SWINE CARCASS STUDIES. I. GENETIC VARIATION AND

COVARIATION IN CARCASS CHARACTERS. II. THE

PROBE AS AN INDICATOR OF CARCASS MERIT

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INTRODUCTION

The concept of heritability is associated with the relative importance of heredity and environment as they influence the variation in a character. Heritability is one of the most fundamental parameters of a population. First, it provides a measure of the genetic variation, that is, of the variation upon which all the possibilities of changing the population by breeding methods depends. Secondly, the value of heritability rests on its property as a measurement of the accuracy with which a genotype can be identified from the phenotype of an individual or a group of individuals. Knowledge of the degree of heritability of a character is very useful in choosing an efficient breeding program, in estimating the gain to be made from selection and in the construction of selection indices.

The relative importance of heredity and environment and their interaction in determining the total variability of a trait is of particular importance to the breeder because the variations due to environment cannot be used to make permanent changes in a population. The hereditary variation, as herein used, refers to the functioning of the genotype as a whole, that is, it consists of a portion due to the additive effects of the genes, a portion due to dominance and a portion due to epistasis.

The application of swine progeny records in selection is based on the assumption that the progeny of an animal are in-

dicative of its genetic composition and that the sibs of the progeny should reproduce accordingly. The extent to which such sibs follow this concept is naturally dependent on the relative genetic and environmental influence on the trait measured. Only in recent years have methods been devised to estimate this relative effect and subsequently predict, in part at least, the results of selection based on progeny records.

Methods of estimating heritability all depend upon the degree to which related animals resemble each other more than less closely related animals. The methods of estimating heritabilities of carcass characteristics are limited because the animals yielding the carcass data cannot themselves be used for breeding purposes. Many extraneous factors, such as years, seasons, breeds, lines and sex can influence measurements of heritability. It is important, therefore, to measure and correct for these extraneous contributions, thereby increasing the accuracy of the heritability estimates.

In recent years much emphasis in animal breeding research has been placed on developing effective systems of breeding that might be used to exploit the phenomenon of hybrid vigor in commercial livestock production. Information is required as to the relative economic importance of the traits, the degree of heritability of each trait, and the genetic and phenotypic correlations between these traits, to determine the optimum emphasis to be placed on each component of net performance in evaluating strains for their performace in crosses.

Phenotypic correlations describe the linear relationships existing between different traits in the same individual within the population under study. Genetic relationships between traits cannot be deduced from phenotypic correlations, because the latter include any environmental correlations that are present. However, methods have been devised for the computation of genetic correlations which measure the degree to which additive deviations in different traits have a common genetic basis. These relationships are useful in prediction of breeding values and in the construction of selection indices.

The external appearance of the live hog, as in the case of all our meat animals, is often quite misleading in predicting its carcass composition. Until recently it has been impossible to appraise potential breeding animals on the basis of their own carcass composition without slaughtering them. Recently a "probing technique" has been devised for measuring the thickness of backfat of the live hog. The accuracy of this measure in predicting carcass merit and the relative ease with which the information can be obtained make the probe one of the most promising tools to date for live hog selection.

The primary objectives of the present study were to (1) obtain estimates of heritability of some swine carcass traits, (2) obtain estimates of phenotypic and genetic correlations between the various carcass traits and rate of gain, and (3) measure the effects on carcass composition of certain environmental factors. A secondary phase of this study deals

with an evaluation of the "probe" as a measure of backfat
deposition and carcass composition and its possible use in
a swine breeding program.

REVIEW OF LITERATURE

Heritability is the fraction of the observed or pheno-
typic variance which is caused by differences between the
genes or the genotypes of individuals. In the broad sense it
refers to the functioning of the whole genotype as a unit and
is used in contrast with environment. In the narrow sense it
is a measure of the extent to which the phenotypic differences
among individuals in a population can be ascribed to differ-
ences in genes which act in an additive manner. The narrow
meaning of heritability is used when the main emphasis is on
expressing what fraction of the phenotypic differences between
parents may reasonably be expected to be recovered in their
offspring. A multitude of extraneous factors other than genes
are capable of inducing differences among individuals. The
problem in any genetical analysis becomes one of controlling
or correcting for the effects of these extraneous factors so
that the differences among individuals will more nearly re-
flect gene differences alone.

Records derived from slaughter tests require careful in-
terpretation in their use as a basis of selection. All sources
of non-genetic variation that may bias the genetic interpret-
ation must be considered. Such factors as sex, carcass weight,
and environment in all its ramifications may contribute im-
portantly to variations in carcass measurements. Failure to
evaluate and discount these contributions could well lead to

serious errors in genetic interpretation of carcass studies. The review of literature that follows is an attempt to discuss some of these factors capable of causing individuals to differ.

a. Influence of Environment on Carcass Composition

McMeekan (1938,1939,1940) was able to produce pigs conforming to predetermined growth curves by controlling the plane of nutrition at different stages of growth. Rapid early growth as fostered by a high plane of nutrition was reflected in an increase of skeletal framework and muscle while slow later growth on a low plane of nutrition reduced the rate of deposition of fat. Thus pigs on a high-low dietary regime were of bacon type, while those on the low-high diet were of the lard type.

Winters, et al. (1949) and Cummings and Winters (1951) conducted an experiment similar to that of McMeekan with the exception that three breeds of swine were used. Changes in the diet occured at 125 pounds and all pigs had access to pasture forage. The pigs that were full-fed throughout the experiment yielded the fattest carcasses, while the pigs that were on a restricted diet throughout the experiment yielded the leannest carcasses. The other two groups, one self-fed to 125 pounds and thereafter receiving a daily allowance of three percent of their body weight, and one fed a three percent of body weight restricted diet to 125 pounds and thereafter full-fed, produced carcasses with about the same degree of fatness, intermediate between the first two groups of pigs mentioned. No apparent

breed differences were noted.

The results of the two experiments by McMeekan and by Winters and associates seemingly differ. However, there were differences in experimental procedure which may have been responsible for some of the differences in the results. In McMeekan's investigation the pigs went on experiment at birth, whereas in Winter's study, the pigs did not go on test until approximately 80 days of age. Thus in McMeekan's study the pigs were on trial during a period of growth when skeletal and muscular tissue were being developed most rapidly. Also, the pigs in Winter's study were fed on pasture and the pigs may have partially compensated for their restricted diet by eating more forage.

A self-fed group of Canadian Yorkshires were found to average .9 inch shorter than a similar hand-fed group with reduced feed intake, Crampton (1937). Further work by Crampton and Ashton (1945,1946) showed that feeding barley gave slower gains and leaner carcasses, while feeding wheat caused faster gains and a decrease in the amount and proportion of lean in the carcasses. B-vitamin supplementation promoted a greater deposition of fat whereas the reduction of protein level from 15 to 13 percent in the period from weaning to 110 pounds live weight did not affect the carcass quality.

The principal effects on the carcasses, of pigs fed a standard small grain ration fortified with APF containing residual amounts of aureomycin, reported by Bowland, et al. (1951), were a reduction in carcass length and an increase in

backfat thickness. It appeared that these deleterious effects may have been due to increased gains during the finishing period. From the work of McMeekan (1940) it seems logical that skeletal growth and length of side would fail to keep pace with a rapid increase in weight during the finishing period. On the other hand, Wilson, et al. (1953) found no increase in fat deposition when the addition of vitamin B_{12} and aureomycin accelerated gains. Perry, et al. (1953) demonstrated that carcasses from pigs fed rations containing aureomycin or surfactants contained significantly more fat, less protein and less moisture than carcasses from pigs fed rations that did not contain these constituents. Backfat thickness at the first rib was significantly greater at the same slaughter weight for carcasses from swine which had been fed antibiotics and surfactants. Rations containing aureomycin, vitamin B_{12}, terramycin or trace mineralized salt were found to have no measurable effects on the chemical composition of the physically separated carcass or physical characteristics of carcasses from 200 pound hogs, Pierce (1954). Further, there apparently was no difference between groups of carcasses as a result of the length of time that the antibiotic supplements were supplied in the ration.

Crampton, et al. (1954a) individually fed 196 purebred Yorkshire pigs from weaning to 200 pounds live weight to study the effect of restricting the feed intake on the quality of the bacon carcass. The feed intake was reduced two pounds per day below the daily allowance under full feeding for the period

from 110 to 200 pounds live weight. The result of the feed restriction was an average reduction in growth rate of .45 pound per day during the last 90 pounds of gain. However, feed efficiency, expressed as the amount of feed required per pound of gain, was equal for the full-fed and restricted groups. The restriction of feed intake during the finishing period increased the quality of the hog carcass for bacon by reducing fat deposition during that period. The actual size of the muscle area in the bacon rashers was increased as well as the percentage of lean. In a companion paper, Crampton, et al. (1954b) reported on the suitability of introducing certain fibrous feeds into the hog finishing ration as a means of improving carcass quality through a reduction in digestible energy. The addition of 45% alfalfa or wheat bran was effective in enhancing bacon carcass quality but decreased the rate of gain. However, when either 25% of wheat bran or wild oats were added to the ration, increases were observed in the percentage Grade A hogs produced, while rate of gain, feed intake and length of feeding period were unaffected. The authors offered no explanation for the improvement in carcass quality that obviously was not directly associated with a decreased rate of gain.

Whatley, et al. (1953) demonstrated that leaner carcasses resulted from reducing the energy content of a self-fed ration during the latter part of the fattening period. However, the reduction in dressing percentage of the pigs on the restricted energy ration offset the advantage of the

leaner carcasses, consequently, the carcass value of the live hogs were not improved. Hereditary differences in carcass value among breeding groups were not associated with differences in dressing percentages.

Lush (1936) in an analysis of the Danish swine progeny testing records found important intra-year differences between stations in belly thickness and daily gain. Differences in carcass length and backfat thickness were small, although statistically significant. Stothart (1937) from performance data of Canadian Yorkshire litters from 19 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. Under the Advanced Registry testing program in Canada, wide variations in climatic conditions are encountered between test stations, and temperature is known to influence rate and economy of gain. Pigs grown out in cold pens in winter grew more slowly and produced a higher quality carcass than the summer fed pigs according to Crampton and Ashton (1946). The effect of temperature and humidity on swine, as they influence gains were demonstrated by Heitman and Hughes (1949).

Johansson and Korkman (1950) from an analysis of 2,995 litters of the Swedish Landrace and Large White breeds demonstrated significant yearly differences in all traits considered. The effect of years was found responsible for the following percentages of the total variation of the various traits: body length, 9; backfat thickness, 14; size and shape of ham, 12; daily gain, 10; age at slaughter, 9; and feed economy, 11.

Fall pigs yielded considerably better carcasses than spring pigs, as was indicated by a 5.02 percent higher adjusted loin equivalent index, Warren and Dickerson (1952). The greater fatness and lower dressing percentage were the major causes of the lower adjusted loin equivalent values of the spring pigs. Also the season means showed the backfat of the fall pigs to be thinner than that of the spring progeny by 2.73 mm.

On the basis of the preceding citations, it is apparent that environmental differences have an important influence on carcass characteristics in swine. It is highly desirable to remove the effects of such influencing factors, or circumvent them, to minimize the non-genetic variations in the data, thereby obtaining a more complete expression of the additive gene differences.

b. Effect of Sex on Carcass Composition

Carcass characteristics are known to be greatly affected by the sex of the pig. Lacy (1932) and Warner, et al. (1934) reported that barrows had a higher percentage of all fat cuts while gilts had a higher proportion of ham and loin. McMeekan (1940) observed that barrows had less bone and muscle and more fat than gilts. The influence of sex on carcass length was reported to be significant although not large, Lush (1936); however, the influence of sex on belly thickness and on the thickness of backfat was highly significant. The significance of these sex differences were recognized by the Danes prior to

1937 and they calculated correction factors to be applied when litters entered on the progeny test were not equally balanced for sex.

The general superiority of carcasses from gilts over those from barrows was further substantiated by the work of Hammond and Murray (1937), Bennet and Coles (1946), and Crampton and Ashton (1945,1946). In an extensive study of the Canadian Yorkshire breed, Fredeen (1953) used the method of least squares to estimate the effects of sex, and then corrected for sex using the calculated constants. Anderson (1954) reported that barrows were .2 inch shorter in body length and .1 inch longer in leg length than females. The barrows also yielded 1.2 percent more fat cuts and 1.4 percent less lean cuts. The gilts had .2 inch less backfat.

The underlying causes of the difference between the sexes in carcass composition were partially elucidated by Comstock and Winters (1944). These workers reported that "the body form changes as animals increase in size since most of the relative growth constants were larger or smaller than one, and that there are genetic differences in the course of changes in form since breed and line differences in relative growth constants were demonstrated."

Whiteman and associates (1953) in their study of the use of specific gravity as a measure of carcass leanness found sex to be an important source of variation. Correlations of specific gravity with other carcass measurements in a group of carcasses including both barrows and gilts were generally

significant and higher than those correlations in another group of carcasses from barrows only. Whiteman (1952) using 82 barrow-gilt full-sib pairs found that the mean difference between the sexes for a number of carcass measurements was highly significant. Gilts were found to be leaner and longer than barrows, to have a lower dressing percentage, but in spite of the latter, yield a higher percentage of lean cuts. Correlation coefficients between differences in age at slaughter and the corresponding sex differences in specific gravity, average backfat thickness and loin lean area were not significantly different from zero, indicating that sex differences in carcass measurements are not due to differences in rate of gain.

c. Effect of Weight on Carcass Composition

The changes that occur in the form and composition of an animal are the result of orderly changes in the proportion of differentially growing parts. McMeekan (1940,1941) in a study of the post-natal development of the pig reported a well-defined differential growth of the major tissues with skeleton, muscle tissue, and fat developing in that order. Thus the skeletal units of the head and trunk exhibited an anterior-posterior gradient from earlier to later developing regions while the limbs showed a centripetal gradient with the lower regions developing first. The muscle tissue surronding the skeletal framework, and the even later developing fat tissue, demonstrated similar anterior-posterior gradients in deposition.

