning traits. This is in agreement with Urban et al. (1966) who reported that as the age of the pig increased the effect of the inbreeding of the dam decreased, while the effect of inbreeding of the litter increased with an increase in age of the pig.

Winters et al. (1947) cited McPhee et al. (1931) as having reported a decrease in vitality of new born pigs and a subsequent decline in survival as inbreeding increased rapidly. A decrease in the size of the litters yielded a lower total weaning weight. Winters et al. (1947) investigated what effect inbreeding as well as other factors had upon the survival of the litter from birth to weaning. They reported that the effects of inbreeding of the dam and of the litter were not significant on survival. The average birth weight of the litter was found to have the greatest effect upon pig survival. A low association between inbreeding of the litter and mortality was reported by Fahmy and Bernard (1971), who found that for each 10 percent increase in litter inbreeding, the percent survival would be expected to decline 0.7 percent. Bereskin et al. (1973) found no effect of inbreeding of the dam on pig survival, but reported a 1.2 percent decline in survival for every 10 percent increase in litter inbreeding. These researchers were able to account for 30 percent of the total variation by combining all the estimates of the relative contributions of different factors affecting the variation in survival rates. The remainder of the unidentified variation was assumed to be random in origin, indicating that survival is a complicated trait which is affected by many unknown factors.

Heritability and Preweaning Traits

Significant estimates of heritability of litter size in swine, according to Urban et al. (1966), are seldom realized because only a small portion of the variance of litter size is additive genetic variance. These researchers carried out a study on the total number of pigs born, the number born alive, and the number at weaning and obtained heritability estimates of $0.09 \pm .04$, $0.08 \pm .04$, and $0.13 \pm .05$ respectively. These estimates were made on litters from gilts and sows combined.

Boylan et al. (1961) studied gilt litters from three inbred lines of swine and reported an overall estimate of heritability of litter size for number of pigs born alive of $0.03 \pm .07$. Separate estimates of heritability for each of the three lines were not significant. These researchers cited Lush and Molln (1942) who reviewed the literature and found that estimates of heritability of litter size (the measure of litter size being the number of pigs born alive in gilt litters) ranged from .10 to .44. Boylan et al. (1961) also cited Cockerham (1952) who reported an estimate of -0.11, and Shelby (1952) who reported .54 for heritability of litter size.

Revelle and Robison (1973) offered an explanation for the low heritability of litter size in swine, suggesting that a negative environmental correlation exists between the litter size of the dam and the daughter. They felt that the increased stress and competition in larger litters could cause delayed physiological maturation of gilts in these litters, and therefore the litters of the next generation would experience a negative maternal effect. This would result in low heritabilities and selection for increased litter size would be ineffective. This study also reported that a granddaughter-granddam regression might better show the direct genetic effects on litter size. The estimate of heritability for litter size by the above method was reported to be $0.28 \pm .26$. The heritability estimate by daughter-dam regression was $0.13 \pm .06$.

Fahmy and Bernard (1970), used the paternal half-sib correlation to estimate the heritability of body weights. A value of $0.07 \pm .35$ was obtained for heritability of birth weight, and $0.10 \pm .36$ was obtained as an estimate of heritability of 21 day weight. Unweighted averages of estimates of heritability were reported as 0.17 and 0.09 respectively for the above two traits.

Research on the Managra breed of swine developed at the University of Manitoba, was reported by Stockhausen and Boylan (1966). They obtained estimates of the heritability of litter size of $0.20 \pm .15$ by the method of parent-offspring regression, and $0.59 \pm .29$ by paternal half-sib correlation. The measure of litter size was the number of pigs born alive in gilt litters from 1961 to 1965. The authors felt that perhaps the large estimates obtained could be explained by the fact that the Managra was a relatively new breed, and possibly had a greater amount of genetic variance present than some standard breeds of swine.

Roy et al. (1968), also working with Managra, reported the estimate of heritability of birth weight estimated from paternal half-sib correlation to be $0.10 \pm .15$. The data came from gilt litters farrowed during the years 1959 to 1965.

In conclusion, it appears that researchers disagree on whether or not the sire has any significant effect upon litter size, and individual and litter weights. However, some agreement on the effects of inbreeding on these traits has been reached. In general, as inbreeding increases preweaning traits suffer some reduction. Also, the reports indicate that the inbreeding of the dam plays an important role on traits at farrowing, but gradually decreases with increasing age of the litter, and that inbreeding of the litter plays a minor role at farrowing and gradually increases in importance as the pigs mature. It can also be said that there is a large amount of relatively unexplained variation associated with these preweaning traits. Consequently consistent estimates of heritability are difficult to obtain.

MATERIALS AND METHODS

Source of Data

The data for the analyses were obtained from records of the Managra breed of swine, developed and maintained at the Glenlea Research Station, University of Manitoba. The Managra has been developed from a foundation of seven different breeds to provide a new breed of swine to be used in commercial crossbreeding. The foundation breeds and their approximate contributions to the Managra are: Swedish Landrace, 45 percent; Wessex Saddleback, 20 percent; Welsh, 12 percent; with the remaining 23 percent contributed about equally by the Berkshire, Minnesota No. 1, Yorkshire, and Tamworth breeds.

In 1959, four separate lines were formed from the gene pool presented above. These lines were maintained independently of each other until 1967, when the number of lines was reduced to two by line-crossing lines 1 and 2 to form Managra Group A, and lines 3 and 4, to form Managra group B. Group A farrows in June-July and group B farrows in January-February each year. All the litters produced come from gilts mated to young boars of a similar age so that the generation interval is one year.

At weaning, one to two males are chosen from each of the best litters of a group. Usually from 60 to 80 males make up the total. At 200 pounds these young boars are ranked on the basis of age and backfat probe, and the best 20 to 25 are kept, along with about 70 to 75 contemporary gilts, selected on the same basis as the boars. At 8 to 8½ months of age the best 15 boars are pen-mated, one boar to five gilts. The matings are planned to minimize inbreeding. Only animals with no common ancestors in the first two generations of their pedigrees are allowed to mate.

Litters farrowed in June-July, 1968 to 1973 inclusive (group A) and litters farrowed in January-February, 1969 to 1974 inclusive (group B) provided the data for this study. The two groups A and B were maintained independently of each other for the most part; however, some individuals of one group were mated to individuals of the other, usually as a result of a shortage of good performance sires in one of the groups.

All the litters used in this study were maintained at one location. Only two litters that farrowed during the periods studied in both groups were omitted from the analyses due to incomplete records. Nine litters were also omitted because the gilts had been pen-mated with more than one boar and therefore, the sire of the litter and his inbreeding value could not be determined. A total then of 530 litters sired by 197 boars provided the data for this thesis. A breakdown of the number of sires and litters by group and by generation is given in table I.

The preweaning traits under study were litter size, individual birth weight of pigs born alive, and individual

TABLE I. Number of Boars, and Gilts that Farrowed in Each Group for Each Generation

	Generation 1	Generation 2	Generation 3	Generation 4	Generation 5	Generation 6	Total
Group A							
No. of boars	17	15	18	13	16	11	90
No. of gilts	28	38	45	49	67	38	265
Group B							
No. of boars	23	14	22	17	15	16	107
No. of gilts	39	37	46	41	51	51	265

Average No. of sires per farrowing period (Group A) = 15

Average No. of sires per farrowing period (Group B) = 17.8

Average No. of gilts farrowing per period in both groups = 44.2

pig weight at three weeks. Litter size was subdivided into the total number of pigs born, the number of pigs born alive, and the number of pigs alive at three weeks of age. Analysis of variance and covariance, and estimates of heritability for these five traits, were obtained separately for each of the two groups of pigs.

