GENETIC IMPROVEMENT OF SWINE

A Thesis

Submitted to the Faculty of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree of

Doctor of Philosophy

in the Department of Animal Science

University of Saskatchewan

by

Wilbert Emil Lentz

September, 1967

BIOGRAPHY

The author was born at Wetaskiwin, Alberta on April 16, 1937. Elementary education was taken in a rural one-room school and secondary education in Wetaskiwin High School. The B. Sc. in Agriculture was awarded in 1959 and the M. Sc. in 1961, both by the University of Alberta. The author has also studied in the Faculties of Education and Pharmacy at the University of Alberta and taught school in Alberta for two years (1962-1964).

GENETIC IMPROVEMENT OF SWINE

Wilbert Emil Lentz

ABSTRACT

An analysis of Canadian R.O.P. data for pigs born in 1964 and 1965 was undertaken with two main objectives in mind. The first was the identification of genetically superior litters and the second was the evaluation of heritability estimates for various performance traits and of the genetic and phenotypic correlations between them.

In order to achieve the first objective it was necessary to investigate the various possible sources of environmental variation since these might have masked genetic differences. Both province and season (month or quarter) effects were statistically significant for most traits but the evidence favored a hypothesis that these differences were, for the most part, reflections of genetic differences between litters tested in the various provinces and periods. There was evidence of a season effect on per cent ham in the carcass and per cent lean in the ham face, but this cannot be considered to be conclusive since data from only one year were available.

Carcass weight was found to have an important influence on all carcass traits including predicted yield and it was recommended that this trait be adjusted for carcass weight before it is utilized in a selection index. Sex of the pig also had a substantial effect on carcass characteristics, with gilt carcasses being superior to barrow carcasses. Sex differences in total fat were significantly smaller in the Lacombe breed than in the other breeds.

Consequently, the R.O.P. sex corrections overcorrected this trait in this breed, but the sex corrections were effective in eliminating sex differences in predicted yield. Sexes also differed in growth rate with barrows growing faster than gilts, especially in the Yorkshire breed. Where sib or progeny testing is being employed and test groups are not balanced for sex it is advisable to apply a sex correction to age at slaughter (adjusted to a constant carcass weight) before it is included in a selection index.

Heritability estimates were very high for all traits except growth rate (age at slaughter). The large sire components of variance which resulted in these high estimates were taken as evidence for the existence of strains of pigs which differ in average genetic merit for a given trait.

On the basis of available information, both from the R.O.P. records studied and from the literature, recommendations for selection procedures were made. While the recommendations were formulated as guidelines for the establishment of a central swine breeding station in Saskatchewan, they should, for the most part, be applicable to R.O.P. and other swine improvement schemes.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. J.M. Bell and Dr. W.E. Howell of the Department of Animal Science, University of Saskatchewan for their assistance in initiating this project and for their comments and suggestions in the preparation of this manuscript. Thanks are also extended to the staff of the Production and Marketing Branch, Canada Department of Agriculture for supplying R.O.P. data cards and for their assistance with the carcass evaluation trial. The willing co-operation of Intercontinental Packers in the latter project is also acknowledged.

Special thanks go to Dr. G.E. Nelms for his suggestions and guidance in the selection of statistical procedures, for his comments and constructive criticism in interpretation of results and preparation of this manuscript, and for his encouragement and inspiration while he was at the University of Saskatchewan on sabbatical leave from the University of Wyoming.

TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

Commercial production of livestock tends to be stratified in one or more ways. One method of stratification, an important one from the livestock improvement point of view, consists of a relatively small number of elite herds or seed stock producers, a large number of multiplier herds, and a much larger number of commercial producers. In the past the position of any given producer has been determined by his reputation -- based on show ring winnings or on herd performance or both -- and by whether or not his herd consisted of registered purebreds.

Saskatchewan has now undertaken to certify purebred swine herds as elite herds if certain performance requirements are met. It is hoped that genetic improvements made in the elite herds will work down through the multiplier herds to commercial herds. However, the standards required for elite herd status are such that very little or no improvement can be expected in the foreseeable future unless the elite breeders are in turn provided with a source of superior breeding stock.

With this problem in mind, the Department of Animal Science, University of Saskatchewan has been promoting the idea of a central swine breeding station. Here the most outstanding breeding stock available would be assembled and superior breeding stock would subsequently be provided for distribution to the elite breeders of the province.

Among other problems which must be resolved before a station can become a reality is the identification of the genetically superior individuals. Another is the charting of a tentative selection procedure, since the latter could have a marked effect on the station design.

With the resolution of these problems as the objective, an analysis of Canadian Record of Performance data for swine was undertaken. The primary objective was the identification of genetically superior litters and a secondary objective was the computation of genetic and phenotypic correlations and heritability estimates for various traits.

REVIEW OF LITERATURE

A. Environmental Effects and Performance

Stothart (49), in an analysis of performance data of Canadian Yorkshire litters from nineteen Experimental Stations over a six-year period, found that station and year differences contributed an important part of the total variance in all carcass characteristics. In a subsequent review of Canadian Yorkshire performance data for the years 1939 to 1949 inclusive Fredeen (15) also found regional differences.

Working with growth curves of another sample of Canadian Yorkshires, Bell (2) concluded that station differences appeared to be associated mainly with differences in performance during the nursing and early post-weaning periods. However, Fredeen (18), in a summary of 1965 R.O.P. data, has stated, "Provincial differences in age at slaughter appear to result primarily from differences in rate of growth at the station."

In a study of Danish Landrace records, Fredeen and Jonsson (20) found that differences between stations accounted for from zero to 4 per cent of the total variance, and that differences between quarters of the year were rather small for carcass length and back fat, but contributed from 5.0 to 6.8 per cent of the total variance for daily gain and feed efficiency. While these pigs were individually hand fed, the authors noted that variation between quarters also occurred under group feeding in old Danish progeny testing stations.

Plank and Berg (39) have also reported seasonal differences in performance, but only when feed intake was restricted and equalized.

B. Effects of Sex

An excellent review of differences between barrow and gilt carcasses has been made by Fredeen (15). The gilt carcasses were leaner, longer, had larger loin areas, and yielded a higher proportion of ham. The picture with regard to rate of gain and efficiency of feed utilization is less clear. It has generally been conceded that barrows grew more quickly than gilts (2, 3, 4, 15, 20, 39) under *ad libitum*, liberal or group feeding. However, with equalized feed intake (39), or individual hand feeding (20), gilts gained more rapidly and more efficiently. The more rapid gains of the barrows with liberal feeding were apparently the direct result of a higher daily feed intake without impairment of efficiency of utilization (2, 3, 10, 20, 21, 39).

Fredeen (16) has advocated that sex balance should not be a criterion in determining eligibility of a litter for R.O.P. This has been made feasible, so far as carcass characteristics are concerned, by adjusting individual carcass traits (8) with sex corrections which were derived from a number of least squares analyses (18). However, under *ad libitum* feeding, as practiced in R.O.P. test stations, the barrows would be expected to grow more quickly, and since no sex correction has been applied to age at slaughter, use of the litter mean for this trait could lead to some error for test litters which are not balanced for sex.

C. Evaluation of Carcass Merit

For litters born previous to 1965, the Canadian R.O.P. carcass evaluation consisted of assigning a score (from zero to a specified maximum) for each of carcass length, backfat thickness, loin area, and belly quality, and reporting the sum of these scores (7). Although minor revisions had been made in the scoring system from time to time, no apparent effort was made to evaluate its effectiveness prior to the study of Fredeen, et al. (19).

Not only did that study show the ineffectiveness of the R.O.P. procedures then in use for predicting the percentage yield of trimmed lean cuts, but it compared a number of alternative methods as well. One of these has been adopted for R.O.P. purposes and is being used on litters born in 1965 and subsequently.

As early as 1952, Hazel and Kline (25, 26) had reported that live backfat probes reflected fatness and leanness as accurately as backfat measurements on the carcasses. This was corroborated by De Pape and Whatley (11), who reported that an average of six live probes was more highly correlated with per cent primal cuts than was backfat thickness measured on the carcass.

D. Selection Procedures in Swine Improvement

Although the method of assessing carcass merit of Canadian R.O.P. pigs is now reasonably accurate, the individuals which are so assessed are useless as breeding stock. Information obtained from them can only be applied to sires, dams, and littermates, and it is regrettable that the live probe method (11, 25, 26) was not considered in the study by Fredeen *et al.* (19).

No matter how, or how accurately carcass merit is evaluated, selection cannot be based on it alone, since feed costs account for seventy to eighty per cent of the cost of rearing a pig to market weight (9). The implication is that, in making selections, some measure of efficiency of feed utilization should be considered along with carcass merit.

With liberal or *ad libitum* feed intake, Plank and Berg (39) found that rapid gains were mainly a reflection of increased feed intake. Pigs with an inherent tendency to fatten tended to eat more, gain faster but less efficiently, and produce inferior carcasses. This, plus a sire X plane of nutrition interaction, led them to suggest that performance testing be done with limited, equalized feeding. This would permit a more positive identification of pigs with the ability to gain both rapidly and efficiently than would be possible with *ad libitum* feeding. The same conclusion has been reached by Hale and Coey (22).