It is highly probable then, that breeds and lines could ex-
hibit differences in carcass composition if the pigs were
slaughtered at a constant weight rather than at a constant
stage of maturity.

Hammond and Murray (1937), in a study involving 900
carcasses of four English breeds of swine, found that a ten
pound increase in carcass weight within the weight range of
130 to 190 pounds was associated with an average increase of
.48 inch in length, .07 inch in belly thickness, .10 inch in
shoulder fat, and .10 inch in loin fat. The rate of fat de-
position decreased with increasing carcass weight but this de-
crease was greatest at the shoulder and least at the loin.
Practically identical results were reported by Stothart (1938)
in his study of 324 Yorkshire carcasses.

Using 60 hogs with a final feed-lot weight ranging from
93 to 250 pounds, Hankins and Ellis (1934) found a correlation
coefficient of .67 between weight of the chilled carcass and
the percentage of fat in the total edible portion of the car-
cass. The corresponding coefficient of determination, .45,
indicates that slightly less than 50 percent of the variation
in fat content of the edible portion of the carcass is assoc-
iated with weight alone, when the latter is regarded as an
independent variable. Aunan and Winters (1949) with only 30
carcasses reported a negative correlation of -.69 between
carcass weight and percentage of the five primal cuts. In a
study of data from 700 carcasses of variable origin, Cummings
and Winters (1951) reported correlations coefficients of .36

between cold carcass weight and index of fat cuts and a nega-
tive correlation of -.38 between cold carcass weight and yield
of the five primal cuts.

Fredeen (1953) in his analysis of the data from 12,084
pigs found it convenient to group the cold carcass weights in-
to discrete intervals of five pounds each, because variation
in carcass weight measured to the nearest quarter pound was
practically continuous. The data were then corrected for car-
cass weight by using the calculated constants. Carcass measure-
ments showed an almost linear response to weight changes. Heav-
ier carcasses were longer, showed an increase in all fat
measurements, a greater loin area, and a greater proportion of
middle as reflected by a decreased percentage of ham and shoul-
der. The fact that all pigs were slaughtered at nearly the
same live weight means that pigs having high yields of fat
automatically have lower yields of lean, except as their total
carcass yields are higher.

Anderson (1954) found that a five pound increase in car-
cass weight resulted in an average increase of .18 inch in
body length, .11 inch in leg length, .18 inch more backfat,
.73 percent more of fat cuts, and percent lean cuts decreased
by .55 percent. All of these changes in carcass composition
associated with weight attained high statistical significance.

d. Influence of Line and Breed on Carcass Composition

Carcass differences between lines and breeds have been
reported by Craft (1953) in his summary of work of the Regional

Swine Breeding Laboratory. This report is concerned with the data from approximately 100 inbred lines within seven breeds and exemplifies the wide source of genetic material that has been under investigation.

Selection on the basis of the progeny test under the Danish system has been effective in changing carcass characteristics in swine produced in Denmark over a period of years according to Lush (1936). Breed differences were noted in response to selection for increase in body length, for increase in belly thickness, and for a decrease in backfat thickness.

Hammond and Murray (1937) observed that first cross pigs from two pure breeds at similar weights produced carcasses in which the backfat and belly thickness were intermediate between the two parental breeds but the body length was slightly above the mean of the parental breeds. Hankins and Ellis (1937) also noted breed differences for backfat measurements, length of carcass and the weight of the various cuts.

Donald (1940) in a study of two groups of bacon pigs found hereditary differences in the relationship between growth rate and carcass characteristics, suggesting that it might be unwise to attempt to make detailed predictions of carcass quality on the basis of growth rate. He further observed hereditary differences in the relationship between backfat thickness and length of loin.

Dickerson (1947) reported that only in yield of lean cuts and in leg length were differences between lines of Poland-Chinas appreciably larger than those between sire progenies

within lines (the error term for testing statistical signif-
icance of line differences.) Blunn and Baker (1947) suggested
that breed differences caused their correlations between fat-
ness and rate of gain to differ from Dickerson's (1947). Their
study was with Durocs whereas Dickerson's study was primarily
with Poland-Chinas.

In a report of the work at the Minnesota station,
Cummings and Winters (1951) found that Poland-Chinas yielded
the highest proportion of hams, and whenever the Poland-
China lines were used in crosses, the ham yield was increased.
The outbred Durocs gave a high yield of belly but of low grade,
because of the excessive amount of fat and a very noticeable
lack of lean. It is suggested that the yield figure in this
case is not adequate in appraising the true value of the car-
cass. The Minnesota No. 1 carcasses produced bacon which was
of excellent quality and higher in yield than that of any other
group in the experiment. The carcasses also had a very high
yield of loin (because of their increased body length) and this
was also shown in crosses between this line and the Poland-
China lines. The most outstanding features of carcasses of the
Minnesota No. 2 breed were high yields of loin, low index of
fat cuts, marked fullness of the "kernel of lean" of the loin,
and increased thickness of the belly.

Whiteman, et al. (1951) in a study of carcasses from in-
bred lines, two-line crosses, three-line crosses and outbred
Durocs, an inbred line of Landrace-Polands, and crosses between
these two breeds found small differences between the breeding

groups within the Duroc breed. The Landrace-Poland carcasses, though somewhat soft, were longer, leaner, and considerably higher in percentage of three lean cuts. In the opinion of the authors, the crossbred carcasses were the most desirable.

In an evaluation of the line performance in crosses, Warren and Dickerson (1952) found that highly significant proportions of the variance in backfat thickness were due to line of sire (.19) and line of dam (.31) effects. Differences between lines in equivalent yield of loin were found to be highly significant.

It seems reasonable in the light of these reports, that differences between breeds and between lines within breeds are of sufficient magnitude to justify considering the effects they might have in causing differences among pigs. These differences are recognized as possibly being hereditary, however, interest in the present study is directed more toward the heritability of intra-line differences than for interline or inter-breed differences.

e. Heritability Estimates

The estimates of heritability of the variance for most of the carcass characteristics are few in number. Sampling errors undoubtedly make a large contribution to the variability of these estimates, although some of the variation may come from genuine differences between breeds.

A summary of the estimates of heritability for the various carcass traits, as found in the literature, are presented

TABLE I HERITABILITY ESTIMATES OF SWINE CARCASS TRAITS

Trait	Estimate	Breed[1]	Method[2]	Reference
Back-	.80	D.L.	(c)	Lush (1936); 122 d.f. for sires
fat	.55	D.L.	(d)	Lush (1936); 320 d.f. for dams
thick-	.47	D.L.	(a)	Lush (1936); average of 3 methods
ness	.12	Duroc	(c)	Blunn & Baker (1947); 40 d.f. sires
	.37	York.	(b)	Stothart (1947); 58 d.f. for sires
	.54	P.C.& L.	(c)	Dickerson (1947); 62 d.f. for sires
	.40	P.C.& L.	(c)	Anderson (1954); 69. d.f. for sires
	.52	L.W.& L.	(c)	Johansson & Korkman (1950); 455 d.f.
shld	.42	York.	(c)	Fredeen (1953); 647 d.f. for sires
back	.33	York.	(c)	Fredeen (1953); 647 d.f. for sires
loin	.48	York.	(c)	Fredeen (1953); 647 d.f. for sires
% Fat	.52	P.C.& L.	(c)	Dickerson (1947); 62 d.f. for sires
Cuts	.69	P.C.& L.	(c)	Anderson (1954); 69 d.f. for sires
Belly	.62	D.L.	(c)	Lush (1936); 122 d.f. for sires
thick-	.44	D.L.	(c)	Lush (1936); 320 d.f. for dams
ness	.46	D.L.	(c)	Lush (1936); average of 3 methods
	.40	L.W.& L.	(c)	Johansson & Korkman (1950); 455 d.f.
Car-	.78	D.L.	(c)	Lush (1936); 122 d.f. for sires
cass	.81	D.L.	(c)	Lush (1936); 320 d.f. for dams
Length	.54	D.L.	(c)	Lush (1936); average of 3 methods
	.42	York.	(b)	Stothart (1947); 58 d.f. for sires
	.40	York.	(c)	Fredeen (1953); 647 d.f. for sires
	.62	L.W.& L.	(c)	Johansson & Korkman (1950); 455 d.f.
	.73	P.C.& L.	(c)	Dickerson (1947); 62 d.f. for sires
	.48	P.C.& L.	(c)	Anderson (1954); 69 d.f. for sires
Leg	.73	P.C.& L.	(c)	Anderson (1954); 69 d.f. for sires
Length	.58	P.C.& L.	(c)	Dickerson (1947); 62 d.f. for sires
	.23	In. Dur.	(c)	Blunn & Baker (1947); 40 d.f. sires
Loin	.16	York.	(b)	Stothart (1947); 58 d.f. for sires
Area	.66	York.	(c)	Fredeen (1953); 647 d.f. for sires
% Lean	.29	P.C.& L.	(c)	Dickerson (1947); 62 d.f. for sires
Cuts	.15	P.C.& L.	(c)	Anderson (1954); 69 d.f. for sires

[1]Breed abreviations given at the end of the table on the following page.

[2]Methods of calculating heritability estimates are given at the end of the table on the following page.

TABLE I CONTINUED

Trait	Estimate	Breed[1]	Method[2]	Reference
Carcass	.35	York.	(c)	Fredeen (1953); 647 d.f. for sires
Score	.35	York.	(b)	Stothart (1947); 58 d.f. for sires
Belly Score	.14	York.	(c)	Fredeen (1953); 647 d.f. for sires
% Shld.	.38	York.	(c)	Fredeen (1953); 647 d.f. for sires
% Ham	.51	York.	(c)	Fredeen (1953); 647 d.f. for sires
Ham Size	.61	L.W.& L.	(c)	Johansson & Korkman (1950);455 d.f.
Ham Circum.	.17	In. Dur.	(c)	Blunn & Baker (1947); 40 d.f. sires

[1] Breed abreviations are as follows: D.L. – Danish Landrace; In. Dur. – Inbred Durocs; York. – Canadian Yorkshire; P.C.& L. – Poland China and Landrace; L.W.& L. – Large White and Landrace.

[2] Methods of calculating heritability are as follows:
(a) Based on the average of three methods using correlations between paternal $\frac{1}{2}$ sibs (122 d.f.), correlations between maternal $\frac{1}{2}$ sibs (320 d.f.), and correlations between progeny averages of sire and son (236 d.f.).
(b) Computed from the regression of the progeny on the mean of the paternal full-sibs.
(c) Paternal $\frac{1}{2}$ sib correlation computed from an analysis of variance.
(d) Maternal $\frac{1}{2}$ sib correlation computed from an analysis of variance.

in Table 1. In general about half of the variance in carcass
length and thickness of backfat are due to additive gene
effects, while the figure for thickness of belly is probably
a little less. In the Danish Landrace the estimates of herit-
ability based on the average of three methods of computation
were thought to be the most reliable, Lush (1936). These
estimates were .47 for backfat thickness and .54 for length.
Higher estimates were obtained by Dickerson (1947) for inbred
lines of Poland-China and Landrace, and by Johansson and
Korkman (1950) for the Swedish Landrace and Large White. This
may indicate actual breed differences in the heritability of
these traits. However, the estimation procedure employed by
Lush (1936) allowed for the relationship probably existing be-
tween sows within a herd whereas, the estimates by the other
authors were not corrected for possible relationship of dams.

The importance of heredity as a source of variation in
loin lean area is borne out by the estimate of .66 for the
heritability of loin area, Fredeen (1953). This estimate is
four times as large as that of Stothart (1947) but the reason
is not apparent. Other measures of carcass leanness, such as
percentage lean cuts, were found to have less than one third
of their variance due to additive effects of genes.

Because of the subjective nature of the measurement of
belly score, and the many factors that influence belly grade
there is reason to suspect that belly score might be lowly
heritable. The estimate of .14 bears this out, since it is
much lower than the heritability for any of the other traits.

f. Phenotypic Correlations

External measurements of the carcass do not provide reliable indications of the quality of the bacon carcass. Therefore, concentration on internal measurements is desirable if further improvement in prediction is desired. Numerous investigators have reported phenotypic correlations between many carcass characteristics in swine. The results of the majority of these investigations are summarized in Table II.

Lush (1936) states that it is perfectly clear and almost inevitable that some of the carcass characteristics 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. Thus thickness of backfat and thickness of belly could be physiologically so closely related to each other that changes in one would tend to be accompanied by changes in the other. The average backfat thickness is highly indicative of the fat content of the edible portion of the pork carcass as shown by Hankins and Ellis (1934). The high positive correlation between average backfat thickness and percentage fat cuts, as well as, the strong negative correlations of backfat thickness with percentage lean cuts, as cited in the accompanying table certainly corroborates this relationship. Some of the early work suggested that the use of the percentage yield of fat cuts might be offered as a fat index of the entire carcass, but from more recent observations, it is doubtful that the belly should be

included in the index because of its great variation in ratio of lean to fat. Correlations of average backfat thickness with loin lean area, lean area of ham, percentage of five primal cuts, and percentage lean in the carcass, are negative and high. This indicates that the fatter carcasses produce less lean meat which, of course, is at least partly automatic when the pigs are slaughtered at a nearly constant weight.

McMeekan (1940) found that a combination of length and depth measurements of the "eye" muscle provided a reliable basis for estimating the amount of muscle in the carcass. The size of the loin eye muscle determines the real value of the pork loin to a large extent. The correlations given in the table between the area of lean in the loin and the percentage of lean cuts are positive and rather high.

Intra-group correlations between specific gravity and area of the loin eye, percentage primal cuts, percentage lean cuts, and carcass length, were positive and highly significant, Brown, et al. (1951). Furthermore percentage of lean cuts was more highly correlated with specific gravity than it was with backfat thickness or area of loin eye. There apparently is little difference between the relationship of specific gravity, percentage of lean cuts or percentage of fat cuts to such other criteria of fatness or leanness as the percentage of ether extract, protein or moisture.

