THE INHERITANCE OF SOME PERFORMANCE AND CARCASS TRAITS IN SWINE

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ABSTRACT

Heritability and genetic correlations among a number of important economic traits were estimated from data obtained on a new breed of swine called Managra and developed at the University of Manitoba. The data were from pigs which were born during nineteen farrowing periods starting in 1959 and ending in 1965. Analyses of data were limited to those animals which were slaughtered for carcass evaluation.

Genetic parameters were estimated by analysis of variance and covariance from the data adjusted for sex and carcass weight differences.

The traits studied and their heritability estimates were: birth weight, .10; weaning weight, .03; post-weaning average daily gain, .33; carcass length, .50; "longissimus dorsi" muscle area, .56; live backfat probe, .13 and mean carcass backfat thickness, .35.

The genetic correlations among the above-mentioned traits with three exceptions were favorable to simultaneous selection. The exceptions were: weaning weight and mean carcass backfat (.83), post-weaning average daily gain and carcass length (-.09) and post-weaning average daily gain and mean carcass backfat (.23). The magnitude of all the genetic correlations were higher in general than those which have been reported in the literature.

The effect of hot carcass weight on carcass trait measurements was estimated by linear regression. Analyses of the data showed that for every ten pounds increase in hot carcass weight carcass length increased .25 inches, mean carcass backfat thickness increased .068 inches and "longissimus dorsi" muscle area increased .16 square inches.

Significant differences (gilts minus barrows) were found in the following traits: birth weight (-.16 pounds), post-weaning average daily gain (-.03 pounds/day), live probe backfat (-.03 inches), carcass length (.45 inches), mean carcass backfat thickness (-.09 inches) and "longissimus dorsi" muscle area (.37 square inches). Sex effects for weaning weight was small and not significantly different from zero ($P > .05$).

Phenotypic correlations were computed among all of the above-mentioned traits and also total number born alive, total number weaned and age at market. These were all within the range of those reported by other workers.

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INTRODUCTION

The cost of producing a bacon pig is governed by a variety of factors, most of which can be controlled by man. Breeding, nutrition, management and disease are the main factors. Of these, breeding is one which has been emphasized, but too often it has been practiced with a limited knowledge of the genetic mechanisms involved.

Fecundity, livability, rate of gain, feed utilization and carcass quality are all traits which have a genetic basis for expression and are of primary significance in the economics of production. By intelligent selection of breeding stock a breeder may effect genetic improvement in one or in several of these traits.

Information must be obtained on each trait if selection is to be effective. Litter size at birth, at weaning and at some later age such as at market weight provide measures of fecundity and livability while rate of gain and feed utilization may be estimated from feeding trials, but carcass merit is more difficult to evaluate.

Selection to improve carcass merit may be accomplished in one of two ways. It may be indirect through live appraisal or it may be accomplished by a carcass test of relatives. Live backfat probe, ultrasonic probing and visual appraisal are three indirect methods in predicting carcass value. The former is the best predictor of cutability, ultrasonic probing looks promising and visual appraisal is of little significant value. Carcass test is the only method performed to supply direct information on the consumer's requirements.

The records that are obtained from slaughter data require careful interpretation in their uses as a basis for selection. All sources of variation that may bias the genetic interpretation must be considered. For example, such factors as sex, carcass weight and pre-slaughter environment may contribute importantly to differences in carcass measurements. Failure to accurately evaluate these contributions might lead to serious errors in genetic interpretation of carcass data.

The objectives of this study were to 1) evaluate the contributions made to several important performance and carcass traits by differences in sex and live or carcass weight and 2) estimate heritability and the genetic correlations among these traits.

REVIEW OF THE LITERATURE

EFFECTS OF ENVIRONMENT

It is generally recognized that each individual reaches its ultimate attainment as a result of the two forces, heredity and environment. The inter-relationship of heredity and environment and their respective influence on the individual's development are of interest and importance to the animal breeder.

Many factors of environmental origin such as nutrition, season of growth, outside versus inside rearing and disease have been found to affect favorably or unfavorably performance and carcass traits in swine.

McMeekan (1940) in his classic work evaluated the effect of different methods of feeding (full- versus restricted-fed) upon the type of carcass produced. Rapid early growth and slow growth later intensified muscular development and inhibited fat deposition. McMeekan also found that growth occurred first by an increase in the number of cells and later by an increase in cell size. The animal that is full-fed early in life will therefore develop the maximum number of cells. The result is that two animals differing in age may have the same loin eye area, but the muscle fibers of the younger animal will be smaller.

Restriction of feed, even though less drastic than in the experiments of McMeekan, yielded similar results for Plank and Berg (1963). Decreased average daily gain and improved feed efficiency and carcass quality were the major effects when comparing hand-fed to full-fed pigs.

Analysing data from swine progeny testing stations, Lush (1936), Stothart (1937), Fredeen (1953), Fredeen and Jonsson (1957), Smith _et al._ (1962) and Smith and Ross (1965) found that stations, seasons and years contributed an important part to the total variance.

Nordskog _et al._ (1944) partitioned the total variance into several components. Environmental effects peculiar to each pig accounted for approximately one-half of the total variance for gain and body weights in all periods of life. In pigs, 21 days of age, 37 percent of the environmental variance could be attributed to effects common for a litter, while at 112 days post-weaning it was reduced to 7 percent. The cross nursing studies of Cox (1962) permitted evaluation of some maternal effects and common environment affecting a litter. Data from progeny testing programs usually do not consider such factors. Consequently, results are biased even if a rigid control of the environmental factors is practiced during the test period.

The abundance of research conducted to study the effects of environment on all traits illustrates the relative importance of these effects in economy of production and also in the measurement of genetic differences. More precise measurement of the genetic differences are possible only with a large degree of environmental control.

EFFECTS OF SEX

A sex difference between barrows and gilts is recognized as a real source of variation. It accounts for a portion of the variance in growth rate and age at market and also has a major influence on carcass traits, particularly on measures of lean and fat. McMeekan (1940) observed that barrows had less bone and muscle and more fat than gilts.

Some differences due to sex, which have been reported by various workers, are summarized in Table I. Some of these differences are not significant, but most of the workers felt that correction was warranted; the values calculated were used in an effort to reduce the variation.

At birth and weaning, females are usually lighter, but the differences found have been small. Craig _et al._ (1955) reported that males were 5 percent heavier at birth and 3 percent heavier at 56 days of age, while Lush _et al._ (1938) quoted a difference of only 1 percent for birth weight, in favor of males.

Comstock _et al._ (1944) reported a small significant sex effect on rate of gain, while most of the other reports state larger differences. The differences for rate of gain are quite variable and such factors as age of castration and length of fattening period may explain the inconsistency in the reported effects. Plank and Berg (1963) observed that barrows and gilts did not react in the same manner with the restriction of energy or protein intake.

Lush (1936) found no significant sex difference in rate of gain of pigs in the Danish system of progeny testing, but the influence of sex on length of carcass was significant

TABLE I — SUMMARY OF SEX DIFFERENCES REPORTED FOR VARIOUS TRAITS

(male minus female)

Live Probe Backfat (inches)	Carcass Backfat (inches)	Carcass Length (inches)	Loin Eye Area (sq. inches)	Rate of Gain (lb./day)	Age at Final Wt. (days)	Total Number of Pigs	References
-	.147	-.341	-.778	.046	4.34	281	Bennett and Coles, 1946
-	.11	-.23	-.53	-	5.4	12084	Fredeen, 1953
-	.14	-.27	-.54	-	-	2768	Fredeen and Lambroughton, 1956
-	.10	-.23	-	.05	-	3742	Fredeen and Jonsson, 1957
-	.10	-.41	-.51	.13	7.1	770	Bruner *et al.*, 1958
-	-	-	-	.06	-	506	Reddy *et al.*, 1959
-	.032	-.21	-.531	.30	-	20	Cahill *et al.*, 1960
-	.13	-.25	-.35	-	-	531	Enfield and Whatley, 1961
-	.11	-.30	-.51	-	-	250	Buck *et al.*, 1962
.19	-	-	-.60	.15	-	107	King *et al.*, 1962
-	.13	-.30	-.53	.01	-	1976	Smith *et al.*, 1962
-	.10	-.40	-.405	-	-	482	Fredeen *et al.*, 1964
-	-	-	-.29	-	-	35	Judge, 1964
.26	-	-	-	-	-	317	Rahnefeld, 1965 (Yorkshire)
.10	-	-	-	-	-	300	Rahnefeld, 1965 (Lacombe)
.07[1]	-	-	-	.01	-	1335	Stockhausen, 1965

[1] Number of pigs = 590

though not large. The influence on belly thickness and on thickness of backfat was, however, highly significant. A sex-station interaction was indicated for these carcass characteristics.

Bennett and Coles (1946) concluded that gilts possessed a very distinct and valuable advantage in carcass value. Buck (1963) measured muscular development and found that, between the weights of 150 to 200 pounds, gilts have a net gain of one pound more lean and one pound less fat than barrows.

Sex differences are usually considered in swine progeny testing programs. To eliminate such variation, the testing of sex balanced groups or correction factors are employed.

EFFECTS OF CARCASS WEIGHT ON CARCASS CHARACTERISTICS

During prenatal and post-natal growth, the body organs and tissues exhibit differential growth patterns. After the pig reaches approximately 125 pounds, the organs and extremities grow at a decreasing rate, but the body muscles and the fat depots increase at a constant rate. These are some of the findings of McMeekan (1940).

Fredeen (1953) in an analysis of the Canadian Yorkshire found that carcass measurements showed a linear response to weight change except at the extremes of the weight range. Heavier carcasses are longer, possess increased amounts of fat and have a greater loin eye area.

Many workers have calculated the regression of carcass measurements on carcass weight as a basis for adjusting carcass measurements to a constant carcass weight. Some of the regression coefficients obtained by regressing carcass measurements on carcass weight as well as some for live backfat probe measurements on live body weight are presented in Table II.

Rahnefeld (1965) found breed and sex differences in average depth of fat measured on the live pig. There were also highly significant differences among regression coefficients for backfat thickness on live weight. Considering the evidence from the regression analysis only, he concluded that up to market weight, the Lacombes deposited fat at a slower rate than the Yorkshires. Such evidence does warrant the need to calculate a set of correction factors for every breed.

PHENOTYPIC CORRELATIONS

Phenotypic correlations describe the linear relationships existing among different traits in the same individuals within the population under study. They are useful in prediction and are required in selection indexes (Hazel, 1943).

Some reported estimates of certain phenotypic correlations among important performance and carcass traits are presented in Table III.

Correlation coefficients between carcass weight and other carcass traits show associations similar to the relationships which are summarized in Table II. An increase in carcass weight will bring about an increase in carcass measurements. In general nearly all of the correlations are in substantial agreement.

Only a small correlation has been found to exist

TABLE II — REGRESSION COEFFICIENTS OF

A) CARCASS TRAITS ON CARCASS WEIGHT

Length[1]	Backfat[1]	Loin Eye Area[2]	d.f.	References
.048	.010 sh. fat	-	171	Hammond and Murray, 1937
-	.010 loin fat	-	171	" " " "
.026	.011	.018	-	Brinks, 1960
-	.0043	-	679	Zoellner, 1961
.047	.009 sh. fat	-	243	Stothart, 1938
-	.008 loin fat	-	243	" "

B) LIVE PROBE BACKFAT ON LIVE WEIGHT

Live Probe	Sex	N	Breeds	References
.00745[3]	barrows	1883	Duroc	Cox, 1963
.00700	gilts	2015	"	" "
.00571	barrows	1899	Hampshire	" "
.00562	gilts	1845	"	" "
.0057	barrows	30	7 inbred lines	Hetzer *et al.*, 1956
.0042	gilts	65	" " "	" " " "
.0034	barrows	28	Lacombe	Rahnefeld, 1965
.0030	gilts	272	"	" "
.0064	barrows	47	Yorkshire	" "
.0073	gilts	270	"	" "
.0052	"	181	Lac. York. cross	" "
.0048	barrows	183	" " "	" "
.0041	"	88	York. Lac. cross	" "
.0038	gilts	93	" " "	" "

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[1] Inches per pound of carcass weight gain

[2] Square inches per pound of carcass weight gain

[3] Inches per pound of live weight gain

TABLE III — PHENOTYPIC CORRELATIONS

	Post-Weaning Rate of Gain	References
Weaning Weight	.37 (Poland China)	Comstock et al., 1942, 1010 d.f.
	.17 (Minn. No. 1)	" " " " 421 d.f.
	.47	Vogt et al., 1963, 1000 pigs
	.41	Chapman and England, 1963, 133 pigs
	.37	Ward et al., 1964, 227 d.f.