Inbreeding coefficients were estimated as shown by Rice et al. (1967). One-half of the numerator of the coefficient of relationship between the sire and dam, or one-half the covariance between the sire and dam yielded the inbreeding value for the offspring. The covariance between sire and dam was calculated by taking one-quarter of the sum of the covariances between each of the parents of the sire and of the dam.

Statistical Analysis

For litter size, a hierarchal classification was used to analyze the data on a within generation basis, with sires and litters within sires (error) as the sources of variation. The form of the analysis is presented in table II as well as expectation of mean squares.

The variance of the variance component estimate of the sire (S) and the standard error were calculated by the general formula (Anderson and Bancroft, 1952) as demonstrated in Becker (1967):

$$var(\sigma_g^2) \cong \frac{2}{K^2}\left(\sum_g \frac{MS_g^2}{f_g + 2}\right)$$

$$S.E.(\sigma_g^2) \cong \sqrt{var(\sigma_g^2)}$$

where:

K = coefficient of the variance component being estimated

MS_g = the g^{th} mean square used to estimate the variance component (σ_g^2)

f_g = the degrees of freedom of the g^{th} mean square.

The sire component of variance (S) estimates one-quarter of the additive genetic variance. The total phenotypic variance of the population was obtained by summing S and W. The estimate of heritability, which represents the proportion of the total phenotypic variance that is due to additive effect of genes, was calculated by:

$$h^2_S = \frac{4S}{S + W}$$

The standard error of heritability (modified from Dickerson, 1960) as demonstrated by Becker (1967) , was calculated by:

$$S.E.(h^2) = 4\sqrt{\frac{var(\sigma^2_S)}{\sigma^2_S + \sigma^2_W}}$$

where:

$\sigma^2_S = S$ (estimate of sire component of variance)

$\sigma^2_W = W$ (estimate of within component of variance)

A hierarchal classification was also used to analyze the data for individual birth weight and individual three week weight. For each trait, a pooled analysis was performed across the six generations. The form of the analysis was similar to that in table III with the addition of between generations as another source of variation.

The variance of the variance component estimates and the standard errors were calculated by the method of Anderson and Bancroft (1952). The component (S) is estimated by:

$$S = \left[M_1 - M_3 - \frac{K_2}{K_1}(M_2 - M_3) \right] \Big/ K_3$$

where:

$S =$ the estimate of the sire component of variance.

From the estimate it can be shown that:

$$\text{Var }(S) = \left[\text{Var }(M_1) + \left(\frac{K_2}{K_1}\right)^2 \cdot \text{Var }(M_2) + \left(\frac{K_2 - K_1}{K_1}\right)^2 \cdot \text{Var }(M_3) \right] \Big/ K^2_3$$

Where:

Var (S) = Variance of S

Var (M_1) = Variance of the mean square for the sires source of variation

Var (M_2) = Variance of the mean square for the dams within sires source of variation

Var (M_3) = Variance of the mean square for the progeny within dams within sires source of variation.

The variances of the mean squares were approximated by substitution of the observed mean square for its expectation in the general expression:

$$\text{Var}\ (M) = 2\ \frac{[E\ (M)]^2}{d.f.}$$

where:

M = any mean square
$E(M)$ = expectation of M
d.f. = degrees of freedom for the mean square M.

The standard errors for variance of the variance component estimates were calculated by taking the square root of the variance.

The sire component of variance (S) represents one-quarter of the additive genetic variance. The total phenotypic variance was calculated by summing S + D + W, and the heritabilities of individual birth weight and individual three week weight were calculated by:

$$h^2_S = \frac{4\ S}{S + D + W}$$

The standard error of heritability (modified by Dickerson, 1960) as described by Becker (1967) is:

$$S.E.\ (h^2_S) = \frac{4\sqrt{\text{Var}\ (\sigma^2_S)}}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

where:

$\text{Var}\ (\sigma^2_S)$ = Variance of S
σ^2_S = S
σ^2_D = D
σ^2_W = W

TABLE II. Analysis of Variance and Expectations of Mean Squares (Litter Size)

Source of Variation	d.f.	Mean Square	Mean Square Expectations
Sires	s - G	M_1	W + KS
Litters within sires	n. - s	M_2	W

where: G = total number of generations

s = total number of sires

n. = total number of litters

$$K = \frac{1}{s-1}\left(n. - \frac{\sum n_i^2}{n.}\right)$$

n_i = total number of offspring from the i^{th} sire

S = variance due to difference among sires

W = variance due to differences among litters within sires

TABLE III. Analysis of Variance and Expectations of Mean Squares (Individual Birth Weight and Three Week Weight)

Source of Variation	d.f.	Mean Square	Mean Square Expectations
Sires	s-G	M_1	$W + K_2D + K_3S$
dams within sires	d-s	M_2	$W + K_1D$
progeny within dams within sires	N-d	M_3	W

where:
G = total number of generations
s = total number of sires
d = total number of dams
N = total number of progeny

$$K_1 = \frac{1}{d-s} \cdot \left[N - \frac{\sum_i \sum_j n^2_{ij}}{n_{i.}} \right]$$

$$K_2 = \frac{1}{s-1} \cdot \left[\frac{\sum_i \sum_j n^2_{ij}}{n_{i.}} - \frac{\sum_i \sum_j n_{ij}^2}{N} \right]$$

$$K3 = \frac{1}{s-G} \cdot \left[N - \frac{\sum_i n^2_{i.}}{N} \right]$$

$n_{i.}$ = total number of offspring from the i^{th} sire

n_{ij} = total number of offspring from the j^{th} dam

S = variance due to differences among sires

D = variance due to differences among dams

W = variance due to difference among sibs

An analysis of the sums of squares and products for the effects of percent inbreeding of the litter and of the dam (X or independent variables) on the five previously mentioned preweaning traits (Y or dependent variables) was computed in the form shown in table lV and demonstrated in Snedecor and Cochran (1967).

Regression coefficients of the various traits on either the inbreeding of the litter or the dam on a within generation basis were calculated by:

$$b = SCP_{XY}\,(\text{Error}) \,/\, SS_{XX}\,(\text{Error})$$

The standard errors were:

$$S.E._b = \sqrt{\frac{SS_{YY}\,(\text{Error}) - R^2 / N-G-1}{SS_{XX}\,(\text{Error})}}$$

Phenotypic correlations between the litter traits and inbreeding were calculated by:

$$r = \frac{COV_{XY}}{\sqrt{\sigma^2_X \; \sigma^2_Y}}$$

where:

$$COV_{XY} = SCP_{XY}\,(\text{Error}) \;/\; d.f.\,(\text{Error})$$

$$\sigma^2_X = SS_{XX}\,(\text{Error}) \,/\, d.f.\,(\text{Error})$$

$$\sigma^2_Y = SS_{YY}\,(\text{Error}) \,/\, d.f.\,(\text{Error})$$

The standard errors of the correlation coefficients were calculated by:

$$S.E._r = \sqrt{\frac{1 - r^2}{d.f.\ (error)}}$$

In the above analyses, the average weight of a pig in a litter at birth and at three weeks was used in obtaining the covariance of these two traits with inbreeding level in the litter and the dam, as opposed to using the individual weight of each pig in a litter.