The correlations between length and backfat measurements are important and negative. The agreement between the results reported by various authors, involving highly variable experi-

Key to the Source of Phenotypic Correlations Presented On

the Opposite Page

(a) Aunan and Winters (1949), 30 hogs.

(b) Stothart (1938), 57 d.f.

(c) Lush (1936), 1285 litters.

(d) Brown, et al. (1951), 64. d.f.

(e) Johansson and Korkman (1950), 1208 litters.

(f) Fredeen (1953), 1638 d.f.

(g) Crampton (1940), 171 d.f.

(h) Dickerson (1947), 746 hogs.

(i) Cummings and Winters (1951), 708 hogs.

(j) Hazel and Kline (1952), 94 hogs.

(k) Bennet and Coles (1946), 179 d.f. - gilts.

(l) Bennet and Coles (1946), 219 d.f. - barrows.

(m) Anderson (1954), 550 hogs.

(n) Whiteman (1952), 101 hogs - barrows and gilts.

(o) Whiteman (1952), 102 hogs - barrows.

(p) Warren and Dickerson (1952), 8 lines.

(q) Dickerson and Grimes (1947), 493 hogs.

TABLE II   PHENOTYPIC CORRELATIONS OF SWINE CARCASS TRAITS

Trait	Back-fat Thick-ness	Spec. Grav.	Loin Lean Area	Percent Lean Cuts	Percent Fat Cuts	Car-cass Wt.	Shld. Fat	Loin Fat	Source[1]
Length	-.22		.38	.12		.41			(a)
	-.20								(c)
	-.38								(c)
	-.62	.56		.54	-.61				(d)
	-.27		-.07				-.22	-.20	(f)
	-.36								(e)
			.06	.10					(g)
	.06			.13	-.14				(m)
			-.18			.39	.06		(b)
			.08				-.23		(k)
			-.02				-.46		(l)
				.03					(h)
					-.11				(i)
Back-fat Thick-ness		-.68	-.37	-.72	.69	.38			(d)
		-.75	-.44	-.78					(n)
		-.48	-.26	-.59					(o)
			-.12				.51	.62	(f)
			-.41						(j)
				-.63	.79	.49			(a)
				-.54					(g)
				-.72	.77				(m)
							.62		(b)
Spec. Grav.			.60	.87					(n)
			.34	.65					(o)
			.46	.84	-.78	-.42			(d)
Per-cent Lean Cuts			.51		-.81	-.35			(d)
			.67						(n)
			.46						(o)
					-.78				(m)
Per-cent Primal Cuts	-.67	.68	.41	.84	-.60	-.29			(d)
	-.58					-.69			(a)
	-.65					-.38			(i)
	-.45								(j)
Shld. Fat						.27			(b)
			-.19					.53	(f)
% Fat Cuts	.75					.36			(i)
			-.47			.09			(d)

[1]Key to the source of the correlations and the degrees of freedom associated with each are given on the opposite page.

mental conditions and materials, is good. The explanation is probably the same as that considered by Lush (1936), namely that slaughter at a constant live weight would require that pigs longer than average be smaller in some other dimension. The correlations between length and loin lean area are erratic varying from .39 to -.18. This could probably be suggested as evidence for strain differences in trait relationships.

All backfat measurements show high positive correlations with one another, and are associated with a smaller loin lean area. Thus an increase of thickness of fat over the back is indicative of an increase of total fat in the carcass, and a corresponding reduction in lean cuts. The ratio of backfat thickness at the shoulder to backfat thickness at the loin decreases earliest in the early maturing breeds. Because the region of the last rib is the latest maturing part of the body, Hammond and Murray (1937) suggested that it should be at this place that the carcass should be cut in order to obtain a proper estimate of its development.

Age at slaughter was found to be correlated -.10 with length of carcass according to Fredeen (1953). At first this correlation seems anomalous, however, a reasonable biological interpretation is that long pigs, with a longer frame for deposition of fat and lean, will be heavier at a given age than their shorter contemporaries. Consequently, holding carcass weight constant would introduce a negative correlation between age and length. A correlation of .14 between age at slaughter

and length was reported by Stothart (1937), but his data were
not corrected to a constant carcass weight.

g. Genetic Correlations

The methods of computing genetic correlations were
developed by Hazel (1943) and Hazel, et al. (1943). Because
of the recent development of the methods of separating the
gross correlations into their genetic and environmental com-
ponents there are few genetic correlations between economic
traits in swine reported in the literature.

Dickerson (1947) computed his genetic correlations from
covariances and variances obtained from differences between
two or more independent sets of mean squares and products.
With this procedure sampling errors may cause the correlations
to fall by chance beyond the range of $+ 1$ to $- 1$. The corre-
lations of the sire deviations are an indication of the ex-
tent to which a pig's own inherited traits are merely differ-
ent physiological expressions of the same genes.

The high positive correlation between backfat thickness
and rate of gain and between percent fat cuts and rate of gain,
along with the strong negative correlations between percent
lean cuts and rate of gain, indicate that more of the genes
which increase the individual's own rate of gain act by ac-
celerating fat deposition than by stimulating bone and muscle
growth. Such genes therefore tend to produce fatter carcasses
at a given live weight. The findings of Hazel, et al. (1943)
that the genetic correlation was no higher than .7 between

TABLE III GENETIC CORRELATIONS OF CARCASS TRAITS, RATE AND

ECONOMY OF GAIN

Trait	Carcass Length	Backfat Thickness	Percent Fat Cuts	Percent Lean Cuts	Loin Lean Area	Feed Per Unit Gain	Rate of Gain	Source[1]
Feed Per Unit Gain	.18	-.15	.05	.28			-1.70	(m)
	.27	-.58	-.72	.64				(h)
	.02	-.01			-.13			(f)
							-.78	(p)
Backfat Thickness	-1.24		1.10	-1.15			.02	(m)
	-.27				-.08	-.01		(f)
	-.42							(e)
							1.34	(h)
Carcass Length			-.53	.65			-.71	(m)
							.06	(h)
					-.17	.02		(f)
Leg Length	.44	.26	-.79	-.08		-.78	-1.81	(m)
						.03	-.57	(h)
% Fat Cuts				-1.53			.56	(m)
							.75	(h)
% Lean Cuts							-.26	(m)
							-.61	(h)
% Shld.	-.02	-.50			.17	-.04		(f)
% Ham	-.23	-.36			.27	-.09		(f)
Shld. Fat	.17	.65			-.16	.03		(f)
Loin Fat	-.11	.74			-.19	.00		(f)
Loin Equiv.						-.21	.15	(p)
180 Day Weight	-.12	.88	.26	-.36				(h)
Age at 200 lbs.	-.15	.05			.10	.37		(f)
72 Day Weight						-.54	.65	(q)

[1] Key to the source of the correlations and the degrees of freedom associated with each are the same as those for Table II, and are listed opposite page 25.

gains in consecutive 56-day periods and was only .45 between gains in the 0-56 and in the 112-168 day periods also indicate that different genes may affect muscle and fat deposition. McMeekan (1940) has emphasized the marked increase in rate of fat deposition relative to rate of muscle growth which occurs between 3 and 4 months of age in swine.

The correlation of measures of carcass fatness, such as backfat thickness and percent fat cuts, with carcass length and leg length are strongly negative. Presumably the relationship is at least in part automatic. Carcasses larger than average in one dimension would show less development in another dimension when slaughter weight is held constant. The same kind of association would hold for the strong negative relationship between percent lean cuts and percent fat cuts and backfat thickness.

The correlation between carcass length and leg length is positive, indicating that they tend to be influenced by the same genes. This is quite reasonable because they are both measures of skeletal development.

In general, feed requirement per unit of gain and rate of gain show opposite associations with carcass composition. This is to be expected in the light of the high negative correlation between feed economy and rate of gain. Dickerson's (1947) results imply that the negative correlation between heritable deviations in feed requirements and carcass fatness is about of the same magnitude as the corresponding positive correlation between rate of gain and carcass fatness. This would suggest

that among individuals of the same inherent rate of gain those
which have inherently lower nutritional requirements for main-
tenance and activity deposit more fat but grow less muscle and
bone.

h. Live Animal Measurements

Extensive studies have been reported on the relation-
ship of such factors as type, conformation, and degree of
finish, to carcass quality in swine. Few attempts, however,
have been made to determine the value of individually re-
corded body measurements for predicting the quality and quant-
ity of a hog carcass. Such information would be particularly
desirable in a breeding program where improvement in carcass
quality is a major objective.

Hetzer, et al. (1950) in a study of eight live animal
measurements found a maximum correlation of .50 between the
yield of the five primal cuts and any of the live animal
measurements. Depth of middle was the most important item in
determining the yield of the primal cuts. Next in importance
were the width of middle and height at the shoulders. Bogart,
et al. (1940) studying the carcass yields of 69 Poland-China
hogs in their relation to the scores and measurements of the
various characteristics in the live animals, found that both
scores and measurements were of little value for predicting
the yields of ham, loin, shoulder and belly.

Kraybill, et al. (1951) estimated body fat in cattle
from measurements in vivo of body water by the use of anti-

pyrine. Body water values determined on 30 head of beef cattle by the antipyrine method agreed closely with values calculated from specific gravity. Body fat values derived from body water values by the antipyrine and specific gravity methods agreed well with the body fat content determined from direct analysis of the carcass samples. The extremely heterogeneous nature of the material consisting of steers, heifers and cows, varying widely in age, weight and condition, undoubtedly influenced the correlations. Chemical methods such as this may be highly accurate, however, their usefulness is limited because of the time and labor involved.

Hazel and Kline (1952) described a simple and rapid "probing" method for measuring backfat thickness of live hogs. The measurements are available immediately. The accuracy of this method is expressed in the correlations of average back-fat thickness on the carcass with the individual live-hog measurements at the following sites: behind the shoulder, .79; middle of the back, .59; middle of the loin over the longissimus dorsi, .67; middle of the loin over the vertebra, .73; and average of the four live-hog measurements, .81. From correlation studies with lean cuts it appeared that live-hog measurements were more accurate indicators of leanness and carcass value than the average of the carcass backfat measurements. In a further study, Hazel and Kline (1953), reported on probes at eight sites in an attempt to refine and improve the accuracy of the "probe technique". The correlations between four backfat measurements taken on carcasses and the percent

of lean cuts and fat cuts were −.75 and .79 respectively. These figures are interpreted as evidence that measurements at some sites reflect fatness and leanness as acccurately as backfat measurements on the carcass. The sites behind the shoulder, over the loin, and on top of the ham have greatest accuracy.

Zobrisky, et al. (1953) found significant negative correlations between lean cuts and the live-hog backfat probes, and significant positive correlations between probes and total fat of the carcass.

MATERIALS AND METHODS

1. Carcass Evaluation

a. Source of data

The carcasses used in this study were those of pigs slaughtered in the Swine Breeding Project conducted at the Oklahoma Experiment Station in collaboration with the Regional Swine Breeding Laboratory. There were 547 carcasses processed in the college meats laboratory at Stillwater and information on the 416 carcasses from the Fort Reno station was obtained through the cooperation of Wilson & Co.,Oklahoma City. Both fall and spring farrowed pigs were used. The Stillwater data were collected from the fall of 1947 through the fall of 1953, whereas the Fort Reno data were collected from the spring of 1950 through the fall of 1953.

The breeding groups embrace a rather diverse origin of genetic material. The data were derived from a highly variable mating system including topcrossing, inbreeding and line crossing within the Duroc breed, Duroc females mated with boars of the Landrace-Poland, Poland-China, Chester White, Minnesota No. 1, Minnesota No. 2, Montana No. 1, Landrace and Hampshire breeds. An analysis on an intra-line, breed, season, station basis did not seem feasible because of the small unequal numbers involved. Moreover many of these reciprocal

crosses, lines, and mating groups were very similar in origin
and did not yield a highly heterogeneous group of carcasses.
Consequently, it seemed logical, to amalgamate into larger
breeding groups some of these lines of similar breeding. All
the topcross, linecross, outbred and inbred Durocs were class-
ified as Durocs resulting in a total of 339 carcasses in this
breeding group at the Stillwater station. Likewise the recip-
rocal crosses of Landrace-Poland and Oklahoma line 8 Durocs
were handled as a group comprising 177 carcasses. A total of
31 carcasses represented the Landrace-Poland breed. Of the
Fort Reno data the largest group was that one including all
of the various kinds of mating within the Duroc breed. All of
the 960 carcasses were classified into ten breeding groups and
a complete description of these groups is summarized in Table
XVI of the Appendix.

A summary of the distribution of carcasses by season
and breeding group is given in Table IV. The separation of the
Duroc breeding group by stations was necessary because of the
difference in herd management and carcass measurements. Two
pigs of each sex from each litter were fed in dry-lot at
Stillwater and one of each sex was selected at random to pro-
vide the carcass information. The Fort Reno pigs were self-fed
on alfalfa pasture, in lots according to mating group. Usually
the first five to ten pigs in a lot, to reach market weight,
were nominated for the carcass test. In the last six of the
eight seasons carcass information was obtained on barrows only.
By discarding the information on 72 gilts the analysis could

TABLE IV DISTRIBUTION OF CARCASSES BY SEASON AND BREEDING GROUP[1]

STILLWATER

Season	Duroc	Duroc x Land.-Pol.	Land.-Pol.
1953 Fall	18	44	11
1953 Spring	--	58	--
1952 Fall	31	--	--
1952 Spring	42	--	--
1951 Fall	16	16	8
1951 Spring	--	47	--
1950 Fall	12	6	2
1950 Spring	26	--	5
1949 Fall	36	6	5
1949 Spring	51	--	--
1948 Fall	33	--	--
1948 Spring	38	--	--
1947 Fall	36	--	--
Totals	339	177	31

FORT RENO

Season	Duroc	Land. x Duroc	Poland x Duroc	Chester x Duroc	White King x 8-9	Minn.No. 2 x Duroc	So. Dak. Hamp. x T-3
1953 F	19	13	16	5	--	--	--
1953 S	20	12	13	8	--	--	--
1952 F	20	8	9	--	4	6	--
1952 S	23	6	14	--	8	8	--
1951 F	17	12	12	--	--	--	7
1951 S	16	15	15	--	--	--	8
1950 F	19	9	--	10	--	5	--
1950 S	29	10	10	--	--	10	--
Totals	163	85	89	23	12	29	15
Barrows	130	75	79	15	10	17	15

[1]See Appendix Table XVI for description of breeding groups.

be very much simplified. Consequently all estimates made from
the Fort Reno data are based on barrows only, the total number
in each breeding group being given as a sub-total in Table IV.
A discussion of the discrepancies of the methods of cutting
and measuring between the two sets of data follows.

b. Method of Slaughtering and Dressing Hogs

Live hog weights are subject to considerable error be-
cause the time at which they are taken varies in relation to
the time of slaughter. Furthermore, individual hogs show a
variable amount of shrink in transit. To minimize these errors
shrunk live weights were obtained and used as the basis of all
yield calculations.

