THE GENETICAL ANALYSIS OF A NEW SWINE BREED

A Thesis

Presented to

the Faculty of Graduate Studies and Research

The University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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February, 1965

ABSTRACT

A swine breed development project was initiated at the University of Manitoba in 1956. One of the prime objectives was to develop a breed which could be used in commercial crossbreeding for the production of market hogs. The project also served as a source of genetic information useful in swine breeding. Seven different breeds were chosen to comprise the foundation stock. The breeds and their approximate contribution to the new breed were: Landrace (Swedish) 45%, Wessex Saddleback 20%, Welsh 12%, Berkshire, Minnesota No. 1, Yorkshire and Tamworth approximately 5% each. Four separate lines of the new breed were formed. Only data from gilt litters was used in analyses. Litters were farrowed during three periods (seasons) each year and only one line of the new breed was farrowed in any one season. A purebred Yorkshire herd was maintained and Yorkshire gilts were farrowed each season at the same time as one of the lines of the new breed.

Intensity of selection in the new breed for performance and carcass traits has been limited up to the present time. No systematic testing of the new breed has been made in commercial crossbreeding production. At the present time performance of the new breed is favorable and compares well with the purebred Yorkshire herd.

Two statistical procedures were used in estimating genetic parameters of the new breed for the three performance traits of litter size at birth (number born alive), post weaning growth rate and backfat thickness as measured by the live probe. The statistical methods employed were parent-offspring regression and paternal half-sib correlation. Heritability estimates obtained by these two methods were pooled to provide one estimate of heritability for each of the performance traits studied.

Overall pooled estimates of heritability for the new breed for litter size and post weaning growth rate obtained from 211 litters and 1,472 individuals were 0.19 ± 0.16 and 0.18 ± 0.05 respectively. These estimates fall within the range of estimates reported by other workers for these traits.

Data collected on 723 individuals for backfat thickness provided a pooled estimate of heritability during 1962 and 1963 for the new breed of 0.13 ± 0.05. This estimate is considerably lower than what might be expected for the trait, but may be due to a high unexplained source of environmental variance among males. It is also possible that this breed is close to a 'biological minimum' for the trait and hence the genetic potential does not exist to make further reductions.

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INTRODUCTION

The eighteenth century was the first really active period in the development of new breeds of livestock. At that time private breeders sought to create new breeds either to suit their own fancy or else were genuinely concerned with the need to produce new and superior strains of livestock. Their desire to protect and preserve the identity of these improved herds led logically to the development of pedigree registries or herd books. Eventually however the idea of maintaining "purebred supremacy" gained precedence over everything else to the point that crossbreeding for commercial production was actively discouraged, and the development of new breeds became a thing of the past.

With the advances made in the field of applied genetics the attitude of animal breeders has undergone a revamping and the development of new breeds of livestock has again assumed importance and is considered desirable where a need is indicated. Hence, it is not surprising that over the past fifty years the livestock industry has witnessed the development of several new breeds.

In 1956 plans for the development of a new breed of swine were first initiated at the University of Manitoba. The primary objective of the program was to provide a new and unique source of genetic material for use in the commercial production of swine in Canada. The project was felt justified owing to the fact that at that time the vast majority of pigs in Canada were of the Yorkshire breed. The Lacombe and the Landrace breeds were only on the verge of making their appearance on the Canadian market, hence it was desirable to have a breed that would combine well with these existing or potential breeds in a planned program of crossbreeding for pork production.

The project also provided a source of information for secondary, but major research objectives. These included the evaluation of responses to selection in a breed of well defined genetic origin and estimation of genotypic parameters of economic traits.

This study has been made at what might be termed an "intermediary phase" of the breed development. The primary objectives are twofold: 1) to record the establishment and genetic origin of the breed, and 2) to obtain estimates of genetic and phenotypic parameters of certain economic traits. These traits are: a) litter size, b) post-weaning growth rate, and c) backfat thickness.

LITERATURE REVIEW

The concept of breed development is not a new one and it is a useful way of attempting to meet the ever present demand for more profitable livestock. It is evident that animal breeders are faced with answering one basic question when faced with the prospect of a breed development project and that is, "are current demands of the industry best satisfied by the development of new breeds or by selective modification of existing breeds?" Fredeen (1963) points out that demands of the livestock industry are dynamic and no one of us is sufficiently clairvoyant to predict with certainty the standards of merit that might be employed even a quarter century hence. Characteristics deemed desirable today may be considered of no consequence, or even detrimental, within the next few years. Perhaps then breed development should be exploited as the most rapid means for effecting genetic change in response to consumer demand, with concerted selection to change established breeds being delayed until the permanence of the demand has been established. The point to be made here is that there is definitely a place in the livestock industry for the development of new breeds. The question of the demands of the industry has already been alluded to and realizing that they are by no means static, changing often abruptly and in an unpredictable manner, the necessity of meeting these demands quickly and efficiently is a matter of prime importance. Naturally there are other advantages to breed development the most obvious of which is probably the stimulus it provides by way of competition. There can be no doubt that the advent of new breeds in the United States contributed materially to the improvement of swine in that country. Breeders apparently showed no inclination to utilize the tools at their disposal in meeting the demand for more profitable livestock until they were literally forced into doing so by the prospect of stiff competition from new breeds. It is likely that the development of the Lacombe in this country has had a similar effect.

Several alternative methods are available to the animal breeder in developing new breeds of livestock. Craft in 1958 outlined three views as to the best method of doing so:

1) Inbreeding should be slow, 15 sows mated to four or more boars per line of the same breed with selection against the undesirables uncovered by inbreeding.

2) Inbreed as rapidly as possible using only three to six sows and one boar per line, or a single sow mated to her sire or son, discarding the poorest lines after two or three generations of inbreeding.

3) A cross of two or more breeds should be used as a

base, inbreed slowly and select for the trait or traits desired.

The third alternative outlined by Craft (1958) was the general method employed in the current breed development project. It can be said that essentially all breed development projects have two basic objectives in mind:

1) To combine in a single strain a maximum of the desirable characters of the parental breeds and

2) To induce the recombination of genetic factors which will result in the production of new and desirable characters not found in the parents.

There is little doubt that use of a crossbred foundation is an efficient way of accomplishing these ends. This is borne out by the success swine breeders in the United States and Canada have had in their breed development projects over the past thirty years or so. This includes such breeds as the Lacombe, Minnesota No. 1, No. 2 and No. 3, Palouse, and several others, all of which have had notable success.

The basic argument then for the use of hybrid populations in breed development is that it is an efficient way of combining in one breed the desirable characteristics of two or more breeds. As pointed out by Fredeen (1963) the very fact that hybrid vigor results from the crossing of breeds is evidence of differences in actual content and/or frequency of genes important in determining performance levels. Where such differences are due to gene content, selection from a hybrid foundation provides the only way whereby the desired genes can be combined in one breed. Fredeen goes on to say that the first cross alone would serve to combine the genes but the crossbreds might also show the deficiencies of either or both of the parent breeds entering the cross; hence the need for selective development from the hybrid. Where breeds differ in gene frequency, selection alone could, in time, serve to bring the two breeds to the same desired level. This objective can however, be obtained more quickly by selection from a hybrid between the two breeds.

Another use of this procedure for developing new breeds is illustrated by the concrete evidence from laboratory studies that selection "limits" can be overcome by crossing plateaued but genetically diverse lines and continuing selection from the hybrid. Fredeen (1963) draws to our attention the fact that with livestock there is absolutely no evidence to suggest that selection has been of sufficient consistency, intensity or duration to have carried any of our breeds to a plateau. At the same time there is however no basis for believing that selection limits must be reached before crossing followed by selection can be justified.

The extensive work which has been done with hybrid foundations has served to dispel ideas formerly held as to their worth in breed development projects i.e.,

1) That use of a crossbred animal for breeding purposes is followed by wide genetic segregation in economically important traits and a general loss in vigor, and

2) That it would be impossible to attain the uniformity of an established breed among the progeny of a crossbred foundation within the span of a human lifetime. Winters et al. (1943) reporting on the development of the Minnesota No. 1 made the observation based on experimental results, that it is possible to proceed much more rapidly with purification from a crossbred foundation than has formerly been assumed. They felt also that F_2 and F_3 populations do not necessarily show a general decline in vigor or so wide a segregation in type and performance as to be undesirable economically. They point out however that the cross employed in their experiment was not as wide as many made by plant breeders. On the basis of this, Winters and his co-workers caution that it is perfectly conceivable that many undesirable recombinations might occur when making use of wider genetic crosses. They felt that the fact that their results revealed no deterioration in F_2 and later generations was due to the superiority of the foundation animals and the rigorous selection practiced did much to keep segregation

under control. If indeed these two criteria were in any way effective in their developmental program, there is no reason to assume different conditions should prevail when several breeds as opposed to only two are used in the foundation stock.

The development of the new breed at Manitoba and of the Minnesota No. 3 in the United States has been based on a much wider genetic base than has generally been practised. Use has been made of seven and eight breeds respectively in the development of these breeds. The rationale for this approach was that if it was possible to effect more rapid genetic improvement through the development of new lines from the crossbred foundation of two complementary, genetically diverse breeds, as contrasted with continued selection within existing breeds, then the same concept should be applicable when several breeds are used. The use of several breeds would give rise to a heterogenous population which might be expected to yield a greater phenotypic variability than less heterozygous populations. Presumably we also succeed in increasing the additive genetic variability of the population. Theoretically at least, it would be considerably greater than where only two breeds are used to make up the foundation stock. Hence, a breed developed from a crossbred foundation would be expected to have not only a greater amount of genetic variance but also greater additive genetic variance. It has already been pointed out that results from crossing of breeds indicate that there exist differences in actual content and/or frequency of genes important in determining performance levels. This being so, it is possible that the wider the genetic base used in the formation of the foundation stock the greater will be the genetic variability and the additive genetic variance. Increase in the additive genetic variance is important from the standpoint that it usually results in larger estimates of heritability. This in turn is desirable because the greater the heritability of a trait, the more effective selection for that trait will be. Table I, (Fredeen (1958)) which provides data on the levels of performance and other pertinent data concerning eight breeds developed and recognized in the United States is evidence of the success swine breeders have had in breed development from hybrid populations. That such marked success has been realized justifies the formation of new breeds from hybrid populations and provides much weight in favor of the formation of new breeds as opposed to the improvement of existing breeds as a means of meeting the practical requirements of swine production.