Since Canadian R.O.P. station tested swine are fed *ad libitum*, the desirability of selecting simultaneously for several traits becomes apparent. The index method of selection, first proposed by Fairfield Smith (46), has been shown, if properly used, to always be at least as good as independent culling levels, while tandem selection is the least effective in all cases (27, 52).

The theoretical considerations of constructing a selection index which gives optimum genetic gains have been discussed by Hazel (24). The required constants include the relative economic values of the various traits, the correlations (both phenotypic and genetic) between them, the variances of the traits and their heritabilities.

The computation of heritability estimates, a concept first introduced by Wright (51), has been discussed by a number of authors (6, 12, 14, 15, 30, 33, 34). Of the various procedures available, Falconer (14) has indicated that the half sib correlation and regression of offspring on sire procedures are the least likely to result in an estimate augmented by an environmental component, while estimates from the full sib correlation method are likely to contain dominance and common environment components, and can seldom do more than set upper limits on heritability.

Numerous estimates of heritability have been reported for various traits in swine. Fredeen (15) has given an excellent review of those published prior to 1953 (primarily for American breeds) and has also given estimates for Canadian Yorkshires. Estimates for various traits of British Large Whites have been reported by King (29) and by Smith _et al_. (44); for British Landrace by Smith and Ross (45); for Danish Landrace by Fredeen and Jonsson (20); and for a new Canadian breed called Managra by Stockhausen and Boylan (48). The worth of these estimates does not, however, go without question. Lerner (30) has stated "The degree of heritability is of fundamental importance in the theory and practice of selection". Hutt (28), another poultry geneticist, has stated, "Although such figures have been determined in scores or even hundreds, no one has yet been able to put h^2 to any very specific practical use. It is commonly said to guide the breeder in what method of selection to use .... In most cases the breeder has already known that situation long before the estimates of heritability were calculated."

Hutt does have a point insofar as an estimate of heritability is applicable only to the population and conditions under which it was derived and neither populations nor environment remain static. This does not, however, invalidate the use of an estimate as a guide in subsequent selection, providing new estimates are periodically computed as selection progresses and environment changes.

Genetic correlations may be computed from analyses similar to those used to derive heritability estimates and procedures have been adequately described (6, 12, 14, 25, 30, 41). Genetic correlations between various traits have been reported by a number of workers (15, 20, 29, 43, 44, 45, 48). The validity of the concept has been demonstrated by Falconer (13), but, like a heritability estimate, a genetic correlation is really only applicable to the population for which it was computed, and is therefore subject to change as the genetic composition of the population is changed by selection.

A simple selection index for Canadian R.O.P. swine, which combines predicted yield and age at slaughter, has been outlined by Fredeen (17). He explains that "Feed requirements have not been included, partly because feed records are taken only for station fed litters (and stations can handle only about three-fifths of all litters entered for test each year) and partly because the measurement of feed on a litter basis adds very little information on genetic differences in feed efficiency beyond that obtained directly from differences in growth rate."

Growth rate would provide a better measure of feed efficiency if feed intake was restricted (22, 39) instead of being provided ad libitum as is the present practice. However, there appears to be no superior alternative under present circumstances.

MATERIALS AND METHODS

A. Carcass Evaluation Trial

Because the data used by Fredeen *et al.* (19) in deriving their yield prediction equations came primarily from Lacombe and crossbred pigs, and because the equations were represented as being generally applicable to Canadian pigs, it seemed worthwhile to conduct a small independent trial to confirm or disprove the general applicability of the theory.

For this purpose, the co-operation of a local abattoir was sought and 90 carcasses, 30 from each of grades A, B and C were used. The carcasses were chosen from a normal commercial run and no attempt was made to determine the history of the pigs. Selection within grades was done at random by a representative of the Production and Marketing Branch, Canada Department of Agriculture, except that an attempt was made to obtain equal numbers of male and female carcasses in each grade. When the accumulation from two days' slaughter failed to provide sufficient grade C female carcasses, 10 female and 20 male carcasses were used for this grade.

In addition to all R.O.P. carcass measurements, complete carcass cut-out data were obtained, using the trimming procedures outlined by Fredeen *et al.* (19), except that the belly was not trimmed. The per cent yield for each carcass was calculated on a lean cuts basis as well as on a hot carcass weight basis. In either case, the numerator was the total of the trimmed weights of ham, picnic, butt, and loin. The denominators were the totals of the untrimmed weights of these four cuts, and hot carcass weight, respectively.

Predicted yield (Y) was calculated for each carcass in three ways, utilizing three different equations derived by Fredeen _et al_. (19). These equations are:

$$Y = 55.26 - 2.115X_1 + 0.937X_2 + 0.456X_3 + 0.604X_4 + 0.124X_5 - 0.063X_6 \quad (1)$$

$$Y = 86.31 - 3.839X_1 + 1.564X_2 \quad (2)$$

$$Y = 93.72 - 4.205X_1 \quad (3)$$

where

X_1 = total fat (in.)

X_2 = loin area (sq.in.)

X_3 = carcass length (in.)

X_4 = % ham in carcass

X_5 = % lean in ham face

X_6 = hot carcass weight

Before using any of the equations, the following sex adjustments were made:

		Males	Females
X_1	Total fat	- 0.2 (in.)	+ 0.2 (in.)
X_2	Loin area	+ 0.24 (sq.in.)	- 0.24 (sq.in.)
X_3	Carcass length	+ 0.2 (in.)	- 0.2 (in.)
X_4	% ham in carcass	+ 0.3 (%)	- 0.3 (%)
X_5	% lean in ham face	+ 1.9 (%)	- 1.9 (%)
X_6	Carcass weight	no sex correction	

Because of the unequal numbers of males and females in the C grade, data for both actual and predicted yields were subjected to least squares analysis (23), with the model including grade and sex effects, and the interaction between grade and sex. Correlations between the various measures of actual and predicted yield were also computed.

B. Analysis of R.O.P. Records

Data for all Yorkshire, Lacombe, and Landrace litters tested in 1963, 1964, and 1965 were obtained in the form of punched computer cards from the Livestock Division, Canada Department of Agriculture, Ottawa. All of the 1963 data were rejected because minimum backfat measurements had not been punched on the cards supplied. The same was true for most litters from the Maritimes in 1964, and therefore, all the litters born in these provinces during 1964 were also rejected. Of the remaining litters, only those which were station tested and from which all four pigs of the test group survived to market were utilized. This left so few litters from British Columbia in 1964 that they too were rejected.

Because the nature of the data for 1964 and for 1965 was different, the procedures used were also different and will be discussed separately.

1. Procedures Used with 1964 Data

These data came on two sets of cards. One set contained individual pig records, one card per pig, and did not contain litter feed efficiency, while the other set, the sow cards, contained litter means for various traits, including feed efficiency. Neither set contained any type of season code. The latter was available from the annual report for R.O.P. swine. It listed litters by province and the period in which they completed the test and gave a summary of the litter's performance, including feed efficiency. Auxiliary data cards containing the sow registration number, period code, and feed efficiency were punched and read into the computer along with the individual pig data cards. Both sets of data were sorted on sow registration number and then merged to produce a data tape which had complete records for each pig, including a period code and its litter's feed efficiency.

The periods, as listed in the annual report, along with the codes assigned to them, are shown in Table 1. No further grouping of months into quarters was imposed, since individual months provide as logical a basis for grouping as an arbitrary grouping into quarters. It should be noted that the coding arrangement used also distinguished between the pigs born early in 1964 which reached market in June, July, or August of 1964 and those born late in the year which reached market during the same months, but a year later.

TABLE 1 - PERIODS OF TEST COMPLETION FOR LITTERS BORN IN 1964

Month test was completed	Code
June - July - August, 1964	1
September	2
October	3
November	4
December	5
January, 1965	6
February	7
March	8
April	9
May	10
June	11
July - August	12

Predicted yield for each pig was computed from total fat and loin area, using an equation provided by Fredeen (18), and shown as equation (2) on page 11.

Because of the unequal numbers involved, least squares procedures (23) were utilized for analysis of variance. The required calculations were done by the University of Saskatchewan's IBM 7040 computer, through the use of a suitably modified program obtained from the University of Wyoming. All statistical results reported here, except for the heritability and genetic correlation analyses, were obtained by this program.

The mathematical model finally chosen for these data included effects due to province, month, breed, and sex. In order to obtain a measure of the uniformity of differences between breeds and between months from province to province a separate analysis was run for each province. The model included effects due to month, breed, sex, and breed X sex interactions in all cases.

Because of the large number of mean squares to be tested and the abundance of degrees of freedom for error, all tests of statistical significance were made at the one per cent level of probability.

2. Procedures Used with 1965 Data

Litters born in 1965 were evaluated under the new scoring system (8, 17) and the data supplied were therefore different from those of the previous year. Only individual pig cards were supplied and each contained the litter's feed efficiency and the quarter of the year in which the litter completed the test, as well as complete identification and carcass data for that pig.

The cards were sorted to remove the home tested litters and the station tested litters of which less than four pigs survived. Some errors in the data cards were detected by ensuring that values for the various variables fell within specified limits. Where the nature of an error thus detected was obvious (i.e. transposed figures), a corrected card was punched and substituted; otherwise the entire litter was rejected.