The carcasses were dressed packer style with head off
and leaf fat removed. The weight of the leaf fat was obtained
for each hog of that group processed in the college meats
laboratory.

c. Carcass Cutting and Measurements

The following measurements were taken at the Stillwater
station on each carcass after it was thoroughly chilled:

carcass length - from the anterior edge of the first rib to
                 the aitch-bone with carcass flat on the
                 table (both sides measured)
average backfat thickness - average of the measurements taken
                 at the first rib, seventh rib, last rib and
                 sixth lumbar vertebra, including skin (both
                 sides measured)
specific gravity - as described by Brown, et al.(1951). In
                 1953 Fall specific gravity was obtained on
                 hams only.
loin lean area - the product of the width times the depth of
                 the loin eye muscle of the right loin cut
                 at the last rib.

The front foot was removed by sawing through the knee joint and the hind foot through the hock joint. The ham was removed from the side by sawing at right angles to the hind leg and mid-way between the aitch-bone and the curvature of the lumbar vertebrae. After reaching the point where the ham flank is properly protected on the belly side, the ham was cut off and rounded so as to leave maximum flank on the belly. The tail bone was removed with a minimum of adhering tissue. The hams were skinned starting at a point on the cushion side about three inches from the wrinkle at the base of the hock and the fat beveled down to a very close trim. The very close trimming of all cuts was thought desirable from a standpoint of minimizing cutting error.

The shoulder was removed at the third rib with a cut at right angles to the backbone. The neck bones and ribs were removed. The shoulders were skinned and trimmed in a similar fashion to that of the hams. The loin was separated from the belly by cutting just below the curve in the backbone at the shoulder end and at the edge of the tenderloin muscle at the ham end. The loins were very closely trimmed. The spare-ribs were removed from the side, taking as little lean as possible and avoiding damage to the belly. The flank end of the belly was cut parallel to the shoulder end leaving the belly as long as possible. The belly edge was straightened and trimmed sufficiently to remove all evidence of "seed".

The four major cuts were weighed separately to a tenth of a pound and recorded. The fat trimmings and skin from all

cuts, and the leaf fat were weighed together and recorded as fat trimmings. The lean trimmings included the glands in the neck and any portions of the lean containing not more than 30 percent of fat trimming from the major cuts.

d. Calculation of Carcass Yields

The yield of each of the wholesale cuts described above was determined for each hog and expressed as a percentage of the shrunk live weight. The combined weight of the two sides was used to calculate dressing percentage. Likewise the combined weight of both the hams, the loins, the shoulders, and the bellies were expressed as a percentage of the shrunk live weight. The percent of lean and fat trimmings were calculated in the same manner. The percentages of ham, loin and shoulder thus obtained were totaled and expressed as the percent lean cuts. The percent primal cuts included the percent lean cuts and the percent belly.

The carcass index is a figure calculated in such a manner as to weight all the major cuts in proportion to their relative economic value. This monetary value is based on the Chicago wholesale pork prices as reported weekly in the National Provisioner for a five year post World War II period. The highest priced cut was assigned a value of 1.0 and an appropriate fraction thereof, was calculated for each of the other cuts. These relationships were then used with the percentage of the respective cuts to determine the loin equivalent or carcass index. For example:

cut	relative value	% chilled carcass	product
loin	1.0	12.0	12.00
ham	.9	12.5	11.25
shoulder	.8	12.8	10.24
belly	.8	11.7	9.36
lean trim	.7	2.2	1.54
fat trim	.2	21.6	4.32

Carcass index = 48.71

Season, locality, consumer preference and other factors will cause these relative values to fluctuate. In fact, the prices used to evaluate the carcasses in the 1954 Feeder's Day Report have the hams with a value of 1.14 times, and the bellies 1.06 times that of the loin, whereas the lean trim has dropped from .7 to .5. In this study the index for all carcasses was calculated using the values cited in the example. Presumably the standardization of measurement defined the goal more accurately and permitted the comparison of all individuals.

The above methods of cutting carcasses and calculating yields apply to the Stillwater data. Some necessary modifications in the Fort Reno data are worthy of mention.

Specific gravity and loin lean area were not obtained on any carcasses processed by Wilson & Co. Less fat was removed from the hams, loins and shoulders. Since only one cut was made to separate the ham from the loin it is conceivable that the ratio of ham to loin could easily be altered. The magnitude of the cutting error, thus introduced by altering the point of separation between cuts to take advantage of changing price relationship, is unknown. Lean trim and fat

trim were not available and consequently are not included in

the carcass index. The index for the Fort Reno pigs, while

being lower, was still comparable within that group. Carcass

length was measured with the carcass hanging on the rail,

and only one side measured. The backfat thickness was measured

at the seventh rib and only on one side. The correlation be-

tween average backfat thickness (average of backfat thickness

at the thinnest part, the thickest part and directly over the

spinous process of the seventh thoracic vertebra) and backfat

thickness at the seventh rib is .94 as reported by Cummings

and Winters (1951).

e. Probe Measurements

The probe measurements available for this study were

made on 53 of the 1953 Spring pigs at Fort Reno, on 58 of the

1953 Spring pigs at Stillwater and on 73 of the 1953 Fall

pigs at Stillwater. Probe measurements were taken behind the

shoulder and at the middle of the loin over the longissimus

dorsi on one side of the 111 pigs pigs of the Spring season.

All of these pigs were subsequently slaughtered by Wilson &

Co. and consequently the backfat thickness was measured at

the seventh rib only. The remaining 73 pigs were probed be-

hind the shoulder, at the middle of the back and the middle

of the loin over the longissimus dorsi on both sides. They

were then processed in the college meats laboratory and back-

fat thickness measured at four places on both sides of the

carcass. This permitted a study of the correlations between

average carcass backfat thickness and average probe backfat

thickness as well as correlations of individual measurements

to determine which sites were most accurate. All of the above

mentioned probe measurements were made when the pigs had

attained a market weight of about 210 pounds.

In addition to these final probe backfat measurements

a series of probes were made on pigs of younger ages to study

the pattern of backfat deposition. Forty eight pigs were se-

lected (12 line 8 Durocs, 12 line 9 Landrace-Polands and 12

each of the reciprocal crosses between these two lines) to be

probed at 56, 84, 112, and 140 days of age. These 48 pigs

were probed behind the shoulder and at the middle of the back

and the middle of the loin over the longissimus dorsi alter-

nating right and left sides with the various ages, and at

market weight the three measurements were taken on both sides.

2. Statistical Procedures

Controlling the environment so that variations in it

will not make discrepancies between the individual's pheno-

type and its breeding value will make selection more accurate

in any breeding program. Control of the environment can be

achieved either physically through actually preventing vari-

ations in the environment or statistically through correcting

for those variations after they have occured. Essentially

this is the application of correction factors to individual

records to remove phenotypic differences resulting from

varying environmental conditions. The effectiveness of the statistical control will depend upon the adequacy of the model chosen for the analysis and on the accuracy of the correction factors.

a. The Model

The method of least squares for estimation in a multiple classification with disproportionate sub-class frequencies has been described by Yates (1934) and the operational procedures in application to animal breeding have been discussed by Henderson (1948) and Hazel (1946). An excellent discussion of the estimation of heritability of various production traits in poultry by use of the variance components procedure is given by King and Henderson (1954).

The following linear model considered to be representative of the biological situation was chosen for the genetic analysis of the Stillwater data.

$$Y_{rijkmp} = \mu + S_r + T_i + B_{ij} + F_{ijk} + D_{ijkm} + E_{ijkmp} \quad (1)$$

where r = 1, 2.
      i = 1, 2,....., 13.
      j = 1, 2, 3.
      k = 1, 2,.....,149.
      m = 1, 2,.....,285.
      p = 1, 2,.....,N_{ijkmp}.

By eliminating the carcass information from 72 gilts the analysis of the Fort Reno data could be very much simplified because no correction for sex had to be made. The Fort Reno data were subject to the following model:

$$Y_{ijkmp} = \mu + T_i + B_{ij} + F_{ijk} + D_{ijkm} + E_{ijkmp} \qquad (2)$$

where i = 1, 2,....., 8.
    j = 1, 2,....., 7.
    k = 1, 2,....., 98.
    m = 1, 2,.....,172.
    p = 1, 2,.....,N_{ijkmp}.

The symbols denote the following for both equations:

Y_{rijkmp} is the observed phenotypic value of the rth sex, of the pth pig, farrowed in the ith season, belonging to the mth litter, sired by the kth sire, in the jth breeding group.

μ is an effect common to all pigs. It is the population mean if all other effects are zero.

T_i is an effect common to all pigs farrowed in the ith season. It measures those effects due to changes in management and nutrition, as well as those differences in measuring carcasses as a result of changing personnel from one season to the next.

B_{ij} is an effect common to all pigs belonging to the jth breeding group and the ith season. It is a measure of the influence breeding group differences would have in causing differences among pigs.

F_{ijk} is an effect common to all pigs of the kth sire, of the jth breeding group and the ith season.

D_{ijkm} is an effect common to all pigs belonging to the mth litter, sired by the kth sire, of the jth breeding group, and in the ith season.

E_{ijkmp} is an effect common to the pth pig, of the mth

litter, sired by the kth sire, of the jth breed-

ing group, and in the ith season. It includes

those environmental effects which can cause litter

mates to differ from one another. Also included in

E are those genetic differences which would exist

between litter mates because of Mendelian segre-

gation. These would include about half of the add-

itive differences, about three-fourths of the domi-

nance variance, most of the epistatic variance and

any non-additive interactions between intra-litter

variations in environment and heredity.

S_r is an effect common to all pigs of the rth sex of

the Stillwater data only. It is a measure of the in-

fluence of sex in causing differences among pigs.

It is assumed that each of the elements, other than u, have

zero means and variance of σ^2, and all covariance among the

elements are zero.

b. Correction for Sex

In the above given model all of the effects are assumed

to be random variables, except sex which is considered to be

a fixed effect. In order to facilitate the computation of a

correction factor for the fixed effect of sex, the full model

was modified and the method of Henderson (1953) was followed.

The pertinent details and mechanics of this method are outlined

in the Appendix, pages 99-106.

In essence the correction for sex was computed by find-
ing the mean difference between full-sib barrows and gilts,
multiplying this difference by the number of female carcasses
involved, and adding it to the dam total. Likewise the sire,
breeding group, season and station totals were adjusted by
adding in a constant according to the number of gilts involved
in the subclasses. The adjusted totals were then used to
obtain the adjusted sums of squares for the analysis of
variance.

c. Heritability Estimates

The ratio of the additive genetic variance to the total
phenotypic variance defines heritability in the narrow sense.
The estimates of heritability based on the narrow definition
are more applicable to animal breeding data because selection
for the effects of dominance, epistasis and interactions be-
tween heredity and environment do not change a population
permanently. Depending on the method used, an actual numerical
estimate of heritability is usually between the narrow and the
broad definitions, almost always including a little of the
epistatic variance and sometimes a little of the dominance
variance according to Lush (1948). Probably the greatest
source of error lies in the proper evaluation of and cor-
rection for the non-linear or joint effects of heredity and
environment.

In order to evaluate the variance components the

expected values of the sums of squares must be found. Usually the expected mean square is found, but it is simpler computationally to equate the expected sums of squares to the observed sums of squares, Appendix Table XVII. The theoretical analysis of variance for heritability estimates is given in Table V. The composition and interpretation of the components of variance for sires (S), for dams (D), and between full-sibs (E) are of particular interest in this study. From simple Mendelian genetic theory, for a population mating at random, and assuming no environmental contribution to the likeness of full- and half-sibs, it may be shown that:

$$S = (\tfrac{1}{4}) \sigma_G^2 + (\tfrac{1}{4})^n \sigma_I^2$$

$$D = (\tfrac{1}{4}) \sigma_G^2 + (\tfrac{1}{4}) \sigma_D^2 + \text{approx.} (\tfrac{1}{4})^n \sigma_I^2 \quad \text{and}$$

$$E = (\tfrac{1}{2}) \sigma_G^2 + (3/4) \sigma_D^2 + \text{almost all of } \sigma_I^2$$

where σ_G^2, σ_D^2, σ_I^2 are the variances attributable to the additively genetic, the dominance and the epistatic sources of variation, respectively, and $\underline{n}$ is the number of factor pairs interacting to produce a given epistatic effect, Lush (1948). One estimate of heritability is obtained from the paternal half-sib correlation as

$$\frac{4\,S}{S + D + E} \qquad (I)$$

The reliability of this estimate depends upon the number of degrees of freedom available for the estimation of (S), the contribution made to the sire component of variance by

epistasis, the validity of the assumption concerning random
mating, and the magnitude of environmental correlations be-
tween paternal half-sibs.