Synonymous with breed development is inbreeding. The inevitability of inbreeding within a closed herd cannot be disputed, and while it is known that inbreeding does

TABLE I

PERFORMANCE CHARACTERISTICS OF NEW BREEDS PRESENTLY RECOGNIZED BY THE INBRED LIVESTOCK REGISTRY, MINNESOTA, U.S.A. (AFTER FREDEEN, 1958)

Breed	Litter Size at Birth	Litter Size at Weaning	Average Daily Gain (Pounds)	Feed/ 100/Gain
Minnesota No. 1	9.5	6.9	1.47	317
Minnesota No. 2	8.3	6.1	1.35	316
Montana No. 1	10.6	8.1	1.40	344
Maryland No. 1	7.3	6.2	-	-
Beltsville No. 1	9.0	6.0	1.45	333
Beltsville No. 2	9.0	5.8	1.46	342
San Pierre	8.9	7.9	1.31	314
Palouse	-	-	1.30	325
Canadian Breeds				
Yorkshire	9.5	-	-	347
Landrace	9.3	-	-	350
Lacombe	8.7	-	-	349

affect most performance traits adversely, in that it is usually accompanied by a loss in vigor, Craft (1958) and others point out that it can, and is used to advantage in breed development. These advantages are for the most part:

1) The uncovering of undesirable genes by making the lines more homozygous, and

2) The fixation of desirable gene combinations within the line or lines.

According to Craft (1958), the traits which have been most sensitive to inbreeding are, number of pigs farrowed and weaned per litter, and growth rate. These same traits however, show most of the heterosis in crosses. Chambers and Whatley (1951) have reported that results with lines inbred slowly indicate that swine breeders can maintain a line indefinitely as a closed herd, without serious loss in litter size or growth rate provided that inbreeding is kept at a low rate, not exceeding three to five per cent per generation, and selection is applied continuously for these traits. Winters _et al._ (1943 and 1948) have reported results which would seem to indicate that lines formed from breed crosses may have been less sensitive to the depressing effects of inbreeding than lines within pure breeds. While inbreeding, as pointed out, is inevitable in a closed herd, and does result in a loss in vigor of important performance traits, the results of these workers is encouraging. They indicate that a program based on the crossing of two or more lines of wide genetic diversity followed by a minimum of inbreeding per generation would produce the most desirable results.

Of great importance in any breed development or improvement program is the maintenance of a constant environment. Comstock and Winters (1944) point out that heritability can be increased only by reducing the sources of environmental variation to a minimum or by making corrections for sources of non-genetic variation that can be measured but cannot be held completely constant. All factors contributing toward efficiency of performance are affected materially by influences other than genetic. In order therefore, that selection of the superior individuals be as effective as possible, it is imperative that all records of performance be gathered under as uniform conditions as possible and where this is impracticable, that suitable correction factors be introduced. The latter is not always accomplished wthout the introduction of some bias to the data and is an added reason why maximum attention should be paid the former.

As a basis for selection, information must be obtained on each of those traits considered of economic importance. Knowledge of the heritability of a trait says Dettmers (1962), is useful because it provides a basis for prediction of results in a selection program. Dettmers (1962) along with other workers, goes on to point out that heritability estimates for any single trait vary widely and the average magnitude appears to depend on the nature of the character itself, for instance lower estimates are generally associated with traits that contribute to fitness.

Litter Size

Stewart (1945a) has said that improvement in livestock in one or several characteristics, through selection depends not only on the genetic variability of the population from which selection is made, but also on the proportion of available animals that are required for breeding purposes. Satisfactory reproduction, or prolificacy, therefore is basic to the whole program of progress in animal breeding because it results in larger populations from which a given number of animals may be selected. As pointed out before there is evidence that characters associated with fitness have heritability estimates low in magnitude. The majority of heritability estimates reported in the literature for litter size range from -.11 to .54 (Table II). Boylan *et al.* (1961) points out that heritability estimates of litter size accompanied by low standard errors are difficult to obtain, consequently it is not surprising that such a wide range of estimates have been reported. Bernard *et al.*

TABLE II

HERITABILITY ESTIMATES OF LITTER SIZE IN SWINE

(AFTER DETTMERS, 1962)

Heritability (at birth)	Method of Estimation	Scope of Study	Reference
-.11 ± .07	Dam-daughter regression	1980 litters	Cockerham (1952)
.07	" " "	969 litters	Bernard *et al.* (1954)
.19 ± .14	" " "	532 comparisons	Cummings *et al.* (1947)
.24	" " "	528 pairs	Blunn and Baker (1949)
.15 ± .23	" " "	475 "	Stewart (1945)
.03 ± .07	" " "	1970 "	Boylan *et al.* (1961)
.11	Paternal half-sib correlation	158 d.f.	Korkman (1957)
.11	" " " "	180 d.f.	Lamprecht-Döring (1953)
.08	" " " "	869 litters	Shelby (1952)
.54	" " " "	691 litters	Shelby (1952)

(1954) investigating the heritability of litter size in swine at various ages obtained estimates ranging from 0.07 to 0.11, none of which were significantly different from zero. Similar results in mice have been obtained by Rahnefeld *et al.* (1962) and Falconer (1960) who reported estimates of 0.11 and 0.15 respectively. Craft (1958) suggests that an overall estimate of 0.15 in swine would seem reasonable. Boylan *et al.* (1961) who reviewed the literature quite extensively feels that the majority of more reliable estimates fall below 0.10, an observation which seems to be borne out by the fact that the higher estimates, such as that obtained by Shelby (1952), are usually accompanied by large standard errors. Boylan *et al.* (1961) concluded from the results of their experiment that heritability for litter size in swine was low and the response to mass selection for increased performance within a line or breed would be negligible. This is in general agreement with what has been found earlier and reported in the literature. Hetzer *et al.* (1940) reported that their results indicated that only a relatively small part of the variance in litter size is hereditary in character. Their conclusions were based on the fact that the genetic part of the variance in their study, was found to account for not more than 20% of the variance in litter size at birth, at 28 days, or at 70 days of age. They were of the opinion however, that despite this small percentage of the total variance that was attributable to genetic factors, it was still large enough to suggest that selection may bring about changes in this character.

It should be pointed out that Hetzer *et al.* (1940) made their investigation on a inbred herd of Chester White swine. This is pointed out because it would be logical to assume that if we could find some way of increasing the genetic portion of the variance in litter size, then the amount of change that could be effected in this trait would also be increased. Theoretically the crossing of two or more genetically diverse breeds would be expected to increase the amount of additive genetic variance. Any increase in the portion of additive genetic variance would be reflected in the size of the heritability estimate. Boylan *et al.* (1961) in comparing the size of heritability estimates obtained for the Minnesota No. 1 and the Minnesota No. 3 felt that the relative magnitude of the values obtained seemed plausible. The values obtained were $.05 \pm .13$ and $.17 \pm .14$. The Minnesota No. 1, they point out, was more closely inbred of the two breeds and the Minnesota No. 3 foundation stock was established using several more lines than was the case for the Minnesota No. 1. For these reasons these workers felt that the Minnesota No. 3 may have possessed more genetic variation. If the opinion of these workers that the amount of additive genetic variance is increased materially by the crossing of several breeds as opposed to two or three, and that this in turn results in higher estimates of heritability, then selection for improvement of the trait is likely to be more effective in a line based on a large amount of genetic diversity.

It is worth mentioning at this point that in the opinion of several workers, litter size is subject to a depressing effect as a result of inbreeding. Hetzer _et al._ (1940) stated that though the genetic portion of variance in litter size was too small to indicate rapid improvement in this trait, it was however large enough to support the conclusion that the gradual decline in the trait observed during the course of the experiment, was at least partly genetic. It is generally accepted that an increase in inbreeding results in an increase of homozygosity of the line and that this in turn would tend to reduce the estimate of heritability. Hence a system of crossbreeding involving several breeds of wide genetic diversity followed by mild inbreeding should produce the best results as far as litter size is concerned. Under such a system we might expect larger heritability estimates than is generally the case.

Other factors having an effect on litter size have been reported by many workers. These factors would include seasonal effects, year effects and differences due to breed. In the case of the latter it is now generally accepted that differences between breeds in respect to average size of litter do exist (Table I). As for the other two factors, results of different experiments are conflicting but it may be well to note the observation of Hetzer et al. (1961) that yearly fluctuations in weather conditions and differences in the incidence of disease and parasites conceivably lower the averages obtained for some if not all traits. Changes in genetic merit may also contribute to differences between years. Hetzer et al. (1940) felt that in respect to the relative importance of these other causes affecting litter size, it would seem that uncontrolled environmental conditions such as temporary changes in health of the sows or in their fertility, are a much more important cause of variation in litter size than such factors as yearly changes in feeding and management, season of birth and age of sows at farrowing.

Growth Rate

Comstock et al. (1942) states that rapid growth of swine is of value to the pork producer for several reasons. It is generally agreed that other things being equal faster growing pigs require less feed per unit gain in weight. Since the pigs that grow faster reach market weight sooner the overhead cost of labor is less and the risk of loss from disease, parasites and accidents is reduced. It follows that growth rate is one of the characters to be considered in any improvement or breed development program.

The relationship, if any, between litter size and growth rate would be of importance to the animal breeder if he were selecting for both these traits simultaneously within the same population.

Rahnefeld et al. (1962), working with mice have reported a small but positive genetic correlation between litter size and growth. They felt that this positive correlation, though small, is of considerable importance for it indicates that while no large desirable correlated response can be expected, an equally undesirable negative correlated response of litter size to selection for growth rate will not occur.

Cockerham (1952) and Vogt et al. (1963) working with swine reported a similar small but positive genetic correlation between litter size and growth rate. The results of these workers indicate that litter size will not be adversely affected as a consequence of selection for growth rate and vice versa. However, Dickerson et al. (1954) suggested that a negative genetic correlation might explain the ineffectiveness of simultaneous selection for increased litter size and faster growth rate in inbred lines of swine developed at the Regional Swine Breeding laboratory (United States North Central Region). The importance of these findings cannot be overemphasized especially in view of the observations made by Comstock and Winters (1944). From their experimental results they felt that the difficulty in maintaining fertility is more likely to interfere with the development of inbred lines than declining growth rate. This is doubly significant since reduced fertility automatically reduces the amount of selection that can be practiced for both fertility and other characters.