	Length	Carcass Backfat	Loin Eye Area	References
Post-Weaning Rate of Gain	-.06	.07	-	Lush, 1936, 1285 litters
	-.03	.10	-	Dickerson, 1947, 746 pigs
	-.002	-.205	-	Fredeen and Jonsson, 1957, 936 males
	-.003	-.060	-	" " " " 136 gilts
	-	-	-.12	King et al., 1962, 53 males
	-	-	-.08	" " " " 54 females
	.13	.01	.02	Smith et al., 1962, 1976 pigs
	-.56	.37	.24	Carpenter and King, 1963, 552 pigs
	.13	-.08	-.04	Smith and Ross, 1965, 2256 pigs

	Carcass Backfat	Yield of Ham	References
Loin Eye Area	-.17	.25	Fredeen, 1953, 6794 pigs
	-.41	-	Hazel and Kline, 1956, 95 pigs
	-.21	.60	Bruner et al., 1958, 385 barrows
	-.19	.54	" " " " 385 gilts
	-.27	-	Enfield and Whatley, 1961, 531 pigs
	-.43	-	King et al., 1962, 53 barrows
	-.49	-	" " " " 54 gilts
	-.13	-	Smith et al., 1962, 1976 pigs
	-.03	.22	Fredeen et al., 1964, 244 barrows
	-.14	.32	" " " " 233 gilts
	-.42	.75	Kline and Goll, 1964, 50 pigs
	-.25	-	Smith and Ross, 1965, 2256 pigs

TABLE III — PHENOTYPIC CORRELATIONS (continued)

	Length	Carcass Backfat	Loin Eye Area	References
Carcass Weight	.39	.62	.13	Stothart, 1938, 243 d.f.
	-	.52	.35	Willman and Krider, 1943, 90 pigs
	.41	.49	.38	Aunan and Winters, 1949, 30 pigs
	.26	.40	.28	Fredeen *et al.*, 1964, 244 barrows
	.07	.26	.26	" " " " 234 gilts
	.12	.10	.17	Kline and Goll, 1964, 50 pigs

	Carcass Backfat	Loin Eye Area	References
Carcass Length	-.39	-	Lush, 1936, 1285 litters
	-.05	-.18	Stothart, 1937, 299 d.f.
	-	.08	Bennett and Coles, 1946, 219 males
	-	-.02	" " " " 179 gilts
	-.22	-	Aunan and Winters, 1949, 30 pigs
	-	-.41	Hazel and Kline, 1952, 95 pigs
	-.23	-.07	Fredeen, 1953, 6794 pigs
	-.24	-	Fredeen and Jonsson, 1957, 1872 pigs
	-.27	-.13	Bruner *et al.*, 1958, 385 barrows
	-.41	-.15	" " " " 385 gilts
	-	.13	Holland and Hazel, 1958, 105 pigs
	-.36	.10	Enfield and Whatley, 1961, 531 pigs
	-.23	-.04	Smith *et al.*, 1962, 1976 pigs
	-.47	.10	Henry *et al.*, 1963, 79 pigs
	-.20	.10	Fredeen *et al.*, 1964, 244 barrows
	-.34	-.08	" " " " 234 gilts
	-.54	-.09	Kline and Goll, 1964, 50 pigs
	-.19	-.09	Smith and Ross, 1965, 2296 pigs

between rate of gain and backfat thickness and between rate of gain and loin eye area but it appears that a small positive association exists with backfat and a negative one with loin eye area. Weaning weight has a positive influence on post-weaning gain. England and Chapman (1962) found a correlation of .32 between birth weight and growth rate from 56 to 154 days of age and of .13 between birth weight and weaning weight. Most reports in the literature have shown that birth and weaning weight have little or no effect on carcass traits.

The reported correlation coefficients between carcass length and other carcass traits are small. The negative correlation of carcass length with carcass backfat indicates a favorable association. The only one which is detrimental is the negative correlation with loin eye area.

DePape and Whatley (1956) found that the relationships with live probe backfat were similar to the ones obtained with carcass backfat, namely -.33 for live probe backfat and length and -.26 for live probe backfat and loin eye area. Very few studies have been reported showing the correlation between carcass backfat and live probe measures of fatness. Furthermore, the relatively small number of animals used in those studies which have been reported detracts from the significance of their findings. Hazel and Kline (1953) reported a value of .81, Hetzer et al. (1956) .72 and DePape and Whatley (1956) .69.

The correlation coefficients between loin eye area and yield of ham is positive and indicates that loin eye area is a relatively good measure of meatiness. Fredeen et al. (1964) reported high correlation coefficients (.80 for barrows and .82 for gilts) between percent yield of lean cuts and percent yield of ham.

HERITABILITY

Widely varying estimates of heritability have been obtained for various productivity traits in swine. The source of differences in these estimates can be explained as due to genetic differences among populations studied, methods of estimation employed and sampling error associated with the estimates. Some of the heritability estimates which have been published are summarized in Table IV. In general estimates of performance traits are more variable while those for carcass traits are more consistent.

According to Baker et al. (1943) the heredity of the pig plays an increasingly important role from birth to 112 days of age in determining rate of gain. These workers calculated the genetic variance in rate of gain during relatively short intervals and found that it increased from 7 percent for the period between birth and 21 days of age to 31 percent for the period between 84 and 112 days of age. Heredity decreased in influence after 112 days and environment played a more important role. Such a situation would in part explain the large differences among estimates for rate of gain.

Rendel (1950) postulated that the effect of litter environment accounted for about one-half the variation in weight

TABLE IV — ESTIMATES OF HERITABILITY OF SOME ECONOMIC TRAITS OF SWINE

Traits	H	Breeds	References
Birth Weight	.06	9 breeds	Lush *et al.*, 1934, 3639 pigs (a)
	.00	Duroc	Baker *et al.*, 1943, 62 sires (a)
	.06	Duroc	Dickerson and Grimes, 1947, 69 d.f. (d)
	.28	Hampshire	Craig *et al.*, 1956, 124 sires (b)
	.07	Hampshire	" " " " 288 litters (c)
	.08	Hamp., Duroc	Willham and Cox, 1963, 267 litters (e)
	.24 ±.10	Inbred line of Poland China	Noland *et al.*, 1966, 106 sires (g)
Weaning Weight	.14	Poland China Minn. No. 1	Comstock *et al.*, 1942, 133 d.f. (f)
	.15	Duroc	Baker *et al.*, 1943, 62 sires (a)
	.08	Duroc	Dickerson and Grimes, 1947 (d)
	.03	Hampshire	Craig *et al.*, 1956, 124 sires (b)
	.24	Hampshire	" " " " 288 litters (c)
	.169	Irish Large White	Broderick, 1960, 582 pigs (g)
	.14 ±.11	Minn. No. 1, 2, 3	Ward *et al.*, 1964, 227 sires (g)
	.13 ±.06	Minn. No. 1, 2, 3	" " " " 72 sires (h)
	.26 ±.07	Minn. No. 1, 2, 3	" " " " 272 dams (d)
	.12 ±.13	Inbred line of Poland China	Noland et al., 1966, 106 sires (g)

TABLE IV — ESTIMATES OF HERITABILITY OF SOME ECONOMIC TRAITS OF SWINE (continued)

Traits	H	Breeds	References
Rate of Gain			
Daily gain to 200 lb.	.24	Danish Landrace	Lush, 1936, 122-320 d.f. (i)
" " " " "	.31	Poland China, Minn. No. 1	Comstock *et al.*, 1942, 133 d.f. (f)
56-112 days	.28	Duroc	Hazel *et al.*, 1943, 55 sires (g)
112-225 lb.	.17	Duroc	" " " " " " "
Wn. to 200 lb.	.40	7 inbred lines	Nordskog *et al.*, 1944, 340 litters (g)
Daily gain	.31	Poland China Landrace	Dickerson, 1947, 62 d.f. (g)
" "	.58	Duroc	Dickerson and Grimes, 1947, 69 d.f. (d)
" "	.66 ±.112	Danish Landrace	Fredeen and Jonsson, 1957, 467 sires (g)
" "	.35 ±.11	Danish Landrace	" " " " " " "
60 lb. to 200 lb.	.42 ±.17	Large White	Duckworth *et al.*, 1961, 124 d.f. (g)
Post-Weaning Gain	.14 ±.08	Minn. No. 1, 2, 3	El-Issawi and Rempel, 1961, 451 d.f. (f)
" " "	.28 ±.06	Minn. No. 1, 2, 3	" " " " 1419 d.f. (j)
Daily gain	.41 ±.009	Br. Large White	Smith et al., 1962, 199 d.f. (g)
" "	.41	British Landrace	Smith and Ross, 1965, 245 d.f. (g)
Post-Weaning Gain	.26 ±.10	Minn. No. 1, 2, 3	Ward *et al.*, 1964, 227 sires (g)
" " "	.30 ±.11	Minn. No. 1, 2, 3	" " " " 72 sires (h)
" " "	.38 ±.09	Minn. No. 1, 2, 3	" " " " 272 dams (d)

TABLE IV — ESTIMATES OF HERITABILITY OF SOME ECONOMIC TRAITS OF SWINE (continued)

Traits	H	Breeds	References
<u>Live Probe Backfat Thickness</u>	.35	Poland China Land. crosses	Reddy <u>et</u> <u>al.</u>, 1959, 425 d.f. (f)
	.20	Poland China Land. crosses	" " " " 463 d.f. (k)
	.53 ±.07	Duroc	Hetzer <u>et</u> <u>al.</u>, 1963, 7 gen. (k)
	.32 ±.09	Yorkshire	" " " " 5 gen. (k)
	.25 ±.06	Hampshire and Duroc	Cox, 1964, 342 sires (g)
	.22 ±.02	Hampshire and Duroc	" " 5113 d.f. (k)
	.35 ±.16	Poland China	Gray <u>et</u> <u>al.</u>, 1964, 18 sires (g)
<u>Carcass Length</u>	.78	Danish Landrace	Lush, 1936, 122 d.f. (g)
	.81	Danish Landrace	" " 320 d.f. (l)
	.54	Danish Landrace	" " (i)
	.73	Poland China, Landrace	Dickerson, 1947, 62 d.f. (g)
	.42	Yorkshire	Stothart, 1947, 58 d.f. (k)
	.398	Yorkshire	Fredeen, 1953, 644 d.f. (g)
	.483 ±.106	Danish Landrace	Fredeen and Jonsson, 1957, 432 d.f. (g)
	.485 ±.114	Danish Landrace	" " " " " " "
	.70 ±.21	Large White	Duckworth <u>et</u> <u>al.</u>, 1961, 24 d.f. (g)

TABLE IV — ESTIMATES OF HERITABILITY OF SOME ECONOMIC TRAITS OF SWINE (continued)