Other estimates of heritability can be made from the
ratios

$$\frac{4\,D}{S + D + E} \quad \text{(II) and}$$

$$\frac{2(S + D)}{S + D + E} \quad \text{(III)}.$$

The amount by which estimate (III) exceeds estimate (I) is a
measure of the combined magnitude of the dominance deviations
and maternal influences. The correlation between half-sibs
must be multiplied by four to obtain an estimate of herita-
bility, thus any sampling errors in estimate (I) and (II)
will be magnified proportionately. It would appear that the
most reliable estimates in this study were derived from
method (I).

Any departure from random mating may change the distri-
bution of additive genetic variance between and within sires
causing the ratios given for estimating heritability to yield
biased estimates. The magnitude of the deviations from random
mating in the data at hand is unknown. Undoubtedly genetic
disassortive mating was prevalent in the Fort Reno data as a
consequence of the breeding program whereby different strains
and breeds were tested for general and specific combining
ability. However, the size limitation of the breeding groups

TABLE V. THEORETICAL ANALYSIS OF VARIANCE FOR HERITABILITY

ESTIMATES   (Fort Reno data)

Source of variation	d.f.	Sums of Squares	Variance Components
Total	N - 1	T	
Between seasons	y - 1	Y - C.T.	
Between breeding groups within seasons	b - y	B - Y	
Between sires within breeding groups	f - b	F - B	S
Between dams within sires	m - f	M - F	D
Between full-sibs	N - m	T - M	E

N = total number of carcasses (341)

y = number of seasons (8)

b = number of breeding groups by season subclasses (34)

f = number of sire by breeding group subclasses (98)

m = number of dam by sire subclasses (172)

Y = uncorrected season sums of squares

B = uncorrected breeding group by season sums of squares

F = uncorrected sire by breeding group sums of squares

M = uncorrected dam by sire sums of squares

often resulted in boars being mated to groups of half-sisters or even more closely related dams. A considerable portion of the Stillwater data came from crossing genetically diverse material, but on the other hand many Duroc carcasses were of those used to evaluate inbred lines. In the absence of more precise information it is assumed that the deviation from random mating was not a major source of error.

Some non-genetic likeness could be produced between paternal half-sibs by common pre-test environment such as being raised under the same herd management in the same season. Also any differences in the health status of the various breeding groups might contribute to the sire component of variance.

Prior to weaning a direct maternal effect is provided by the intra-uterine environment, and this coupled with the common pre-test environment and particularly the unique suckling ability of the individual dams, are responsible for some non-genetic likeness between full-sibs. Furthermore the practice of feeding the litter as a unit creates some post-weaning common environment which may introduce a positive or negative correlation between litter mates. The net effect is a reduction in the variance within the litters with a corresponding increase in the dam component of variance and consequently a full-sib estimate is not reliable.

King and Henderson (1954) suggest that a sire-dam interaction (dominance and or epistasis) exists, but this interaction cannot be estimated because dams are mated to only one

sire in a given season. Therefore, if there is any sire-dam
interaction it is included in the estimate of the variance
component due to dams, (D).

d. Phenotypic Correlations

All phenotypic correlations are based on the variances
and covariances within season and breeding group. This method
of computation eliminates any effect of differences between
the means of seasons and breeding groups. Thus any time trends
or season differences, such as changes in cutting techniques
from season to season, do not influence the correlations.

e. Genetic Correlations

Hazel (1943) states that " to measure genetic corre-
lations it is necessary to correlate one trait in one animal
with the other trait in a relative." There is no method avail-
able for separating the genetic and environmental correlations
for the two traits measured upon the same animal. The genetic
correlation is estimated by

$$\frac{\text{cov. } S_1 \, S_2}{\sqrt{\sigma^2_{S_1} \cdot \sigma^2_{S_2}}}$$

where $\sigma^2_{S_1}$ and $\sigma^2_{S_2}$ are the sire components of variance,
and cov. $S_1 \, S_2$ is the sire component of covariance for traits
1 and 2. The components are obtained from the analysis of
variance of paternal half-sibs. These components include the

variance from the additive gene effects as well as a small portion of the epistatic variance. Estimates of genetic correlations based on genic variance and covariance are relatively free from the effects of the particular mating system employed according to Fredeen (1953).

RESULTS AND DISCUSSION

Part I. Carcass Measurements

a. Mean and Variability of Traits

Table VI delimits the population under investigation.
With the exception of dressing percentage and carcass weight
the standard deviation for all carcass measurements on the
Stillwater pigs is larger than the corresponding figures for
the Fort Reno data. This is partially explained by the change
from regular trimming to very close trimming of the primal
cuts in 1949 by the college personnel. Also a considerable
portion of the Stillwater data comes from inbred lines and
covers five more season than the Fort Reno data so that se-
lection and time trends could be important sources of vari-
ation. The magnitude of the standard deviation for carcass
weight is undoubtedly partially conditioned by the change in
market weight in 1951. Prior to that time the pigs were
slaughtered at approximately 225 pounds and since then at
about 15 pounds lighter.

The standard deviation of .94 for carcass length of the
Fort Reno barrows compares favorably with .84 found by Fredeen
(1953) and .53 found by Anderson (1954); both of the later be-
ing on data corrected for cold carcass weight and sex. A
single minimum backfat thickness measurement had a standard

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TABLE VI. MEANS AND STANDARD DEVIATIONS OF CARCASS AND LIVE
ANIMAL TRAITS

	Fort Reno		Stillwater		
	mean[1]	standard deviation	mean[2]	standard deviation	adj. mean[3]
1. Carcass length	28.6	0.94	29.0	0.99	28.8
2. Backfat thickness	1.83	0.24	1.78	0.57	1.86
3. Loin lean area[4]	--	--	4.83	1.03	4.62
4. Specific gravity[4]	--	--	1.031	0.011	1.029
5. Dressing percent	72.2	1.87	72.9	1.71	73.1
6. Percent lean cuts	36.5	1.60	34.5	3.53	34.2
7. Percent primal cuts	50.0	1.62	45.9	2.86	45.5
8. Percent ham	13.4	0.82	12.2	1.55	11.9
9. Percent loin	11.1	0.89	10.4	1.46	10.1
10. Percent shoulder	12.1	0.74	11.9	1.01	11.8
11. Percent belly	13.5	1.21	11.8	1.46	12.0
12. Carcass index	43.52	1.55	45.62	2.05	45.32
13. Initial weight	51.0	15.31	37.7	9.74	37.7
14. Average daily gain	1.58	0.19	1.60	0.24	1.65
15. Carcass weight	147.0	8.04	152.0	7.88	153.0
16. Probe[5]	1.86	0.16	1.66	0.22	1.76

[1] Based on 341 barrows.

[2] Based on 547 pigs, both sexes included.

[3] Based on 547 pigs with females adjusted to a barrow basis.

[4] Loin lean area and specific gravity were not available in the Fort Reno data.

[5] Based on 53 Fort Reno pigs and 131 Stillwater pigs.

deviation of .15, Fredeen (1953) whereas Anderson (1954) reported .45 for the sum of four backfat measurements. These are in keeping with the standard deviation of .24 for backfat thickness at the seventh rib found in this study. The variability of those measurements, that were akin to other studies, was not drastically different from them.

The mean carcass length of the Stillwater pigs was longer by .4 inch than the mean length of the Fort Reno pigs. The Stillwater adjusted mean carcass length was .2 inch shorter than the mean of their unadjusted counterparts. Thus the longer mean carcass length of the Stillwater pigs, is to no small extent, the result of approximately half of this group being gilts. Barrows, on the average, have greater backfat thickness than gilts; consequently the adjusted mean for this trait is rightly expected to be larger than the unadjusted mean. Keeping in mind the effects of sex on carcass composition as reported in the review of literature, and noting the constants for sex correction given in Table VIII the differences between the means of the adjusted and unadjusted Stillwater data are anticipated. The discrepance between the means of the Fort Reno and the Stillwater adjusted data, however, still cannot be entirely ascribed to breed differences. The percentages of the primal cuts, taken individually and collectively, for the Fort Reno pigs are higher than the corresponding percentages for the Stillwater adjusted data largely due to the differences in trimming and cutting involved. The adjusted mean carcass index at Stillwater is higher than the index on the Fort Reno

TABLE VII. TRAIT MEANS SUMMARIZED BY BREEDS

STILLWATER

Trait	Duroc	Duroc x Land.-Pol.	Land.-Pol.
1. Carcass length	28.6	29.1	29.4
2. Backfat thickness	1.95	1.74	1.55
3. Loin lean area	4.30	4.85	5.71
4. Specific gravity	1.025	1.036	1.038
5. Dressing percentage	72.9	73.4	74.1
6. Percent lean cuts	33.6	35.3	35.5
7. Percent primal cuts	44.7	46.7	47.1
8. Percent ham	11.6	12.4	12.9
9. Percent loin	9.8	10.7	10.4
10. Percent shoulder	11.8	11.6	11.8
11. Percent belly	11.6	12.0	11.9
12. Carcass index	45.25	45.12	47.26
13. Initial weight	37.4	38.6	35.8
14. Average daily gain	1.59	1.77	1.58
15. Carcass weight	154.	152.	153.
16. Probe	1.97	1.75	1.55

FORT RENO

Trait[1]	Duroc	Land. x Duroc	Poland x Duroc	Chester x Duroc	White King x 8-9	Minn.No. 2 x Duroc	So. Dak. Hamp. x T-3
1.	28.2	29.3	28.5	27.8	29.5	29.3	28.6
2.	1.99	1.71	1.74	1.96	1.67	1.68	1.78
5.	72.4	71.4	72.5	72.7	73.0	72.8	72.0
6.	35.7	36.6	37.4	35.8	38.1	37.7	36.9
7.	49.6	49.9	50.5	49.1	51.1	51.0	50.0
8.	13.0	13.4	13.9	13.5	14.0	13.8	13.5
9.	10.6	11.5	11.3	10.6	11.9	11.5	11.0
10.	12.1	11.7	12.3	11.6	12.2	12.3	12.3
11.	14.0	13.3	13.1	13.4	13.0	13.4	13.2
12.	43.02	43.59	44.06	42.77	44.68	44.49	43.57
13.	49.0	50.6	53.8	55.8	63.2	46.2	47.6
14.	1.58	1.63	1.61	1.56	1.45	1.39	1.60
15.	148.	145.	147.	147.	148.	149.	146.
16.	1.85	1.84	1.87	1.87			

[1] Trait number refers to those traits given in the upper half of the table.

barrows because fat and lean trimmings are included in the former but not in the latter.

Trait means are presented by breeds for both stations in Table VII. The range of carcass weights within a breeding group was narrow and the means by breed and station are practically identical. The probable increased accuracy of estimates that could be garnered by correcting for the variance associated with differences in carcass weight did not appear to justify the extra time and manipulations required.

b. Effect of Sex on Carcass Composition

The differences between barrows and gilts in carcass characteristics were pointed out in the review of literature. In order that the variation due to sex in the present study would not influence the estimates of heritability, constants were computed to adjust gilts to a barrow basis. These constants along with those found by other workers using slightly different procedures are presented in Table VIII.

The direction of the difference between barrows and gilts for all carcass traits measured was the same as that found in all published data known to the author. The gilts were .60 inch longer than litter mate barrows, a difference about three times as large as that found by Anderson (1954) and Fredeen (1953). The latter two investigators used data corrected for cold carcass weight and other than this, genuine breed differences might account for the discrepance. Barrows had .20 inch thicker backfat than gilts and this difference

TABLE VIII. CONSTANTS FOR SEX CORRECTION OBTAINED FROM LEAST
SQUARES ANALYSIS (female - male)

Trait	Stillwater[1] data	Fredeen[2] (1953)	Anderson[3] (1954)	Bennet and[4] Coles(1946)
Carcass length	.60	.23	.19	.34
Backfat thickness	-.20	-.12	-.23	-.15
Loin lean area	.55	.53		.78
Specific gravity	.006			
Dressing percentage	-.56			
Percent lean cuts	1.58		1.35	
Percent primal cuts	1.14			
Percent ham	.76	.57		.40
Percent shoulder	.22	.12		.50
Percent loin	.64			
Percent belly	-.60			
Carcass index	.76			
Average daily gain	-.14			
Carcass weight	-1.98			
Probe	-.22			

[1] Differences based on 547 pigs; 339 of Duroc breeding, 31 of Landrace-Poland breeding, and 177 of reciprocal crosses.

[2] Differences based on over 12,000 purebred Canadian Yorkshire pigs slaughtered under the auspices of the Advanced Registry program in Canada.

[3] Differences based on 550 Poland-China, Landrace and Line crosses of these breeds fed in R.O.P. trials at Iowa Agric. Exp. Station.

[4] Differences based on 281 Yorkshires.

between sexes is in excellent agreement with that found by other workers. Gilts had a higher percentage of all lean cuts, individually and collectively, and consequently were .76 of a unit superior in carcass index.

Differences between sexes in the amount of muscle and fat indicate that barrows have stored a considerably greater amount of energy than gilts in their carcasses at the same weight. This raises the rather interesting point that the differences between the two sexes may be regarded as being due to a difference in the "physiological" level of nutrition, so far as the major body tissues are concerned. It is generally accepted that the use to which nutrients are put by the animal body is largely under hormonic control; in the sexually active female as compared with the sexually inactive castrate male, a smaller total proportion of the nutrients are absorbed and directed towards bone, muscle, and fat formation. In consequence the female is on a relatively lower level of nutrition in respect to these tissues. The relative difference between the two sexes on the high-high and low-low nutrition levels fed by McMeekan would lend additional support to this in that both a very high and a very low external level of nutrition tended to reduce the sex difference. Thus a functional basis provides an adequate explanation of the facts. Under a limited supply growth gives way to function, and under an ample supply those organs whose functions are more directly associated with growth benefit relatively more.

c. Heritability Estimates

The estimates of heritability in the present study are
on an intra-season and breeding group basis and as such make
no analysis of the differences between breeds and years. The
variation due to sex has been removed by correction factors
applied to the Stillwater gilt data and the measurements on
the Fort Reno gilts were not utilized. Thus the estimates in-
dicate to what extent differences between contemporary pigs
of the same sex are caused by differences in heredity. These
estimates are presented in Table IX. The paternal half-sib
estimates are based on 64 degrees of freedom for sires in the
Fort Reno data and 127 degrees of freedom for sires at
Stillwater.