Predicted yield was computed from the six-factor R.O.P. equation (8) (equation (1) on page 11). Although the sex corrections (page 11) were utilized in computing yield, the unadjusted values were retained so that least squares estimates of differences between sexes could be obtained.

The analysis of variance model included province, quarter, breed and sex effects, and the province X quarter and breed X sex interactions. A separate analysis was also conducted within each province to estimate province interactions with breeds.

The quarter codes as punched on the data cards sent from Ottawa, were based strictly on the calendar quarters and did not distinguish between the early born litters which reached market in quarters 2 and 3 of 1965 and those born late in the year which reached market in quarters 2 and 3 of 1966. To ascertain whether or not there was a confounding of age and quarter effects, another model was used which, in addition to province, quarter, breed, and sex effects and a province X quarter interaction, included age at slaughter as an effect. For this purpose, ages were arbitrarily grouped into 8 classes, beginning with pigs aged 135 days and less and increasing by 10 day intervals. For this analysis and the one outlined below actual ages at slaughter were used, for all other analyses the age was adjusted to a carcass weight of 155 pounds according to the

R.O.P. procedure (8).

The preliminary analyses of Fredeen (18) indicated that there was a confounding of province differences and carcass weight, so a final analysis was carried out in which the effects of province, sex, age, and carcass weight were removed. In this analysis only Yorkshire data were utilized and ages were grouped into 12 classes, beginning with 140 days and less, with an interval of 5 days. By treating carcass weight as a continuous variable, regression coefficients on this trait were also obtained.

All mean squares were tested at the one per cent level of probability.

C. Heritability and Genetic Correlation Analysis

A nested classification was used for this analysis. Sums of squares, mean squares, and variance component coefficients were computed as outlined by Anderson and Bancroft (1) for unequal subclass numbers. Variance and covariance components were computed and variances of these components were obtained by the method of Rahnefeld *et al.* (42). Heritability estimates were calculated from the variance components (6, 12, 14, 20, 30) but with the modification suggested by Fredeen (15) to take into account the relationship between sows mated to a given sire. Genetic correlations were taken to be the ratio of the sire component of covariance to the square root of the product of the sire components of the variances (41). Standard errors of heritability estimates were computed by the method of Stockhausen and Boylan (48), and of genetic correlations by the method of Falconer (14). Phenotypic correlations were obtained as outlined by Bogart (6).

The analysis utilized data from 1965 only, and was confined to the Yorkshire breed since the available degrees of freedom in the other breeds would have been insufficient for reliable estimates. The analysis was carried out within sexes so that separate estimates were obtained for barrows and for gilts.

RESULTS AND DISCUSSION

A. Carcass Evaluation Trial

The ranges, by grade, for length, hot carcass weight, maximum shoulder fat, and maximum loin fat (the basis of the grade standards) are given in Table 2, along with the mean and standard deviation for total fat.

Least squares estimates for grades and for sex differences are shown in Table 3 for carcass weight, carcass length, total fat, per cent ham in the carcass, per cent lean in the ham face, and loin area. Grade differences for per cent ham in the carcass and for carcass weight were non-significant at the 5 per cent level, grade effects for all other traits were significant at the 1 per cent level. All grade X sex interactions were non-significant and no interaction terms are included for this reason. Sex differences were significant for per cent ham and for loin area.

Least squares estimates for grade and sex effects and the interaction between grade and sex were also computed for the various measures of actual and predicted yields. The results for the main effects are shown in Table 4, grade effects being significant at the 1 per cent level in all cases. All interactions were non-significant at the 5 per cent level.

TABLE 2 - A SUMMARY OF CARCASS VARIABILITY BY GRADE

Grade	Carcass length range (in.)	Carcass weight range (lb.)	Max. shoulder fat range (in.)	Max. loin fat range (in.)	Total fat Mean (in.)	Total fat Standard deviation
A	30.0 - 32.8	142 - 169	1.3 - 2.0	1.0 - 1.4	3.66	0.344
B	28.4 - 31.5	145 - 169	1.4 - 2.2	1.4 - 1.7	4.67	0.264
C	27.8 - 31.4	128 - 174	1.9 - 2.8	1.6 - 2.2	5.40	0.419

TABLE 3 - LEAST SQUARES ESTIMATES OF GRADE AND SEX EFFECTS FOR SELECTED CARCASS TRAITS

	Carcass weight (lb.)	Carcass length (in.)	Total fat (in.)	% ham	% lean in ham face	Loin area (sq. in.)
Grade A	157.1[a]	31.12[a]	3.66[a]	24.51[a]	67.33[a]	4.48[a]
Grade B	158.9[a]	30.45[a,b]	4.67[b]	24.12[a]	51.29[b]	3.91[b]
Grade C	157.3[a]	29.57[b]	5.58[c]	24.02[a]	45.06[c]	3.78[b]
Males - Females	0.16	0.26	0.09	- 0.57*	- 0.51	-0.30**

Values bearing the same superscript do not differ significantly ($P < .05$)

* $P < 0.05$

** $P < 0.01$

TABLE 4 - LEAST SQUARES ESTIMATES OF GRADE AND SEX EFFECTS FOR ACTUAL AND PREDICTED YIELDS

	Actual yields (%)		Predicted yields (%)		
	Lean cuts	Hot carcass	Equation (1)	Equation (2)	Equation (3)
Grade A	79.68	48.65	79.16	79.27	78.33
Grade B	75.77	45.79	73.85	74.49	74.09
Grade C	72.93	43.54	71.09	71.56	71.08
Males - Females	- 0.63	- 0.26	+ 1.54**	+ 1.47**	+ 1.29**

Grades were all different from each other ($P < .01$)

** $P < 0.01$

The relative predictive efficiencies of the three equations (Page 11) for predicting actual yields may be ascertained from Table 5.

TABLE 5 - RESIDUAL VARIANCES AS PER CENT OF TOTAL VARIANCES FOR PREDICTION EQUATIONS

Predictor	d.f.	% yield - lean cuts	% yield - hot carcass
Equation (1)	83	30.88	31.49
Equation (2)	87	30.98	33.95
Equation (3)	88	34.76	41.49
Total variance	89	12.913	7.505

DISCUSSION

These results clearly confirm the predictive efficiencies reported by Fredeen et al. (19) for the equations derived by them. The fact that equation (2), utilizing only total fat and loin area, was virtually as good as equation (1), the R.O.P. equation, lends support to using equation (2) for predicting yield for litters born in 1964.

The discrepancy between actual and predicted yields for sex differences also indicates, with equal clarity, that the sex adjustments employed were not applicable to the carcasses in this trial. Of the several explanations possible, the most probable is that since they were commercially produced the majority of pigs would likely have had feed intake restricted. It has been shown (39) that under these conditions males would tend to grow slower than females and would tend to produce relatively better carcasses. The sex corrections employed were developed for *ad libitum* fed pigs and their effectiveness under those conditions cannot be ascertained from this trial.

B. Analysis of R.O.P. Records

Data from litters born during 1964 in Quebec, Ontario, Manitoba, Saskatchewan, and Alberta were combined for analysis of variance for predicted yield, age at slaughter, total fat, and loin area. Observed mean squares are shown in Table 6. All effects were significant ($P < .01$) except for breed differences in loin area. The magnitude of breed and sex differences is shown in Table 7.

Unbiased estimates of overall means and of deviations from these means due to month of completing test and due to breed are shown by provinces in Table 8 to 11, for predicted yield, age at slaughter, total fat, and loin area, respectively. Month differences were significant in all cases with the exception of yield in Manitoba and Alberta, age at slaughter in Saskatchewan, and total fat in Alberta. Breeds did not differ significantly in loin area and only in Alberta did they differ in total fat and in predicted yield. Breed differences for age at slaughter were significant in all provinces except Alberta and Saskatchewan. There was no breed X sex interaction for any trait in any province.

TABLE 6 - MEAN SQUARES - ANALYSIS OF 1964 DATA FROM FIVE PROVINCES

Source	d.f.	Predicted yield	Age at slaughter	Total fat	Loin area
Provinces	4	44.79**	11228.4**	2.204**	12.111**
Months	11	18.76**	3619.6**	.768**	1.220**
Breeds	2	25.37**	6259.1**	1.637**	.130
Sexes	1	44.77**	32724.5**	117.185**	192.539**
Error	2453	4.68	222.7	.223	.229

** P $<$ .01

TABLE 7 - OVERALL MEANS, DEVIATIONS DUE TO BREED AND SEX, AND STANDARD DEVIATIONS FOR 1964 DATA FROM FIVE PROVINCES

	Predicted yield	Age at slaughter	Total fat	Loin area
Overall mean	77.84	169.65	3.89	4.123
Deviations from mean				
Yorkshires	+ .194	+ 3.92	- .05	+ .015
Lacombes	- .375	- 3.17	+ .10	+ .002
Landrace	+ .181	- .75	- .05	- .017
Males	- .135	- 3.66	+ .22	- .280
Females	+ .135	+ 3.66	- .22	+ .280
Standard deviations	2.16	14.92	.47	.478