Traits	H	Breeds	References
Carcass Length	.50	Duroc, Beltsville No. 1, Hampshire	Enfield and Whatley, 1961, 57 sires (g)
	.60 ±.10	Br. Large White	Smith *et al.*, 1962, 199 d.f. (g)
	.87	British Landrace	Smith and Ross, 1965, 245 sires (g)
Carcass Backfat	.80	Danish Landrace	Lush, 1936, 122 d.f. (g)
	.55	Danish Landrace	" " 320 d.f. (l)
	.47	Danish Landrace	" " (i)
	.37	Yorkshire	Stothart, 1947, 58 d.f. (k)
	.54	Poland China, Landrace	Dickerson, 1947, 62 d.f. (g)
	.42	Yorkshire	Fredeen, 1953, 644 d.f. (g)
	.516 ±.115	Danish Landrace	Fredeen and Jonsson, 1957, 432 d.f. (g)
	.576 ±.115	Danish Landrace	" " " " " " "
	.42	Duroc, Beltsville	Enfield and Whatley, 1961, 57 d.f. (g)
	.60 ±.19	Large White	Duckworth *et al.*, 1961, 24 d.f. (g)
	.67	Br. Large White	Smith *et al.*, 1962, 199 d.f. (g)
	.74	British Landrace	Smith and Ross, 1965, 245 d.f. (g)

TABLE IV — ESTIMATES OF HERITABILITY OF SOME ECONOMIC TRAITS OF SWINE (continued)

Traits	H	Breeds	References
Loin Eye Area	.16	Yorkshire	Stothart, 1947, 58 d.f. (k)
	.66	Yorkshire	Fredeen, 1953, 644 d.f. (g)
	.79	Duroc, Beltsville No. 1, Hampshire	Enfield and Whatley, 1961, 38 d.f. (g)
	.35 ±.09	Br. Large White	Smith *et al.*, 1962, 199 d.f. (g)
	.49	British Landrace	Smith and Ross, 1965, 245 d.f. (g)

Methods of analysis code:
(a) proportion of variance attributable to heredity
(b) variance components
(c) combined regression values
(d) regression of offspring on dam
(e) correlation among full sib
(f) intrasire regression of offspring on dam
(g) paternal half-sib correlations
(h) sire offspring regression
(i) average of three estimates
(j) gross regression method
(k) parent offspring regression
(l) maternal half-sib

up to weaning. Litter size and milking capacity of the sow have substantial effects on weaning weights. Comstock _et al._ (1942) concluded that pre-weaning nutrition is not optimum for the young pig to express its genetic potential. The intra-litter correlation between weaning weight and rate of gain from 50 to 200 pounds was .201 for all creep-fed pigs and -.039 for the pigs that received no supplementary feed. The additive genetic variance in weaning weight is therefore partially masked by maternal influence.

The estimates of live probe backfat are similar to those of carcass backfat. Such an agreement increases the value of the live probe as a tool for selection.

The estimates of Fredeen and Jonsson (1957) indicate that a sex influence is not hereditary, but phenotypic in mode of action. Even if, strictly speaking, sex is genetically determined, it is conveniently classified as "environmental" because the techniques employed to measure its effects are the same as those for truly non-genetic factors. Therefore, the standard methods of analysis will not detect any difference unless a genotype by sex interaction exists. Plank and Berg (1963) tested for such an interaction but found it not to be significant. The sex difference in the estimates for rate of gain is explained by Fredeen and Jonsson (1957) to be due to the effects of castration which could have created a non-genetic correlation between male litter mates. Consequently, the sire component would have been inflated at the expense of the dam component.

Carcass traits are all highly heritable and differences among the estimates of heritability might indicate a breed or population difference, but it is more likely a consequence of the different methods of analysis or sampling error.

GENETIC CORRELATIONS

Genetic correlations among traits are important and of interest in that they provide the basis for estimating the correlated response in traits other than those for which selection is practised. They are essential for the construction of selection indexes.

Most of the genetic correlations that are reported in the literature came from the analysis of progeny testing data. Most of them are concerned with the inherited relationships among carcass traits. Some estimates of genetic correlations are presented in Table V.

The relationships found among the various traits are favorable and in most cases the magnitude of the coefficients indicate that improvement of the non-selected traits can be attained. Rate of gain and backfat thickness, in general have very low values, indicating that two different sets of genes are involved. The negative correlation between carcass length and loin eye area is the only one which may hinder progress. Even if it is of small magnitude serious loss could occur unless special caution is used in weighting the relative economic value of each trait. This would be especially true if one was utilizing a selection index.

TABLE V — GENETIC CORRELATIONS

	Carcass Length	Loin Eye Area,	Rate of Gain	References
Carcass Backfat				
Mean	1.34	-	-	Dickerson, 1947, 61 sires
Shoulder	-.172	-.161	-	Fredeen, 1953, Yorkshire, 564 sires (a)
Rib	-.267	-.077	-	" " " " " "
Loin	-.110	-.190	-	" " " " " "
Mean	-.19	-.10	-	Enfield and Whatley, 1961, 57 sires for length and 38 sires for loin eye area (a)
Mean	-.471	-	-.186	Fredeen and Jonsson, 1957, Danish Landrace, 432 d.f. for sires (a)
Mean	-.319	-	-.170	
Shoulder	-.32	-.42	-.04	Smith *et al.*, 1962, Br. Large White, 199 d.f. for sires (a)
Rib	-.29	-.27	.13	
Loin	-.42	-.42	-.01	
Mean	-.22	-.36	-.26	Smith and Ross, 1965, Br. Landrace, 245 d.f. for sires (a)
Mean	-.45	-	.05	Smith, 1965, Large White (a)
Mean	-.01	-	-.06	Smith, 1965, Landrace (a)
Mean	-.47	-	.05	Smith, 1965, Large White (b)
Mean	-.62	-	-.46	Smith, 1965, Landrace (b)
Mean	-.40	-	-.42	Smith, 1965, Large White (c)
Mean	-.03	-	-.43	Smith, 1965, Landrace (c)

TABLE V — GENETIC CORRELATIONS (continued)

	Loin Eye Area	Rate of Gain	References
Carcass Length	-	.06	Dickerson, 1947, 61 sires
	-.166	-	Fredeen, 1953, Yorkshire, 564 sires (a)
	-.14	-	Ehfield and Whatley, 1961, 38 d.f. for sires
	-	.086	Fredeen and Jonsson, 1957, Danish Landrace, 432 d.f. for sires (a)
	-	.079	

	Weaning Weight	References
Post-Weaning Gain	.69	Ward *et al.*, 1964 (d)
	.47	Vogt *et al.*, 1963, 479 d.f. (e)

	Rate of Gain	References
Live Probe Backfat	.698	Zoellner, 1962 (f)
	.59	Cox, 1959 (e)

(a) paternal half-sibs
(b) sire son regression
(c) dam son regression
(d) pooled of three methods
(e) dam offspring regression
(f) parent offspring regression

Live probe backfat and carcass backfat, even if they are two similar measures of fatness, do not reflect the same picture as far as the genetic correlations with rate of gain are concerned. Live probe backfat and rate of gain are positively correlated while carcass backfat and rate of gain show coefficients which are essentially zero.

The estimates of Fredeen and Jonsson (1957) indicate that sex has no influence on the genetic correlations among rate of gain, backfat thickness and carcass length. The various reliable estimates tend to show that real breed differences exist. One might still question such a statement because of the relatively small number of estimates. Fredeen and Jonsson (1957), when trying to explain the discrepancy between Dickerson's values and their own, stated that a possible difference was due to breed differences. Most of Dickerson's data came from pigs which were inbred lines of Poland China and in which the major emphasis of selection had been daily gain. Fredeen and Jonsson analysed data from the Danish Landrace in which the major emphasis in selection had been on carcass quality.

Craft (1958), in a report on the progress of swine breeding in the last fifty years, emphasized that genetic correlations among economically important characters are needed so that practical selection indexes based on two or more traits could be constructed.

THE DATA

SOURCE AND DESCRIPTION

The data for this study were obtained from the University of Manitoba swine breeding project. Stockhausen (1965) described in detail the breed development phase of the project. Foundation stock, mating system, selection methods and inbreeding were discussed.

Briefly, one of the prime purposes of the project was to develop a new meat-type breed of swine. It was initiated in 1956 by combining seven different breeds. The contribution of the seven breeds to the composition of the herd, which provides the data for this study, was approximately 45 percent Swedish Landrace, 20 percent Wessex Saddleback, 12 percent Welsh and the remaining 23 percent contributed about equally from the Berkshire, Minnesota No. 1, Yorkshire and Tamworth breeds.

The new breed is composed of four separate lines each farrowing at a different season of the year. Three farrowing periods occur each year and the four lines farrow in sequence over four farrowing periods. Approximately 6 to 8 young boars and 20 to 25 gilts are used each generation to continue each line.

Data used in this study were from pigs born in the years 1959 to 1965 inclusive. Pigs born in 1959 were considered to be equivalent to at least the F_2 generation of the foundation crosses made to initiate the new breed.

The performance traits for which genetic parameters were estimated in this study were birth weight, weaning weight, post-weaning average daily gain and thickness of backfat as measured by the live probe. Phenotypic parameters were also computed for all of the above-mentioned traits and for the following: total number born alive, total number weaned and age at market.

Birth weight was taken within 12 hours after birth. Weaning weight was recorded at approximately 42 ±1 days of age. Post-weaning average daily gain was measured as the average daily increase in weight from weaning to approximately 190 pounds (market weight). Measurements of backfat thickness on the live pigs were taken to the nearest .1 inch using the probing technique described by Hazel and Kline (1952). Briefly, three measurements were taken on each side of the pig about 1 1/2 inches off the midline of the body as follows: 1) immediately behind the shoulders, 2) at the last rib and 3) over the loin (directly up from the stifle joint). The average from each location was in turn averaged to give a single measure of backfat thickness per individual. These measurements were available only for the years 1962 to 1965 inclusive.

The carcass traits were hot carcass weight, backfat thickness, length, loin eye area (cross section of longissimus dorsi muscle) and carcass grade.

Hot carcass weight was taken at the time of slaughter with the head on and after the pig was eviscerated and hair removed. The carcasses were graded by the Production and Marketing Service of the Canada Department of Agriculture. Carcass length, backfat thickness and loin eye area were taken 48 hours after slaughter on the chilled carcass.

Three backfat thickness measurements were taken on each side of the split carcass: shoulder backfat was measured opposite the first rib, rib backfat opposite the last rib and loin backfat opposite the last lumbar vertebra. The two measurements for each side were then averaged. In the earlier years, from 1959 to 1961, the fat thickness was measured on only one side of the carcass. Mean carcass backfat thickness used in the analysis was the average of the three sites described above.

Carcass length was measured on the left side of the hanging split carcass from the anterior of the first rib to the aitch bone.

The right side of the carcass was cut perpendicular to the spinal column between the seventh and eighth vertebra counting from the posterior. A tracing was drawn of the cross section of the longissimus dorsi muscle. The cross sectional area of the muscle was obtained by using a planimeter and calculated to the nearest .1 square inch.

Data used in the analysis were limited to those data obtained from pigs within the weight range of 160 to 220 pounds at market and not exceeding 217 days of age at market weight. The number of observations for each trait and sex are given in Table VI. The numbers vary because data for all traits on every animal were not available.

TABLE VI — NUMBER OF OBSERVATIONS FOR EACH TRAIT

Traits	Barrows	Gilts	Total
Total Number Born Alive	824	451	1275
Total Number Weaned	824	451	1275
Birth Weight	824	451	1275
Weaning Weight	824	451	1275
Post-Weaning Gain	824	451	1275
Mean Live Probe Backfat	346	150	496
Age at Market	824	451	1275
Carcass Length	787	431	1218
Mean Carcass Backfat	789	432	1221
Loin Eye Area	382	175	557

The unadjusted data were used in the computation of the phenotypic correlations between the following traits: post-weaning average daily gain, mean live probe backfat, age at market, carcass length, mean carcass backfat and loin eye area. The rest of the estimates were calculated using adjusted data, that is, if adjustment of the traits were performed.