Numerous studies, varying sample sizes, period of development and method of analyses have yielded a wide range of heritability estimates for growth rate (Table III). These results do not indicate that estimates differ in relation to the period of growth considered. The ranges given may represent genuine differences among the populations studied, but according to Fredeen (1958) allowance must be made for sampling error and/or the possibility of error due to the inclusion of unmeasured non-genetic effects. The importance of sampling error and bias is more evident when two or more methods have been employed in estimating heritabilities. The work of Whatley (1942), Krider et al. (1946), Dickerson and Grimes (1947), and Fredeen and Jonsson (1957) all yielded larger estimates from intra-sire regression of offspring on dam as compared to those obtained

TABLE III

HERITABILITY ESTIMATES OF GROWTH RATE IN SWINE

(AFTER FREDEEN, 1953)

Rate of Gain	Estimate of h^2	Method of Estimation	d.f.		References
Wn. - 200 lb.	.21	Offspring-parent regression	312		Nordskog *et al.* (1944)
56 - 112 days	.18	" " "	312		Nordskog *et al.* (1944)
Daily gain to 200 lb.	.31	" " "	133		Comstock *et al.* (1942)
56 - 140 or 156 days	.28	" " "	1419		El-Issawi and Rempel (1961)
56 - 140 or 156 days	.28	" " "	69		Blunn *et al.* (1947)
Daily gain	.43	Offspring-midparent regression	69		Dickerson and Grimes (1947)
" "	.44	Offspring-sire regression	69		" " " "
" "	.58	Offspring-dam regression	69		" " " "
Daily gain-200 lb.	.24	Mat. half-sib correlation	320		Lush (1936)
112 days-225 lb.	.14	Pat. half-sib correlation	40	(sires)	Blunn and Backer (1947)
56 days - 225 lb.	.18	" " " "	40	"	Blunn and Backer (1947)
Daily gain	.31	" " " "	62	"	Dickerson (1947)
Daily gain-200 lb.	.41	" " " "	122		Lush (1936)
50 - 200 lb.	.26	" " " "	133		Comstock *et al.* (1942)
56 - 112 days	.28	" " " "	55	(sires)	Hazel *et al.* (1943)
112 days - 225 lb.	.17	" " " "	55	(sires)	Hazel *et al.* (1943)
Wn. - 200 lb.	.40	" " " "	320	(litters)	Nordskog *et al.* (1944)
56 - 112 days	.35	" " " "	16		Blunn *et al.* (1953)
44 - 176 lb.	.67 ♂	" " " "	432		Fredeen and Jonsson (1957)
" " "	.35 ♀	" " " "	432		Fredeen and Jonsson (1957)
" " "	.45 ♂	" " " "	5996	(pigs)	Jonsson and King (1962)
" " "	.27 ♀	" " " "	5996	(pigs)	Jonsson and King (1962)

by paternal half-sib correlation. Dickerson and Grimes (1947) have interpreted this as resulting from an antagonism between the dam's direct and transmitted influence on this trait. The results of Nordskog *et al.* (1944) are not in agreement with those of these workers however. Nordskog *et al.* (1944) reported estimates of 0.21 and 0.40 for growth rate as measured from weaning to two hundred pounds market weight. These estimates were obtained by regression of offspring on parent and by paternal half-sib correlation respectively. It becomes apparent however that the range in estimates reported in the literature for growth rate can be attributed in part to the different methods employed in their estimation.

As has been mentioned previously growth rate along with litter size show most of the heterosis in crosses (Craft 1958). Hence as postulated for litter size the crossing of several lines of wide genetic diversity would also increase the amount of additive genetic variance for growth rate. We would expect therefore, larger heritability estimates than would normally be the case where fewer lines and/or lines more closely related were used in the cross. The results obtained by Sumption *et al.* (1961) in the development of the Minnesota No. 3 suggests that this method of increasing the additive genetic variability for growth rate, and hence also the effectiveness of selection for improvement of the trait, is a valid one.

Backfat Thickness

Literature reports indicate that carcass traits in general are highly heritable. Estimates for backfat thickness are presented in Table IV. Lush in 1936 stated that under the Danish system of progeny-testing swine every effort was being made to reduce the thickness of backfat.

Figure I shows that these efforts have been highly successful. During the period 1926-1927, the distribution was essentially normal with a mean of 4.03 cm.; a range of 2.6 to 6.5 cm., and a standard deviation of 0.441. By 1955-1956, the situation had changed considerably, the mean now being 3.20 cm., the range 2.3 to 4.5 cm., and the standard deviation 0.302 cm. The progressive skewing of the curves that has accompanied this change has been due to the reduction of the maximum expression of the trait without any appreciable change at the lower extreme. It is of interest that in thirty years, the lower limit has been reduced by only 0.3 cm. According to Fredeen (1958) this situation should be interpreted as evidence that a biological minimum for backfat thickness exists in the range of 2.0 to 2.5 cm. Such a limit, if it exists, could condition the amount of improvement that may be expected in this trait as well as those with which it is genetically correlated (Fredeen and

TABLE IV

ESTIMATES OF HERITABILITY FOR THICKNESS OF BACKFAT IN SWINE

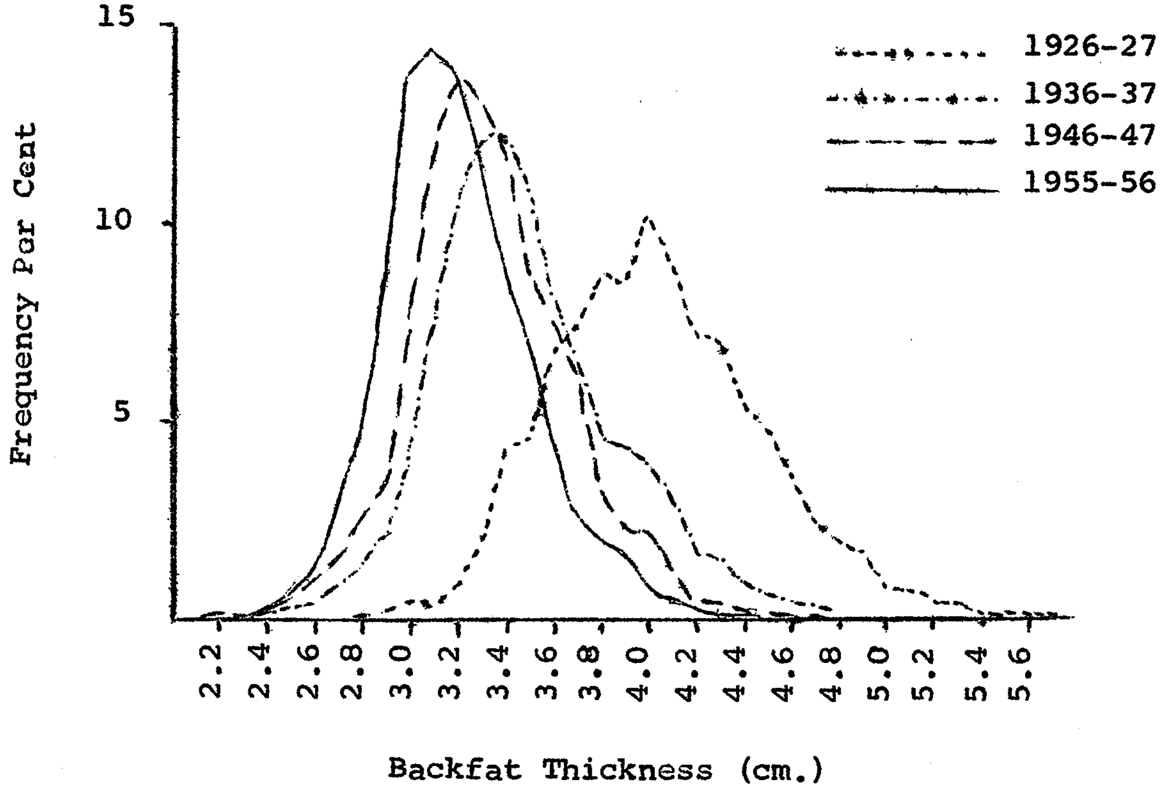
(AFTER FREDEEN, 1953)

Estimate of h^2	Method of Estimation	d.f.	References
.80	Pat. half-sib correlation	122	Lush (1936)
.55	Mat. half-sib correlation	320	Lush (1936)
.47	Av. of 3 methods[1]		Lush (1936)
.12	Pat. half-sib correlation	40 (sires)	Blunn and Baker (1947)
.37	Off. mid-parent reg.	58	Stothart (1947)
.54	Pat. half-sib correlation	173 litters	Dickerson (1947)
.52	" " " "	445	Johanson and Korkman (1950)
.42	" " " "	57 (sires)	Enfield and Whatley (1961)
.84	Mat. half-sib correlation	191 (sires)	" " " "
.63	Full-sib correlation	248	" " " "
.52	Pat. half-sib correlation	432	Fredeen and Jonsson (1957)
.58	" " " "	432	" " " "

[1]This estimate is based on an average of three estimates using correlation between paternal sibs (122 d.f.) correlation between maternal sibs (320 d.f.) and correlation between progeny averages of sire and son (236 d.f.).

Figure I

FREQUENCY DISTRIBUTIONS FOR THICKNESS OF BACKFAT OF DANISH LANDRACE PIGS TESTED AT THE OFFICIAL PROGENY TEST STATIONS SINCE 1926 (AFTER FREDEEN 1958)



Jonsson (1957)). Lush (1936) points out that backfat is similar to body length in that the ideal is not either extreme but the intermediate. Carcasses with too little backfat are found to be too soft to suit the market demand and hence while selection is being made at the upper extreme in order to reduce the maximum, it would seem likely that selection at the lower extreme is either in an upward direction or else it is directed at keeping the minimum value as stable as possible. What is important however, is that there exists enough additive genetic variance in a population so that selection for the trait will be effective. Lush (1936) felt there was "abundant additive genetic variance" to permit this, and more recently Enfield and Whatley (1961) felt that evidence from their study indicated that selection for reduction of thickness of backfat would be slightly effective. Fredeen and Jonsson (1957) caution that there is uncertainty as to whether backfat thickness may be indefinitely reduced without creating undesirable changes in other important factors influencing carcass quality. However, apart from going to an extreme, results of several workers, including Fredeen and Jonsson (1957), Fredeen (1958), Stothart (1938) and Lush (1936), are quite encouraging, for they appear to be in general agreement on the point that genetic relationships indicated are such as to ensure desired genetic improvement when selection is based on any one of feed efficiency, length, rate of gain or thickness of backfat. Thus, for example, selection for length alone will give in correlated responses, a reduction in thickness of backfat and improvement in both rate of gain and efficiency of gain.