TABLE 8 - OVERALL MEANS, DEVIATIONS DUE TO MONTHS AND BREEDS, AND STANDARD DEVIATIONS BY PROVINCE FOR PREDICTED YIELD

	Quebec	Ontario	Manitoba	Saskatchewan	Alberta
Overall mean	77.97	78.40	78.18	77.52	77.69
Deviations from mean					
June - July - August	.40	- .07	- .32	- .36	.21
September	.57	- .26	-1.42	.21	- .60
October	- .52	- .32	.16	.84	.18
November	-1.17	- .36	-1.19	- .03	- .26
December	- .25	.19	.48	.06	.04
January, 1965	- .22	- .70	.24	-2.49	.24
February	-..86	- .19	.39	.22	.47
March	.31	- .19	.00	.63	- .44
April	- .11	.83	.02	.50	.35
May	.30	.80	- .83	.04	.03
June	1.54	.50	1.12	.40	- .04
July - August	-	- .24	1.33	-	- .18
Yorkshires	- .08	.14	- .31	.15	.35
Lacombes	-	- .21	.46	- .30	- .35
Landrace	.08	.07	- .14	.15	-
Standard deviations	2.19	2.02	2.34	2.12	2.05

TABLE 9 - OVERALL MEANS, DEVIATIONS DUE TO MONTHS AND BREEDS AND STANDARD DEVIATIONS BY PROVINCE FOR AGE AT SLAUGHTER

	Quebec	Ontario	Manitoba	Saskatchewan	Alberta
Overall mean	177.1	175.8	159.3	170.5	170.7
Deviations from mean					
June - July - August	-10.1	- 5.7	1.8	- .7	2.3
September	1.5	5.1	6.6	2.0	12.5
October	3.2	5.6	2.1	.9	12.2
November	4.7	4.0	1.5	- 1.4	.3
December	- 4.9	.5	- 8.1	3.8	- 1.9
January, 1965	- 2.5	- 5.1	- 2.9	- 1.6	- 6.1
February	13.3	-10.3	- 2.8	- 4.4	- 4.4
March	4.2	- 1.2	2.6	- 5.0	- 3.9
April	7.2	.7	- 4.1	- 2.4	- 2.8
May	- 8.2	- .4	5.1	4.8	- 5.4
June	- 8.5	- 4.6	- 5.6	3.9	- 5.4
July - August	-	11.2	3.8	-	2.6
Yorkshires	3.4	- .4	6.6	3.3	2.2
Lacombe	-	5.7	-16.9	- 2.9	- 2.2
Landrace	- 3.4	- 5.3	10.3	- .5	-
Standard deviations	14.5	15.1	13.1	13.0	15.2

TABLE 10 - OVERALL MEANS, DEVIATIONS DUE TO MONTHS AND BREEDS AND STANDARD DEVIATIONS BY PROVINCE FOR TOTAL FAT

	Quebec	Ontario	Manitoba	Saskatchewan	Alberta
Overall mean	3.93	3.78	3.85	3.90	3.88
Deviations from mean					
June - July - August	- .20	.02	.04	.03	- .04
September	- .12	.02	.29	- .09	.05
October	.07	.08	- .03	- .22	- .12
November	.29	.08	.22	-..02	.07
December	.09	- .09	- .27	- .04	.02
January, 1965	.03	.17	- .04	.59	- .03
February	.14	.06	.10	- .03	- .14
March	- .06	.03	.01	- .09	.08
April	.08	- .16	- .03	- .07	.04
May	- .05	- .18	.20	.01	- .02
June	- .28	- .05	- .20	- .07	.03
July - August	-	..01	- .29	-	.08
Yorkshires	.03	- .02	.01	- .06	- .08
Lacombes	-	..06	- .09	.09	.08
Landrace	- .03	- .04	.08	- .02	-
Standard deviation	.47	.44	.49	.47	.46

TABLE 11 - OVERALL MEANS, DEVIATIONS DUE TO MONTHS AND BREEDS, AND STANDARD DEVIATIONS BY PROVINCE FOR LOIN AREA

	Quebec	Ontario	Manitoba	Saskatchewan	Alberta
Overall mean	4.31	4.23	4.25	3.95	4.03
Deviations from mean					
June - July - August	- .25	.00	- .12	- .15	.03
September	.08	- .12	- .20	- .10	- .26
October	- .16	- .02	.04	- .01	- .19
November	- .02	- .03	- .21	- .06	.00
December	.07	- .11	- .35	- .07	.07
January, 1965	- .06	- .03	.06	- .14	.08
February	- .19	.04	.49	.06	- .06
March	.04	- .04	.02	.19	- .09
April	.12	.15	- .07	.16	.33
May	.07	.08	- .03	.05	- .03
June	.29	.20	.22	.07	.04
July - August	-	- .12	.14	-	.08
Yorkshires	.03	.05	- .17	- .06	.03
Lacombes	-	.01	.08	.02	- .03
Landrace	- .03	- .06	.10	.04	-
Standard deviations	.52	.47	.51	.42	.43

For litters born in 1965 additional data enabled the computation of per cent ham in the carcass and per cent lean in the ham face. These were included in the analysis along with adjusted age and total fat, loin area, and predicted yield. Data from all provinces were utilized in obtaining the mean squares shown in Table 12.

The manner in which months of completion of test were grouped into quarters may have led to a confounding of age and quarter effects, so another analysis was conducted in which the effects of age at slaughter were removed. The mean squares observed are shown in Table 13. While there was a tendency for differences between quarters to be increased and for the province X quarter interaction to be decreased, the effect of removing age on decreasing province differences was more marked and more consistent.

Unbiased estimates of overall means and of deviations due to breed-sex subclasses on the basis of the first model are shown (Table 14) for adjusted age and for total fat. Unbiased estimates of overall means and of deviations due to breeds and sexes are shown for the other traits in Table 15.

For purposes of the within-province analysis, data from Nova Scotia and New Brunswick were grouped, since each province had small numbers of litters tested and the pigs from both provinces were tested at the same station. Unbiased estimates of overall means and of deviations due to quarter and breed are shown for the various traits, by

TABLE 12 - MEAN SQUARES - ANALYSIS OF 1965 DATA FROM ALL PROVINCES

Source	d.f.	Yield	Adjusted age	Total fat	Loin area	Per Cent ham	Per cent lean in ham face
Provinces	8	81.52**	5064.6**	3.773**	5.752**	46.27**	290.3**
Quarters	3	31.50**	866.1**	1.019**	.291	167.28**	3109.4**
Breeds	2	11.88	37357.6**	.361	.643	51.22**	1137.0**
Sexes	1	11.10	26272.8**	73.545**	145.076**	204.01**	6822.5**
Provinces X Quarters	24	16.33**	896.9**	.806**	2.157**	13.06**	389.8**
Breeds X Sexes	2	11.05	1150.1**	1.018**	.167	.52	77.3
Error	3159	4.69	221.5	.213	.262	1.28	35.8

** $P < .01$

TABLE 13 - MEAN SQUARES - ANALYSIS OF 1965 DATA FROM ALL PROVINCES WITH AGE REMOVED AS AN EFFECT

Source	d.f.	Yield	Total fat	Loin area	Per cent ham	Per cent lean in ham face
Provinces	8	64.63**	3.141**	5.593**	42.31**	240.6**
Quarters	3	36.78**	1.230**	.290**	171.09**	3013.8**
Breeds	2	6.47	.113	1.257**	55.92**	625.3**
Sexes	1	27.37	93.677**	186.575**	226.24**	8132.0**
Age	7	74.79**	3.247**	.741**	6.69**	346.7**
Province X Quarter	24	14.87**	.732**	2.171**	12.97**	370.8**
Error	3154	4.54	.207	.261	1.27	35.1

** $P < .01$

TABLE 14 - OVERALL MEANS, DEVIATIONS DUE TO BREED - SEX SUBCLASSES AND STANDARD DEVIATIONS

	Adjusted age (days)	Total fat (inches)
Overall means	166.6	3.83
Deviations from means		
Yorkshire males	3.6	.18
Yorkshire females	10.0	- .22
Lacombe males	- 8.1	.16
Lacombe females	- 4.0	- .11
Landrace males	- 5.6	.19
Landrace females	4.1	- .20
Standard deviations	14.9	.46

TABLE 15 - OVERALL MEANS, DEVIATIONS DUE TO BREED AND SEX, AND STANDARD DEVIATIONS

	Yield (%)	Loin area (sq.in.)	Per cent ham	Per cent lean in ham face
Overall means	78.09	4.24	25.30	56.29
Deviations from means				
Yorkshires	.08	- .02	- .25	1.21
Lacombes	- .17	- .01	- .01	- .22
Landrace	.09	.03	.25	- .99
Males	.07	- .25	- .30	-1.72
Females	- .07	.25	.30	1.72
Standard deviations	2.17	.51	1.13	5.98

TABLE 16 - OVERALL MEANS, DEVIATIONS DUE TO QUARTER AND BREED, AND STANDARD DEVIATIONS BY PROVINCE FOR PREDICTED YIELD

	P.E.I.	N.S.- N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
Overall means	78.32	78.00	77.92	78.73	78.04	78.78	77.88	77.29
Deviations from means								
Quarter 1	- .07	- .02	.37	.82	.97	- .07	.28	- .07
Quarter 2	.09	.13	.22	.40	.35	.24	.01	.26
Quarter 3	- .30	- .25	.08	- .66	-1.05	- .70	- .54	.33
Quarter 4	.28	.14	- .67	- .56	- .27	.53	.25	- .52
Yorkshire	- .64	- .21	.03	.43	- .11	- .06	.17	- .02
Lacombe	.35	- .18	- .04	- .31	- .13	.14	- .17	- .27
Landrace	.28	.39	.07	- .12	.24	- .07	-	.29
Standard deviations	2.37	1.86	2.15	2.11	2.11	2.20	2.30	2.03