TABLE 1V. Analysis of Sums of Squares and Sums of Cross-Products

Source of Variation	d.f.	$\sum x^2$	$\sum xy$	$\sum y^2$
Total	N-1	SS_{XX}(Total)	SCP_{XY}(Total)	SS_{YY}(Total)
Between Generations	G-1	SS_{XX}(Gen.)	SCP_{XY}(Gen.)	SS_{YY}(Gen.)
Litters Within Generations (Error)	N-G	SS_{XX}(Error)	SCP_{XY}(Error)	SS_{YY}(Error)
Reduction due to Regression	1			R^2
Deviations from Regression	N-G-1			SS_{YY}(Error) - R^2

Where:

$\sum x^2$ = analysis of variance of the independent variable

$\sum y^2$ = analysis of variance of the dependent variable

$\sum xy$ = analysis of the covariance between the independent and dependent variables.

N = total number of litters

G = total number of generations

SS_{XX} = sum of squares of variable X

SS_{YY} = sum of squares of variable Y

SCP_{XY} = sum of cross-products of variables X and Y

$$R^2 = \left[SCP_{XY}(\text{Error})\right]^2 \Big/ SS_{XX}(\text{Error})$$

RESULTS AND DISCUSSION

Phenotypic means for the total number of pigs born, the number of pigs born alive, and the number of pigs at three weeks of age for each of the six generations under study are shown in table V for both groups A and B. For group A, the overall means and standard errors for the three measures of litter size were $8.72 \pm .14$, $8.00 \pm .14$, and $6.67 \pm .15$ respectively. For group B, the overall means and standard errors were $9.57 \pm .15$, $8.86 \pm .15$ and $7.72 \pm .15$ respectively. These overall averages show that group B litters were larger than those of group A by .85 of a pig in total number born, and by .86 of a pig in number born alive. However, group B litters were larger than group A litters by 1.05 of a pig, on the average, at three weeks of age. This increase in the difference between groups for litter size can be accounted for by the differences in pig mortality from birth to three weeks of age. From the overall averages for number born alive and number at three weeks given above, it was calculated that percent mortality for group A was 16.6 and 12.9 for group B.

Perhaps group B pigs, which are born in January - February as compared to group A pigs which farrow in June - July, experience a more favourable environment during their first few weeks of life resulting in lower mortality in group B. It could also be that group B pigs are more physiologically mature in terms of reproductive capability than group A pigs at time of mating, which is approximately

TABLE V. Generation Means and Standard Errors for Litter Size

Group	Generation	Total Number Born	Number Born Alive	Number at 3 Weeks
A	1	9.07 ± .41	8.71 ± .40	7.21 ± .47
	2	8.37 ± .40	7.66 ± .40	7.06 ± .39
	3	8.47 ± .23	7.87 ± .23	6.27 ± .30
	4	9.14 ± .33	8.20 ± .30	7.11 ± .31
	5	8.69 ± .29	7.88 ± .30	6.18 ± .35
	6	8.63 ± .41	7.92 ± .38	6.68 ± .38
	(Overall Means)	(8.72 ± .14)	(8.00 ± .14)	(6.67 ± .15)
B	1	9.95 ± .40	8.92 ± .40	7.85 ± .43
	2	9.92 ± .33	9.11 ± .31	7.59 ± .34
	3	10.17 ± .35	9.61 ± .37	8.18 ± .37
	4	8.44 ± .48	7.98 ± .45	6.83 ± .42
	5	9.29 ± .32	8.65 ± .31	7.43 ± .34
	6	9.65 ± .31	8.88 ± .29	8.29 ± .29
	(Overall Means)	(9.57 ± .15)	(8.86 ± .15)	(7.72 ± .15)

8 months after farrowing. This may explain, to a degree, the general trend of group B to be approximately one pig per litter larger than group A over the three measures of litter size taken. Although group B litters were consistently larger than group A litters overall, there was no noticeable change in litter size within either group through the six generations under study.

Of the average total number of pigs born per litter, 8.3 percent were born dead in group A and 7.4 percent were born dead in group B (necrotics excluded), indicating that the incidence of pre-natal mortality is lower in group B. However, the average number of pigs born dead per litter was almost identical in the two groups (.72 in group A and .71 in group B).

The phenotypic means of individual birth weight and individual three week weight for each generation and for both groups A and B are presented in table VI. The overall averages for group A were 2.84 $\pm$ .01 pounds for individual birth weight, and 10.19 $\pm$ .05 pounds for individual three week weight. The corresponding averages for group B were 3.06 $\pm$ .01 pounds and 10.92 $\pm$ .05 pounds respectively. Overall, group B pigs tended to be heavier at birth than group A pigs by .22 of a pound which is 7.8 percent of the average birth weight of an individual in group A. At three weeks of age, the difference between the average weights of group B and group A increased to .73 of a pound, but still amounted to only 7.2 percent of the average individual

TABLE VI. Generation Means and Standard Errors for Individual Birth Weight and Three Week Weight

Group	Generation	Individual Birth Weight (lb)	Individual 3 Week Weight (lb)
A	1	2.74 ± .04	9.68 ± .15
	2	2.87 ± .03	10.67 ± .12
	3	2.93 ± .03	10.42 ± .13
	4	2.89 ± .03	10.11 ± .13
	5	2.73 ± .02	9.81 ± .09
	6	2.89 ± .03	10.55 ± .12
	(Overall Means)	(2.84 ± .01)	(10.19 ± .05)
B	1	3.07 ± .03	10.96 ± .14
	2	3.04 ± .04	10.87 ± .15
	3	3.02 ± .03	10.80 ± .13
	4	2.97 ± .03	11.69 ± .14
	5	3.05 ± .03	10.26 ± .12
	6	3.16 ± .03	11.10 ± .12
	(Overall Means)	(3.06 ± .01)	(10.92 ± .05)

three week weight of an individual in group A. This indicates that group B pigs were larger at birth and also at three weeks, but the difference between the two groups changed only to a small degree in terms of percent of body weight.

The overall average rates of gain for both groups from birth to weaning, calculated by taking the difference between the average individual birth and three week weights and dividing by 21, were: .35 pounds per day for group A, and .37 pounds per day for group B. These results, as well as the relatively stable difference between groups for weights from birth to weaning, suggest that mothering ability is comparable for both groups.

Over six generations the average birth weights and average three week weights remained relatively the same and no consistent trends, either increasing or decreasing, were observed in group A or group B.

By multiplying the average individual birth weight by the corresponding average total number born, the average total litter weight produced per gilt for both groups, was calculated to be: 24.76 pounds for group A, and 29.28 pounds for group B. Apparently, group B is superior to group A in terms of reproductive performance. This superiority is probably due, in part, to higher maternal ability in group B, as this group not only produces larger litters, but also heavier pigs.

Effect of Sire and of Dam on Preweaning Traits.

Analysis of variance was performed on the total number of pigs born, the number born alive, the number at three weeks, individual birth weight, and individual three week weight for both groups A and B. (The tables of analysis of variance can be found in the appendix). The variation due to generations was removed from all analyses. A significant effect of sire on individual three week weight of offspring was found for group B ($p < .05$). No significant effect of sire was evident from any of the remaining analyses. These results are in agreement with those of Wilson et al. (1962), and Dzaparidze (1935), Krahlinger et al. (1939), and Musson (1946) as cited by Rahnefeld and Swierstra (1970), all of whom reported no effect of sire on litter size in swine. However, Rahnefeld and Swierstra (1970), and Minkema (1967) have reported a significant effect of sire on litter size in swine. The apparent effect of sire on three week weight found in this study would indicate that the sire has some influence on weight of pigs at three weeks.

Further research on effect of sire for both litter size and individual pig weights should be carried out, perhaps with a larger body of data than was available for this study.

For the analysis of variance of individual birth weight and of individual three week weight, between dams within sires was included as a source of variation and was found to be highly significant ($p < .01$) in both analyses for both groups A and B. These results were not unexpected as individual birth weight is influenced by the dams reproductive potential, and individual three week weight is influenced by both the dams reproductive potential and milking and maternal ability.