It has generally been found that gilts have less backfat than barrows at the same weight. The significance of a sex difference is however limited to scoring and carcass grading standards. Fredeen and Jonsson (1957) found no difference in heritability estimate for barrows and gilts. They obtained estimates of 0.52 and 0.58 for males and females respectively and in addition observed that most of the genetic correlations agree reasonably well for the two sexes.

In conclusion it can be stated that the traits under study have been found, in general, to exhibit sufficient additive genetic variance to ensure desired genetic improvement, and the genetic correlations between the traits are such that selection for any one will provide the desired response in the others. The rate or magnitude of the improvement will depend of course on the heritability exhibited by the separate traits, in this case from low to relatively high, and also on the intensity of selection. Since results reported in the literature indicate that the amount of additive genetic variance for any one trait varies from one population to another, it is to be expected that heritability estimates will also vary from one population to another. In order to achieve accurate prediction of results in a selection program therefore, it is essential for the animal breeder to have a knowledge of the heritability estimates of the traits under selection.

History of the Breed Development

One of the primary reasons for the development of a new breed of swine at the University of Manitoba was that it should combine well and produce a maximum amount of heterosis when crossed with the existing breeds of the Canadian swine industry. For this reason the new breed was designed to be as genetically different as possible from other breeds.

Initially three breeds were selected to comprise the foundation stock. These were the Wessex Saddleback, Welsh and Landrace (Swedish). The choice of these breeds was based on particular attributes of each and their expected contribution to the new breed.

A brief description and the particular attributes of each of these foundation breeds is given below:

Wessex Saddleback - This is an English breed, black in color but with a white belt. It had an established reputation for fertility, prolificacy and milking ability. In addition, it was known to thrive under adverse feeding conditions. It's main defect was inferior carcass quality.

Welsh - Another English breed, white in color and noted for it's hardiness under English conditions. It was capable of producing acceptable carcasses. It's main defect was a slow rate of growth.

Landrace (Swedish) - This breed was selected for its rapid growth rate and its superior carcass quality.

Other breeds included in the foundation stock were the Berkshire, Minnesota No. 1, Yorkshire and Tamworth. These breeds were included primarily to increase the population size and also to increase the genetic diversity.

The initial foundation stock consisted of nine bred Wessex Saddleback gilts, a boar of the same breeding and two Welsh boars, all imported in late 1956 from England. To this group were added two Landrace boars from Canadian herds. In order to increase the population size and also the genetic base of the new breed, it was decided in 1957 to add a number of females of different breeding. Accordingly, three crossbred sows of (Berkshire) male x (Yorkshire x Tamworth) female breeding and two sows of Minnesota No. 1 male x (Yorkshire x Tamworth) female breeding were included. These additional sows had performed quite well in a crossbreeding project and hence it was felt that they would make a useful contribution. Finally in 1958 two Landrace x Wessex females and a third Landrace boar were purchased in Canada to complete the foundation herd. The summary below lists the 22 foundation animals:

9 Wessex Saddleback females

3 Berkshire x (Yorkshire x Tamworth) females

2 Minnesota No. 1 x (Yorkshire x Tamworth) females

2 Landrace x Wessex Saddleback females

1 Wessex Saddleback male

2 Welsh males

3 Landrace males

From this initial foundation stock four separate lines were developed. In this study these lines shall be referred to as lines 1, 2, 3 and 4 respectively, and the breed as a whole as Breed "M".

It is not possible to state accurately the eventual composition of the new breed. In 1959 the crossbred population was approximately 40% Landrace, 25% Wessex Saddleback, 20% Welsh, 5% Berkshire, 5% Minnesota No. 1, and 2½% each Yorkshire and Tamworth. The per cent composition of the herd in 1960 and 1962 has not deviated to any great extent from the figures given above (Table V). The initial plan called for equal representation of Landrace, Welsh and Wessex Saddleback; approximately 25% each. The higher percentage of Landrace arose because of breeding difficulties encountered with one of the foundation Welsh males and the subsequent substitution of a Landrace male.

TABLE V

PER CENT COMPOSITION OF EACH OF THE FOUNDATION BREEDS IN BREED "M" IN 1960 AND 1962

Year	Line	Landrace	Wessex	Welsh	Minn. No. 1	Berk.	York	Tam.
1960	1	49.1	23.8	9.5	4.8	5.2	5.1	2.5
	2	38.1	25.0	10.8	4.8	9.4	6.5	5.4
	3	53.4	13.9	14.0	1.4	8.9	4.2	4.2
	4	47.6	12.5	13.4	4.6	6.4	11.9	3.6
	Av.	47.0	19.0	11.9	3.9	7.5	6.8	3.9
1962	1	48.6	24.2	11.3	4.8	5.1	3.4	2.5
	2	34.1	27.9	12.2	4.2	9.3	6.8	5.4
	3	53.3	13.2	12.5	2.3	8.1	5.3	5.2
	4	41.7	13.6	15.4	3.9	5.9	14.3	3.4
	Av.	44.4	19.7	12.8	3.8	7.1	7.5	4.2

Mating System

Matings were planned originally with two main objectives in mind:

1) To keep inbreeding to a minimum and

2) To achieve the desired percentage of each of the foundation breeds in the new breed. The matings were set up in such a way as to facilitate the formation of the four distinct lines already referred to. There has been no interchange between the lines. In the summer of 1962 the mating system was changed slightly. Matings were made at random among selected individuals except that full-sib matings were avoided. No particular effort has been exercised subsequently in mating the least related individuals.

The breeding schedule employed provided for farrowing four times during an approximately 15 month period. Each of the four farrowing times represented a different line in the breed. All offspring were from females having their first litter except in the early generations of the breed, some females were retained for two or more litters in order to increase the herd size rapidly. Gilts and boars were mated at approximately 11 months of age. This age at breeding, while older than is the practice in the industry, was necessitated because of operational procedures in the use of farrowing facilities. The program was designed so that approximately 20 to 30 gilts farrowed during each farrowing period. Approximately five to six sires were represented in each line each farrowing. The average length of each farrowing season was approximately six weeks.

Selection Methods

Selection of breeding stock was practiced separately within each of the four lines. Essentially mass selection has been the method employed in this program, i.e., selection has been based primarily on the individuals own phenotype. Independent culling levels have of course been established. In the early generations emphasis was placed on selection for body color, type and freedom from physical defects. At that time, only those individuals which were free from defects and which showed the least color were saved. However, selection in the early generations was also based on litter performance for traits up to and including weaning, individual performance for growth, rate of gain and litter-mate performance for carcass quality (approximately one-half of each litter was marketed at 200 pounds). At the present time, while selection for type as well as color and physical defects is still practiced, emphasis has been placed on selection for thickness of backfat as measured by the live probe (Hazel and Kline (1952)), post weaning growth and age at 190 pounds.

Initial selection of boars was primarily on a within litter basis with weaning weight the major criterion of selection. All non-selected males were castrated at that time. The selected males were grown out in groups to a final weight of approximately 190 pounds. At that time they were weighed and backfat thickness was measured by use of the live probe. Selection of the males to be used to sire the next generation was then made on the basis of the independent culling levels discussed above.

The initial selection of females was made at market weight. This selection was also based on the independent culling levels discussed previously.

It may be seen that individual performance as well as litter performance was utilized in selecting from each line the individuals which produced the next generation.

Concurrently with the breed development project was the maintenance of a purebred Yorkshire herd. The primary purpose of the Yorkshire herd was to provide contemporary animals as a basis for measuring the relative performance of Breed "M". One to two sires and six to eight dams were used each generation in the Yorkshire herd. New sires purchased from purebred breeders, were regularly introduced into the herd.

Inbreeding

The present level of inbreeding varies slightly with the lines. The average within lines ranges from 12 to 15%. The average increase in the inbreeding coefficient per generation over the period 1958 to 1963 ranges from 2 to 4% (Table VI).

TABLE VI

AVERAGE INBREEDING COEFFICIENTS PER LINE PER GENERATION FOR BREED "M"

Year	1	2	3	4
1958	-	-	-	-
1959	.0532(47.4)[1]	.0179(29.4)	.0851(55.6)	.0292(63.0)
1960	.0238(52.4)	.0563(90.9)	.0564(81.0)	-
1961	.0632(100.0)	.0848(100.0)	-	.0235(100.0)
1962	.1198(100.0)	-	.1006(100.0)	.0707(100.0)
1963	-	.1392(100.0)	.1544(100.0)	.1267(100.0)
Av. Increase Per Generation	2.22%	4.04%	2.31%	3.25%

[1]The figures in brackets represent the percentage of litters which actually possessed some degree of inbreeding.

The Data

Source and Description

The data for this study were obtained in a breed development program at the University of Manitoba. Data from the project were available for the years 1958 to 1963 inclusive. It was decided however, that for purposes of this study data obtained only from the F_2 and subsequent generations should be used. Those litters farrowed in 1960 corresponded to the F_2 generation (Table VIa).

The performance traits for which parameter estimates are computed in this study are litter size at birth, postweaning gain (weaning to approximately 190 pounds), and thickness of backfat as measured by the live probe. Litter size was taken as the total number of pigs born alive in a litter. Only the record of the first litter of a gilt was used in the analyses for litter size.

Growth rate data used were for postweaning growth only, i.e., from weaning at approximately 42 days of age to market weight. It was decided to consider all pigs within a range of approximately 160 to 220 pounds and at an age not exceeding 215 days as having reached market weight. All others were excluded from the analysis.