METHODS OF ANALYSIS

GENERAL COMMENTS

All but the more easily computed values presented here were calculated by use of an I.B.M. 1620 computer.

Analyses were done on a within season of farrow and separately by sex. It was felt that no real differences existed among the four lines of the breed and the data were considered coming from one population. Data obtained from gilts for post-weaning gain, live backfat thickness and all carcass traits except hot carcass weight and grade were adjusted to a barrow basis. These two considerations provided substantially more degrees of freedom in the computation of the estimate of genetic parameters and consequently reduced the standard error of the estimates.

CORRECTION FACTORS

1. Effect of carcass weight on carcass traits

The effect of hot carcass weight on the magnitude of the measurements of the various traits was examined by linear regression. The regression coefficients obtained were used as a basis for calculating factors to adjust the measurements to a constant hot carcass weight. Analyses were done within farrowing season and sex. The regression coefficients were pooled separately by sex. The estimates for males and females were not significantly different from each other. Subsequently the two coefficients were averaged, weighting each inversely to its approximated variance, to yield one estimate.

2. Effect of sex on all traits

Performance traits (birth weight, weaning weight, post-weaning average daily gain, live probe backfat adjusted to 190 pounds) and adjusted carcass trait measurements were tested for sex differences. Sex effects, expressed as a difference in the mean value of the respective traits for each sex (gilts versus barrows) were determined by the following procedure. A mean was computed for each trait for each sex by season of farrow. The difference was then calculated between each sex by season. An overall average difference for each trait was obtained by averaging the individual values of each season, weighting each difference inversely to its approximated variance (Cochran and Cox, 1953). The actual computation of the variance of the difference for each of the individual values was done as shown by Steel and Torrie (1960) for the case where sample sizes are unequal. The standard error of the overall average difference was taken as the square root of its variance.

CORRELATION COEFFICIENTS

Correlation coefficients were obtained on a within farrowing season and sex classification. The method of pooling correlation coefficients by the Z transformation (Snedecor, 1956) was used to obtain an overall average coefficient. The pooling was done over season and sex.

ESTIMATION OF GENETIC PARAMETERS

All carcass measurements were adjusted to a hot carcass weight of 148 pounds and live backfat probe to a live weight of 190 pounds for analyses of variance and covariance. Measurements of post-weaning gain, live backfat probe, carcass length, shoulder, rib, loin and mean carcass backfat and loin eye area were adjusted to a barrow basis using the overall average sex difference for each trait as a basis for adjustment.

The form of variance analysis and expectation of mean squares are presented in Table VII. This analysis provided estimates of the sire (S), dam (D) and within full-sib family (W) components of variance which in turn provided the basis for the various estimates of genetic parameters.

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

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

It follows that

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

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

TABLE VII — ANALYSIS OF VARIANCE AND MEAN SQUARE EXPECTIONS

Sources of Variation	d.f.	Mean Square	Mean Square Expectations
Among farrowings	$f - 1$		not relevant
Among sires within farrowings	$s - f$	M_1	$W + k_2D + k_3S$
Among dams within sires and farrowings	$d - s$	M_2	$W + k_1D$
Within full-sib families and farrowings	$N - d$	M_3	W

f = number of farrowing seasons

s = total number of sires

d = total number of dams

N = total number of individuals

S = variance due to differences among sires

D = variance due to differences among dams

W = variance due to differences among full-sibs

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

$$k_2 = \frac{1}{s - f}\left[\sum_i \sum_j \frac{1}{n_{ij}} \sum_k n_{ijk}^2 - \sum_i \frac{1}{n_i} \sum_j \sum_k n_{ijk}^2\right]$$

$$k_3 = \frac{1}{s - f}\left[N - \sum_i \frac{1}{n_i} \sum_j n_{ij}^2\right]$$

n_i = total number of offspring from the ith farrowing

n_{ij} = total number of offspring from the jth sire in the ith farrowing

n_{ijk} = total number of offspring from the kth dam mated to the jth sire in the ith farrowing

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

k_1, k_2 and k_3 are defined in Table VII

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

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

where M = any mean square

E (M) = expectation of M

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

The sire component of variance (S) was taken to be an estimate of 1/4 of the additive genetic variance. The phenotypic variance (P) was obtained as the sum of S, D and W and heritability, which expresses the proportion of the total variance that is attributable to the average effects of genes was estimated, thus:

$$H = \frac{4S}{S + D + W}$$

The variance of the estimate of heritability V (H) was obtained as follows

$$V(H) = \frac{V(4S)}{V(P)}$$

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

The standard error of the estimate of heritability S.E. (H) is simply the square root of the variance.

$$S.E.\ (H) = \sqrt{V\ (H)}$$

The method for determining expectation of cross-products from the analysis of covariance described by Hazel et al. (1943) was employed to estimate components of covariance. The expectation of the mean products have components of co-variance rather than variance, their coefficients being the same as those for the expected mean squares shown on Table VII.

The genetic correlations between any two traits were estimated by the following formula:

$$R_{g(xy)} = \frac{S_{cov(xy)}}{\sqrt{S_x \cdot S_y}}$$

where S_x = sire component of variance for the trait (x)

S_y = sire component of variance for the trait (y)

$S_{cov(xy)}$ = sire component of covariance for the traits (x) and (y)

Standard errors of the genetic correlations were calculated according to the method described by Reeve (1955) and by Robertson (1959) and is as follows:

$$S.E._{R_{g(xy)}} = \frac{1 - \left[R_{g(xy)}\right]^2}{\sqrt{2}} \sqrt{\frac{S.E.\ (H_x) \cdot S.E.\ (H_y)}{H_x \cdot H_y}}$$

where $S.E._{R_{g(xy)}}$ = standard error of genetic correlation coefficient

$R_{g(xy)}$ = genetic correlation between traits (x) and (y)

S.E. (H_x) = standard error of heritability of trait (x)

S.E. (H_y) = standard error of heritability of trait (y)

H_x = heritability estimate of trait (x)

H_y = heritability estimate of trait (y)

Estimates of genetic correlations are usually subject to rather large sampling errors and therefore seldom very precise. Robertson (1959) states that unless both the correlation coefficient and heritability estimates are high, the sampling variance of $R_{g(xy)}$ will be much greater than the coefficient itself.

Estimates of genetic correlations were calculated between all the combinations of the following traits: birth weight, weaning weight, live probe backfat, post-weaning gain, carcass length, mean carcass backfat and loin eye area.

RESULTS AND DISCUSSION

MEANS

Unweighted means and their standard errors for each line and also the unweighted means for the breed are given separately by sex in Table VIII and Table IX. The following performance traits are included in the former: birth weight, weaning weight, post-weaning gain and age at market. The latter table contains mean live probe backfat adjusted to 190 pounds body weight and the carcass traits (length, mean backfat thickness and loin eye area) adjusted to a hot carcass weight of 148 pounds.

The means are not from a random sample of the breed because they were computed from the data available from only those animals which were slaughtered.

The performance of each line in terms of the different traits suggest that variability among lines does exist. Nutrition experiments were superimposed upon the breeding project and also disease problems occurred in various seasons. These environmental effects could have brought about sampling errors and might explain that differences were not found for birth and weaning weight, but were found for all other traits. Sampling error as an explanation for the differences among lines is confirmed by the inconsistency that exists between the two measures of fatness. For barrows, line 1 and line 2 have the largest value for carcass backfat thickness and line

TABLE VIII — UNWEIGHTED MEANS BY SEX AND LINE FOR PERFORMANCE TRAITS

Line	Birth Weight (pounds)		Weaning Weight (pounds)		Post-Weaning Gain (pounds/day)		Age at Market (days)	
	N	Mean	N	Mean	N	Mean	N	Mean
				Barrows				
1	207	3.12[1] ±.041	207	20.0 ±.32	207	1.303 ±.010	207	175.93 ±1.09
2	210	3.19 ±.043	210	21.4 ±.39	210	1.305 ±.012	210	170.38 ±1.13
3	182	3.11 ±.040	182	20.8 ±.37	182	1.238 ±.010	182	180.31 ±1.05
4	225	2.96 ±.037	225	21.5 ±.33	225	1.250 ±.009	225	180.80 ±0.98
Pooled	824	3.09 ±.020	824	20.9 ±.18	824	1.274 ±.005	824	176.86 ±.532
				Gilts				
1	128	3.04 ±.054	128	20.4 ±.44	128	1.268 ±.012	128	177.82 ±1.35
2	135	2.89 ±.051	135	21.3 ±.52	135	1.276 ±.012	135	172.78 ±1.18
3	98	3.01 ±.052	98	20.8 ±.47	98	1.220 ±.014	98	182.63 ±1.47
4	90	2.89 ±.082	90	22.0 ±.59	90	1.218 ±.018	90	183.10 ±1.76
Pooled	451	2.96 ±.031	451	21.1 ±.25	451	1.245 ±.007	451	179.08 ±0.72

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[1] These means were obtained by summing the line averages separately by sex and season and dividing by the number of averages (N). The accompanying standard error was 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. The pooled means and standard errors were calculated separately by sex in the same manner as the line means and standard errors.

TABLE IX — UNWEIGHTED MEANS BY SEX AND LINE FOR CARCASS TRAITS ADJUSTED TO 148 POUNDS CARCASS WEIGHT AND LIVE PROBE BACKFAT THICKNESS ADJUSTED TO 190 POUNDS LIVE WEIGHT

Line	Carcass Length (inches) N	Carcass Length (inches) Mean	Mean Carcass Backfat Thickness (inches) N	Mean Carcass Backfat Thickness (inches) Mean	Loin Eye Area (square inches) N	Loin Eye Area (square inches) Mean	Live Probe Backfat Thickness (inches) N	Live Probe Backfat Thickness (inches) Mean
				Barrows				
1	197	31.07[1] ±.06	197	1.331 ±.008	98	3.47 ±.04	87	1.199 ±.008
2	202	30.77 ±.06	204	1.374 ±.010	73	3.95 ±.04	49	1.194 ±.010
3	177	30.68 ±.05	177	1.290 ±.009	100	3.64 ±.05	93	1.253 ±.010
4	211	30.98 ±.06	211	1.265 ±.010	111	3.66 ±.04	117	1.218 ±.006
Pooled	787	30.88 ±.03	789	1.315 ±.005	382	3.68 ±.02	346	1.216 ±.004
				Gilts				
1	120	31.57 ±.07	120	1.278 ±.013	53	3.82 ±.06	42	1.196 ±.013
2	130	31.23 ±.08	131	1.278 ±.012	42	4.28 ±.06	28	1.152 ±.017
3	95	31.15 ±.06	95	1.160 ±.012	55	4.12 ±.06	53	1.186 ±.007
4	86	31.18 ±.12	86	1.161 ±.014	25	4.17 ±.10	27	1.169 ±.012
Pooled	431	31.28 ±.04	432	1.219 ±.006	175	4.10 ±.03	150	1.176 ±.006

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[1] same method used as for Table VIII

3 and line 4 have the smallest. The situation is reversed for live probe backfat. No such trend can be found for gilts.

It is logical from such evidence to drop the line classification and consider all the pigs as representing a single population.

THE EFFECT OF SEX ON ALL TRAITS

The estimated effects of sex upon the different characters studied are shown in Table X. The standard errors of the differences are also given. The three sites of carcass backfat thickness (shoulder, rib and loin) are included because they were used to adjust the data for the heritability estimate analyses.