Level of Inbreeding

The average percent inbreeding of the sire, the dam, and the litter for each of the six generations and for both groups is shown in table VII and presented graphically in figures 1, 2, and 3. It can be seen that the two groups possessed approximately the same average level of homozygosity, group A being slightly higher than group B, for the first three generations. At this point in time, some animals, unrelated to those in group B, were used for breeding purposes within that group. Subsequently, the average inbreeding of the litters of group B was reduced in generation 4, and it follows that the average inbreeding of the breeding stock in generation 5 would be reduced by approximately the same amount.

A few animals outside of group A were used for breeding purposes in that group, but the average inbreeding was not affected to any large extent. However, because unrelated animals were used for breeding stock in both groups A and B, the expected change in inbreeding within a closed line as shown by Lush (1945) was not calculated. The two lines of Managra have been maintained as separate and distinct lines for the most part, however, partly for practical reasons in

TAVLE VII. Generation Means and Standard Errors for the Level of Percent Inbreeding of the Sire, the Dam, and the Litter

Group	Generation	Fx of Sire (%)	Fx of Dam (%)	Fx of Litter (%)
A	1	7.13 ± 1.30	5.97 ± .95	11.66 ± .81
	2	10.21 ± .90	11.76 ± .34	12.63 ± .53
	3	10.61 ± .51	13.05 ± .40	13.01 ± .66
	4	13.92 ± .30	13.82 ± .33	15.41 ± .25
	5	14.60 ± .30	15.20 ± .19	13.79 ± .49
	6	14.90 ± .30	13.89 ± .68	13.22 ± .92
B	1	4.13 ± .04	4.05 ± .08	11.31 ± .51
	2	9.80 ± .67	11.22 ± .75	11.68 ± .71
	3	11.29 ± .54	11.60 ± .59	12.73 ± .35
	4	11.91 ± .33	12.60 ± .46	6.93 ± .90
	5	6.54 ± .63	5.47 ± .81	7.23 ± .32
	6	7.52 ± .26	7.61 ± .31	9.69 ± .12

Figure 1.

Generation Means for Percent Inbreeding of the Sires of Groups A and B

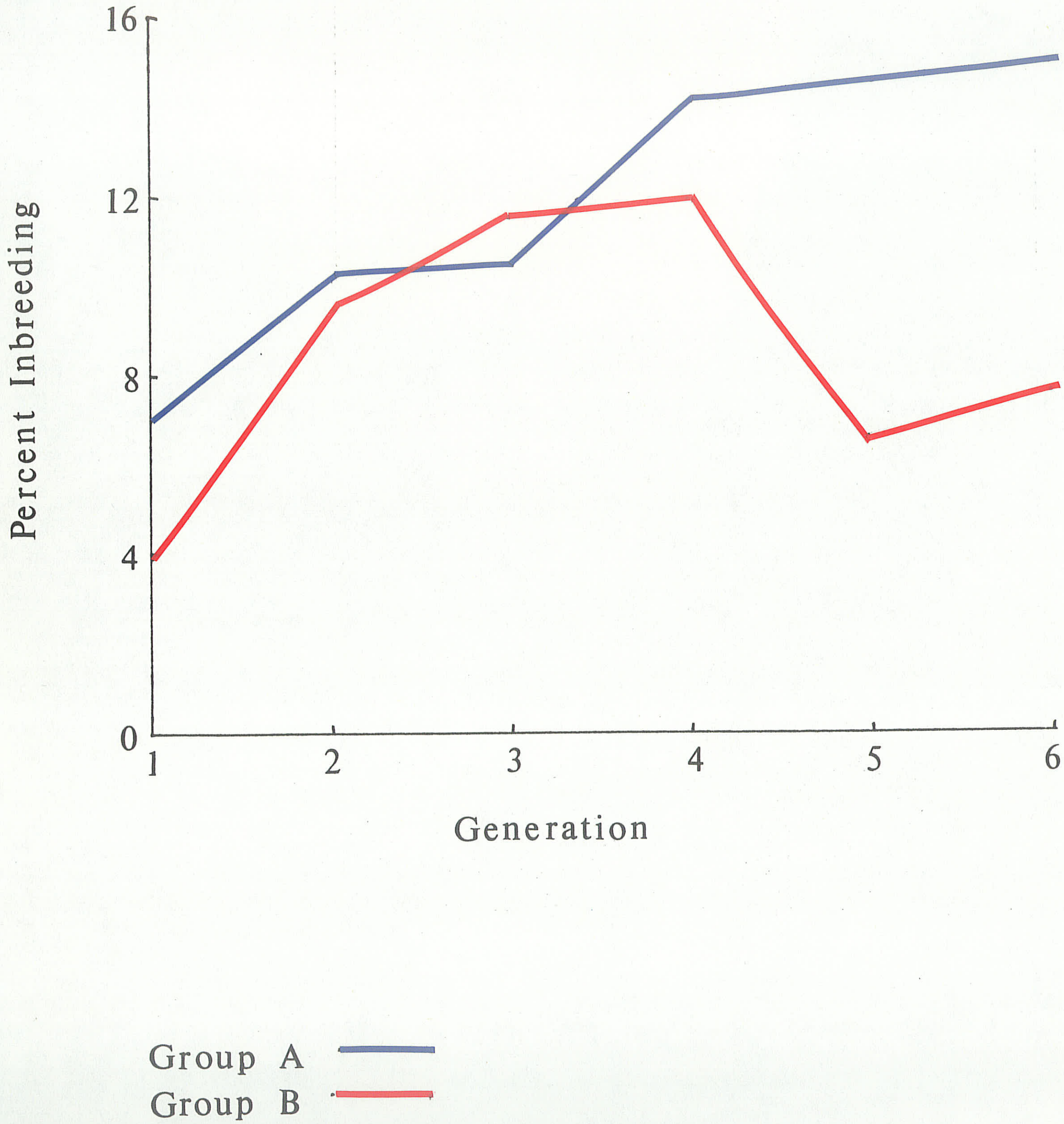


Figure 2.