The average of three probes taken on the left and

TABLE VIa

THE 'F' GENERATION OF EACH LINE ARRANGED

BY YEARS 1960 TO 1964 INCLUSIVE

Line	1960	1961	1962	1963	1964
1	F_2	F_3	F_4	-	F_5
2	F_2	F_3	-	F_4	F_5
3	F_2	-	F_3	F_4	F_5
4	-	F_2	F_3	F_4	-

right side of each individual at each of three standard locations along the back, provided three measures of the thickness of backfat per individual. These in turn were averaged to give a single measure of the thickness of backfat per individual. The method of probing was that devised and explained by Hazel and Kline (1952). The mean backfat thickness of each pig was adjusted by linear regression to a constant body weight of 190 pounds.

Methods of Analysis

i) General comments

a) All but the more easily computed parameters have been computed by the use of an I.B.M. 1620 computer.

b) Analyses were made within each line by season, year and sex. In the case of litter size where information was available for only one sex, analyses were conducted by season and year for each line.

ii) General procedures in parameter estimation

Standard statistical procedures were employed to obtain the various intermediate quantities from which the ultimate parameters were estimated.

1. Parent-offspring covariances and regression

In the case of both sire-offspring and dam-offspring the variates used in computation were the sire and dam phenotypic values and the offspring phenotypic values. This method was chosen rather than the intra-sire regression of offspring on dam because it was felt that more degrees of freedom would be available and hence more reliable estimates would be obtained. It was felt justified in doing this since mating was essentially at random in the more recent generations and should therefore have introduced no bias. Any deviation from non-randomness in the early generations was felt to have been so small that it would have little effect on the reliability of the estimates obtained.

The 'b' values obtained by this analysis were subjected to a standard covariance analysis to test for homogeneity in order to validate pooling of the data. This pooling resulted in the computation of an average 'b' value ($\overline{b}$), and a weighted 'b'. The latter was arrived at by weighting the individual 'b' values inversely to their variances. The general form of this analysis is as outlined by J. Li (1957). These computations were carried out on the I.B.M. 1620 computer.

2. Analysis of variance and covariance

The form of variance analysis and expectations of mean squares are presented in Table VIb. Separate analyses were conducted by line and sex, within each season of each year. Results were then pooled by line for each sex and then finally by sex. In any pooled analysis the form is analogous to that in Table VIb with the addition of another source of variation.

TABLE VIb

ANALYSIS OF VARIANCE AND MEAN SQUARE EXPECTATIONS

Source of Variance	d.f.	Mean Square	Mean Square Expectations
Sires	s - 1	M_1	$W + k_2D + k_3S$
Dam Within Sires	d - s	M_2	$W + k_1D$
Within Full-Sib Families	N - d	M_3	W

where:

s = total number of sires

d = total number of dams

N = total number of individuals

$$k_1 = \frac{1}{(d - s)}\left[N - \sum_i\left(\frac{\sum_j n_{ij}^2}{n_i}\right)\right]$$

$$k_2 = \frac{1}{(s - 1)}\left[\sum_i\left(\frac{\sum_j n_{ij}^2}{n_i}\right) - \frac{\sum_i\sum_j n_{ij}^2}{N}\right]$$

$$k_3 = \frac{1}{(s - 1)}\left[N - \frac{\sum_i n_i^2}{N}\right]$$

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

n_{ij} = total number of offspring from the j^{th} dam mated to the i^{th} sire

S = variance due to differences among sires

D = " " " " " dams

W = " " " " " full-sibs

The variances of variance component estimates were obtained as outlined by Comstock and Robinson (1951).

The estimate of S was

$$\hat{S} = \left[M_1 - \left(\frac{k_2}{k_1}\right) M_2 + \frac{(k_2 - k_1)}{k_1} M_3 \right] / k_3$$

It follows that

$$V(\hat{S}) = \frac{V(M_1)}{k_3^2} + \left[\frac{k_2}{k_1 k_3}\right]^2 V(M_2) + \left[\frac{k_2 - k_1}{k_1 k_3}\right]^2 V(M_3)$$

where:

$V(M_1)$ = variance of the mean square for between sires source of variance.

$V(M_2)$ = variance of the mean square for dams within sire source of variance.

$V(M_3)$ = variance of the mean square for within litters source of variation.

(k_1, k_2 and k_3 are as defined in Table VIb).

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

$$V(M) = \frac{2\left[E(M)\right]^2}{f}$$

where:

M = any mean square

$E(M)$ = expectation of M

d.f. = degrees of freedom for the mean square M

Since S represents one-quarter the additive genetic variance, and the sum of $S + D + W$ represents the total phenotypic variance of the population, it is necessary to solve for each of these components in order to compute estimates of heritability. The formula used for these computations is as follows

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

It follows that the variance of h^2 is

$$V\ (h^2) = \frac{V\ (4S)}{V\ (P)}$$

(where P = total phenotypic variance (i.e. $S + D + W$)).

$$= \frac{16\ V\ (S)}{P^2}$$

and

$$\text{Standard Error } (h^2) = \sqrt{V\ (h^2)}$$

iii) Performance traits

a) Litter size - in estimating parameters for litter size both the methods of analysis described above were used i.e., 1) regression of daughter's litter size record on her dam's record, and 2) paternal half-sib correlation.

b) Growth rate and backfat thickness - the same statistical procedures used in the case of litter size have also been employed here with only slight differences. In the case of the regression analysis it has been somewhat more extensive. The data was arranged by sex and separate regressions run such as to include the regression of

a son's record on 1) his sire and 2) his dam

a barrow's record on 1) his sire and 2) his dam

a gilt's record on 1) her sire and 2) her dam

The paternal half-sib correlation analysis was also done separately for each sex.

Heritability estimates were also calculated for these traits using maternal half-sib and full-sib correlation.

All analyses were made within each line, season and year. The 'b' values were tested for homogeneity and the data pooled in order to provide one estimate of heritability for each trait for the breed as a whole.

RESULTS AND DISCUSSION

Annual averages and standard errors for each line are presented in Table VII, for the three performance traits of litter size (number born alive), postweaning growth rate and thickness of backfat. In the case of the last two traits, averages for the sexes have been presented separately. No data for postweaning growth rate or thickness of backfat **were** available for boars prior to 1962.

The performance of each line in terms of average litter size has been good and the standard errors accompanying the means presented in Table VII suggest that variability within each line for this trait has been high. This is evident from the high coefficient of variability of 27.5% which has been estimated for the breed as a whole. The Minnesota No. 3 which was developed from as wide a genetic base as Breed "M" is reported by Sumption et al. (1961) to exhibit a similarly large coefficient of variability for litter size. From results reported in the literature by these workers, an average coefficient of variability for litter size for this breed was estimated to be 27.7%. Several factors may be responsible for the high coefficients of variability reported for these breeds:

1) Environmental effects may be playing an important part and

TABLE VII

MEANS AND STANDARD ERRORS FOR LITTER SIZE, POSTWEANING GROWTH RATE AND BACKFAT THICKNESS FOR EACH LINE AND SEX

Year and Season	Line	Litter Size		Postweaning Daily Gain (Pounds) Gilts		Barrows		Boars		Backfat Thickness (Inches) Gilts		Barrows		Boars	
		N	$\overline{X}$	N	$\overline{X}$	N	$\overline{X}$	N	$\overline{X}$	N	$\overline{X}$	N	$\overline{X}$	N	$\overline{X}$
1960															
W	1	20	9.15±.70	78	1.29±.01	59	1.30±.01								
S	2	21	9.49±.45	82	1.28±.01	57	1.29±.02								
F	3	18	8.88±.54	61	1.25±.02	44	1.25±.02								
1961															
W	4	16	9.62±.45	62	1.27±.01	44	1.29±.02								
S	1	18	9.20±.41	53	1.37±.01	31	1.37±.02								
F	2	31	9.46±.56	99	1.24±.01	77	1.24±.01								
1962															
W	3	14	8.39±.54	43	1.25±.01	26	1.31±.02	17	1.21±.04	43	1.11±.02	24	1.32±.03	17	0.95±.05
S	4	19	8.29±.58	48	1.31±.02	46	1.28±.02	23	1.20±.04	48	1.10±.01	46	1.17±.01	23	1.08±.02
F	1	21	9.68±.49	62	1.28±.02	50	1.31±.02	21	1.31±.04	64	1.12±.01	50	1.16±.01	23	1.08±.02
1963															
W	2	27	9.63±.56	69	1.31±.02	63	1.29±.02	26	1.50±.03	71	1.16±.01	63	1.20±.01	26	1.08±.02
S	3	28	8.39±.54	88	1.18±.01	33	1.17±.03	21	1.25±.03	88	1.20±.01	33	1.23±.01	21	1.18±.01
F	4	24	8.37±.62	33	1.22±.02	27	1.21±.02	23	1.23±.04	33	1.19±.01	27	1.21±.01	23	1.17±.01
Overall Average		9.05 ± .16			1.27		1.28		1.28		1.15		1.22		1.09

2) As the mean litter size increases the standard deviation may increase proportionately to an even greater extent. It may also be accounted for by the large amount of genetic variability in the foundation population.

The average litter size of Breed "M" as a whole was estimated as $9.05 \pm .16$[1] (Table VII), and compares favorably with those averages presented earlier in Table I for some long established breeds in the Canadian and United States swine industry. It is unfortunate that the means for these breeds were not accompanied by their standard deviations as no comparison can now be made with Breed "M" in respect to the relative amount of variability existing within these established breeds for litter size.

The average daily gain for each individual was calculated for the period from weaning at approximately 42 days of age to 190 pounds market weight. The means presented by sex for this trait in Table VII represent the average daily gain per individual per line. An overall average for Breed "M" for each sex was calculated using the same method as was described for the calculation of the overall mean for litter size. These means were 1.27, 1.28 and 1.28 for gilts,

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[1] This overall mean was obtained by summing the yearly averages of each line and dividing by the number of averages summed (N). The accompanying standard error was also calculated by summing the variances for each mean and then dividing by N^2. The square root of this figure was taken as the standard error of the overall mean.

barrows and boars respectively. It is evident from these means (Table VII) that barrows exhibited little or no advantage in overall mean performance for postweaning gain. In direct contrast to these results Fredeen and Jonsson (1957) reported a small but highly significant superiority in average daily gain for females. However, Russell (1930) reported a 5.4% advantage for barrows for average daily gain, Johansson and Korkman (1950) found females of the Swedish Landrace to have a 1.5% disadvantage in average daily gain, and Fredeen (1953) reported Yorkshire barrows to average 5.4 days younger than their litter mate gilts at 200 pounds live weight. It is possible that the rate of gain of the different sexes is dependent upon several factors and hence might vary from population to population. These factors would include such things as method of feeding, type and form of ration and general management practices.