TABLE 17 - OVERALL MEANS, DEVIATIONS DUE TO QUARTER AND BREED AND STANDARD DEVIATIONS BY PROVINCE FOR ADJUSTED AGE

	P.E.I.	N.S.- N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
Overall means	162.3	166.8	165.0	172.5	163.6	170.4	167.7	168.7
Deviations from means								
Quarter 1	1.7	3.8	3.8	4.6	4.7	- 1.4	- 2.3	- 2.8
Quarter 2	2.8	- 1.9	-2.4	.3	2.2	- 1.6	- 3.4	2.0
Quarter 3	- 1.0	- 1.5	.8	- 2.3	- 4.4	4.0	2.7	6.3
Quarter 4	- 3.4	- .3	-2.2	- 2.6	- 2.5	- 1.1	2.9	- 5.4
Yorkshire	4.1	6.8	5.0	7.7	10.0	5.6	4.5	11.6
Lacombe	- 4.9	- 6.2	- 3.2	- 6.7	-11.7	- 4.1	- 4.5	- 3.2
Landrace	.8	- .6	- 1.8	- 1.0	1.6	- 1.5	-	- 8.4
Standard deviations	15.8	13.0	13.4	17.7	13.6	14.3	12.9	12.2

TABLE 18 - OVERALL MEANS, DEVIATIONS DUE TO QUARTER AND BREED, AND STANDARD DEVIATIONS BY PROVINCE FOR TOTAL FAT

	P.E.I.	N.S.- N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
Overall means	3.79	3.77	3.85	3.69	3.78	3.70	3.85	4.07
Deviations from means								
Quarter 1	-.02	.02	-.05	-.17	-.18	.00	-.08	.00
Quarter 2	-.06	-.06	-.01	-.05	-.17	.05	.03	.06
Quarter 3	.06	.09	-.01	.14	.19	.09	.09	-.06
Quarter 4	.02	-.05	.08	.08	.16	-.14	-.03	-.01
Yorkshires	.06	.12	.10	-.05	.03	-.01	-.06	-.12
Lacombe	-.04	-.08	-.15	-.01	.10	-.05	.06	.07
Landrace	-.01	-.05	.06	.06	-.13	.07	-	.05
Standard deviations	.47	.42	.45	.45	.45	.46	.52	.44

TABLE 19 - OVERALL MEANS, DEVIATIONS DUE TO QUARTER AND BREED, AND STANDARD DEVIATIONS BY PROVINCE FOR LOIN AREA

	P.E.I.	N.S.- N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
Overall means	4.44	4.22	4.27	4.26	4.27	4.09	4.02	3.98
Deviations from means								
Quarter 1	-.07	-.05	-.29	.06	.02	.17	.12	.10
Quarter 2	.13	-.10	.12	-.06	-.08	.09	.05	.25
Quarter 3	.04	.25	.07	-.07	-.09	-.35	-.15	.10
Quarter 4	-.11	-.09	.10	.07	.15	.09	-.03	-.45
Yorkshire	-.29	-.06	.19	.10	-.11	-.02	-.02	-.30
Lacombe	.02	-.11	-.19	-.12	.09	-.06	.02	.27
Landrace	.27	.18	.01	.02	.02	.08	-	.03
Standard deviations	.59	.51	.52	.49	.50	.50	.48	.42

TABLE 20 - OVERALL MEANS, DEVIATIONS DUE TO QUARTER AND BREED, AND STANDARD DEVIATIONS BY PROVINCE FOR PER CENT HAM

	P.E.I.	N.S.- N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
Overall means	25.06	24.90	25.78	25.81	24.63	25.85	25.08	25.36
Deviations from means								
Quarter 1	.16	- .05	.46	.07	.00	- .57	- .27	- .36
Quarter 2	.45	1.12	.55	.99	.21	1.09	1.47	1.29
Quarter 3	- .75	- .67	- .77	- .27	- .15	- .11	- .84	- .14
Quarter 4	.15	- .40	- .24	- .78	- .06	- .41	- .36	- .78
Yorkshire	.04	- .05	- .33	- .18	.07	- .50	- .13	- .44
Lacombe	- .16	- .18	.21	- .21	.48	.07	.13	- .13
Landrace	.11	.24	.12	.39	- .55	.43	-	.58
Standard deviations	1.35	1.16	1.21	1.08	1.16	1.13	1.00	.88

TABLE 21 - OVERALL MEANS, DEVIATIONS DUE TO QUARTER AND BREED, AND STANDARD DEVIATIONS BY PROVINCE FOR PER CENT LEAN IN HAM FACE

	P.E.I.	N.S.- N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
Overall means	55.75	56.87	54.35	57.07	58.00	56.21	57.46	55.39
Deviation from means								
Quarter 1	-1.36	.92	.94	2.10	3.79	1.02	1.12	.21
Quarter 2	-3.20	-4.34	-2.63	-3.35	-2.22	-3.46	-7.07	-4.54
Quarter 3	1.50	1.24	4.02	- .31	-2.09	-1.61	2.57	3.31
Quarter 4	3.06	2.18	-2.33	1.56	.52	4.05	3.37	1.02
Yorkshire	-1.91	.61	2.33	2.15	- .28	1.75	.17	1.82
Lacomber	1.89	.06	-2.44	-1.86	-1.71	-1.38	- .17	- .98
Landrace	.02	- .67	.11	- .29	1.99	- .37	-	- .84
Standard deviations	6.17	5.75	6.60	5.78	5.53	6.11	6.03	4.96

TABLE 22 - SIGNIFICANT QUARTER AND BREED EFFECTS

Trait	Effect	P.E.I.	N.S.- N.B.	Que.	Ont.	Man.	Sask.	Alta.	B.C.
Yield	Quarter	n.s.	n.s.	n.s.	**	**	**	n.s.	n.s.
	Breed	n.s.	n.s.	**	**	**	**	**	**
Age	Quarter	n.s.	n.s.	**	**	n.s.	**	**	n.s.
	Breed	n.s.	**	**	**	**	**	**	**
Total fat	Quarter	n.s.	n.s.	n.s.	**	**	**	n.s.	n.s.
	Breed	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Loin area	Quarter	n.s.	**	**	**	**	**	**	**
	Breed	**	**	**	**	n.s.	n.s.	n.s.	**
Per cent ham	Quarter	**	**	**	**	n.s.	**	**	**
	Breed	n.s.	n.s.	**	**	**	**	**	**
Per cent lean	Quarter	**	**	**	**	**	**	**	**
	Breed	n.s.	n.s.	**	**	n.s.	**	n.s.	n.s.

** P $<$ .01
n.s. P $>$ .01

TABLE 23 - MEANS, BY PROVINCES, FOR LIVE WEIGHT AT SLAUGHTER, CARCASS WEIGHT, AGE AT SLAUGHTER, AND DAYS ON TEST, FOR 1965 YORKSHIRES[1]

Province	Live wt. (lb.)	Warm carcass wt. (lb.)	Age at slaughter	Days on test
P.E.I.	197.7	153.9	166.0	97.6
N.S.	196.2	152.7	171.8	102.0
N.B.	195.5	152.8	171.4	96.1
Que.	195.3	155.3	170.7	95.3
Ont.	191.3	151.0	174.6	104.3
Man.	189.0	149.5	166.5	95.9
Sask.	193.7	149.9	170.4	100.1
Alta.	194.5	152.5	168.5	95.0
B.C.	194.4	153.4	182.2	102.2

[1] Means are quoted from Fredeen (18), and were computed for Station tested pigs marketed in Quarters 3 and 4 of 1965 and Quarters 1 and 2 of 1966 only.

TABLE 24 - MEAN SQUARES FOR VARIOUS TRAITS WITH PROVINCE, SEX, AGE, AND CARCASS WEIGHT EFFECTS REMOVED[1]

Source	d.f.	Yield	Total fat	Loin area	Per cent ham	Per cent lean in ham face
Province	8	52.46**	1.354**	5.333**	30.66**	200.6**
Sex	1	17.26**	60.210**	133.560**	152.62**	4565.8**
Age	11	29.15**	1.534**	.450	2.61	231.0**
Regression on carcass wt.	1	1099.09**	55.422**	23.715**	92.58**	426.5**
Error	1978	4.92	.219	.278	1.57	46.0

** P < .01

1 For 1965 Yorkshires only.

TABLE 25 - REGRESSION COEFFICIENTS AND THEIR STANDARD ERRORS FOR VARIOUS TRAITS ON CARCASS WEIGHT [1]

Trait		Regression coefficient	Standard error
Predicted yield	(%/lb.)	- .120	.008
Total fat	(in./lb.)	.0270	.0017
Loin area	(sq. in./lb.)	.0177	.0019
Per cent ham	(%/lb.)	- .0349	.0045
Per cent lean in ham	(%/lb.)	- .0749	.0246

[1] For 1965 Yorkshires only.

provinces, in Tables 16 to 21, inclusive. Significance of these effects is indicated in Table 22.