Statistically significant ($P < .05$) differences in means for sex were found for some traits and illustrate the influence of sex effect upon the expression of performance and carcass traits (Table X). The differences found in this study are generally less than those which have been reported (Table I).

No adjustment of birth and weaning weights were made for differences arising from sex. In general differences found were small or trivial. Lush _et al._ (1934) reported that phenotypic variance for birth weight among pigs of the same sex was nearly as large (only 1.1 percent less) as the variance of the combined population of the two sexes. Males were slightly but significantly heavier at birth than females. He pointed out that other factors such as litter size, age and

TABLE X — AVERAGE SEX DIFFERENCES USED TO ADJUST TRAIT MEASUREMENTS

Traits	Number of Barrows	Number of Gilts	Mean Difference (Barrows - Gilts)	Standard Error of Difference
Birth Weight (lb.)	795	451	.1603*	.0336
Weaning Weight (lb.)	795	451	-.0873	.2845
Post-Weaning Gain (lb./day)	795	451	.0288*	.0074
Live Probe Backfat (inches)	319	150	.0329*	.0065
Carcass Length (inches)	760	431	-.4493*	.0441
Shoulder Backfat (inches)	762	432	.0692*	.0031
Rib Backfat (inches)	762	432	.1001*	.0076
Loin Backfat (inches)	762	432	.0868*	.0096
Mean Backfat (inches)	762	432	.0858*	.0074
Loin Eye Area (sq. inches)	353	175	-.3702*	.0347

*$P < .01$

size of dam were more important in determining birth weight than sex of the pig. This is also true for weaning weight. Craig et al. (1956) reported that sex accounted for only 3 percent of the phenotypic variance in weight of pigs 56 days of age. In this study females had a heavier weaning weight than males. This can be explained by the fact that the heavy males at weaning were kept for boars.

Sex effect on post-weaning gain is small but in favor of the barrows. Conflicting results are found in the literature. Fredeen and Jonsson (1957) reported a small but highly significant superiority of approximately 1.7 percent in average daily gain for females. Lush (1936), Bennett and Coles (1946) show figures that are significantly in favor of barrows. King et al. (1962) measuring pigs at different weights found no sex difference for daily gain measured from 56 days of age to 75 pounds but highly significant differences ($P < 0.01$) for average daily gain measured from 56 days of age to 125 and 225 pounds. The effect of sex on growth and development is most noticeable at the time when an individual reaches puberty which occurs in pigs between the weights of 125 to 200 pounds. Therefore, a breed of pigs which reaches sexual maturity at a lighter weight will show more pronounced sex differences than one in which sexual maturity is not reached until a heavier weight. Differences for sex effects on average daily gain will also depend on the period from which the measurement is calculated.

The time at which sexual maturity occurs is also reflected in carcass measurements. Females yield longer carcasses with less fat and greater loin eye area. King *et al.* (1962) and Fredeen *et al.* (1964) report that gilts yield a higher percentage of lean cuts and of lean meat in the ham. Conversely the fat trim is reduced.

The results obtained in this study as well as the earlier findings recorded in the literature suggest that the sex hormones cause greater bone growth and greater development of muscle and less deposition of fat in both boars and gilts than in castrates. Since castration of males removes the primary source of androgens, the lack of male hormones in barrows could be responsible for a greater deposition of fat and a smaller muscular development than in gilts.

EFFECT OF CARCASS WEIGHT ON CARCASS MEASUREMENTS

It has been known for a number of years that the relative rate of fat versus muscle deposition in swine differs considerably depending on age and size of the animal (McMeekan, 1940). Because fat is being laid down over an ever increasing body area it seemed reasonable to assume for the present study that a linear relationship existed between backfat and carcass weight. It was also assumed that carcass length and loin eye area behave in a similar manner with respect to carcass weight.

The regression coefficients of carcass measurements on carcass weight and their respective standard errors are presented in Table XI. These coefficients are in agreement

TABLE XI — REGRESSION COEFFICIENTS OF CARCASS MEASUREMENTS ON HOT CARCASS WEIGHT (POUNDS)

Traits	b	Standard Error of b
Carcass Length (inches)	.0251[1]	.0032
Shoulder Backfat "	.00712	.00070
Rib Backfat "	.00676	.00054
Loin Backfat "	.00696	.00070
Mean Backfat "	.00677	.00054
Loin Eye Area (sq. inches)	.0161	.0024

[1] all regression coefficients are significantly different from zero ($P < .01$)

with those reported in the literature (Table II).

The reported sex differences among regression coefficients were also apparent in this study. The regression coefficient for mean backfat on carcass weight was .00707 ±.00069 for barrows and .00629 ±.00086 for gilts. A similar situation existed for loin eye area. The 'b' value for gilts was .0203 ±.0045 and for barrows it was .0146 ±.0029. Length was only slightly affected. Due to the relatively high standard errors, no sex difference was found between 'b' values for any trait ($P < .05$). One pooled estimate over both sexes was used to adjust the carcass measurements to a constant carcass weight.

The effect of body weight on measures of the live probe backfat was examined at an earlier date for this breed. The regression coefficient computed was .0025 per pound increase in body weight. This value was used to adjust the mean of the live probe backfat measurements to a constant live weight of 190 pounds.

PHENOTYPIC CORRELATIONS

Phenotypic correlations are measures of the association among different traits. Their usefulness in constructing selection indexes cannot be overemphasized. Several important correlations between performance and carcass traits were examined in this study (Table XII). Most of these are in agreement with previously published coefficients (Table III).

TABLE XII — PHENOTYPIC CORRELATIONS

(both sexes pooled)

	Total Number Weaned	Birth Weight	Weaning Weight	Post-Weaning Gain	Live Probe Backfat	Carcass Length	Mean Carcass Backfat	Loin Eye Area	Age at Market
Total Number Born	.68**	-.26**	-.25**	-	.05	-.04	-.00	.04	-
Total Number Weaned		-.14**	-.24**	-	.00	-.01	-.02	.10*	-
Birth Weight			.34**	.15**	-.20**	.10**	-.04	.04	-
Weaning Weight				.22**	-.17**	.12**	-.04	.01	-
Post-Weaning Gain					.07	.05	.24**	.17**	-.90**
Live Probe Backfat						-.13**	.48**	-.17**	.02
Carcass Length							-.19**	.02	.04
Mean Carcass Backfat								-.16**	-.15**
Loin Eye Area									-.11**

* P < .05
** P < .01

None of these simple correlations can be interpreted without considering carefully the inter-relation of the several factors that might influence the observed relationships. Some of these characters are physiologically correlated with each other as the result of their being in part the result of the same body function and perhaps in part the result of manifold effects of the same genes.

The coefficients can roughly be divided into two groups on the basis of association among themselves, one group, the performance traits and the other, the carcass characteristics. Post-weaning gain seems to fall in between the two groups.

Total number born alive appeared to have no important association with any of the carcass traits. Total number weaned provided similar results except with loin eye area. No biological explanation can be given for this significant correlation. Litter size at birth accounts for as much variation in weaning weight as litter size at weaning. Early in life maternal influence is very important and birth weight itself has only a small effect on weaning weight. Lodge et al. (1961) found that among litters only 8 percent of the variation in eight week's weight could be accounted for by variation in birth weight, but management practices such as creep feeding could account for 26 percent of the variation in weaning weight.

Ward et al. (1964) reported a value of .37 for the correlation between post-weaning rate of gain and weaning weight. Their value is higher than the one (.22) found in this study. It is impossible to determine if this is a true difference, but it should be noted that their pigs were weaned at 56 days of age whereas pigs in this study were weaned at 42 days of age.

When one examines the correlation between growth rate and backfat thickness (backfat measured either on the live pig or the carcass) he must also consider muscular development. Rate of gain was positively associated with carcass backfat and only slightly with live probe backfat. The significant correlation between post-weaning average daily gain and loin eye area can be explained by the fact that the fast growing pigs develop to a greater extent their muscular structure than the slow growing pigs. The earlier maturing pigs will then have deposited less fat to reach a given weight. This would explain the negative correlation between backfat (carcass and live probe) and loin eye area.

Age at market was another measure of growth considered. The correlation coefficients associated with age produced similar results to those with rate of gain (the signs were reversed). The large correlation between age and rate of gain emphasizes the fact that both methods can be used to measure growth.

The two measures of backfat (live probe and carcass) showed a low correlation between each other. No obvious reasons for such a situation were apparent. Measurement error could be part of the explanation. Another reason which seems to be more logical is the fact that the site of measurement is not the same. Conclusions by Hetzer *et al.* (1956) and Charette (1963) support the superiority of the live probe for estimating carcass lean.

The correlations found between carcass length and the other traits are very much in agreement with what has been reported. If length increases or decreases, backfat thickness behaves conversely. The findings of Bowland *et al.* (1965) support the positive correlation between weaning weight and carcass length found here. They also found that heavy weaners have a flatter but not larger loin eye area and longer pigs have a larger loin eye area and less backfat.

In general the phenotypic correlations found in this study are in good agreement with those reported in the literature.

HERITABILITY ESTIMATES

The paternal half-sib correlation method was the only analysis used to obtain an estimate of additive genetic variance. As compared to the parent-offspring regression method, it is sometimes biased from variance in genotype-environment interaction. Plank and Berg (1963) suggest that such interaction does not occur for carcass traits because parents and offspring develop in different environments in so far as year effects are concerned.

The estimated additive genetic variance and heritability for seven traits which were studied here are presented in Table XIII. The three sites of carcass backfat thickness are also included. The standard errors about these estimates are all fairly large. This is partially due to the large variability of within full-sib family and partially to the relatively few degrees of freedom for sires.

These estimates of heritability are in the range of published data which were summarized in Table IV.

The additive genetic variance for birth and weaning weight is small. The heritability estimates were not significantly different from zero[1/]. Maternal influence, indicated by the large dam component, plays an important role in determining the phenotype of the individuals. It is generally assumed that genetic differences among individuals begin to make themselves felt by weaning and, at the time of slaughter, account for about 30 percent of variation in weight. The lower estimate for weaning weight than for birth weight is probably due to sampling error.

The effect of common litter environment accounts for about one-half of the variation in weight up to weaning and less from then on (Rendel, 1950). Cox (1963) tried to assess

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[1/] 't' test performed by dividing the standard error into the estimate of heritability. Degrees of freedom for sires were used to determine the 't' value.

TABLE XIII — ESTIMATES OF WITHIN FULL-SIB FAMILY (W), DAM (D) AND SIRE (S) COMPONENT OF VARIANCE, ADDITIVE GENETIC VARIANCE (4S) AND HERITABILITY (H) FROM ANALYSIS OF VARIANCE

Traits	d.f.[1]	W	D	S	4S	H	S.E.[2]
Birth Weight	85	.1708	.1267	.0079	.0314	.1029	±.1485
Weaning Weight	54	11.7492	11.6020	.1881	.7524	.0320	±.2316
Post-Weaning Gain	85	.0124	.0028	.0014	.0055	.3332*	±.1365
Carcass Length	85	.3909	.1131	.0725	.2901	.5032* *	±.1628
Loin Eye Area	54	.1141	.0116	.0205	.0819	.5603*	±.2218
Live Probe Backfat	45	.0049	.0007	.0002	.0008	.1319	±.1889
Shoulder Carcass Backfat	85	.0247	.0013	.0018	.0073	.2623*	±.1075
Rib Carcass Backfat	85	.0152	.0004	.0019	.0076	.4333* *	±.1252
Loin Carcass Backfat	85	.0219	.0028	.0017	.0067	.2547*	±.1165
Mean Carcass Backfat	85	.0131	.0011	.0014	.0054	.3465* *	±.1225

[1] degrees of freedom for sires
[2] standard error of H

*P < .05
* *P < .01

true genetic differences by cross nursing pigs of different genetic constitutions. He found that 13 percent of the total variance within cross nursing sets came from common post-natal factors. He stated that this was likely a minimum estimate.