The overall means for Breed "M" and the contemporary Yorkshire herd are presented in Table VIII. The average daily gain for gilts and barrows is greater for Breed "M" than for the purebred Yorkshire herd. It should be pointed out that the means presented for the Yorkshires were obtained from considerably less data than was the case for Breed "M". However, a comparison of these average daily gains with those for the breeds presented in Table I shows that the average daily gain of Breed "M" and the contemporary Yorkshire herd

TABLE VIII

POSTWEANING GAIN - MEANS AND STANDARD ERRORS AND COEFFICIENTS OF VARIABILITY FOR EACH SEX FOR BREED 'M' AND THE CONTEMPORARY YORKSHIRE HERD

		Gilts	Barrows	Boars
Breed 'M'	$\bar{x}$	1.27 ± .004	1.28 ± .006	1.28 ± .015
	CV	9.2	10.2	
Contemporary Yorkshire	$\bar{x}$	1.20 ± .012	1.25 ± .013	-
	CV	10.3	8.9	

are low. There are two possible explanations why the gains for Breed "M" and the Yorkshires should be so low in comparison to the breeds shown in Table I:

1) There may have been a difference in the period over which the rate of gain was measured and

2) The incidence of disease in the herds involved in this project has been high and probably has had an adverse effect.

It should also be borne in mind that the breeds presented in Table I are for the most part United States breeds and presumably have been maintained on higher energy rations. Stothers (1962) made the observation from results of nutritional experiments using gilts and barrows of Breed "M", that average daily gain was affected by the type and form of ration fed.

The variability which exists within Breed "M" for postweaning gain does not appear as high as might be expected in view of the genetic diversity of the foundation stock. The coefficient of variability for gilts and barrows was estimated as 9.2 and 10.2% respectively. However, the average coefficient of variability for the Minnesota No. 3 calculated from the results reported by Sumption et al. (1961) was 11.7%. These estimates are three to four times as great as the value of 3.5% reported by Fredeen and Jonsson (1957) for a group of Landrace pigs.

Mean backfat thickness were 1.15, 1.22 and 1.09

for gilts, barrows and boars respectively (Table VII). These overall means were approximated in a similar manner as for postweaning growth rate and litter size. Boars were found to have significantly less backfat than either barrows or gilts and barrows significantly more than gilts ($P < .01$)[1]. Fredeen and Jonsson (1957), Fredeen (1953) and others have also reported that gilts are generally thinner in backfat. No information was available in the literature with respect to backfat measurements in boars specifically.

The means for backfat thickness of some of the more recently developed breeds in the United States and Canada are presented in Table IX. It is quite obvious that the United States breeds have greater depth of fat than is generally the case for the Canadian breeds. It is possible that these means were obtained from pigs which were heavier at the time of probing. However, selection for low backfat thickness has been practiced in Canada for many years with breeds presumed to be superior in this trait.

The coefficients of variability for barrows and gilts was found to be 6.7 and 7.5% respectively. These

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[1]Approximate statistical tests were carried out in order to arrive at this conclusion. The overall means were considered as linear functions and the standard error of the difference between the two means being tested was calculated by summing the variances of the two means and taking the square root. Test used was the conventional 't' test with $n_1 + n_2 - 4$ degrees of freedom.

TABLE IX

BACKFAT THICKNESS - MEANS FOR SOME OF THE ESTABLISHED BREEDS

IN THE UNITED STATES AND CANADA

Breed	Average Backfat Thickness (Inches)	Reference
Palouse	1.39 ± .04	Ensminger *et al.* (1950)
Chester White	1.79 ± .09	Ensminger *et al.* (1950)
Yorkshire	1.44	W. W. Green (1955)
Maryland No. 1	1.39	W. W. Green (1955)
Landrace[1]	1.37	Fredeen and Jonsson (1957)
	1.26	Fredeen and Jonsson (1957)
Canadian Yorkshire	1.16 ± .01 males	Rahnefeld (1965)[2]
	1.23 ± .01 females	" "
	1.33 ± .03 barrows	" "
Canadian Lacombe	1.19 ± .01 males	" "
	1.22 ± .01 females	" "
	1.26 ± .02 barrows	" "

[1]Fredeen and Jonsson used Danish Landrace pigs in Denmark.
[2]Personal communication. University of Manitoba 1965.

estimates are in close agreement with the estimates of 7.2 and 6.5% for barrows and gilts of the Landrace breed reported by Fredeen and Jonsson (1957). However, other workers have reported higher coefficients of variability for this trait (Dickerson (1947)).

Generally the means for the three performance traits presented in Table VII indicate that the performance of Breed "M" has been comparable to that of other breeds on the Canadian and United States market, and that the level of variability which exists in the population for the performance traits under consideration is sufficiently high in all cases to warrant an attempt at improvement through selection.

Selection Differentials

The selection differentials presented in Tables X - XII for each of the performance traits considered in this study have been weighted by the number of offspring left by each dam. They have been estimated in the conventional manner i.e., the mean of the selected individuals weighted by the number of offspring, minus the mean of the population from which they were selected. The mean selection differential for litter size for Breed "M" was 1.03. The overall mean selection differential among the gilts for postweaning gain and backfat thickness were found to be .00 and -.02 respectively. Similar estimates for the boars

TABLE X

SELECTION DIFFERENTIALS FOR EACH LINE AND GENERATION FOR LITTER SIZE

Line	F_2	F_3	F_4	Av.
1	.70	.18	-	.44
2	1.95	-	-	1.95
3	.04	-	-	.04
4	1.69	-	-	1.69
Overall Av.				1.03

TABLE XI

SELECTION DIFFERENTIALS FOR GROWTH RATE AND BACKFAT THICKNESS FOR EACH LINE AND GENERATION OF GILTS

Trait	Line	F_2	F_3	F_4	Average
Postweaning Growth Rate	1	.05	.03	-	.04
	2	.00	-.08	-	-.04
	3	-.01	.00	-	.00
	4	.03	.02	-	.02
	Overall Av.				.00
Backfat Thickness	1	-	-	-	-
	2	-	-	-	-
	3	-	-.03	-	-.03
	4	-	-.02	-	-.02
	Overall Av.				-.02

TABLE XII

SELECTION DIFFERENTIALS FOR BOAR POSTWEANING GAIN AND BACKFAT THICKNESS FOR EACH LINE PER GENERATION

Trait	Line	F_2	F_3	F_4	Average
Postweaning Growth Rate	1	-	-	-	-
	2	-	-	-	-
	3	-	.01	-	.01
	4	-	.10	-	.10
	Overall Av.				.05
Backfat Thickness	1	-	-	-	-
	2	-	-	-	-
	3	-	.04	-	.04
	4	-	.00	-	.00
	Overall Av.				.02

turned out to be .05 and .02 respectively.

Litter Size

The results of the dam-offspring regression analysis and the paternal half-sib correlation for all lines comprising Breed "M", as well as the overall pooled estimates of heritability are presented in Table XIII. The separate estimates for each line are in themselves pooled estimates and are seen to vary considerably. The overall pooled estimate for the breed was 0.18 ± 0.16 obtained by dam-offspring regression and 0.44 ± 0.59 obtained by paternal half-sib correlation (Table XIV). These two estimates are not significantly different from each other and in order to obtain a more reliable estimate for the breed these estimates were pooled, weighting each inversely to their variance. This yielded a single estimate of 0.19 ± 0.16 which was not significantly different from zero ($P > .05$).

Fredeen (1963) points out that the statistical method used for estimating heritability is dependent upon the trait for which an estimate is desired. In order to obtain some information as to the best method of estimating heritability for the traits under consideration here, the paternal half-sib correlation and the parent-offspring regression methods were employed.

The parent-offspring regression analysis as the

TABLE XIII

LITTER SIZE - ESTIMATES OF HERITABILITY AND STANDARD ERRORS OBTAINED BY THE PATERNAL HALF-SIB CORRELATION AND DAM-OFFSPRING REGRESSION METHODS

(POOLED ESTIMATES ARE ALSO SHOWN)

Line	d.f.	Dam-Daughter Regression Heritability	(Sire) d.f.	Paternal Half-Sib Correlation Heritability	Dam-Daughter Regression and Paternal Half-Sib Correlation Pooled
1	54	.01 ± .28	12	.50 ± .95	.05 ± .27
2	60	.38 ± .32	10	-.20 ± 1.11	.24 ± .29
3	42	-.16 ± .38	7	.70 ± 1.38	-.10 ± .37
4	42	.96 ± .52	9	1.56 ± 1.26	1.05 ± .48
Pooled	206	.18 ± .16	48	.44 ± .59	.19 ± .17

TABLE XIV

LITTER SIZE - ESTIMATES OF HERITABILITY AND ADDITIVE GENETIC VARIANCE

Trait		Method of Analysis: Parent-Offspring Regression	Method of Analysis: Paternal Half-Sib Correlation
Litter Size	Heritability	.19 ± .17	.44 ± .59
	Additive genetic variance	2.50	2.97

basis for estimating heritability is advantageous in the sense that it is subject to less bias from variance in genotype-environment interaction than the half-sib correlation method. This is because parents and offspring develop in different environments in so far as year effects are concerned.

So long as mating is at random among selected males and females and provided that the total variance was measured among contemporary individuals in the same herd and location, then the gross regression method, like the intra-sire regression method yields an unbiased estimate of one-half the heritability. With the exception of the early generations random assignment of females to sires (except for avoiding full-sib matings) has been the consistent practice in this swine breeding project. In view of the fact that the data used in this analysis were obtained from individuals which were all raised at one location, the gross regression method was chosen over the intra-sire regression method. It was also felt that the gross regression method would yield more reliable estimates owing to the availability of more degrees of freedom.