The heritability estimate for carcass length of .67 is
in good agreement with other estimates reported in the liter-
ature which range from .40 to .78 by the same and by different
methods. The fact that this character is a skeletal one and as
such develops early in life would leave less opportunity for
it to be affected by environment. It is possible that carcass
length more nearly approaches its maximum genetic development
in the faster growing Stillwater pigs. This would allow these
pigs more genic variability in carcass length than the Fort
Reno pigs which were less mature and still increasing in length
at a relatively uniform rate.

Backfat thickness has a rather high predictive value of

TABLE IX. HERITABILITY ESTIMATES

| | Fort Reno barrows[1] | | Stillwater (adjusted)[2] | |
	$\dfrac{4\,S}{S+D+E}$	$\dfrac{2(S+D)}{S+D+E}$	$\dfrac{4\,S}{S+D+E}$	$\dfrac{2(S+D)}{S+D+E}$
Carcass length	.67	.70	.89	.68
Backfat thickness	.76	.68	.22	.60
Loin lean area	--	--	.71	.52
Specific gravity	--	--	.14	.43
Percent lean cuts	.04	.55	.00	.00
Percent primal cuts	.00	.00	.47	.53
Percent ham	.91	.74	.85	.61
Percent loin	.16	.50	1.31	.97
Percent shoulder	.59	.40	.16	.74
Percent belly	.44	.70	.74	.55
Carcass index	.24	.63	.75	.59
Average daily gain	1.11	.97	.09	.85

[1]Based on 64 degrees of freedom for sires.

[2]Based on 127 degrees of freedom for sires.

carcass fatness, can be easily measured without mutilation of the carcass and consequently has been studied more than any other carcass characteristic. The majority of estimates of heritability of this trait have centered around .50 with a range of .12 to .80. The estimate of .76 from the Fort Reno barrow data, however is higher than most estimates. In four instances out of 34 only one sire was used in a breeding group within a season causing the paternal half-sib correlation to be biased upward due to common environment. The number of sires by season and breeding group are given in Appendix Table XXIII. Futhermore the pigs nominated for slaughter test were a group selected from within the line on the basis of their reaching market weight earliest. There was a difference of .13 pounds in average daily gain of the test pigs as compared with the rate of gain of all their litter mates, Table XXIV. As shown in Table VIII the Stillwater barrows gained .14 pound per day more than their litter mate gilts. Thus the difference in rate of gain between the Fort Reno test and non-test pigs was large-ly due to the fact that approximately half of the latter group were gilts. However, the selection that was practiced would reduce the variation between sib test pigs in rate of gain and possibly to some extent in carcass traits. The Stillwater pigs were the progeny of a number of sires within a line and season and the carcass test pigs were selected at random from the four pigs on feed test. The estimate of .22 for backfat thickness from the Stillwater data is very low compared to those found

in the literature.

It is doubtful if there was much selection of sires on the basis of sib performance in carcass traits. However, the nature of this selection would cause sires within a breeding group to be more alike genetically than if the sires were a random sample of all those born within that group. Selection of sires would reduce the sire component of variance and consequently the heritability estimate would be biased downward.

The amount by which the third estimate exceeds the first estimate may be taken as an indication of the magnitude of dominance and maternal environmental influences. It is most unlikely that these influences would be the same for all characteristics. Common intra-uterine and common post-weaning environment would be among the causes of maternal effects in pigs. Litter mates were fattened in the same pen and thus any common post-weaning environment would be included as a maternal influence.

The only previous estimates of heritability of loin lean area are .16 and .66 by Stothart (1947) and Fredeen (1953), respectively. The data for the first of these estimates was part of a much more extensive set of data from which the second estimate was computed. The workers concerned offered no explanation for the discrepance. The estimate of heritability of loin lean area of .71 found in this study is not in agreement with the observation that in general measures of leanness are considerably less heritable than measures of

carcass fatness.

The heritable variation in percent lean cuts in this study was very low and the reports found in the literature are less than .30. The Stillwater data yielded a negative sire component of variance which was assumed to be an estimate of zero. This occured presumably because the variation within paternal half-sib groups was larger than the variation between groups by different sires. That is, the pigs from a particular sire were no more alike than if the pigs had been chosen at random from the population. Specific gravity likewise falls in the range of the low estimates and the only other estimate known to the writer is one of .66 made by Whiteman (1952) on a much smaller sample of the same data. The estimate from his sample was expected to be too high because of the relatively high relationship between dams mated to the same sire.

Percent primal cuts was another measure that yielded a negative sire component of variance from the Fort Reno data. Presumably the variation in cutting procedure employed by the commercial packing plant to capitalize on changing prices of different cuts did much to increase the correlation between carcasses cut on the same day and decrease the correlation between carcasses from pigs by the same sire that were cut two weeks or a month later. This would influence both the percent lean cuts and the percent primal cuts as they are composites of a number of cuts.

About three-fourths of the variance was found to be genic in the measurement of carcass index of the Stillwater pigs.

Warren and Dickerson (1952) reported the heritability of ad-
justed loin equivalent to be .53 by a method of estimation in
which they assumed that the sire-line variance represented one
fourth of the total heritable variation. Dickerson (1947)
estimated the heritability of the ratio of fat to lean cuts,
which is a comparable measure, to be .59. The much lower esti-
mate of .24 for the heritability of the Fort Reno carcass in-
dex is partly attributable to sampling error because of the
smaller number of sires. Because the carcass index is made up
of the primal cuts weighted according to economic value it is
very subject to variation in cutting different carcasses in
the same season. The Stillwater index is a more stable measure
in that the cuts were consistently trimmed closely and also it
includes the fat and lean trimmings.

The percent ham was the most highly heritable trait
studied and there was good agreement between the estimates
from the two sets of data. The only other estimate of this
trait was made by Fredeen (1953) and was found to be .50 for
the Canadian Yorkshire. This may indicate a genuine breed
difference.

The Fort Reno data yielded a heritability estimate of
.16 for percent of loin and this is compatible with estimates
for other lean cuts whose genic variance is one third or less.
The reason for the exceptionally high estimate for the cor-
responding trait from the Stillwater data is not fully known.
The Stillwater adjusted means for traits given by breeds in
Table VII indicated that the Duroc and Landrace-Poland parent

breeds had .3 and .9 percent less loin respectively, than the reciprocal crosses. This apparent heterotic effect could very well have resulted in an increased correlation between paternal half-sibs for this trait. Multiplication by four to get the heritability estimate would magnify it proportionately.

It is a reasonable assumption that the correlation between half-sibs introduced by the common test environment would have a more pronounced effect on sire differences in growth rate than on sire differences in carcass measurements. Thus an estimate of heritability of growth rate based on paternal half-sib correlations would tend to be biased upward. The common environment and the selection of pigs for the slaughter test that had attained market weight earliest, that is had gained more rapidly, undoubtedly are to no small extent responsible for the unusually high estimate for average daily gain of the Fort Reno pigs. In as much as all pigs from each sire were fed out in the same pasture lot, differences between sires could be accentuated by this environmental effect and heritability over-estimated. Likewise, the post-weaning pen environment would increase the correlation between sibs. This is offered as one explanation of the much higher heritability estimate for rate of gain by Method III than by Method I for the Stillwater pigs. In these experiments an attempt was made to treat the progeny of all sires alike, however, some unintentional and undetected differences might have occurred.

d. Phenotypic Correlations

The phenotypic correlations summarized in Table X were computed on an intra-season, intra-breeding group basis and thus are free of any seasonal trends and differences between breeding group means. The phenotypic correlations measure the relationship between two traits as expressed in the same individual. As such they are composed of both genetic and environmental influences which may or may not be working in the same direction. The correlations are based on measurements made on 341 barrows from the Fort Reno station. The sex correction for the Stillwater data adjusted the dam totals and not the individual measurements, consequently correlations were not run on the adjusted data.

The interpretation of these simple correlations is contigent upon the understanding of a number of inter-related influencing factors. All test pigs were slaughtered at a reasonably constant live weight. Since this weight is a function of all the component parts of the carcass, this restriction automatically produces some negative correlations. The relationship previously cited, namely, that an increase in one dimension will generally require that some other dimension be reduced is an important one. Also the physiological similarity between some measurements must be considered.

The correlation between length and backfat thickness is negative and in good agreement with similar correlations presented by Lush (1936) for the Danish Landrace, Fredeen (1953)

for the Canadian Yorkshire and Johansson and Korkman (1950) for the Swedish Landrace and Large White. The most plausible explanation is that given by Lush, namely, that slaughtering at a constant live weight would require that the pigs longer than average be smaller in some other dimension, that is, backfat.

TABLE X. PHENOTYPIC CORRELATIONS - Fort Reno Barrows[1]

	Backfat Thickness	Percent Lean Cuts	Carcass Index	Average Daily Gain
Carcass length	-.34**	.19**	.14**	.13*
Backfat thickness		-.47**	-.39**	.07
Percent lean cuts			.72**	-.11*
Carcass index				-.04

**Significant at the 1% level.
 *Significant at the 5% level.
[1]Based on 326 degrees of freedom.

Increased length is associated with an increase in percent lean cuts and although the correlation was only .19 it was highly significant. Of five other estimates found in the literature one was .54 and four were .13 or less indicating a consistent but weak association. On the other hand, Crampton (1940) reported no relationship between length of side and percent of lean in the bacon rasher. Aunan and Winters (1949) found no significant correlation between length and the percent separable lean of the carcass. While loin lean area was not available for the Fort Reno data the reports of its relation-

ship to length as found by other investigators have been very
erratic. It would appear that the relationship between carcass
length and carcass leanness varies with strains and breeds and
that all long hogs are not necessarily lean.

Backfat thickness was found to be negatively correlated,
-.47, with percent lean cuts; a correlation coefficient of .14
being required for significance at the 1 percent level. This
is slightly lower than the association of -.63, -.72, -.54,
and -.72 found by Aunan and Winters (1950), Brown, et al.
(1951), Cobb (1952) and Anderson (1954), respectively and all
on American breeds. Considering backfat thickness as a measure
of the fat content of the carcass, the pigs having the thicker
backfat will automatically have lower yields of lean, except
as their total carcass yields are higher. When the depth of fat
covering increases, the percentage of fat in the fat tissue
increases, and the percentages of moisture and protein de-
crease; these changes are accompanied by a change in the com-
position of the fat tissue, which results in a lowering of
the refractive index (hardening of the fat) and an improvement
in the quality of the meat, Scott (1930a).

There has however, been some disagreement concerning the
relation of average backfat thickness and loin lean area.
Fredeen (1953) and Hazel and Kline (1952) reported a negative
correlation of -.12 and -.41 respectively while Aunan (1949)
reported a positive correlation of .15 and Bennet and Coles
(1946) found the correlation to be essentially zero in both
sexes.

Since the carcass index of the Fort Reno pigs includes shoulder, ham, loin and belly, each weighted according to economic value, it follows that the index should be negatively correlated with backfat thickness. Percent of lean cuts is highly correlated with carcass index, a natural consequence of the relationship between a part and the whole.

Average backfat thickness and percent lean cuts are correlated .07 and -.11 respectively with average daily gain. These associations are in excellent agreement with those of Cobb (1952) who obtained a correlation of .07 between rate of gain and backfat thickness and -.04 between rate of gain and percent lean cuts, after correcting for sex, years, breeds and lines of breeding. Blackmore (1953) reported a negative correlation between average daily gain and an index of carcass leanness and a positive one between average daily gain an index of carcass fatness, and although they were not significant be believed them to be real. The correlations with average daily gain of all traits studied were small and generally not significant . They were however, in the same direction as those found by the majority of other workers and to that extent may be taken as supporting evidence. The correlation between carcass length and rate of gain of .13 was significant at approximately the 2 percent level. This may be compared with a correlation of -.10 between length and age at slaughter found by Fredeen (1953). It appears that longer pigs, have a longer frame for deposition of fat and lean, and thus when slaughter weight was held constant, the faster growing pigs were longer.

Scott (1930) and Callow (1935) have shown that the long type
of pig had a faster growth rate than the short type.

Backfat thickness showed a weak positive association
with rate of gain while the correlation of lean cuts with the
latter was negative and significant at the 5 percent level.
Both the sign and the magnitude of these correlations were
similar to those found by other workers. Thus the fast gain-
ing pigs have a slight tendency to have more fat in their car-
casses at slaughter.

e. Genetic Correlations

The genetic correlations presented in Table XI were
computed by the method outlined in the appropriate section
under Materials and Methods. The required sire components of
covariance were obtained from an analysis of covariance con-
ducted according to the same hierarchial classification as
the analysis of variance. The reliability of the estimates
of the components of variance and covariance depend upon the
number of degrees of freedom associated with the appropriate
mean square or mean product. In this analysis there were 63
degrees of freedom for sires as compared with 326 degrees of
freedom for the corresponding phenotypic correlations and
hence any interpretations should be made with caution.

The present estimate of -.46 for the genetic correlation
between carcass length and thickness of backfat may be com-
pared with -.45 reported by Johansson and Korkman (1950), -.27
by Fredeen (1953) and -1.24 by Anderson (1954). These are in

substantial agreement with the corresponding phenotypic corre-
lations found in this study. The negative correlation between
carcass length and percent lean cuts is not in agreement with
other studies or the corresponding phenotypic correlation
found in this study. There is no apparent reason for this
occurrence other than sampling error.

TABLE XI   GENETIC CORRELATIONS — Fort Reno Barrows

	Backfat Thickness	Percent Lean Cuts	Carcass Index	Average Daily Gain
Carcass length	-.46	-.48	-.12	.37
Backfat thickness		-2.66	-.40	.57
Percent lean cuts			.87	-.55
Carcass index				.24

Based on 63 degrees of freedom.