Generation Means for Percent Inbreeding of the Dams of Groups A and B

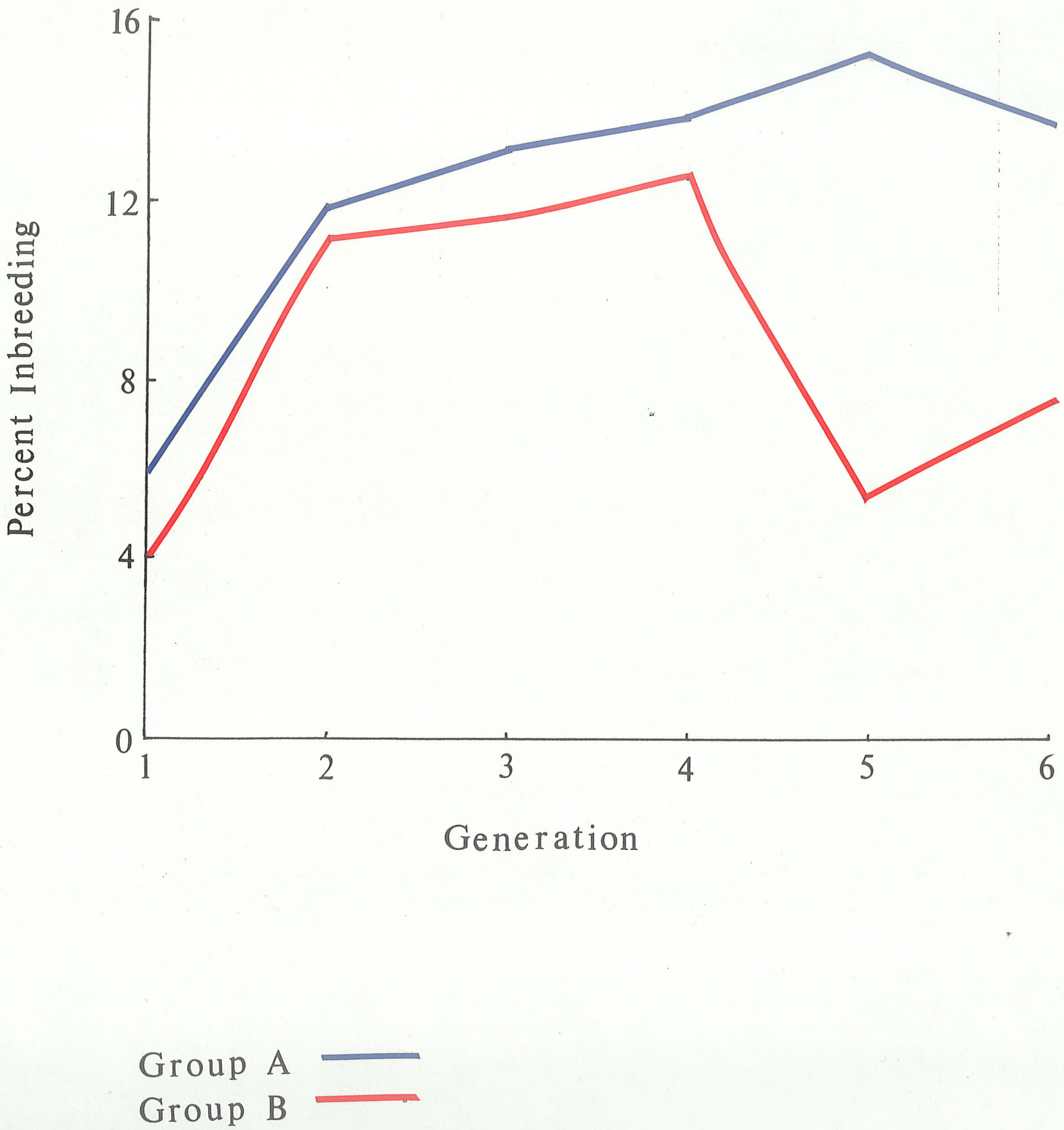
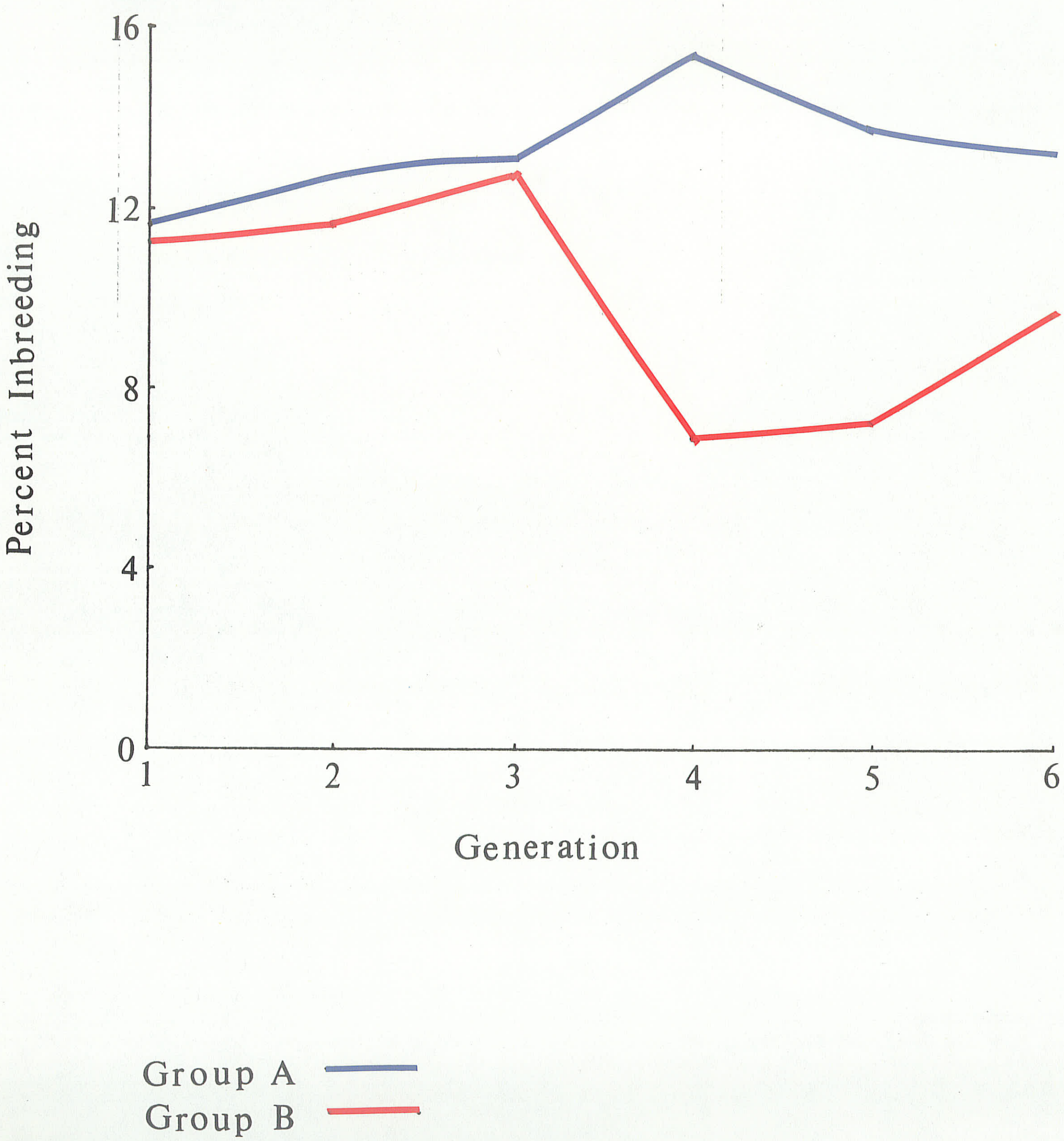


Figure 3.

Generation Means for Percent Inbreeding of the Litters of Groups A and B



terms of the capacity and operation of the research barn, but also to enable linecrosses to be made between the lines. Such crosses might become necessary for example if levels of inbreeding in one or both lines became too high or if one line, while excellent for most traits, became fixed for some undesirable trait. The ability to correct such a defect by introductions from the other line, while maintaining the excellence in other traits, could be important.

It should be remembered that an inbreeding coefficient must be relative to some group, usually a purebred population. The Managra breed, however, is from a crossbred foundation and is of recent origin, and therefore the inbreeding values calculated for this breed cannot be compared to estimates of inbreeding found in other pure breeds of swine. The changes in inbreeding, however, over the six generations studied, show the trends in inbreeding for the two groups.

Effect of Inbreeding of the Dam and of the Litter on Preweaning Traits.

Changes in each of the five preweaning traits studied with each ten percent increase in inbreeding of litter, and with each ten percent increase in inbreeding of the dam, for each generation are shown in appendix tables 16 and 17. The changes in these traits for each ten percent increase in inbreeding of the litter and of the dam, on a within generation basis, are presented in tables VIII and IX respectively. As inbreeding increases in both the litter and the dam in both groups, almost all the traits show a negative response.