In order to help elucidate province differences, provinical means for live weight at slaughter, carcass weight, age at slaughter, and days on test are shown in Table 23 for Yorkshire pigs. The mean squares observed for the removal of regression on carcass weight, along with province, sex, and age effects, are shown in Table 24.

Observed regression coefficients with their standard errors, for the regression of several carcass traits on carcass weight are shown in Table 25.

DISCUSSION

1. Month and Quarter Effects

Month and quarter effects were significant for most traits, both on an overall basis and within provinces, but there were no apparent patterns or trends for these effects except for per cent ham in the carcass and per cent lean in the ham face. Since some consistency would have been expected for all traits if these differences were reflections of physiological differences due to seasons, as suggested by Fredeen and Jonsson (20), it can only be concluded that the major portion of the variance removed by quarters is due to some other source. The most cogent hypothesis is that the observed month (quarter) deviations are a reflection of the particular sires, dams, and herds whose litters completed the test during that time. Further evidence for a non environmental cause comes from the lack of agreement in quarter deviations for Alberta and British Columbia, since British Columbia pigs were tested at the Alberta stations.

However, pigs from litters completing tests in quarter 2 consistently had more ham than average while those from quarters 3 and 4 had less. Pigs from quarter 2 also had consistently smaller proportions of lean in the ham face. These differences may very well have been, for the most part, due to environmental influences.

Whatever the cause for the quarter effects in these two traits might have been, its impact on the selection of breeding stock is small. Per cent ham and per cent lean in the ham play a relatively minor role in the calculation of predicted yield, and this calculation can only be applied in selecting relatives. Months and quarters therefore appear to be relatively unimportant in the selection of breeding stock and no serious error should result if they are ignored.

2. Differences Between Provinces

Differences between provinces were statistically significant for all traits in both years. Unbiased estimates of province means showed substantial differences for most traits, with the largest differences occurring in age at slaughter. However, when the latter was adjusted to a constant 155 pound carcass weight, as was done with 1965 data, the between-province differences were diminished. This is not unexpected in the light of data shown in Table 23.

Indeed, it has been shown (15, 37, 40) that weight influences traits other than age at slaughter and one might expect that removing the effect of carcass weight might reduce differences between provinces for the other traits as well.

While Table 24 does show a further reduction of the mean squares for provinces when the effect of carcass weight was removed, as compared with just removing age effects (Table 13), this result is not conclusive since the mean squares in Table 24 were for the Yorkshire breed only, while those in Table 13 included all three breeds. Rahnefeld (40) has reported that the regression coefficient for back fat on weight differed for Yorkshires and Lacombe pigs, and since this may also apply to other traits, it was considered necessary to confine the last analysis to one breed.

Even after removing the effects of carcass weight, province differences in age at slaughter remained (Table 17). From the differences in number of days on test (Table 23), Fredeen (18) concluded that a substantial proportion of the difference between provinces in age resulted from differences in growth rate at the station. While differences in environment, leading to differences in growth rate, are suggested, they would have had to affect the breeds differently if they were a major factor. Furthermore, province differences for the other traits remained after removal of effects of both carcass weight and age (Table 24). If these differences were environmental in origin, they were effected independently of growth rate. A more plausible explanation would appear to be that province differences actually reflect differences in average genetic merit of the pigs tested in the various provinces. This does not deny the fact that there is some difference in environment and management between stations -- it merely affirms that, in light of the considerable variation between breeds from province to province, genetic differences are indicated as the major source of province differences.

3. Sex Differences

The sexes differed in growth rate and in all carcass traits (Tables 7, 14, and 15). Least squares estimates of sex differences for the two years were in substantial agreement with each other and with the R.O.P. sex corrections, although, departures from the latter were sufficient to result in small sex differences in predicted yield. This would not be expected to have any appreciable effect on the relative ranking of a litter test group which was unbalanced for sex. However, this is not true of age at slaughter. The estimated difference of 6.4 days in age between Yorkshire males and females (Table 14) would result in an index (17) of 2.3 higher for a test group of four barrows compared with a sex balanced group, and an equivalent amount lower if the test group consisted of four gilts. While this is not a great difference, it can easily be corrected for and it is proposed that age be adjusted for sex before it is used in computation of a selection index.

4. Breed Differences

Significant differences between breeds were indicated for several traits. Among the more notable differences in the 1965 data is the greater uniformity between sexes in the Lacombe breed in both total fat and growth rate. The indication is that one sex correction should be used for Yorkshire and Landrace pigs and another for Lacombe pigs.

While other differences might be indicated on an overall basis, it is more informative to consider breed differences on a province to province basis. Yorkshires were the slowest growing pigs in all provinces. Lacombes grew fastest except in British Columbia where Landrace were superior. The mean adjusted age of Lacombes varied from 151.9 days in Manitoba to 166.3 days in Saskatchewan, while for the Yorkshires it ranged from 166.4 in Prince Edward Island to 180.2 in Ontario and 180.3 in British Columbia. For Landrace, the range was 160.3 in British Columbia to 171.5 in Ontario.

Similar comparisons could be made for other traits if one had a specific purpose for comparing breeds. In the present case breed differences would not be important in selecting breeding stock, since purebred swine are being dealt with and selection would have to be done within breeds.

5. Effects of Carcass Weight

The present R.O.P. policy (8) requires that no pig being station tested be kept past an age of 200 days and also that the fourth pig of a test group be marketed at the same time as the third one. These restrictions, plus the tendency of stations to market pigs at varying weights (Table 23), introduced considerable variation into carcass weight.

The importance of adjusting age to a constant weight is self-evident in the light of this policy. As for the carcass traits, the importance of carcass weight is obvious from Table 24. Since carcass merit is being assessed on the basis of predicted yield, there is no need for adjusting individual carcass traits because the yield predicting equation presumably can estimate the yield as accurately for a carcass which is above or below the standard weight as it can for those at the standard weight. However, Table 25 shows that for an increase in 10 lb. of carcass weight the predicted yield decreases by 1.20 per cent. This is the result of pigs putting on more fat in the latter stages of growth (15, 37, 40) and acts to the disadvantage of heavier carcasses. Since an average difference of 10 lb. in a test group's carcass weight would affect its index on the basis of yield by 3.4, it would seem justifiable to adjust predicted yield to a standard carcass weight before using it in the computation of an index. The regression coefficient listed in Table 25 should be well suited for this purpose.

C. Heritability and Genetic Correlation Analysis

Only data from 1965 Yorkshires were utilized for these analyses. Values for all traits were adjusted to a standard carcass weight of 155 pounds by use of the R.O.P. procedure for age and the regression coefficients (Table 25) for other traits. Per cent ham in the carcass and per cent lean in the ham face were also adjusted for quarter effects (Table 16). Observed mean squares, their expected composition, and the variance components are given in Tables 26 to 28.

Heritability estimates, computed on the basis of 16/5 times the sire component to take into account relationship between dams mated to a particular sire (15), are shown in Table 29. Genetic correlations are given in Table 30 and phenotypic correlations in Table 31.

DISCUSSION

1. Heritability Estimates

The estimates obtained for heritability of age at slaughter are in substantial agreement with the value of 0.546 reported by Fredeen (15). However, his estimates for individual fat measurements, ranging from 0.376 to 0.476, are substantially below the values for total fat reported here. King (29) obtained an estimate of 0.464 for the average of three fat measurements and Fredeen and Jonsson (20) obtained values of $0.516 \pm .115$ for males and $0.576 \pm .115$ for females. Smith and Ross (45) reported the heritability of backfat thickness in British Landrace as 0.74 and that

TABLE 26 - MEAN SQUARES FOR HERITABILITY ANALYSIS

Source	d.f.	Age	Yield	Total fat	Loin area	Per cent ham	Per cent lean in ham face
Yorkshire barrows							
Provinces	8	2424.4	51.62	1.328	3.454	53.29	266.4
Sires within provinces	249	443.7	10.22	.457	.559	12.31	104.2
Dams within sires	226	285.2	4.91	.256	.222	5.77	42.7
Within litters	541	158.2	2.77	.134	.129	.94	20.3
Yorkshire gilts							
Provinces	8	2374.0	29.49	.786	2.536	41.83	336.4
Sires within provinces	245	436.1	10.24	.419	.655	10.90	109.8
Dams within sires	216	291.2	5.10	.208	.291	5.24	49.8
Within litters	505	138.6	2.53	.109	.136	.84	19.8

TABLE 27 - EXPECTED COMPOSITION OF MEAN SQUARES

Provinces	$\sigma_w^2 + k_4 \sigma_d^2 + k_5 \sigma_s^2 + k_6 \sigma_p^2$
Sires within provinces	$\sigma_w^2 + k_2 \sigma_d^2 + k_3 \sigma_s^2$
Dams within sires	$\sigma_w^2 + k_1 \sigma_d^2$
Within litters	σ_w^2