Backfat thickness and percent lean cuts are apparently
strongly negatively correlated. The particular procedure used
to compute the genetic correlations permits them to fall out-
side the range of + 1 to - 1 due to chance. Keeping in mind
the relationship between index and lean cuts the correlation
between backfat thickness and index is in the right direction.

Like the phenotypic correlations fatness and leanness
show opposite relationships, of about the same magnitude, to
average daily gain. Dickerson (1947) and Anderson (1954)
found rate of gain to be more highly associated with fatness
than with leanness. This coupled with his finding that the

heritable variation is larger for amount of fat than for amount of muscle and bone lead Dickerson to the conclusion that selecting the fast gaining animals for breeding will increase the inherent growth rate more for fatty tissue than for muscle and bone. On the other hand, Cummings and Winters (1951) in nearly all instances found no association between growth rate and yield of primal cuts or index of fat cuts. Thus, results of the investigations by Dickerson (1947), Anderson (1954), Blunn and Baker (1947), Cummings and Winters (1951) and the present study indicate that varying degrees in the combination of growth characteristics and carcass characteristics do exist with different breeds.

The phenotypic correlation between carcass index and rate of gain is negative while the corresponding genetic correlation is positive and neither one of them is significant. It may be implied that the relationship between these two traits was not accurately evaluated. Furthermore the association between length and index is positive when measured phenotypically but when the environmental variations are removed the relationship is negative. This would suggest non-randomness of environmental influences, that is, the sire progeny cutting well were being treated more favorably than the poor cutting sire progeny.

Part II. Probe Measurements

a. Accuracy of Probes at Slaughter Weight

The writer measured the backfat thickness by the probe
technique for the first time on the pigs farrowed in the
spring of 1953. Attempts to evaluate the predictive value of
the probe more thoroughly were made by probing pigs of the
subsequent season at different ages and weights. A striking
difference was noted between correlations of carcass traits
with the average of two probes taken the first season and the
correlations of carcass traits with the average of six probes
taken the following season. This and the experience gained by
the author in probing over 100 pigs the first season un-
questionably influenced the accuracy of measurements taken
in the following season. In the first group of 111 pigs back-
fat thickness was measured on the carcass at the seventh rib
only and was correlated .36 with the average of probes be-
hind the shoulder and over the loin of the live hog before
slaughter. In the second group probes were taken on both sides
behind the shoulder, over the loin and over the back and the
average was correlated .69 with the average carcass backfat
thickness. These and other pertinent intra-breed and sex
correlations are presented in Table XII. A comparison of the
predictive value of two methods of measuring backfat thickness
was made by correlating the two measurements with a number of
carcass traits.

Percent lean cuts was correlated -.57 with probe back-fat and -.66 with carcass backfat. The correlations of back-fat thickness with carcass length, specific gravity, carcass index, and percent primal cuts were higher when backfat thickness was measured on the live animal by the probe than when measured on the carcass. These correlations imply that measurements taken on live hogs before slaughter are as accurate indicators of leanness and yield of primal cuts as measurements of backfat thickness on the carcasses after slaughter.

TABLE XII   CORRELATIONS OF CARCASS TRAITS AND TWO MEASURES

OF BACKFAT THICKNESS

	Carcass[1] backfat	Average of[1] six probes	Average of[2] two probes
Carcass backfat	----	.69	.36
Percent lean cuts	-.66	-.57	-.07
Percent primal cuts	-.58	-.67	-.13
Loin lean area	-.28	-.26	--
Ham specific gravity	-.30	-.36	--
Carcass index	-.43	-.55	-.37
Carcass length	-.11	-.33	-.05

[1]Intra-breed and intra-sex correlations with 68 d.f.

[2]Intra-breed and intra-sex correlations with 104 d.f.

b. Predictive Value of Probes at Lighter Weights

The probe offers a practical means of estimating

accurately the difference in fatness of live hogs. This is particularly useful in experimental selections of breeding stock. The question arises as to the proper age or weight to probe and at what site or combination of sites greatest accuracy can be obtained. The information garnered from the 48 pigs probed at 56, 84, 112 and 140 days of age and at market weight of about 210 pounds is pertinent. As might be expected probing at 56 and 84 days have little value in predicting the carcass backfat at slaughter weight. Fat is the latest developing of the major body tissues and at stages of growth up to about 112 days the potential variation in fat deposition between individuals has not been expressed. The correlation between the two backfat measurements increases with increasing age so that at slaughter weight the intra-class correlation between the two measurements was .68. There

TABLE XIII   MEANS AND VARIABILITY OF PROBE BACKFAT AND

CORRELATIONS WITH CARCASS BACKFAT

Probe measurements[1]	Correlations[2] total	intra	Mean probe	Standard deviation
S-B-L at 56 days (one side)	.16	.01	.23	.08
S-B-L at 84 days (one side)	.29	.11	.49	.16
S-B-L at 112 days (one side)	.63	.30	1.07	.21
S-B-L at 140 days (one side)	.83	.51	1.49	.32
S-B-L at final age (one side)	.86	.65	1.65	.26
S-B-L at final age (both sides)	.85	.68	1.64	.25
S-L at final age (one side)	.84	.67	1.70	.25
S-L at final age (both sides)	.86	.69	1.69	.24
S-B at final age (both sides)	.81	.59	1.69	.28
Carcass backfat	--	--	1.60	.25

[1]S- probe behind the shoulder; B- probe over the back; L- probe over the loin.

[2]Total correlation with 71 d.f., intra-breed and and sex correlation with 68 d.f.

was no difference between the total correlation of 140 day probe and probe at slaughter weight with carcass backfat but when the variations due to breed and sex were removed the correlation involving the probe at slaughter weight was .68 compared with .51 for the correlation involving the 140 day probe. Thus when selecting replacement gilts on the basis of backfat thickness greater accuracy can be expected if they are not probed before they reach about 200 pounds. Presumably earlier measurement of boars would have more application at the present time because the effects of ranting on backfat deposition have not been determined. It is suggested that in a further study of the use of the probe as a selection tool that boars, barrows, and gilts be probed at various weight intervals from about 130 pounds to at least 200 pounds.

TABLE XIV   CORRELATION OF WEIGHT AND PROBE MEASURED ON

THE SAME DAY

| | probe measurements taken at | | | |
	56 days	84 days	112 days	140 days
56 day weight	.48			
84 day weight		.54		
112 day weight			.61	
140 day weight				.64

Probe measurements taken at three sites. Intra-breed and sex correlations with 42 d.f.

The probe at 140 days of age had a larger standard deviation than the same measurement taken at any other time. As shown in Table XIV the probe becomes more dependent on weight as the latter increases so that at 140 days about 41

percent of the variation in probe measurements were assoc-
iated with variation in weight. As a result of the difference
in growth rate between the two breeds it was noted that the
Durocs were 20 pounds heavier than the Landrace-Polands in
average live weight at 140 days of age. The magnitude of the
variability in live weight at this age partially explains the
large standard deviation of 140 day backfat probe. McMeekan
(1940) demonstrated that there is more variation in later de-
veloping tissues, fat, than in earlier developing tissues,
skeletal and bone.

TABLE XV   AVERAGE BACKFAT PROBE AT DIFFERENT AGES OF LINES 8,
9 AND THEIR RECIPROCAL CROSSES

Age in days	Average wt. in lbs.	Probe backfat		
		Line 8	Crossbreds	Line 9
56	39	.28	.21	.22
84	74	.54	.47	.49
112	128	1.17	1.06	1.04[1]
140	185	1.75	1.48	1.34[2]
155-161	211	1.87	1.60	1.45

[1] This measurement is interpolated for 128 pound weight from
measurements at 112 and 140 days. The actual probe at
112 days was .97 inch at 117 pounds.

[2] This measurement is interpolated for 185 pound weight from
measurements at 140 and 161 days. The actual probe at
140 days was 1.29 inches at 165 pounds.

Table XV gives the mean backfat thickness as measured
by the probe at monthly intervals from weaning to the time

the pigs attained a slaughter weight of about 210 pounds.
Some of the measurements on the Landrace-Polands were inter-
polated to a live weight basis comparable to the Durocs and
crossbreds. There were only slight differences between lines
in rate of backfat deposition up to about 128 pounds. The
Durocs deposited an average of .58 inch of backfat as compared
with .42 inch for the crossbreds and .30 inch for the Landrace-
Polands in the period from about 128 to 185 pounds. It is
suggested that the probe could be very useful in studying the
pattern of fat deposition of lines and breeds.

c. Patterns of Growth and Backfat Deposition

Figure 1 shows the pattern of backfat deposition for
the three lines previously mentioned. The faster growing,
fatter line 8 Durocs had about .1 inch more fat at initial
weight and maintained that difference to 84 days. From 112
to 140 days the Durocs seemed to deposit fat more rapidly
than the line 9 Landrace-Polands or the crossbreds. After 140
days the rate of fat deposition appeared to level off and was
quite similar for all breeds. Apart from the apparent less
backfat of the crossbreds at 56 days and maintaining that
difference to 84 days, the crossbreds were intermediate be-
tween the parent lines in backfat thickness. This would
suggest that the genes influencing backfat deposition act
largely in an additive manner.

The accuracy with which differences between individuals

in a group can be determined will be influenced by the live
weight range of the individuals at the time the probe measure-
ments are made. From the standpoint of labor and management
probing animals within a very narrow weight range may not be
feasible. However, with the accumulation of more data cor-
rection for live weight of individuals by a regression tech-
nique seems plausible. Plotting backfat probe in inches
against weight in pounds (Figure 2) suggests that the re-
lationship between them is approximately linear. Selection
of pigs to produce leaner carcasses using the backfat probe
as a tool would appear to be particularly valuable if the
measurements were taken after about 185 pounds live weight
when differences in potential backfat thickness had been ex-
pressed.