TABLE VIII. Change in Preweaning Traits for each 10 Percent Increase in Inbreeding of the Litter on a Within Generation Basis

Group	Total Number Born b	s.e.	Number Born Alive b	s.e.	Number at 3 Weeks b	s.e.	Average Individual Birth Weight (lb) b	s.e.	Average Individual 3 Week Weight (lb) b	s.e.
A	- .51 ±	.35	- .46 ±	.34	-1.07 ±	.38	.02 ±	.01	- .35 ±	.23
B	- .27 ±	.44	- .29 ±	.43	- .55 ±	.44	.04 ±	.08	- .09 ±	.34

b = regression coefficient

s.e. = standard error

TABLE IX. Change in Preweaning Traits for each 10 Percent Increase in Inbreeding of the Dam on a Within Generation Basis

Group	Total Number Born b	s.e.	Number Born Alive b	s.e.	Number at 3 Weeks b	s.e.	Average Individual Birth Weight (lb) b	s.e.	Average Individual 3 Week Weight (lb) b	s.e.
A	.12 ±	.48	- .13 ±	.47	- .02 ±	.51	- .02 ±	.08	- .11 ±	.44
B	- .06 ±	.40	- .20 ±	.39	- .37 ±	.39	- .12 ±	.07	- .21 ±	.31

b = regression coefficient

s.e. = standard error

This is in agreement with Bereskin et al. (1968), (1969), and (1970), and also in agreement with the literature as reviewed by Bereskin. The effect of increased inbreeding of the litter on average individual birth weight, however, is shown to be slightly positive for both groups, but the regression coefficients indicate the increase is almost zero.

The inbreeding of the litter shows a greater effect upon litter size and individual weight at three weeks than it does at birth. Group A showed a decrease of about half a pig per litter for every ten percent increase in inbreeding of the litter at birth. At three weeks a decrease of slightly over one pig per litter was found. The decreases in litter size at birth and at three weeks of age for every ten percent increase in inbreeding of the litter in group B are approximately 0.3 and 0.6 of a pig respectively. In both groups, the inbreeding of the litter has a negative effect upon individual weight at three weeks while at birth, as already mentioned, the effect was almost zero. Bereskin et al. (1970) and Urban (1966) reported that the inbreeding of the litter becomes increasingly more important, with respect to preweaning traits, as the pigs increase in age, which is in agreement with the results found in this study.

The changes in preweaning traits associated with each ten percent increase in inbreeding of the dam are generally small, but negative, and rather insignificant. The differences between the two groups are slight except for the change in the number of pigs at three weeks. The effects of inbreeding of the dam on litter size at birth are approximately the same for both groups, indicating that the environment for group B pigs from birth to three weeks allows for the detrimental effects of the inbreeding of the dam to be expressed, in terms of pig mortality. Group B litters are reduced by .37 of a pig for each ten percent increase in inbreeding of the dam, while group A litters are reduced by only .02 of a pig.

Correlation Between Inbreeding and Preweaning Traits.

Phenotypic correlations between the inbreeding of the litter and preweaning traits, and inbreeding of the dam and preweaning traits are given in tables X and XI. Generally, the correlation coefficients in both these tables are negative, but all are close to zero, indicating a rather low association between inbreeding and these preweaning traits.

Estimates of Heritability

Estimates of heritability obtained from paternal half-sib correlation for all the preweaning traits under study are presented in table XII. The heritability estimates of litter size shown here are relatively consistent over both groups, with most of the estimates close to zero. Group A and B differ, however, in the estimate of heritability of individual weight, especially at three weeks. Some of the variation here may be attributable to sampling error, however, as the standard errors are large for individual birth and three week weight.

TABLE X. Phenotypic Correlation Between Inbreeding of the Litter and Preweaning Traits

Group	Total Number Born r ± s.e.	Number Born Alive r ± s.e.	Number at 3 Weeks r ± s.e.	Average Individual Birth Weight r ± s.e.	Average Individual 3 Week Weight r ± s.e.
A	-.09 ± .06	-.08 ± .06	-.18 ± .06	.02 ± .06	-.09 ± .06
B	-.04 ± .06	-.04 ± .06	-.08 ± .06	.03 ± .06	-.02 ± .06

r = correlation coefficient

s.e. = standard error

TABLE XI. Phenotypic Correlation Between Inbreeding of the Dam and Preweaning Traits

Group	Total Number Born r ± s.e.	Number Born Alive r ± s.e.	Number at 3 Weeks r ± s.e.	Average Individual Birth Weight r ± s.e.	Average Individual 3 Week Weight r ± s.e.
A	.02 ± .06	-.02 ± .06	-.003 ± .06	-.02 ± .06	-.02 ± .06
B	-.01 ± .06	-.03 ± .06	-.06 ± .06	-.11 ± .06	-.04 ± .06

r = correlation coefficient

s.e. = standard error

TABLE XII. Heritability Estimates of Litter Size and of Individual Birth Weight and Three Week Weight Obtained from Paternal Half-Sib Correlation

	Total Number Born		Number Born Alive		Number at 3 Weeks		Individual Birth Weight		Individual 3 Week Weight	
Group	h^2	s.e.	h^2	s.e.	h^2	s.e.	h^2	s.e.	h^2	s.e.
A	$-.03$	$\pm .02$	$-.01$	$\pm .02$	$.04$	$\pm .04$	$.04$	$\pm .15$	$-.16$	$\pm .14$
B	$.05$	$\pm .03$	$.03$	$\pm .03$	$-.09$	$\pm .02$	$.11$	$\pm .15$	$.25$	$\pm .17$

h^2 = heritability

s.e. = standard error

SUMMARY AND CONCLUSION

The effects of sire and of inbreeding of the dam and of the litter on litter size (total number born, number born alive, number at three weeks) and on individual birth and three week weight were examined over six generations for two groups of the Managra breed of swine.

It was found that the sire had no significant effect on litter size and little or no effect on individual weights at birth and three weeks. Increases in inbreeding of the dam were found to have a small, but generally negative effect on preweaning traits, as had increases in inbreeding of the litter. The inbreeding of the litter had a larger effect at three weeks than at birth. Estimates of heritability were low and had large standard errors indicating the large amount of unexplained random variation in the preweaning traits studied.

LITERATURE CITED

Anderson, R.L. and T.A. Bancroft. 1952. Statistical Theory in Research. McGraw Hill Book Company, New York.

Becker, W.A. 1967. Manual of Procedures in Quantitative Genetics. Second Edition. Washington State University Press, Pullman, Washington.

Bereskin, B., C.E. Shelby, K.E. Rowe, W.E. Urban Jr., C.T. Blunn, A.B. Chapman, V.A. Garwood, L.N. Hazel, J.E. Lasley, W.T. Magee, J.W. McConty and J.A. Whatley Jr. 1968. Inbreeding and Swine Productivity Traits. Journal of Animal Science. 27: 339-350.

Bereskin, B., C.E. Shelby and L.N. Hazel. 1969. Monte Carlo Studies of Selection and Inbreeding in Swine. I. Genetic and Phenotypic Trends. Journal of Animal Science. 29: 678-686.

Bereskin, B., C.E. Shelby, K.E. Rowe, W.E. Rempel, A.E. Dettmers and H.W. Norton. 1970. Inbreeding and Swine Productivity in Minnesota Experimental Herds. Journal of Animal Science. 31: 278-288.

Bereskin, B., C.E. Shelby and D.F. Cox. 1973. Some Factors Affecting Pig Survival. Journal of Animal Science. 36: 821-827.

Boylan, W.J., W.E. Rempel and R.E. Comstock. 1961. Heritability of Litter Size in Swine. Journal of Animal Science. 20: 566-568.