The heritability estimate for birth weight was small and within the range of what had been reported. The trait itself is a reflection of prenatal growth which is governed by homeostatic mechanisms. Selection via homeostatic mechanisms acts to maintain an optimum body size at birth. Excessively large piglets will not pass easily through the genital tract and, if they do, may be born dead. Any increase in birth weight over the optimum will probably lead to ill effects.

The estimate for weaning weight was expected to be higher. Any existing additive genetic variance may have been masked by maternal effects such as milking capacity of the sow.

Post-weaning gain is a very important economic trait and from this study a relatively large amount of additive genetic variance was found. Selection for an increase in this trait should be effective if it is accompanied by a relatively high selection differential. Stockhausen (1965) analysing this trait and using a greater portion of the same population found a similar heritability estimate for barrows (.34) and for gilts (.42) based on the paternal half-sib correlation method. The estimate of this study is about the same as those already published.

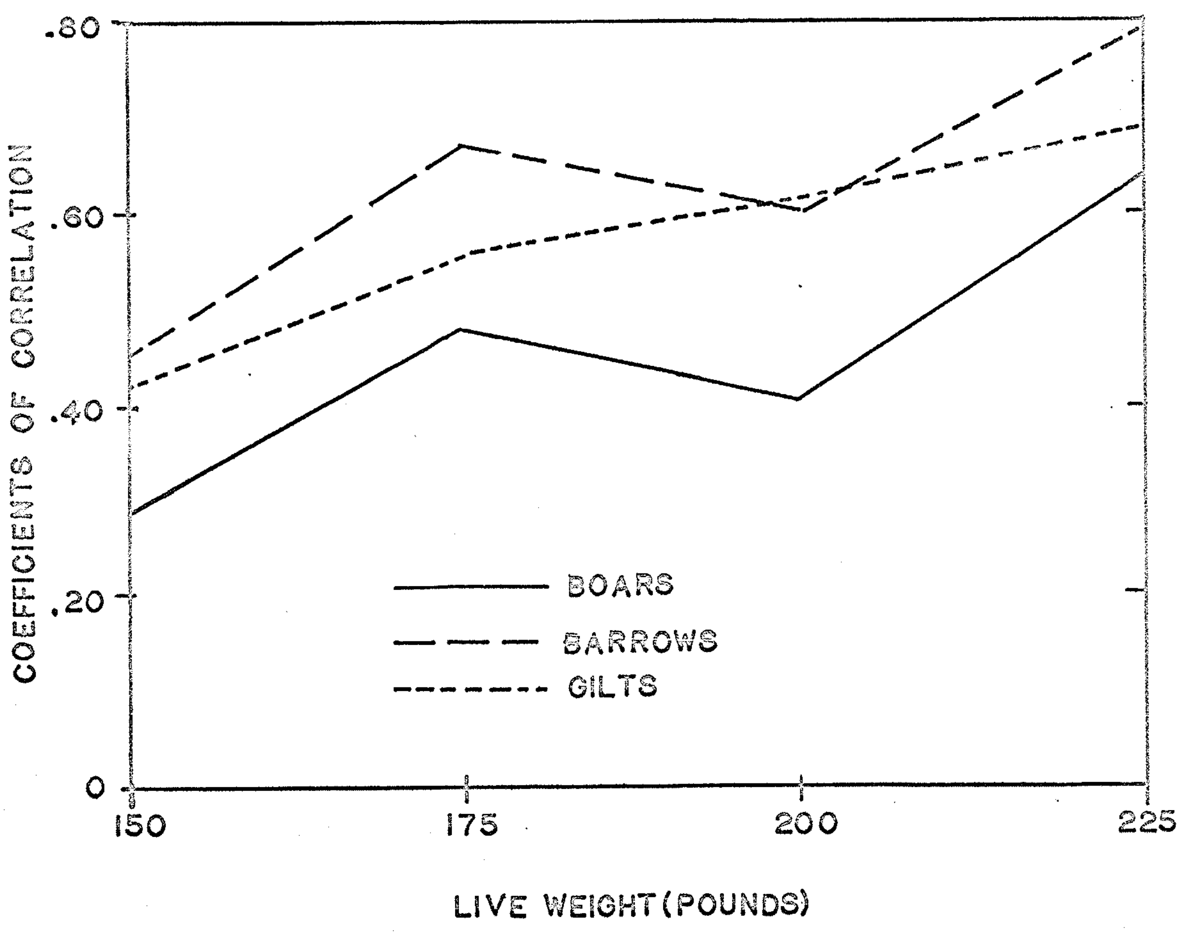
The low estimate for live probe backfat cannot be readily explained. In comparison, the estimate for carcass backfat is 2 to 3 times as large. Hetzer _et al._ (1956) probably provided a partial answer to such a discrepancy. Figure I illustrates the fact that 200 pounds is an erratic live weight at which to take live probes. The correlation between carcass weight and backfat decreases around 200 pounds and then increases as the pig gets heavier. One would therefore advocate from such evidence that live probe backfat measurements be taken at an earlier date when the pig is lighter.

The carcass backfat estimate is lower than what is found in the literature. The explanation of Stockhausen (1965) seems to be a logical in explaining this low estimate. His contentions are 1) that the high variation introduced by nutritional studies will decrease the sire component of variance and 2) that the biological minimum theory could explain why the genetic potential of the breed is less than that of several other breeds.

Carcass length and loin eye area are highly heritable. Any selection for these two traits should yield a significant response given a favorable selection differential.

Components of variance (D and S) presented in Table XIII provide information about maternal influence. Birth and

FIGURE I. INTRA-LINE CORRELATIONS OF CARCASS BACKFAT THICKNESS WITH LIVE HOG BACKFAT MEASUREMENTS AT FOUR WEIGHTS. (AFTER HETZER *ET AL*., 1956.)



weaning weight carry a large amount of maternal influence as indicated by the relatively large dam component. For example, the dam component for weaning weight is 64 times larger than the sire component. Post-weaning gain and, for some unknown reasons, carcass length also carry some maternal influence. No difference is apparent between the sire and dam components of loin eye area and of measures of backfat thickness. Maternal effects are therefore non-existent and selection should not be restrained.

GENETIC CORRELATIONS

Seldom in animal breeding is it feasible to restrict selection to a single trait. Improvement in performance merit, which is the aggregate expression of several traits, requires instead some form of simultaneous selection for each trait. The subsequent rate of improvement will depend upon the selection differential, the heritability of each trait and the genetic relations that exist among them.

Table XIV summarizes the genetic correlation between the seven economically important traits of this study. The additive genetic covariance and the standard errors are also included. All these correlation coefficients are generally larger than those reported in the literature (Table V).

It is questionable if a real population difference exists between this breed and the established breeds. What is most significant at this point is whether the correlations are favorable or unfavorable. Most show a favorable relationship.

TABLE XIV — ESTIMATES OF GENETIC CORRELATIONS (R_g) AND ADDITIVE GENETIC COVARIANCE ($4S_{cov}$)

(R_g above the diagonal and $4S_{cov}$ below the diagonal)

	Birth Weight	Weaning Weight	Post-Weaning Gain	Carcass Length	Mean Carcass Backfat	Loin Eye Area	Live Probe Backfat
Birth Weight (85)[1]		>1	.07 ±.54[2]	.23 ±.46	.42 ±.41	.83 ±.17	.17 ±.99
Weaning Weight (85)	.3670		.28 ±1.12	.49 ±.82	.83 ±.35	>1	<-1
Post-Weaning Gain (85)	.0009	.0180		-.09 ±.25	.23 ±.25	.48 ±.22	<-1
Carcass Length (85)	.0220	.2296	-.0036		-.11 ±.24	.42 ±.21	-.47 ±.18
Mean Carcass Backfat (85)	.0055	.0530	.0012	-.0042		-.27 ±.25	.46 ±.40
Loin Eye Area (54)	.0420	.2664	.0010	.0640	-.0056		-.56 ±.36
Live Probe Backfat (45)	.0008	-.0628	-.0026	-.0070	.0009	-.0045	

[1] degrees of freedom for sire

[2] standard error of R_g

The following genetic correlations are a possible hindrance in a selection program: birth weight with carcass backfat, weaning weight with carcass backfat and post-weaning gain with carcass backfat. All the genetic correlations are greater in magnitude than the phenotypic correlations.

Weaning weight is a measure of rate of gain from birth but as mentioned by Comstock _et al._ (1942) pre-weaning nutrition is usually not optimum for the individual to express its genetic potential and is not equal for all individuals. Unless nutrition is equalized and maximized, weaning weight is a poor criterion of the inherited ability to grow. The effect of creep-feeding as a remedial situation is clearly demonstrated by those researchers. If all pigs to be considered in selection express their genetic potential early in life, weaning weight can have some value in selection, otherwise it can be a misleading measurement.

The genetic correlation found here between live probe and carcass backfat thickness was only .45. This value was expected to be approximately 1.0 if the two measurements of backfat are the same trait. The discrepancy between the correlations for rate of gain with live probe backfat and carcass backfat may indicate that the two measurements of backfat are not measurements of the same trait. All the evidence in this study supports this concept. The very few published phenotypic correlations between these two measurements emphasize this point. The decision as to which is the better measurement for the prediction of carcass quality is left to research.

The negative correlation between rate of gain and carcass length should not be of major concern to the animal breeder. The magnitude is small and the coefficient is probably equal to zero. In this case, one can say that different genetic mechanisms are involved.

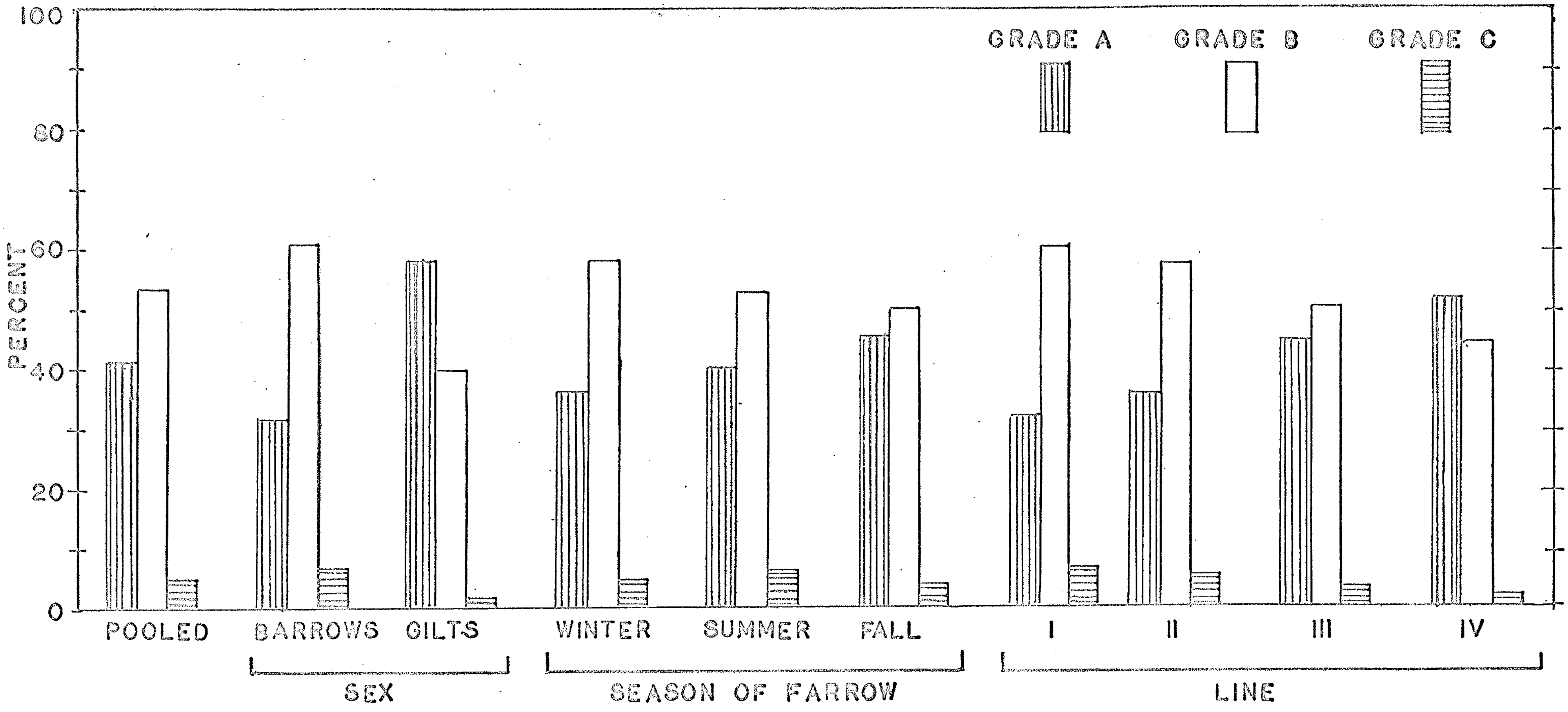
The exact magnitude of the different parameter estimates can be questioned in many instances. Some bias can be due to the following conditions: common litter environment early in life, nutritional experiments and epistasis. These biases cannot be evaluated adequately but as far as the carcass traits are concerned a minimum of these would be present.