Estimates of heritability for litter size reported in the literature vary from -.11 to .54. This wide range of values may represent genuine differences among populations studied, but is more likely due to imprecision of the various estimates. In the present study all the estimates reported here fall well within the range of the values reported in the literature. From these values, it seems likely that the more reliable estimates of heritability for litter size are those obtained using large bodies of data. Boylan et al. (1961) obtained an estimate of .03 ± .07 with a sample size of 1970 pairs. The results of Cockerham (1952), Cummings et al. (1947) and others are in general agreement with this concept. At any rate, these estimates are the more reliable in view of the smaller standard errors which accompany them. Boylan et al. (1961) in his review points out that the best estimate of average litter size is probably less than 0.10. The fact that the estimates reported here are well above this figure may be attributed in part to sampling error. However, many (if not the great majority) of estimates reported in the literature are from long established breeds. This estimate is from a newly formed breed and considering the genetic diversity of the foundation stock presumably has a greater amount of genetic variance which may account for the larger estimate.

Growth Rate

The heritability estimates obtained by the dam and sire-offspring regression methods for all gilts, barrows and boars are presented in Table XV. As these estimates were

TABLE XV

GROWTH RATE - ESTIMATES OF HERITABILITY OBTAINED

BY PARENT-OFFSPRING REGRESSION

		Dam-Offspring		Sire-Offspring	Pooled
	d.f.	Regression Heritability	d.f.	Regression Heritability	Regression Heritability
All Gilts	773	.14 ± .08	118	.16 ± .18	.15 ± .07
All Barrows	545	.10 ± .10	57	.42 ± .22	.16 ± .09
All Boars	126	.64 ± .28	41	-.14 ± .40	.38 ± .22
All Sexes Pooled					.17 ± .05

not found to be significantly different from each other, they were pooled by weighting each inversely to its variance. This procedure provided estimates of .15 ± .07, .16 ± .09 and .38 ± .22 for gilts, barrows and boars respectively.

The estimates of heritability obtained by the paternal half-sib correlation are presented in Table XVI. By this method estimates of .43 ± .48, .34 ± .49 and .76 ± .85 were obtained for gilts, barrows and boars respectively. These estimates were not found to be significantly different from each other or from the pooled estimates obtained for the parent-offspring regression. These estimates were therefore pooled with the pooled regression estimates. The three estimates obtained in this manner (Table XVI) were in turn pooled to provide an overall estimate of .18 ± .05 for the breed for postweaning growth rate.

Estimates of heritability of daily gain reported in the literature vary from 0.14 to 0.66. The overall estimate of 0.18 falls well within the range of values reported in the literature.

In the present study estimates of heritability obtained from paternal half-sib correlation were nearly twice as large as those obtained from parent-offspring regression analysis. Sampling error most likely accounts for these differences in view of the large standard errors which accom-

TABLE XVI

GROWTH RATE - ESTIMATES OF HERITABILITY OBTAINED BY PATERNAL HALF-SIB CORRELATION AND BY POOLING THE ESTIMATES AS OBTAINED BY THIS METHOD AND THE PARENT-OFFSPRING REGRESSION

	(Sire) d.f.	Paternal Half-Sib Correlation Heritability	Pooled Regression and Paternal Half-Sib Correlation Heritability
All Gilts	56	.43 ± .48	.16 ± .07
All Barrows	53	.34 ± .49	.17 ± .09
All Boars	27	.76 ± .85	.46 ± .26
All Sexes Pooled			.18 ± .05

pany the estimates. However, it is recognized that an environmental correlation with the sire component of variance as pointed out by Dickerson (1959) could cause an upward bias in the estimates from paternal half-sib correlation. Conversely the estimates from parent-offspring regression could be biased downward and reflect under estimates of the parameter. Dickerson (1959) indicates a possible bias in estimates by dam-offspring regression due to a positive or negative correlation of environmental effects on the dam with the direct maternal influence on her young. Further investigation of possible bias is indicated by these results.

A comparison of heritability estimates from paternal, maternal and full-sib correlation is possible with estimates obtained by these three methods as shown in Table XIX. The estimates for growth rate by the three methods are nearly the same and suggest that dominance variation and maternal influences are not of major importance for the phenotypic expression of this trait.

Backfat Thickness

Fredeen and Jonsson (1957), who estimated heritability of backfat thickness for barrows and gilts, obtained estimates of 0.52 and 0.58 respectively. The estimates of heritability obtained in the present study from parent-offspring regression and paternal half-sib correlation are not in general agreement with the estimates obtained by these workers (Table XVII). The estimates obtained by parent-offspring regression are well below what one would expect as a reasonable estimate for this trait as suggested by values reported in the literature (See Table IV). Of particular interest here are the estimates of 0.07 ± .07 and 0.19 ± .13 for gilts and barrows respectively. When these estimates are compared with those obtained by the paternal half-sib correlation, the complete reversal of the magnitude of the estimates so far as the sexes are concerned is interesting. While the differences between the estimates can be accounted for by sampling error, an examination of the components of variance suggest that environmental effects may also be a factor (Table XVIII). In an effort to determine whether environmental effects were actually playing a part in this difference between the estimates for barrows and gilts, additional estimates were calculated using the dam component of variance. This procedure yielded estimates of 0.22 and 0.73 for gilts and barrows respectively (Table XIX) and indicates that environmental effects have a greater effect upon barrows than gilts. Stothers (1962) who conducted nutritional experiments on these pigs observed that backfat measurements were affected in both gilts and barrows by the form and the method in which the different rations were fed. He states, "the extent of the ration effect was more marked in barrows". Thus, the

TABLE XVII

BACKFAT THICKNESS - ESTIMATES OF HERITABILITY OBTAINED BY PARENT-OFFSPRING REGRESSION AND PATERNAL HALF-SIB CORRELATION

	Method of Analysis	
	Parent-Offspring Regression Heritability	Paternal Half-Sib Correlation Heritability
All Gilts	.07 ± .07	.67 ± .71
All Barrows	.19 ± .13	.06 ± .90
All Boars	.22 ± .13	.004 ± .99
All Sexes Pooled	.13 ± .06	.33 ± .49
Overall Heritability for Breed 'M'	.13 ± .06	

TABLE XVIII

BACKFAT THICKNESS - ESTIMATES OF VARIANCE COMPONENTS

(POOLED BY SEX)

Components	Symbol	d.f.	Gilts	d.f.	Barrows	d.f.	Boars
Sires	S	29	.0010	27	.0001	27	.00001
Dams Within Sires	D	82	.0003	70	.0013	52	.00402
Within Litters	W	230	.0046	140	.0055	48	.00587
Total	P		.0059		.0069		.00990

(where P = phenotypic variance i.e. S + D + W) environmental effect affecting the barrows may well be real.

The overall heritability estimate from pooled regression for the breed was 0.13 ± .06 (Table XVII), that by the paternal half-sib correlation was 0.33 ± .49, and these two estimates pooled provided one estimate for the breed of 0.13 ± .05. The estimate as obtained by the parent-offspring regression is well below the great majority of estimates reported in the literature for the trait, while the estimate of .33 from the paternal half-sib correlation is closer to the average of the estimates reported by the different workers. It should be noted, however, that neither of these estimates are significantly different from zero.

A comparison was made earlier between Breed "M" and some of the long established breeds in the United States for average backfat thickness. At that time, it was stated that in general the United States breeds were fatter. It might be that the United States breeds exhibit greater variability for the trait, and hence improvement within them would be more rapid. Little evidence exists in the literature as to the extent of the variability within the breeds in the United States. However, Fredeen and Jonsson (1957) obtained a coefficient of variability of approximately 6.9% for a group of Landrace pigs. The coefficient of variability for backfat thickness in this study was 7.1%. These coefficients are in close agreement with each other and suggest that the variability within these populations is not very high. Fredeen (1958) commenting on results reported by Lush (1936) stated that in all probability a biological minimum for backfat thickness is approximately 1.00 inches. In view of the averages of 1.22 ± .006 and 1.15 ± .004 for barrows and gilts in this study, it is reasonable to assume that this breed is closer to the minimum than any of the American breeds. In effect this may mean that there is less genetic potential for the reduction of backfat within Breed "M" than is the case for the breeds which have greater depth of backfat. If this is so, then the low estimate of heritability of 0.13 ± .05 obtained for this breed for backfat thickness may be explained in part by this lack of genetic potential for improving the trait.

TABLE XIX

HERITABILITY ESTIMATES FOR LITTER SIZE, POSTWEANING GROWTH RATE AND THICKNESS OF BACKFAT AS OBTAINED BY THE ANALYSIS OF VARIANCE AND USING THE SIRE, DAM AND FULL-SIB COMPONENTS

Trait		$\frac{4S}{S + D + W}$	$\frac{4D}{S + D + W}$	$\frac{2(S+D)}{S + D + W}$
Litter Size		.4425	-.7261	-.3358
Postweaning Growth Rate	(Males)	.3405	.4464	.3934
	(Females)	.4295	.5506	.4900
Backfat Thickness	(Males)	.0641	.7289	.3965
	(Females)	.6711	.2148	.4430

SUMMARY

The development of a new breed of swine from a crossbred foundation was initiated at the University of Manitoba in 1956. The three primary breeds Welsh, Wessex Saddleback and Landrace (Swedish) comprise approximately 75% of the breed with the remaining 25% being made up with Berkshire, Minnesota No. 1, Tamworth and Yorkshire.

Data collected over the four year period, 1960 to 1964, for the three performance traits of litter size at birth (number born alive), postweaning growth rate and backfat thickness were analyzed to obtain means, selection differentials and estimates of heritability for each trait.

The means for the three traits compared favorably with other established breeds in Canada and the United States. Means for postweaning growth rate and backfat thickness were calculated separately for each sex. No significant difference was observed in postweaning growth rate between gilts, barrows and boars. A highly significant difference was found between boars and gilts, and gilts and barrows. In this regard barrows were found to be fatter than gilts and boars. Gilts had less fat than boars.

Two statistical procedures were used in estimating genetic parameters for the new breed. These were parent-offspring regression and paternal half-sib correlation.

Overall pooled estimates of heritability for the new breed for litter size and postweaning growth rate, obtained from 211 litters and 1,472 individuals, were 0.19 $\pm$ 0.16 and 0.18 $\pm$ 0.05 respectively. These estimates fall within the range of estimates reported by other workers for these traits.

Data collected on 723 individuals from 1962 and 1963 for backfat thickness provided a pooled estimate for the new breed of 0.13 $\pm$ 0.05. This estimate was considerably lower than what might be expected for the trait, but may be due to a high unexplained source of environmental variance among males. It is also possible that this breed is close to the 'biological minimum' for the trait and hence the genetic potential does not exist to make further reductions.