Dickerson, G.E. 1960. Techniques for Research in Quantitative Animal Genetics. Techniques and Procedures in Animal Production Research. pp. 56-105. American Society of Animal Production Publication.

Fahmy, M.H. and C. Bernard. 1970. Genetic and Phenotypic Study of Pre- and Post-Weaning Weights and Gains in Swine. Canadian Journal of Animal Science. 50: 593-599.

Fahmy, M.H, and C. Bernard. 1971. Causes of Mortality in Yorkshire Pigs from Birth to 20 Weeks of Age. Canadian Journal of Animal Science. 51: 351-359.

Lush, J.L., 1945. Animal Breeding Plans. Third Edition. Iowa State University Press. Ames, Iowa.

Minkema, D. 1967. Some Factors Affecting Litter Size in Swine. Animal Breeding Abstracts. 35: 652.

Parker, R.J. 1973. Development of the Managra - A New Breed of Swine. Department of Animal Science, University of Manitoba. (Unpublished paper).

Rahnefeld, G.W. and E.E. Swierstra. 1970. Influence of the Sire on Litter Size in Swine. Canadian Journal of Animal Science. 50: 671-675.

Revelle, T.J. and D.W. Robison. 1973. An Explanation for the Low Heritability of Litter Size in Swine. Journal of Animal Science. 37: 668-675.

Rice, V.A., F.N. Andrews, E.J. Warwick and J.E. Legates. 1967. Breeding and Improvement of Farm Animals. Sixth Edition. McGraw-Hill Book Company.

Roy, G.L., W.J. Boylan and M.E. Seale. 1968. Estimates of Genetic Correlations Among Certain Carcass and Performance Traits in Swine. Canadian Journal of Animal Science. 48: 1-6.

Schilling, P., W. North and R. Bogart. 1968. The Effect of Sire on Litter Size in Mice. Journal of Heredity. 59: 351-352.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical Methods. Sixth Edition. Iowa State University Press. Ames, Iowa.

Stockhausen, C.W.F. and W.J. Boylan, 1966. Heritability and Genetic Correlation Estimates in a New Breed of Swine. Canadian Journal of Animal Science. 46: 211-216.

Turner, H.T., R.H. Hayman, L.K. Tiffit and R.W. Prunster. 1962. Response to Selection for Multiple Births in the Australian Merino: A Progress Report. Animal Production. 4: 165-176.

Urban, W.E. Jr., C.E. Shelby, A.B. Chapman, J.A. Whatley Jr. and V.A. Garwood. 1966. Genetic and Environmental Aspects of Litter Size in Swine. Journal of Animal Science. 25: 1148-1153.

Wilson, S.P., J.A. Whatley Jr., J.V. Whiteman and R.D. Morrison. 1962. Influence of Sire and Line of Breeding on Sow Productivity. Journal of Animal Science. 21: 119-122.

Winters, L.M., J.M. 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. Journal of Animal Science. 6: 288-296.

APPENDIX

TABLE 1. Analysis of Variance in Total Number Born.

Group	Source of Variation	d.f.	Mean Square	F
A	S	84	4.54	N.S.
	W	175	5.41	
B	S	101	6.73	N.S.
	W	158	5.23	

S = variance due to differences between sires

W = variance due to differences between litters within sires

N.S. = Not significant

TABLE 2. Analysis of Variance in Number Born Alive.

Group	Source of Variation	d.f.	Mean Square	F
A	S	84	4.64	N.S.
	W	175	4.99	
B	S	101	6.19	N.S.
	W	158	5.24	

S = variance due to differences between sires

W = variance due to differences between litters within sires

N.S. = Not significant

TABLE 3. Analysis of Variance in Number at Three Weeks.

Group	Source of Variation	d.f.	Mean Square	F
A	S	84	6.53	N.S.
	W	169	5.43	
B	S	101	4.11	N.S.
	W	157	6.89	

S = variance due to differences between sires
W = variance due to differences between litters within sires
N.S. = Not Significant

TABLE 4. Analysis of Variance in Individual Birth Weight.

Group	Source of Variation	d.f.	Mean Square	F
A	S	84	1.28	N.S.
	D	175	1.09	**
	W	1855	0.15	
B	S	101	1.81	N.S.
	D	158	1.46	**
	W	2083	0.22	

S = variance due to differences between sires

D = variance due to differences between dams within sires

W = variance due to differences between progeny within dams within sires

N.S. = Not Significant

** ($p < 0.01$)

TABLE 5. Analysis of Variance in Individual Three Week Weight.

Group	Source of Variation	d.f.	Mean Square	F
A	S	84	13.31	N.S.
	D	169	14.15	**
	W	1469	2.50	
B	S	101	28.65	*
	D	157	19.75	**
	W	1773	3.36	

S = variance due to differences between sires

D = variance due to differences between dams within sires

W = variance due to differences between progeny within dams within sires

N.S. = Not Significant

**($p < 0.01$) ; *($p < 0.05$)

TABLE 6. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Litter (X) and Total Number Born (Y).

Group	Source of Variation	d.f.	$\sum x^2$	$\sum xy^2$	$\sum y^2$
A	T	264	4507.21	-175.92	1347.34
	G	5	320.65	38.75	20.18
	W	259	4186.56	-214.68	1327.16
	R	1			11.01
	D	258			1316.15
B	T	265	4260.91	216.62	1589.09
	G	5	1288.44	296.57	83.48
	W	259	2972.47	- 79.95	1505.61
	R	1			2.15
	D	258			1503.46

T = Total

G = Generations

W = Within

R = Variance due to regression

D = Deviations from regression

TABLE 7. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Litter (X) and Number Born Alive (Y).

Group	Source of Variation	d.f.	Σx^2	Σxy^2	Σy^2
A	T	264	4507.24	-197.77	1289.78
	G	5	320.66	- 4.80	22.55
	W	259	4186.58	-192.97	1267.23
	R	1			8.89
	D	258			1258.34
B	T	264	4261.03	168.80	1515.83
	G	5	1288.46	253.59	62.61
	W	259	2972.57	- 84.79	1453.22
	R	1			2.42
	D	258			1450.80

T = Total

G = Generations

W = Within

R = Variance due to regression

D = Deviations from regression

TABLE 8. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Litter (X) and Number at Three Weeks (Y).

Group	Source of Variation	d.f.	$\sum x^2$	$\sum xy^2$	$\sum y^2$
A	T	258	4310.92	-431.64	1511.10
	G	5	307.54	- 4.47	45.27
	W	253	4003.38	-427.17	1465.83
	R	1			45.58
	D	252			1420.25
B	T	263	4241.88	34.94	1561.69
	G	5	1271.91	197.68	64.21
	W	258	2969.97	-162.76	1497.48
	R	1			8.92
	D	257			1488.56

T = Total

G = Generations

W = Within

R = Variance due to regression

D = Deviations from regression

TABLE 9. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Litter (X) and Average Individual Birth Weight (Y).

Group	Source of Variation	d.f.	$\sum x^2$	$\sum xy^2$	$\sum y^2$
A	T	264	4506.87	10.89	40.13
	G	5	320.71	2.60	1.27
	W	259	4186.16	8.29	38.86
	R	1			.02
	D	258			38.84
B	T	264	4261.19	20.38	49.30
	G	5	1288.48	8.64	.80
	W	259	2972.71	11.74	48.50
	R	1			.05
	D	258			48.45

T = Total

G = Generations

W = Within

R = Variance due to regression

D = Deviations from regression

TABLE 10. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Litter (X) and Average Three Week Weight (Y).