In summary, it is felt that sufficient genetic variability exists in all traits to warrant selection. The trait on which concentration should be put is post-weaning gain. It is believed so for three reasons: the mean performance for the character is low, the trait is easily measured and additive genetic variance is sufficient to yield an increase given a reasonable selection differential. The genetic correlations among rate of gain and other traits are all favorable except carcass backfat.

CARCASS GRADES

Figure II portrays the relative level of performance of the population for carcass grades evaluated by the Canadian Grading system. This system has been criticized a number of

FIGURE II. PERCENT CARCASS GRADES SEPARATED BY SEX, SEASON OF FARROW AND LINE



times in the past decade. It is not completely obsolete as a method to evaluate the carcass of pigs because the system discriminates against short and fat carcasses. Comparing the histograms with the means for carcass traits in Table IX, it is noted that backfat has a negative association and to a lesser extent loin eye area a positive association with the percent of grades A, B and C. This is not surprising because the grading system is based on carcass backfat measurements and length. The effect of season in which the pig is grown is quite apparent. This is another reason why environmental control is a must if one is faced with the task of selecting progenitors of the next generation.

SUMMARY

The objective of this study was to estimate heritability and the genetic correlations among several economically important performance and carcass traits in swine. The influence of hot carcass weight upon carcass traits, the effect of sex on all traits and phenotypic correlations were also estimated.

The data were obtained from the University of Manitoba swine breeding project and include information on the pigs that were slaughtered for nineteen farrowing seasons starting in 1959 and ending in 1965.

The traits for which genetic parameters were estimated were birth weight, weaning weight, post-weaning average daily gain, live probe backfat thickness, carcass length, mean carcass backfat thickness and "longissimus dorsi" muscle (loin eye area). Phenotypic parameters were computed for all of the above-mentioned traits and also for total number born alive, total number weaned and age at market. The number of observations for each trait varied because the data were not available for all traits from every animal.

The data were corrected for differences in sex for all traits except for birth and weaning weight. The data were adjusted to a constant carcass weight for all carcass measurements and to a constant live body weight for the backfat probe. These adjustments were done prior to the analyses of variance

and covariance.

Regression coefficients of carcass measurements on hot carcass weight were all found to be statistically different from zero ($P < .01$). Analyses of the data showed that for every ten pound increase in hot carcass weight carcass length increased .25 inches, mean carcass backfat thickness increased .068 inches and "longissimus dorsi" area increased .16 square inches.

Sex was found to have an important influence on all carcass traits. Carcass length was .45 inches more, mean carcass backfat thickness was .09 inches less and "longissimus dorsi" muscle area was .37 square inches more for gilts than for barrows. The sex effects on the performance traits were small and significantly different from zero ($P < .05$).

The phenotypic correlations estimated the interdependence among all traits. Measurements at birth and weaning had little association with carcass measurements. Statistically significant correlations ($P < .05$) were found for all carcass measurements except between carcass length and loin eye area. Post-weaning average daily gain had a small but favorable association with all the other traits except with the two measures of backfat thickness.

An estimate of heritability was calculated for each of the following characters (the value in brackets is the estimate): birth weight (.10), weaning weight (.03), post-weaning average daily gain (.33), carcass length (.50), loin eye area

(.56), live probe backfat (.13) and shoulder (.26), rib (.44), loin (.25) and mean (.35) carcass backfat thickness. These are all within the range of those reported by other workers.

Genetic correlations found among traits were generally favorable so that genetic gain for a trait will be enhanced in a program of simultaneous selection. Three genetic correlations were found to be unfavorable. They were the correlation between weaning weight and mean carcass backfat, post-weaning gain and carcass length and post-weaning gain and mean carcass backfat. In general the magnitude of all the genetic correlations was higher than of those which have been reported in the literature.

The magnitude of the heritability estimates of most of these traits is large enough to suggest that improvement is possible given a favorable selection differential.

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APPENDIX

TABLE I — MEANS - BIRTH WEIGHT

Year,	Season,	Line	Barrows N	 $\overline{X}$	 S.E.	Gilts N	 $\overline{X}$	 S.E.
59	W	1	22	3.261	.1225	12	3.417	.1165
59	Sp	2	20	3.225	.1215	15	3.083	.1477
59	Su	3	33	3.212	.1089	23	3.152	.1086
59	F	4	69	3.047	.0626	42	2.833	.0872
60	W	1	68	3.055	.0654	52	2.918	.0668
60	Su	2	64	3.340	.0809	45	2.844	.0990
60	F	3	54	3.333	.0696	22	3.307	.0986
61	W	4	39	3.032	.0867	21	3.202	.1263
61	Su	1	30	3.183	.0981	17	3.279	.1818
61	F	2	77	3.182	.0526	52	2.909	.0755
62	W	3	29	2.784	.0975	1	2.750	-
62	Su	4	53	2.910	.0839	5	2.700	.2894
62	F	1	56	3.161	.0696	24	2.969	.1013
63	W	2	49	3.020	.0771	23	2.739	.1106
63	Su	3	32	3.234	.0769	34	3.110	.0694
63	F	4	32	2.992	.0915	8	3.094	.1826
64	W	1	31	2.919	.0901	23	2.620	.1076
64	F	3	34	2.978	.0934	19	2.829	.1297
65	W	4	32	2.813	.0905	14	2.643	.1631

TABLE II — MEANS - WEANING WEIGHT

Year, Season, Line			Barrows			Gilts		
			N	$\bar{X}$	S.E.	N	$\bar{X}$	S.E.
59	W	1	22	21.82	.7775	12	23.00	.8616
59	Sp	2	20	23.60	1.0916	15	22.33	1.3369
59	Su	3	33	11.70	.8159	23	19.70	.9033
59	F	4	69	22.12	.5527	42	21.69	.8104
60	W	1	68	19.41	.5536	52	20.44	.5757
60	Su	2	64	19.73	.6304	45	19.62	.9008
60	F	3	54	23.13	.7059	22	23.82	1.0924
61	W	4	39	21.51	.7141	21	21.62	.5710
61	Su	1	30	20.37	.8380	17	23.41	1.3091
61	F	2	77	18.65	.6880	52	18.94	.9047
62	W	3	29	19.10	.8757	1	29.00	-
62	Su	4	53	21.08	.6862	5	21.20	1.3191
62	F	1	56	20.57	.6736	24	19.29	1.1091
63	W	2	49	23.78	.6242	23	24.48	.9280
63	Su	3	32	20.62	.9469	34	18.24	.8987
63	F	4	32	20.50	.8519	8	24.00	1.9180
64	W	1	31	17.87	.7445	23	15.65	.9422
64	F	3	34	21.38	.8241	19	21.26	.8051
65	W	4	32	22.22	.7966	14	21.57	1.4777

TABLE III — MEANS - POST-WEANING AVERAGE DAILY GAIN

Year,	Season,	Line		Barrows			Gilts	
			N	$\bar{X}$	S.E.	N	$\bar{X}$	S.E.
59	W	1	22	1.321	.0329	12	1.243	.0370
59	Sp	2	20	1.370	.0363	15	1.318	.0319
59	Su	3	33	1.205	.0187	23	1.190	.0265
59	F	4	69	1.237	.0143	42	1.132	.0187
60	W	1	68	1.317	.0125	52	1.297	.0147
60	Su	2	64	1.323	.0184	45	1.259	.0140
60	F	3	54	1.285	.0196	22	1.298	.0361
61	W	4	39	1.269	.0199	21	1.241	.0241
61	Su	1	30	1.376	.0255	17	1.357	.0224
61	F	2	77	1.243	.0143	52	1.239	.0169
62	W	3	29	1.315	.0209	1	1.180	-
62	Su	4	53	1.278	.0182	5	1.280	.0755
62	F	1	56	1.303	.0185	24	1.255	.0278
63	W	2	49	1.283	.0256	23	1.293	.0247
63	Su	3	32	1.174	.0268	34	1.180	.0181
63	F	4	32	1.182	.0226	8	1.201	.0283
64	W	1	31	1.200	.0206	23	1.188	.0225
64	F	3	34	1.209	.0208	19	1.214	.0253
65	W	4	32	1.281	.0219	14	1.229	.0244

TABLE IV — MEANS - AGE AT MARKET

Year,	Season,	Line	Barrows N	 $\overline{X}$	 S.E.	Gilts N	 $\overline{X}$	 S.E.
59	W	1	22	170.09	2.81	12	175.33	4.36
59	Sp	2	20	165.55	3.02	15	168.07	2.46
59	Su	3	33	179.60	2.19	23	180.65	3.58
59	F	4	69	174.09	1.62	42	186.55	2.56
60	W	1	68	166.68	1.21	52	167.08	1.53
60	Su	2	64	166.44	1.74	45	172.89	2.01
60	F	3	54	168.85	1.90	22	169.22	3.24
61	W	4	39	178.62	2.23	21	176.38	3.09
61	Su	1	30	170.50	3.29	17	166.24	2.75
61	F	2	77	172.83	1.69	52	173.78	2.17
62	W	3	29	173.38	2.54	1	175.00	-
62	Su	4	53	177.66	2.01	5	175.80	6.03
62	F	1	56	177.00	1.96	24	183.42	3.23
63	W	2	49	176.84	2.41	23	175.83	2.68
63	Su	3	32	189.47	2.85	34	188.50	1.18
63	F	4	32	193.38	2.55	8	188.62	4.52
64	W	1	31	195.39	2.39	23	197.04	2.63
64	F	3	34	191.21	2.25	19	192.79	2.80
65	W	4	32	180.34	2.54	14	185.64	3.51

TABLE V — MEANS - LIVE PROBE BACKFAT

Year,	Season,	Line	Barrows N	 $\overline{X}$	 S.E.	Gilts N	 $\overline{X}$	 S.E.
62	W	3	27	1.309	.0257	1	1.230	-
62	Su	4	53	1.170	.0119	5	1.096	.0206
62	F	1	56	1.155	.0115	24	1.149	.0206
63	W	2	49	1.194	.0097	23	1.152	.0171
63	Su	3	32	1.222	.0119	34	1.224	.0097
63	F	4	32	1.212	.0088	8	1.198	.0223
64	W	1	31	1.243	.0102	23	1.242	.0142
64	F	3	34	1.229	.0094	19	1.148	.0105
65	W	4	32	1.272	.0086	14	1.214	.0168