For barrows		For gilts	
k_1	= 2.04	k_1	= 2.01
k_2	= 2.18	k_2	= 2.12
k_3	= 3.91	k_3	= 3.77
k_4	= 2.33	k_4	= 2.31
k_5	= 5.76	k_5	= 5.58
k_6	= 104.96	k_6	= 100.90

TABLE 28 - VARIANCE COMPONENTS FOR HERITABILITY ANALYSIS

Source	Age	Yield	Total fat	Loin area	Per cent ham	Per cent lean in ham face
Yorkshire barrows						
Provinces	18.10	.370	.0073	.0260	.359	1.26
Sires	38.30	1.322	.0493	.0846	1.588	15.34
Dams	62.29	1.046	.0597	.0458	2.369	10.99
Within litters	158.17	2.772	.1342	.1289	.943	20.26
Yorkshire gilts						
Provinces	18.42	.165	.0026	.0168	.277	1.94
Sires	36.14	1.325	.0546	.0940	1.435	15.45
Dams	75.91	1.280	.0492	.0774	2.191	14.93
Within litters	138.58	2.527	.1089	.1355	.840	19.82

TABLE 29 - HERITABILITY ESTIMATES AND THEIR STANDARD ERRORS

	Barrows	Gilts
Age	.474 ± .155	.461 ± .167
Yield	.823 ± .166	.826 ± .175
Total fat	.649 ± .163	.821 ± .173
Loin area	1.044 ± .173	.980 ± .183
Per cent ham	1.037 ± .208	1.028 ± .213
Per cent lean in ham	1.054 ± .181	.985 ± .188

TABLE 30 - GENETIC CORRELATIONS AND THEIR STANDARD ERRORS (ABOVE DIAGONAL FOR BARROWS, BELOW DIAGONAL FOR GILTS)

	1	2	3	4	5	6
1. Age	--	-.070±.174	.080±.192	.015±.165	-.208±.181	.218±.164
2. Yield	-.254±.141	--	-.934±.037	.843±.084	.080±.129	.841±.106
3. Total fat	.229±.138	-.935±.033	--	-.742±.131	.113±.146	-.845±.141
4. Loin area	-.245±.157	.802±.063	-.683±.096	--	.069±.124	.669±.113
5. Per cent ham	-.380±.191	.426±.144	-.409±.145	.173±.133	--	-.026±.131
6. Per cent lean in ham face	.104±.170	.719±.096	-.648±.123	.600±.118	.129±.139	--

TABLE 31 - PHENOTYPIC CORRELATIONS (ABOVE DIAGONAL FOR BARROWS, BELOW DIAGONAL FOR GILTS)

	1	2	3	4	5	6
1. Age	--	.100	-.136	-.006	-.025	.128
2. Yield	.176	--	-.868	.660	.288	.695
3. Total fat	-.176	-.876	--	-.414	-.147	-.520
4. Loin area	.090	.675	-.464	--	.154	.480
5. Per cent ham	-.005	.337	-.247	.179	--	.023
6. Per cent lean in ham face	.168	.690	-.511	.461	.036	--

of Large Whites as 0.66, while Stockhausen and Boylan (48) obtained a value of 0.11$\pm$ .04 for Managra.

The values obtained for total fat in the present study seem somewhat high, in spite of the variability in the estimates obtained by other workers. The values obtained for loin area, per cent ham, and per cent lean in the ham face are even higher and quite unrealistic. A clue about the origin of these high estimates is contained in the relative sizes of the sire, dam, and within litter components of variance. Contrary to expectations, the sire component was actually larger than the dam component for loin area and per cent lean in the ham face, and for per cent ham the sire component was even larger than the within litter component.

While a portion of this preponderance of the sire effect might be attributable to a closer relationship, on the average, between dams mated to a particular sire than the half sib estimate of Fredeen (15), this would have accounted for a small portion at best. Another explanation could result from units smaller than provinces which differ in average genetic merit, but within which the pigs are relatively uniform. The difference between such units would be reflected in the sire component while the relative uniformity within each would contribute to the relatively small dam and within litter components. A unit might consist of an entire province, a portion of one or more provinces, or an individual herd. Such units represent strains of pigs which differ in average genetic merit for a particular trait.

While this explanation does not afford a precise evaluation of heritabilities when the strain effects are excluded, the indication is that they would be relatively large. Selection for these traits would therefore be feasible and effective.

2. Genetic and Phenotypic Correlations

Interpretation of these correlations is not aided by the postulated existence of strains. If one or more strains were superior or inferior for several traits, the observed genotypic and phenotypic correlations between these traits would be augmented, while if some strains were superior in one trait and inferior in another the correlations would be reduced. The resultant degree of distortion would be determined by the deviation of the correlations within strains from those of the overall population and by the extent to which the pigs in the population fell into the various strains.

On the average, selection for low total fat, large loin area, or a large proportion of lean in the ham face would all bring about a marked improvement in predicted yield -- a result which is not unexpected since the former are used in the computation of the latter. Selection for minimal backfat would tend to increase loin area and the proportion of lean in the ham face, but the correlated response would be greater in barrows than in gilts. The tendency to also increase the per cent ham would, on the other hand, be confined to gilts.

Selection for rapid growth would not be expected to have much effect on the other traits. This result may be due to the *ad libitum* feeding policy, since rapid growth could reflect either very efficient feed utilization or an increased feed capacity and the correlations for the two situations might be quite different. On the basis of the available data, however, the selection for rapid growth should be accompanied by simultaneous selection for one or more other traits.

RECOMMENDATIONS FOR A CENTRAL BREEDING STATION

Recommendations in this section are based on the author's interpretation of the results obtained by other workers as well as those reported here. The recommendations and suggestions were formulated specifically for the organization and operation of a central swine breeding station, but many would be equally applicable to the evaluation of R.O.P. swine.

A. Selection of Initial Breeding Stock

Since the index method of selection has been shown to be most efficient (24, 27, 52), the procedure originally contemplated would have been based on an index computed from values appropriately adjusted for environmental effects. The hypothesis of strains of pigs differing in specific characters has resulted in a revision of this procedure. It is recommended that animals be selected for their superiority in one or more of the following traits: total back fat, loin area, per cent ham, or per cent lean in the ham face, the selection being made on the basis of the performance of littermates or progenies. In each case the litter's performance in other traits, especially age and feed efficiency, should be considered along with the performance of other litters from the same boar.

For each of the traits only a few outstanding sows and a boar would be required since there should be little or no selection for one or more generations so that gene recombination might occur.

B. Subsequent Selection Procedure

The first question that must be resolved is whether to use individual selection, sib selection, or progeny testing. Smith (43) has recommended that progeny testing in Britain be replaced by performance testing because this would allow more intensive selection and a greater rate of improvement from the same testing facilities. Fredeen (15) has also pointed out that progeny testing in swine is inappropriate because the reproductive rate is rapid and the heritabilities of the major performance traits are high. He favored sib selection. However, in a selection experiment with pigs, Minkema *et al*. (38) found individual selection to be 1.9 times as effective as sib selection in spite of the inaccuracies of ultrasonics and other methods of evaluating the live animal.

In addition, it was observed in the present study that, with the exception of per cent ham in the carcass, the within litter variance accounted for from 39 to 57 per cent of the total variance. Fredeen (15) found within litter variance accounting for as much as 70 per cent of the total. With this degree of variation within litters, the use of sib selection has no place for any trait which can be evaluated even crudely on the live animal. The case for performance testing and individual selection is clear.

Another question which arises is whether feed intake should be *ad libitum* or restricted. The former has been used widely on the assumption that pigs with an inherent tendency to fatten rapidly could be identified and eliminated. At best, the method aids in the identification of the worst animals, not the best. The use of restricted feeding in conjunction with performance testing has been advocated by Plank and Berg (39) and by Hale and Coey (22). By selecting for rapid growth on restricted feed intake selection is automatically also being carried out for efficiency of feed utilization. Since the caloric content of stored fat is much higher than that of lean tissue, one might also expect the faster growing pigs on limited feed to be relatively leaner. The procedure of Hale and Coey (22) of feeding pigs *ad libitum* to 130 pounds liveweight and restricting feed intake to 5 pounds per day thereafter seems suitable.

The heritability of litter size in swine has been shown to be very low (35, 48) and improving this trait by selection is therefore not feasible. Since it is an important trait, the solution is to not permit it to deteriorate in the first place. This can be accomplished by imposing an independent culling level on fertility and litter size. It is therefore suggested that gilts be selected for growth rate with an independent culling level on fertility and that all pigs from small litters also be culled.

Selection differentials for boars would be substantially greater than for gilts. It is proposed that one boar be selected for every five gilts and that selection be based on a combination of growth rate and live backfat probes. The way in which these should be combined for maximum genetic gain is unknown at present since the limited equalized feed intake would impose a completely different environment from that of the pigs studied here. Variances, too, would not only be different but might also change rapidly in the first few generations. An index is therefore impractical until some parameters of the population become known and independent culling levels will have to be resorted to initially.

In order to find out more about the population it is suggested that, at least initially, two boars be chosen at random from each litter for slaughter at market weight. Complete R.O.P. carcass data for each would not only yield more data for further selection of boars, but would also permit evaluation of both genetic and phenotypic correlations between traits under station conditions. It may well prove feasible on the basis of those correlations to base selection solely on growth rate, with an independent culling level for fertility.