Group	Source of Variation	d.f.	$\sum x^2$	$\sum xy^2$	$\sum y^2$
A	T	258	4310.82	-165.19	595.70
	G	5	307.40	- 25.54	35.92
	W	253	4003.42	-139.65	559.78
	R	1			4.87
	D	252			554.91
B	T	263	4242.09	- 46.31	943.88
	G	5	1271.64	- 20.72	50.59
	W	258	2970.45	- 25.60	893.29
	R	1			.22
	D	257			893.07

T = Total

G = Generations

W = Within

R = Variance due to regression

D = Deviations from regression

TABLE 11. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Dam (X) and Total Number Born (Y).

Group	Source of Variation	d.f.	$\sum x^2$	$\sum xy^2$	$\sum y^2$
A	T	264	4053.68	- 16.04	1347.34
	G	5	1827.30	- 43.75	20.18
	W	259	2226.38	27.71	1327.16
	R	1			.35
	D	258			1326.81
B	T	264	6430.92	-120.11	1589.09
	G	5	2694.10	- 97.34	83.49
	W	259	3736.82	- 22.77	1505.60
	R	1			.14
	D	258			1505.46

T = Total

G = Generations

W = Within

R = Variance due to regression

D = Deviations from regression

TABLE 12. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Dam (X) and Number Born Alive (Y).

Group	Source of Variation	d.f.	$\sum x^2$	$\sum xy^2$	$\sum y^2$
A	T	264	4051.63	-162.44	1287.00
	G	5	1825.45	-134.39	22.54
	W	259	2226.18	- 28.05	1264.46
	R	1			.35
	D	258			1264.11
B	T	264	6429.31	- 73.99	1515.83
	G	5	2691.96	2.31	62.64
	W	259	3737.35	- 76.30	1453.19
	R	1			1.56
	D	258			1451.63

T = Total

G = Generations

W = Within

R = Variance due to regression

D = Deviations from regression

TABLE 13. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Dam (X) and Number at Three Weeks (Y).

Group	Source of Variation	d.f.	$\sum x^2$	$\sum xy^2$	$\sum y^2$
A	T	258	4027.53	-181.82	1511.10
	G	5	1816.53	-176.38	45.28
	W	253	2211.00	- 5.44	1465.83
	R	1			.01
	D	252			1465.82
B	T	263	6401.27	-240.89	1561.69
	G	5	2670.99	-104.33	64.22
	W	258	3730.28	-136.56	1497.47
	R	1			5.00
	D	257			1492.47

T = Total

G = Generations

W = Within

R = Variance due to regression

D = Deviations from regression

TABLE 14. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Dam (X) and Average Individual Birth Weight (Y).

Group	Source of Variation	d.f.	$\sum x^2$	$\sum xy^2$	$\sum y^2$
A	T	264	4053.31	- 3.31	40.10
	G	5	1826.77	2.11	1.29
	W	259	2226.54	- 5.42	38.81
	R	1			.01
	D	258			38.80
B	T	264	6430.54	- 59.48	49.30
	G	5	2693.75	- 14.08	.80
	W	259	3736.79	- 45.40	48.50
	R	1			.55
	D	258			47.95

T = Total

G = Generations

W = Within

R = Variance due to regression

D = Deviations from regression

TABLE 15. Analysis of Sums of Squares and Sums of Cross-Products of Percent Inbreeding of the Dam (X) and Average Individual Three Week Weight (Y).

Group	Source of Variation	d.f.	$\sum x^2$	$\sum xy^2$	$\sum y^2$
A	T	258	4027.62	- 5.18	594.98
	G	5	1816.60	18.41	- 467.11
	W	253	2211.02	- 23.59	1062.09
	R	1			.25
	D	252			1061.84
B	T	263	6397.90	96.14	944.16
	G	5	2671.04	173.14	50.58
	W	258	3726.86	- 77.00	893.59
	R	1			1.59
	D	257			892.00

T = Total

G = Generations

W = Within

R = Variances due to regression

D = Deviations from regression

TABLE 16. Change in Preweaning Traits for each 10 Percent Increase in Inbreeding of the Litter for each Generation.

Group	Generation	Total Number Born b	±	s.e.	Number Born Alive b	±	s.e.	Number at 3 Weeks b	±	s.e.	Average Individual Birth Weight (lb) b	±	s.e.	Average Individual 3 Week Weight (lb) b	±	s.e.
A	1	- .68	±	.97	- .76	±	.95	- .86	±	1.11	.47	±	.20	.11	±	.69
	2	.55	±	1.26	- .21	±	1.27	- .99	±	1.20	-.003	±	.19	.37	±	.70
	3	- .31	±	.53	- .28	±	.53	-1.36	±	.72	- .19	±	.13	- .84	±	.65
	4	-2.43	±	1.88	-3.83	±	1.65	-3.71	±	1.73	.37	±	.26	-3.03	±	1.31
	5	- .13	±	.73	- .34	±	.75	-1.21	±	.86	.07	±	.12	.02	±	.38
	6	-1.06	±	.72	- .26	±	.68	- .56	±	.68	- .09	±	.10	- .51	±	.41
B	1	- .87	±	1.27	-1.23	±	1.27	-1.86	±	1.35	.02	±	.20	- .65	±	1.17
	2	-1.07	±	.75	-1.09	±	.70	- .85	±	.79	.13	±	.17	.63	±	.65
	3	- .65	±	1.46	-1.02	±	1.56	.77	±	1.53	-.002	±	.27	- .56	±	1.29
	4	- .01	±	.85	.20	±	.80	- .65	±	.74	- .06	±	.12	- .35	±	.47
	5	1.01	±	1.41	.72	±	1.40	.82	±	1.53	.61	±	.24	.75	±	.94
	6	4.48	±	3.47	- .26	±	.68	2.89	±	3.22	-1.13	±	.73	- .22	±	2.91

b = regression coefficient

s.e. = standard error

TABLE 17. Change in Preweaning Traits for each 10 Percent Increase in Inbreeding of the Dam for each Generation.

Group	Generation	Total Number Born b	±	s.e.	Number Born Alive b	±	s.e.	Number at 3 Weeks b	±	s.e.	Average Individual Birth Weight (lb) b	±	s.e.	Average Individual 3 Week Weight (lb) b	±	s.e.
A	1	.51	±	.84	.34	±	.83	.26	±	.97	- .18	±	.19	- .31	±	.59
	2	1.81	±	1.96	2.50	±	1.94	1.13	±	1.91	.09	±	.29	.09	±	1.12
	3	.09	±	.89	.43	±	.89	.66	±	1.11	- .17	±	.23	- .66	±	.99
	4	1.52	±	1.42	.48	±	1.31	-1.02	±	1.16	.002	±	.20	- .68	±	1.04
	5	-2.99	±	1.87	-3.79	±	1.91	-4.25	±	2.23	- .02	±	.32	.68	±	.98
	6	- .46	±	1.00	- .87	±	.91	.48	±	.92	.16	±	.14	.35	±	.57
B	1	-6.54	±	7.80	7.32	±	7.86	6.36	±	8.46	.79	±	1.22	9.06	±	7.09
	2	- .72	±	.72	- .92	±	.68	-1.64	±	.71	- .04	±	.17	1.01	±	.61
	3	.27	±	.89	- .53	±	.94	- .45	±	.93	.01	±	.16	-1.28	±	.76
	4	3.10	±	1.60	2.64	±	1.52	2.87	±	1.40	- .18	±	.24	- .69	±	.93
	5	- .56	±	.55	- .47	±	.55	- .46	±	.60	- .23	±	.09	- .27	±	.37
	6	.18	±	1.45	.40	±	1.51	- .46	±	1.35	-.001	±	.31	- .01	±	1.21

b = regression coefficient

s.e. = standard error