TABLE VI — MEANS - LOIN EYE AREA

Year, Season, Line			Barrows			Gilts		
			N	$\bar{X}$	S.E.	N	$\bar{X}$	S.E.
59	W	1	17	3.400	.0920	9	3.700	.1106
60	F	3	9	3.833	.1633	7	4.486	.1405
61	F	2	34	3.968	.0604	20	4.285	.0755
62	W	3	29	3.493	.0890	1	4.200	-
62	Su	4	53	3.798	.0524	5	4.260	.2272
62	F	1	53	3.753	.0512	21	4.262	.1152
63	W	2	39	3.936	.0609	22	4.277	.0967
63	S	3	29	3.614	.0724	30	3.897	.0600
63	F	4	27	3.600	.0611	6	4.167	.1174
64	W	1	28	3.246	.0590	23	3.513	.0516
64	F	3	33	3.615	.0640	18	3.989	.0804
65	W	4	31	3.581	.0729	14	4.079	.1259

TABLE VII — MEANS - CARCASS LENGTH

Year,	Season,	Line	Barrows N	 $\overline{X}$	 S.E.	Gilts N	 $\overline{X}$	 S.E.
59	W	1	20	30.58	.1224	11	31.54	.1193
59	Sp	2	20	30.66	.2015	14	31.39	.2267
59	Su	3	33	30.49	.1038	23	31.16	.1338
59	F	4	69	30.82	.0808	42	31.51	.1207
60	W	1	68	30.93	.1009	52	31.37	.1218
60	Su	2	64	30.57	.0908	43	30.91	.1185
60	F	3	54	30.66	.1053	22	31.18	.1294
61	W	4	31	30.31	.1330	19	30.76	.1880
61	Su	1	28	30.89	.1431	13	31.57	.1587
61	F	2	76	30.65	.0812	51	31.08	.0996
62	W	3	27	30.72	.0984	1	32.30	-
62	Su	4	53	31.07	.0970	5	30.96	.2713
62	F	1	53	31.29	.1031	21	31.47	.1724
63	W	2	42	31.20	.0976	22	31.54	.1310
63	Su	3	30	30.84	.1077	32	30.93	.1185
63	F	4	27	31.42	.1391	6	31.48	.3535
64	W	1	28	31.66	.1503	23	31.92	.1724
64	F	3	33	30.72	.1194	18	31.33	.1318
65	W	4	31	31.26	.1785	14	31.16	.3559

TABLE VIII — MEANS - MEAN CARCASS BACKFAT

Year,	Season,	Line	Barrows N	$\bar{X}$	S.E.	Gilts N	$\bar{X}$	S.E.
59	W	1	20	1.406	.0179	11	1.328	.0286
59	Sp	2	20	1.382	.0261	15	1.276	.0341
59	Su	3	33	1.395	.0170	23	1.328	.0253
59	F	4	69	1.366	.0142	42	1.259	.0172
60	W	1	68	1.415	.0167	52	1.316	.0159
60	Su	2	62	1.435	.0171	42	1.307	.0189
60	F	3	54	1.354	.0144	22	1.290	.0264
61	W	4	31	1.481	.0322	19	1.356	.0365
61	S	1	28	1.399	.0211	13	1.332	.0354
61	F	2	76	1.373	.0141	51	1.321	.0168
62	W	3	27	1.368	.0219	1	1.080	-
62	S	4	53	1.291	.0164	5	1.108	.0282
62	F	1	53	1.312	.0159	21	1.291	.0274
63	W	2	46	1.307	.0206	23	1.207	.0228
63	Su	3	30	1.180	.0264	32	1.077	.0185
63	F	4	27	1.068	.0187	6	1.023	.0409
64	W	1	28	1.123	.0194	23	1.125	.0305
64	F	3	33	1.155	.0211	18	.944	.0281
65	W	4	31	1.120	.0223	14	1.059	.0330

TABLE IX — REGRESSION COEFFICIENTS OF CARCASS MEASUREMENTS ON HOT CARCASS WEIGHT (POUNDS) SEPARATELY BY SEX

Traits	d.f.	b	S.E.
Barrows			
Carcass Length (inches)	767	.0265	.0040
Shoulder Backfat "	767	.0073	.0009
Rib Backfat "	767	.0064	.0007
Loin Backfat "	767	.0075	.0009
Mean Backfat "	767	.0071	.0007
Loin Eye Area (sq. inches)	364	.0146	.0029
Gilts			
Carcass Length (inches)	414	.0226	.0052
Shoulder Backfat "	414	.0069	.0011
Rib Backfat "	414	.0055	.0010
Loin Backfat "	414	.0061	.0012
Mean Backfat "	414	.0063	.0009
Loin Eye Area (sq. inches)	166	.0203	.0045

TABLE X — PHENOTYPIC CORRELATIONS SEPARATELY BY SEX

(barrows above the diagonal and gilts below the diagonal)

	Total Number Born	Total Number Weaned	Birth Weight	Weaning Weight	Post-Weaning Gain	Live Probe Backfat	Carcass Length	Mean Carcass Backfat	Loin Eye Area	Age at Market
Total Number Born		.68	-.24	-.24	-	.10	-.06	.02	.05	-
Total Number Weaned	.68		-.13	-.25	-	.03	-.03	.01	.12	-
Birth Weight	-.28	-.17		.34	-	-.23	.13	-.03	.01	-
Weaning Weight	-.28	-.23	.33		-	-.22	.13	-.06	.00	-
Post-Weaning Gain	-	-	-	-		.06	.10	.21	.18	-.90
Live Probe Backfat	-.08	-.08	-.13	-.04	.11		-.18	.48	-.14	.04
Carcass Length	-.02	.03	.03	.11	-.04	-.03		-.19	.03	-.00
Mean Carcass Backfat	-.04	-.07	-.08	-.01	.31	.47	-.19		-.12	-.13
Loin Eye Area	.02	.04	.09	.03	.15	-.26	-.01	-.23		-.11
Age at Market	-	-	-	-	-.89	-.02	.12	-.18	-.10	

TABLE XI ANALYSIS OF VARIANCE

Traits	Source of Variation	d.f.	Mean Squares	(k)	Values
Birth Weight	A	18	1.6385	1	2.979
	S	85	.7105	2	3.588
	D	276	.5483	3	10.815
	W	822	.1708		
Weaning Weight	A	11	179.1200	1	2.163
	S	54	46.2663	2	2.851
	D	160	36.8444	3	7.655
	W	312	11.7492		
Live Probe Backfat	A	8	.1126	1	2.282
	S	45	.0086	2	2.955
	D	122	.0066	3	7.646
	W	266	.0049		
Post-Weaning Average Daily Gain	A	18	.1715	1	2.979
	S	85	.0373	2	3.588
	D	276	.0207	3	10.815
	W	822	.0124		
Carcass Length	A	18	5.5484	1	2.979
	S	85	1.5812	2	3.588
	D	276	.7279	3	10.815
	W	822	.3909		
Mean Carcass Backfat	A	18	.7495	1	2.979
	S	85	.0318	2	3.588
	D	276	.0165	3	10.815
	W	822	.0131		
Loin Eye Area	A	11	2.6396	1	2.163
	S	54	.3037	2	2.851
	D	160	.1391	3	7.655
	W	312	.1141		

TABLE XII — ANALYSIS OF COVARIANCE

Traits	Source of Variation	d.f.	Mean Cross-Products	(k)	Values
Birth Weight and Weaning Weight	A	18	2.9018	1	2.979
	S	85	2.5192	2	3.588
	D	276	1.3663	3	10.815
	W	822	.5811		
Birth Weight and Live Probe Backfat	A	8	-.1073	1	2.282
	S	45	-.0153	2	2.955
	D	122	-.0140	3	3.380
	W	266	-.0042		
Birth Weight and Post-Weaning Gain	A	18	.1193	1	2.979
	S	85	.0162	2	3.588
	D	276	.0130	3	10.815
	W	822	.0087		
Birth Weight and Carcass Length	A	18	-1.8472	1	2.979
	S	85	.1320	2	3.588
	D	276	.0642	3	10.815
	W	822	.0235		
Birth Weight and Mean Carcass Backfat	A	18	.5351	1	2.979
	S	85	.0027	2	3.588
	D	276	-.0102	3	10.815
	W	822	-.0003		
Birth Weight and Loin Eye Area	A	11	.4049	1	2.163
	S	54	.0950	2	2.851
	D	160	.0096	3	7.655
	W	312	-.0060		
Weaning Weight and Live Probe Backfat	A	8	-2.3123	1	2.282
	S	45	-.2128	2	2.955
	D	122	-.0792	3	7.646
	W	266	-.0334		
Weaning Weight and Post-Weaning Gain	A	18	1.5434	1	2.979
	S	85	.3109	2	3.588
	D	276	.2330	3	10.815
	W	822	.0906		
Weaning Weight and Carcass Length	A	18	.4444	1	2.979
	S	85	1.8172	2	3.588
	D	276	1.0211	3	10.815
	W	822	.1645		

TABLE XII — ANALYSIS OF COVARIANCE (continued)

Traits	Source of Variation	d.f.	Mean Cross-Products	(k)	Values
Weaning Weight and Mean Carcass Backfat	A	18	.1943	1	2.979
	S	85	.0604	2	3.588
	D	276	-.0721	3	10.815
	W	822	-.0196		
Weaning Weight and Loin Eye Area	A	11	12.7695	1	2.163
	S	54	.2675	2	2.851
	D	160	-.1807	3	7.655
	W	312	.0129		
Live Probe Backfat and Post-Weaning Gain	A	8	-.0521	1	2.282
	S	45	-.0056	2	2.955
	D	122	-.0005	3	7.646
	W	266	.0004		
Live Probe Backfat and Carcass Length	A	8	-.1641	1	2.282
	S	45	-.0283	2	2.955
	D	122	-.0141	3	7.646
	W	266	-.0112		
Live Probe Backfat and Mean Carcass Backfat	A	8	-.0837	1	2.282
	S	45	.0063	2	2.955
	D	122	.0041	3	7.646
	W	266	.0031		
Live Probe Backfat and Loin Eye Area	A	8	-.4115	1	2.282
	S	45	-.0165	2	2.955
	D	122	-.0072	3	7.646
	W	266	-.0047		
Post-Weaning Gain and Carcass Length	A	18	-.0826	1	2.979
	S	85	.0045	2	3.588
	D	276	.0112	3	10.815
	W	822	-.0030		
Post-Weaning Gain and Mean Backfat Thickness	A	18	.1903	1	2.979
	S	85	.0050	2	3.588
	D	276	.0019	3	10.815
	W	822	.0034		
Post-Weaning Gain and Loin Eye Area	A	11	.1795	1	2.163
	S	54	.0262	2	2.851
	D	160	.0055	3	7.655
	W	312	.0009		

TABLE XII — ANALYSIS OF COVARIANCE (continued)

Traits	Source of Variation	d.f.	Mean Cross-Products	(k)	Values
Carcass Length and Mean Carcass Backfat	A	18	-1.1193	1	2.979
	S	85	-.0364	2	3.588
	D	276	-.0247	3	10.815
	W	822	-.0236		
Carcass Length and Loin Eye Area	A	11	-.7591	1	2.163
	S	54	.0772	2	2.851
	D	160	-.0371	3	7.655
	W	312	-.0109		
Mean Carcass Backfat and Loin Eye Area	A	11	.4834	1	2.163
	S	54	-.0255	2	2.851
	D	160	-.0126	3	7.655
	W	312	-.0063		