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A P P E N D I X

TABLE 1

DAM-OFFSPRING COVARIANCE ANALYSIS - LITTER SIZE

Line	d.f.	x^2	xy	y^2
1	58	230.9828	6.3966	283.8794
2	63	378.8572	64.4286	479.7143
3	45	241.2000	-5.4666	300.9778
4	45	93.7778	24.8889	295.6445
Pooled	211	1004.6170	120.7210	1387.7350

TABLE 2

ANALYSIS OF VARIANCE - LITTER SIZE

Line	Source of Variation	d.f.	Mean Squares	(k)	Values
1	A	2	1.775	(1)	1.691
	S	12	5.538	(2)	1.768
	D	18	3.442	(3)	2.089
	W	25	6.077		
2	A	1	.010	(1)	1.611
	S	10	7.310	(2)	1.856
	D	25	9.330	(3)	2.060
	W	26	6.667		
3	A	1	2.540	(1)	1.709
	S	7	9.359	(2)	1.887
	D	16	4.047	(3)	2.152
	W	20	8.409		
4	A	1	19.730	(1)	1.815
	S	9	11.658	(2)	1.726
	D	14	1.487	(3)	2.038
	W	20	7.508		
Pooled	A	8	6.669	(1)	1.691
	S	38	8.158	(2)	1.803
	D	73	5.216	(3)	2.109
	W	91	7.073		

TABLE 3

ANALYSIS OF VARIANCE FOR GILTS - POSTWEANING GAIN

Line	Source of Variance	d.f.	Mean Squares	(k)	Values
1	A	2	.137	(1)	3.133
	S	15	.030	(2)	3.650
	D	41	.018	(3)	4.239
	W	137	.011		
2	A	2	.080	(1)	3.174
	S	15	.041	(2)	3.870
	D	59	.020	(3)	4.209
	W	181	.011		
3	A	2	.098	(1)	3.004
	S	13	.046	(2)	4.342
	D	41	.016	(3)	4.089
	W	135	.010		
4	A	2	.090	(1)	2.842
	S	13	.025	(2)	3.154
	D	32	.012	(3)	3.609
	W	95	.011		
Pooled	A	11	.146	(1)	3.063
	S	56	.036	(2)	3.754
	D	173	.017	(3)	4.068
	W	548	.011		

TABLE 4

ANALYSIS OF VARIANCE - GILTS - BACKFAT THICKNESS

Line	Source of Variance	d.f.	Mean Squares	(k)	Values
1	S	5	.024	(1)	2.930
	D	15	.007	(2)	3.173
	W	43	.004	(3)	9.806
2	S	5	.012	(1)	2.729
	D	19	.005	(2)	3.133
	W	46	.005	(3)	11.408
3	A	1	.239	(1)	3.018
	S	9	.022	(2)	4.263
	D	28	.006	(3)	3.922
	W	92	.006		
4	A	1	.180	(1)	2.315
	S	10	.006	(2)	2.837
	D	20	.004	(3)	3.156
	W	49	.003		
Pooled	A	5	.107	(1)	2.764
	S	29	.015	(2)	3.389
	D	82	.006	(3)	3.662
	W	230	.005		

TABLE 5

ANALYSIS OF VARIANCE - BARROWS - POSTWEANING GAIN

Line	Source of Variance	d.f.	Mean Squares	(k)	Values
1	A	2	.063	(1)	2.438
	S	14	.037	(2)	3.178
	D	35	.019	(3)	3.298
	W	88	.011		
2	A	2	.059	(1)	2.707
	S	15	.038	(2)	3.210
	D	51	.028	(3)	3.598
	W	128	.017		
3	A	2	.148	(1)	1.866
	S	12	.035	(2)	2.489
	D	35	.011	(3)	2.561
	W	53	.014		
4	A	2	.048	(1)	2.162
	S	12	.020	(2)	2.835
	D	31	.014	(3)	2.967
	W	64	.016		
Pooled	A	11	.092	(1)	2.341
	S	53	.033	(2)	2.953
	D	152	.019	(3)	3.129
	W	333	.015		

TABLE 6

ANALYSIS OF VARIANCE - BARROWS - BACKFAT THICKNESS

Line	Source of Variance	d.f.	Mean Squares	(k)	Values
1	S	4	.018	(1)	2.529
	D	12	.010	(2)	3.903
	W	33	.005	(3)	9.280
2	S	5	.011	(1)	2.560
	D	17	.004	(2)	3.196
	W	40	.003	(3)	10.051
3	A	1	.123	(1)	1.580
	S	8	.010	(2)	2.022
	D	23	.012	(3)	2.257
	W	24	.007		
4	A	1	.035	(1)	2.134
	S	10	.005	(2)	2.847
	D	18	.006	(3)	3.003
	W	43	.006		
Pooled	A	5	.101	(1)	2.123
	S	27	.010	(2)	2.824
	D	70	.008	(3)	2.990
	W	140	.005		

TABLE 7

ANALYSIS OF VARIANCE - BOARS - POSTWEANING GAIN

Line	Source of Variance	d.f.	Mean Squares	(k)	Values
1	S	5	.062	(1)	1.431
	D	10	.037	(2)	1.416
	W	7	.022	(3)	3.600
2	S	5	.004	(1)	1.470
	D	10	.032	(2)	1.891
	W	10	.012	(3)	4.231
3	A	1	.012	(1)	1.354
	S	8	.024	(2)	1.629
	D	16	.020	(3)	1.668
	W	12	.015		
4	A	1	.006	(1)	1.637
	S	9	.093	(2)	1.765
	D	16	.025	(3)	1.956
	W	19	.019		
Pooled	A	5	.308	(1)	1.478
	S	27	.050	(2)	1.684
	D	52	.027	(3)	1.777
	W	48	.017		

TABLE 8

ANALYSIS OF VARIANCE - BOARS - BACKFAT THICKNESS

Line	Source of Variance	d.f.	Mean Squares	(k)	Values
1	S	5	.022	(1)	1.431
	D	10	.004	(2)	1.416
	W	7	.005	(3)	3.600
2	S	5	.004	(1)	1.470
	D	10	.011	(2)	1.891
	W	10	.009	(3)	4.231
3	A	1	.487	(1)	1.354
	S	8	.016	(2)	1.629
	D	16	.025	(3)	1.668
	W	12	.007		
4	A	1	.009	(1)	1.637
	S	9	.009	(2)	1.765
	D	16	.004	(3)	1.956
	W	19	.004		
Pooled	A	5	.126	(1)	1.478
	S	27	.013	(2)	1.684
	D	52	.012	(3)	1.777
	W	48	.006		

TABLE 9

DAM-OFFSPRING COVARIANCE ANALYSIS - GILTS - POSTWEANING GAIN

Line	d.f.	x^2	xy	y^2
1	193	3.2052	.0528	2.9842
2	250	3.5261	.2531	3.7215
3	192	2.5200	.2649	2.8396
4	143	1.2128	.1862	1.9643
Pooled	778	12.0887	1.8472	12.2783

TABLE 9a

DAM-OFFSPRING COVARIANCE ANALYSIS - GILTS - BACKFAT THICKNESS

Line	d.f.	x^2	xy	y^2
1	-	-	-	-
2	-	-	-	-
3	88	1.2080	.0842	.3471
4	33	.0975	.0206	.0795
Pooled	121	1.3056	.1047	.4272

TABLE 10

SIRE-OFFSPRING COVARIANCE ANALYSIS - GILTS - POSTWEANING GAIN

Line	d.f.	x^2	xy	y^2
1	-	-	-	-
2	-	-	-	-
3	88	.5370	.1352	1.0594
4	33	.2155	-.0347	.6930
Pooled	121	1.2944	.1518	1.4007

TABLE 10a

SIRE-OFFSPRING COVARIANCE ANALYSIS - GILTS - BACKFAT THICKNESS

Line	d.f.	x^2	xy	y^2
1	-	-	-	-
2	-	-	-	-
3	88	1.3624	.0859	.3471
4	33	.1966	-.0501	.0795
Pooled	121	2.1576	.0189	.4272

TABLE 11

DAM-OFFSPRING COVARIANCE ANALYSIS - BARROWS - POSTWEANING GAIN

Line	d.f.	x^2	xy	y^2
1	140	1.9339	-.1083	2.2501
2	197	2.0487	.5046	4.2636
3	103	1.2625	-.0254	1.8612
4	110	1.1685	.0222	1.7704
Pooled	550	7.7124	1.0861	10.5256

TABLE 11a

SIRE-OFFSPRING COVARIANCE ANALYSIS - BARROWS - POSTWEANING GAIN

Line	d.f.	x^2	xy	y^2
1	-	-	-	-
2	-	-	-	-
3	33	.2155	-.0347	.6930
4	27	.7990	.1999	.2980
Pooled	60	1.2505	.2500	1.0216

TABLE 12

DAM-OFFSPRING COVARIANCE ANALYSIS - BARROWS - BACKFAT THICKNESS

Line	d.f.	x^2	xy	y^2
1	-	-	-	-
2	-	-	-	-
3	33	.4460	.0594	.1510
4	27	.0936	.0011	.0632
Pooled	60	.5397	.0611	.2162

TABLE 12a

SIRE-OFFSPRING COVARIANCE ANALYSIS - BARROWS - BACKFAT THICKNESS

Line	d.f.	x^2	xy	y^2
1	-	-	-	-
2	-	-	-	-
3	33	.5886	.0937	.1510
4	27	.0590	-.0149	.0632
Pooled	60	1.0803	.0498	.2162

TABLE 13

DAM-OFFSPRING COVARIANCE ANALYSIS - BOARS - POSTWEANING GAIN

Line	d.f.	x^2	xy	y^2
1	21	.2465	.1763	.8387
2	26	.1872	.1055	.4707
3	38	.3899	.0810	.7049
4	46	.5265	.0524	1.6189
Pooled	131	1.7879	.5316	5.1543

TABLE 13a

DAM-OFFSPRING COVARIANCE ANALYSIS - BOARS - BACKFAT THICKNESS

Line	d.f.	x^2	xy	y^2
1	-	-	-	-
2	-	-	-	-
3	21	.3035	.0266	.0666
4	23	.0731	.0377	.0827
Pooled	44	.3766	.0640	.1506