C. Station Design

The only aspects of station design which are important from the selection point of view are that provision be made for environmental control and for individual limited feeding of pigs over 130 pounds.

Environmental control is stressed only because variations in environment might introduce biases which could have an adverse effect on the rate of genetic improvement. By providing a windowless building which is fully air conditioned to maintain a steady uniform temperature throughout the year and in which the length of day is controlled, seasonal effects would be greatly reduced if not eliminated. Pigs which are superior in such an environment must of necessity be genetically superior since the environmental contribution would be a constant. Selection under these conditions would therefore result in a maximum rate of genetic improvement.

In making these recommendations, it is realized that genotype X environment interactions have been demonstrated. It is however considered improbable that such an interaction would be deleterious to the selection procedures outlined since the controlled environment suggested for the station would not be extreme but would rather be somewhere near the mean of the variable environment encountered in commercial production. It is also expected that any special adaptation to the station environment will be more than offset by the greater rate of improvement resulting from a reduced environmental augmentation of performance, and that such adaptation would be limited by periodic introduction of new stock -- a necessary step with intense selection in a finite population.

REFERENCES

1. Anderson, R.L. and Bancroft, T.A. 1952. Statistical theory in research. McGraw-Hill Book Company, Inc., Toronto.

2. Bell, J.M. 1964. A study of rates of growth of Yorkshire, Lacombe, Landrace, and crossbred pigs from birth to 200 lb. Can. J. Animal Sci. 44, 315-319.

3. Bell, J.M. 1964. Nutrient requirements for Canadian Yorkshire swine. IV. A study of the lysine, tryptophan, riboflavin, and pantothenic acid requirements of pigs weighing 50 to 100 pounds. Can. J. Animal Sci. 44, 106-113.

4. Bell, J.M. 1965. Nutrient requirements for Canadian Yorkshire swine. V. A study of the lysine and protein requirements of finishing pigs weighing from 100 to 200 lb. Can. J. Animal Sci. 45, 105-110.

5. Biswas, D.K., Hurt, P.V., Chapman, A.B., First, N.L., and Self, H.L. 1966. Feed efficiency and carcass desirability in swine. J. Animal Sci. 25, 342-347.

6. Bogart, Ralph. 1959. Improvement of livestock. The Macmillan Company, New York.

7. Canada Department of Agriculture. 1954. Record of performance of swine. Ottawa, Canada.

8. Canada Department of Agriculture. 1967. Record of performance for swine. Ottawa, Canada.

9. Carroll, W.E., Krider, J.L., and Andrews, F.N. 1962. Swine production, 3rd ed. McGraw-Hill Book Company, New York, N.Y.

10. Charette, L. A. 1961. The effects of sex and age of male at castration on growth and carcass quality of Yorkshire swine. Can. J. Animal Sci. 41, 30-39.

11. De Pape, J. G. and Whatley, J.A. Jr. 1956. Live hog probes at various sites, weights, and ages as indicators of carcass merit. J. Animal Sci. 15, 1029-1035.

12. Dickerson, Gordon E. 1960. Techniques and procedures in animal production research. 57-105. Techniques for research in quantitative animal genetics. American Society of Animal Science.

13. Falconer, D.S. 1954. Validity of the theory of genetic correlation. J. Heredity 45, 42-44.

14. Falconer, D.S. 1961. Introduction to quantitative genetics. Oliver and Boyd, Edinburgh.

15. Fredeen, H.T. 1953. Genetic aspects of Canadian bacon production. Can. Dept. Agr. Publ. 889.

16. Fredeen, H.T. 1965. Litter size and sex balance as criteria of eligibility for progeny or sib testing of pigs. Can. J. Animal Sci. 45, 85-90.

17. Fredeen, H.T. 1966. Changes in R.O.P. (swine) carcass evaluation - 1965. 45th Ann. Feeders' Day Report, University of Alberta, Edmonton.

18. Fredeen, H.T. Personal communication.

19. Fredeen, H.T., Berg, R.T., Bowland, J.P., and Doornenbal, H. 1964. Prediction of yield and value of hog carcasses. Can. J. Animal Sci. 44, 334-346.

20. Fredeen, H.T. and Jonsson, Per. 1957. Genic variance and covariance in Danish Landrace swine as evaluated under a system of individual feeding of progeny test groups. Z. Tierz. Zucht Biol. 70, 348-363.

21. Friend, D.W., Cunningham, H.M., and Nicholson, J.W.B. 1963. The feeding value of dried potato pulp for pigs. Can. J. Animal Sci. 43, 241-251.

22. Hale, R.W. and Coey, W.E. 1963. Genotype - environment interactions in a herd of bacon pigs. J. Agricultural Sci. 61, 81-88.

23. Harvey, Walter R. 1960. Least squares analysis of data with unequal subclass numbers. USDA ARS 20-8.

24. Hazel, L.N. 1943. The genetic basis for constructing selection indexes. Genetics 28, 476-490.

25. Hazel, L.N. and Kline, A.E. 1952. Mechanical measurements of fatness and carcass value of live hogs. J. Animal Sci. 11, 313-318.

26. Hazel, L.N. and Kline, A.E. 1953. Accuracy of eight sites for probing live pigs to measure fatness and leanness. J. Animal Sci. 12, 894 (abs.).

27. Hazel, L.N. and Lush, J.L. 1942. The efficiency of three methods of selection. J. Heredity 33, 393-399.

28. Hutt, F.B. 1964. Animal genetics. The Ronald Press Company, New York, N. Y.

29. King, J.W.B. 1957. The heritability of carcass traits in British bacon pigs. Proc. British Soc. Animal Prod. 49-69.

30. Lerner, I. Michael. 1958. The genetic basis of selection. John Wiley and Sons, Inc. New York, N.Y.

31. Lerner, I.M. and Donald, H.P. 1966. Modern developments in animal breeding. Academic Press, New York, N.Y.

32. Lucas, I.A.M. and Calder, A.F.C. 1956. The response of different types of pigs to varying levels of feeding from weaning to bacon weight, with particular reference to carcass quality. J. Agric. Sci. 47, 287-323.

33. Lush, J.L. 1940. Intra-sire correlations or regressions of offspring on dam as a method of estimating heritability of characteristics. Amer. Soc. Animal Prod. Proc. 33, 293-301.

34. Lush, J.L. 1949. Heritability of quantitative characters in farm animals. Proc. 8th Intern. Congr. Genet. 356-375.

35. Lush, J.L. and Molln, A.E. 1942. Litter size and weight as permanent characteristics of sows. U.S.D.A. Tech. Bull. 836.

36. Magee, W.T. 1962. Relationship between daily feed consumption and feed efficiency. J. Animal Sci. 21, 880-882.

37. McMeekan, C.P. 1940. Growth and development in the pig with special reference to carcass quality characters. J. Agricultural Sci. 30, 276-569.

38. Minkema, D., Bekedam, M., Kroeske, D., and Stegenga, T. 1964. A selection experiment with pigs: Comparison of the effectiveness of individual selection and sib selection. Neth. J. Agric. Sci. 12, 318-329.

39. Plank, R.N. and Berg, R.T. 1963. Inheritance and plane of nutrition in swine. I. Effects of season, plane of nutrition, sex, and sire on feedlot performance and carcass characteristics. Can. J. Animal Sci. 43, 72-85.

40. Rahnefeld, G.W. 1965. Breed and sex effects on the relationship between weight and fatness in Lacombe and Yorkshire swine and their reciprocal crosses. Can. J. Animal Sci. 45, 33-36.

41. Rahnefeld, G.W., Boylan, W.J., and Comstock, R.E. 1962 Genetic correlation between growth rate and litter size in mice. Can. J. Genet. Cytol. 4, 289-295.

42. Rahnefeld, G.W., Boylan, W.J., Comstock, R.E., and Singh, M. 1963. Mass selection for post-weaning growth in mice. Genetics 48, 1567-1583.

43. Smith, C. 1965. Results of pig progeny testing in Great Britain. Animal Prod. 7, 133-140.

44. Smith, C., King, J.W.B., and Gilbert, N. 1962. Genetic parameters of British Large White bacon pigs. Animal Prod. 4, 128-143.

45. Smith, C. and Ross, G.J.S. 1965. Genetic parameters of British Landrace bacon pigs. Animal Prod. 7, 291-301.

46. Smith, H. Fairfield. 1936. A discriminant function for plant selection. Annals of Eugenics,7, 240-252.

47. Steel, Robert G.D. and Torrie, James H. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Toronto.

48. Stockhausen, C.W.F. and Boylan, W.J. 1966. Heritability and genetic correlation estimates in a new breed of swine. Can. J. Animal Sci. 46, 211-216.

49. Stothart, J.G. 1937. Analysis of swine progeny records. Dom. Dept. of Agr. (Canada) Pub. 550 Tech Bul. No. 6.

50. Stothart, J.G. 1947. A study of parental-progeny correlations with Canadian bacon hogs. Sci. Agr. 27, 354-363.

51. Wright, S. 1921. Systems of mating. I. The biometric relations between parent and offspring. Genetics 6, 111-123.

52. Young, S.S.Y. 1961. A further examination of the relative efficiency of three methods of selection for genetic gains under less restricted conditions. Genet. Res. 2, 106-121.