Figure 3 shows the relationship between age and weight.
For the crossbreds the growth pattern is unlike that for fat
deposition in that it parallels the faster growing parent
line. This may be taken as evidence for non-additive gene
action influencing growth rate and is compatible with the
low heritability estimate of .09 found for average daily gain
of the Stillwater pigs.
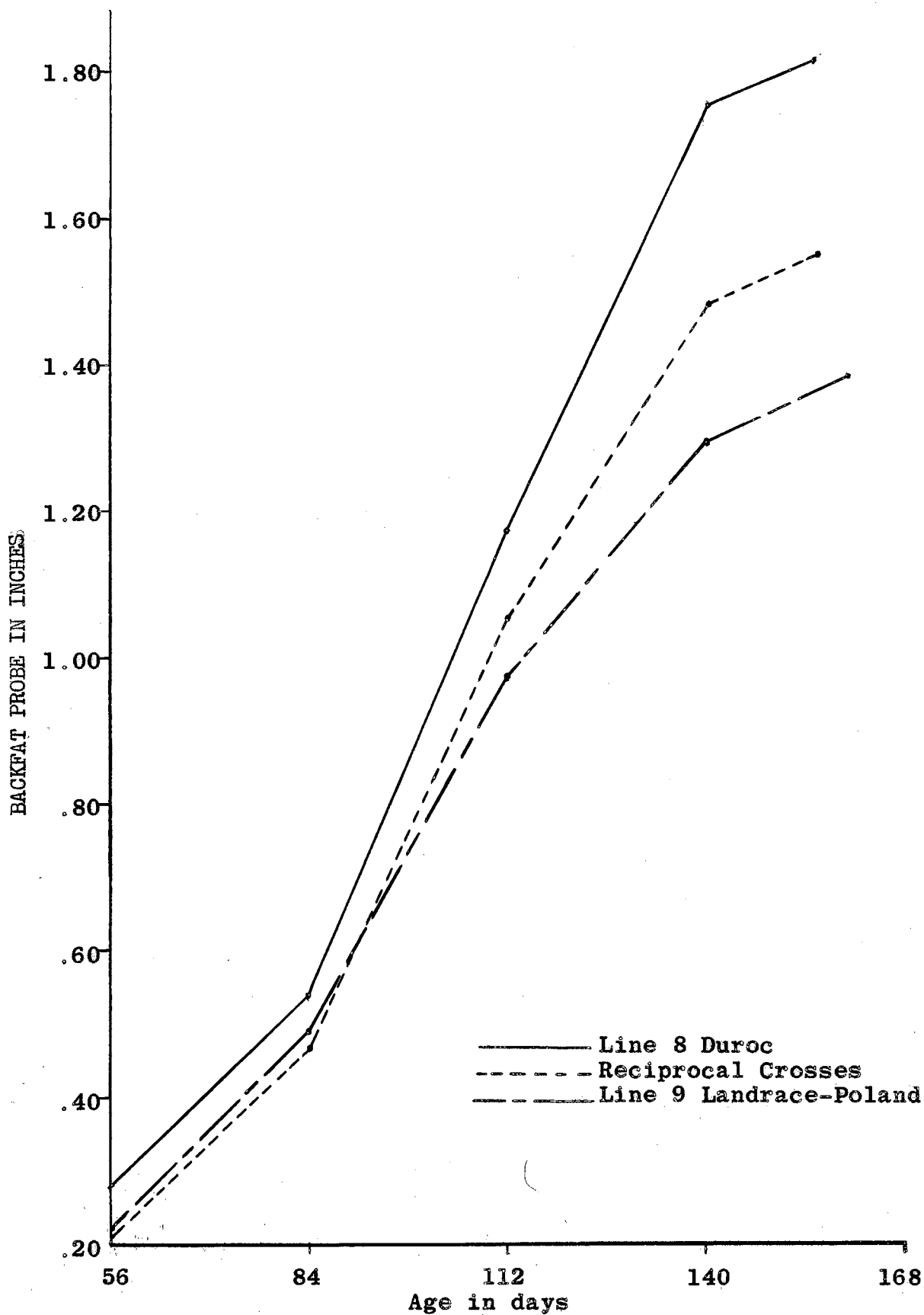
FIGURE 1 RELATIONSHIP BETWEEN AGE AND BACKFAT THICKNESS
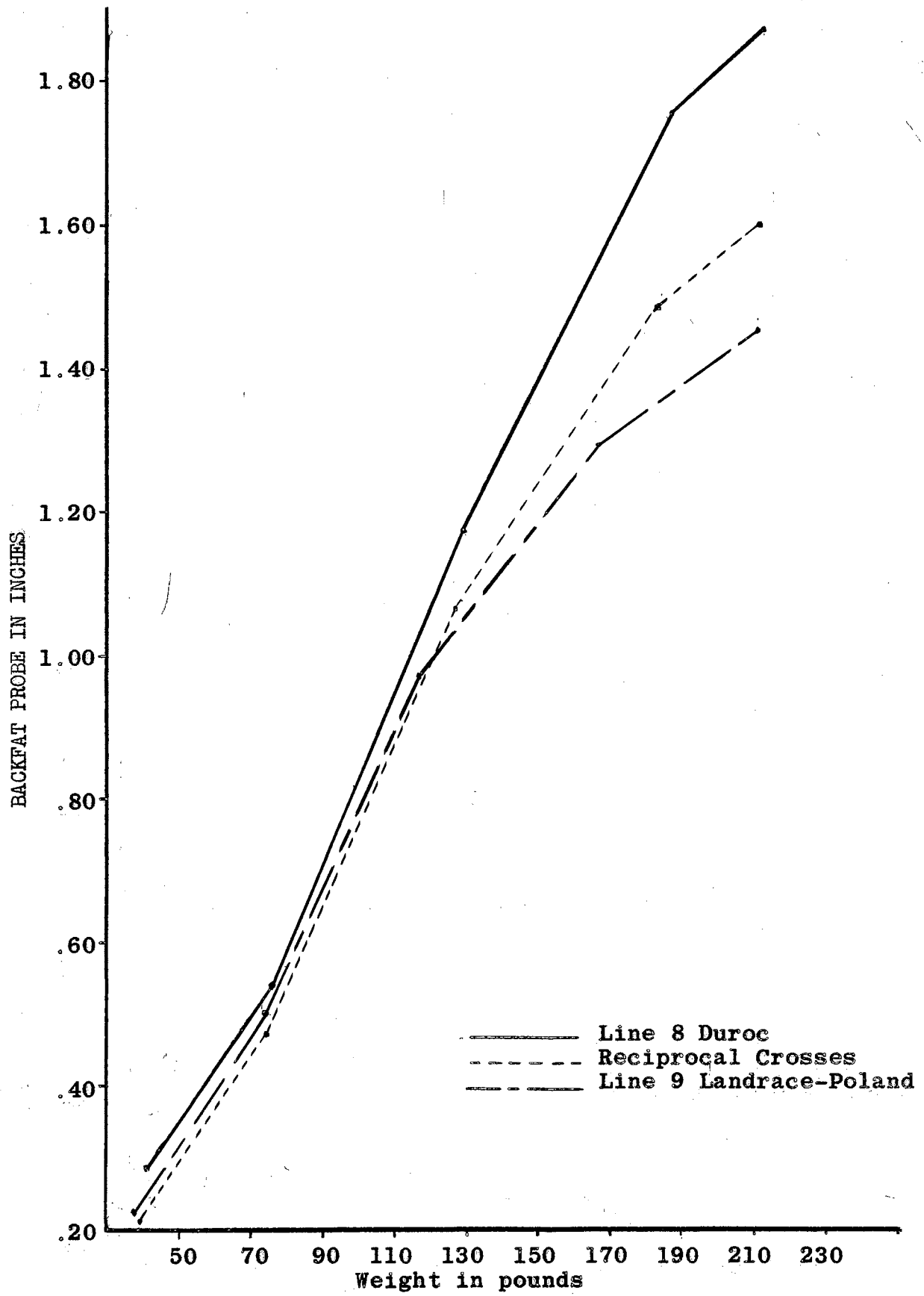
FIGURE 2 RELATIONSHIP BETWEEN WEIGHT AND BACKFAT THICKNESS
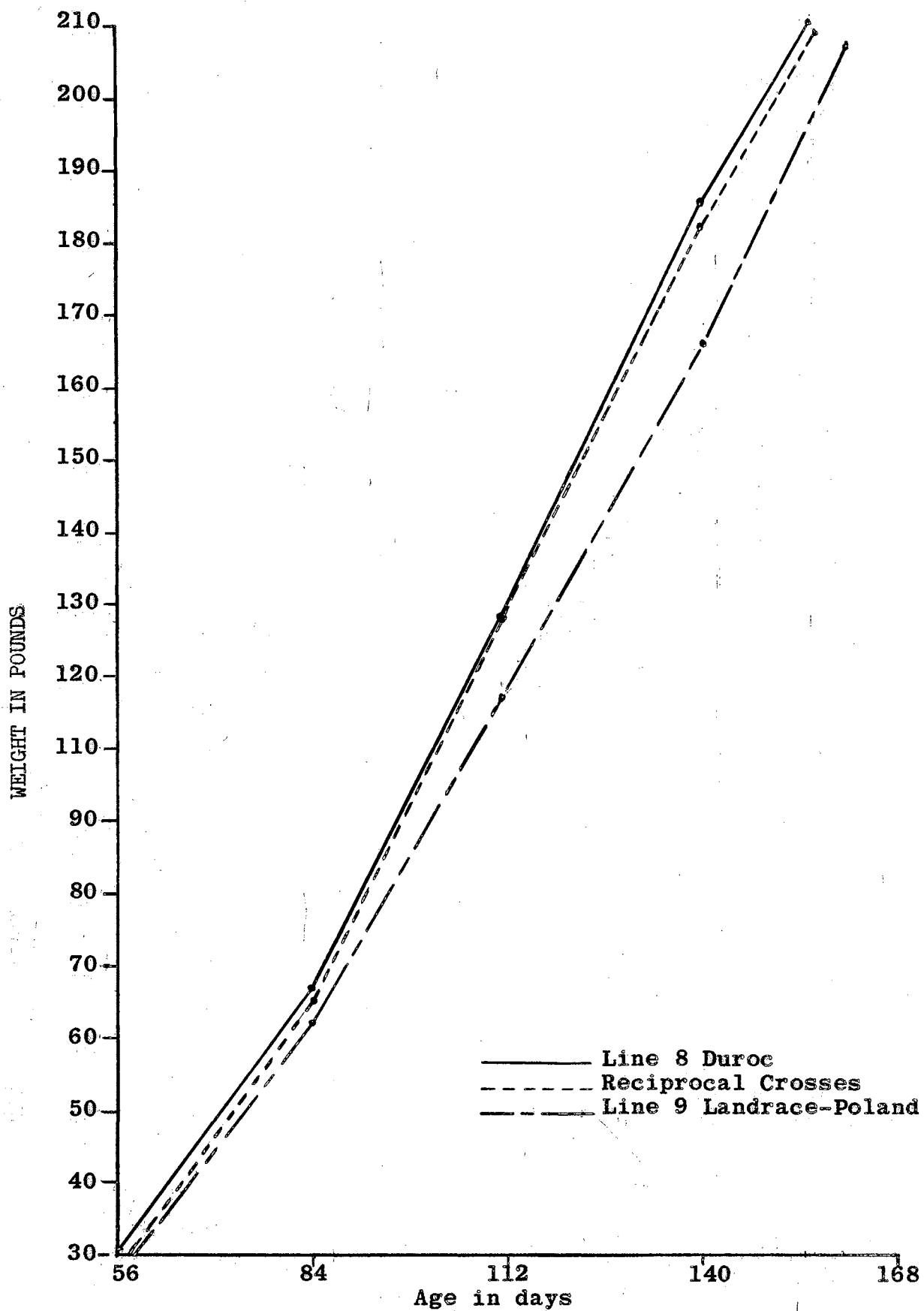
FIGURE 3 RELATIONSHIP BETWEEN AGE AND WEIGHT

APPLICATION

The permanent improvement that can be accomplished by selection is in proportion to the accuracy with which genetic differences among individuals can be recognized. Since genotypes cannot be evaluated directly, selection must be practiced for some estimate of the genotype based on measurable characteristics. Consequently, the magnitude of the correlation between the genotype and the variable used as a basis of selection is of paramount importance.

Dickerson and Hazel (1944) concluded that a regular plan of progeny testing is unlikely to increase, and may reduce, progress unless (1) the progeny test information becomes available early in the tested animal's lifetime, (2) the reproductive rate is low, (3) the basis for making early selection is relatively inaccurate and (4) heritabilities are low.

The genetic gain which can be made by selecting for several traits simultaneously within a group of animals is the product of (1) the selection differential, (2) the multiple correlation between aggregate breeding value and the selection index, and (3) genetic variability, Hazel (1943). The first of these may be very small due to the breeders carelessness and particularly the lack of a well defined standard of perfection, and is limited by the rate of reproduction for each species, while the third is relatively

beyond man's control. One of the greatest possibilities of increasing the progress from selection is by insuring that the second is as large as possible. Methods of maximizing this correlation have been studied for many years but much improvement can still be wrought.

The confusing effects of environment, dominance and epistasis in masking genotypes causes the progress to be considerably less than it might be if the genotypes could be recognized precisely. The study of Hazel (1943) indicates that the indices constructed for swine probably permit about 35 to 40 percent as much gain as could be made with a perfect index, which is the limit of what could be achieved if the exact Mendelian composition of every animal were known.

The fundamental reason for the superior efficiency of the selection index is that variation between animals is much greater in net or total merit for n characters than in any one of them. Since the superiority of selected parents depends directly upon the amount of variation upon which the selection is based, the advantage of an index which includes all of the important characters is obvious. In an index superiority in one trait is allowed to offset inferiority in other traits.

The one factor needed most for a more precise method of improving our hogs is a standard of perfection for carcass quality. The yield of the five primal cuts expressed as a percentage of cold carcass weight is probably the best single appraisal, yet this standard is subject to considerable error because of differences in quality of the carcasses. With the

present increasing demand for a meat type hog greater emphasis must be placed on the development and use of adequate measures of carcass leanness. Specific gravity and loin lean area can be used to evaluate carcass composition, however the latter necessitates some mutilation of the carcass and the former seems to be affected to a considerable extent by non-heritable variations. Backfat thickness on the other hand appears to be more highly heritable – an observation borne out by numerous other studies. Its association with carcass leanness is strongly negative indicating that selection against backfat should be effective in producing leaner carcasses.

The general effect of genetic antagonism between different desirable characteristics is to make selection less effective for all of them. Hence, the negative genetic correlation between growth rate and yield of lean cuts in the carcass helps explain why progress in swine improvement has been slow in spite of the amount of variation in each of the desired characteristics which appears to be hereditary. Basing selection on a properly balanced combination of all the desired characteristics avoids wide fluctuations in any one of them, but progress remains slower than if different genes controlled each characteristic.

Rate of gain and fatness were positively correlated. Hence, effective selection for rapid growth would also increase fatness. Reports by Baker, et al.(1943), Hazel, et al. (1943), and Blunn, et al.(1953) have indicated the feasibility

of selecting for rate of growth for the period from 56 to 112 days. The data of McMeekan (1940) show that skeletal and muscle growth was more pronounced compared to that of fat at 112 days. Table XIII showing backfat probe means in this study tend to bear this out. Thus selection at about 112 days might provide an effective means of improving growth rate without excessive increase in fatness. Selection at this earlier age would be more nearly for rapid growth of muscle and bone than for fat.

The importance of a measure for appraising potential breeding stock on the basis of their own carcass composition without slaughtering them cannot be over-emphasized. The probe can be used as such a measure and is the most promising tool to date. The probe method of measuring backfat on the live pig is an excellent means of selecting against fatness. The correlations between backfat thickness and percent primal cuts, loin lean area, ham specific gravity and carcass index were all higher when backfat thickness was measured on the live pig than when it was measured on the carcass. This technique is very simple and accurate for measuring fatness in prospective breeding stock. An important feature of this method lies in the fact that the information becomes available immediately and thus would shorten the generation interval compared with selection on the basis of a progeny and or sib test. It also has the advantage over the sib test in that more intense selection could be practiced because of the

larger number of animals available for breeding purposes.
Lofvenberg (1953) in a study of the selection intensity in
the first generation of a reciprocal recurrent selection
program indicated that the selection differentials for rate
and efficiency of gain and for carcass index were small,
especially for sows.

Fredeen (1954)indicates that if selection is based on
own performance entirely, then using the probe or X-ray for
carcass measurements would result in the rate of improvement
being about 139 percent of that obtained from a standard
progeny test litter wherein two pigs of each sex are slaught-
ered for the carcass information. If selection was based on
sib performance the relative efficiency would go up to about
138 percent with very low heritabilities and be about 126
percent with heritabilities of .5 compared to the progeny
test described above.

With the current selection index in use at this station
giving equal weight to economy of gain,rate of gain, and car-
cass quality and if sib and own performance are given about
equal value the optimum rate of improvement should be real-
ized by slaughtering a minimum of 2 and a maximum of 3 pigs
per litter to provide the required carcass measurements.
Fredeen (1954) has shown that if own and sib performance re-
ceive approximately equal emphasis in selection, then the
testing of 4 pigs from a litter is not compatible with the
maximum rate of genetic improvement even in the case where
the heritabilities are low. With more emphasis on the probe

for selection of gilts on the basis of their own performance
the test litters could be reduced to 3 barrows thus enhancing
the selection differential for females.

The advantage of the smaller size test litter is further
enhanced if non-genetic differences between litters contribute
importantly to the total variance in the population. This
situation does not appear to exist accept for growth rate, and
individual merit rather than sib performance may be used as
the selection criterion for this trait. Probably the most rapid
procedure of improving our present hogs would be to utilize an
index involving traits measurable on the live animal. It is
suggested that such an index include 154 day weight, possibly
following a preliminary selection at about 112 days, the probe
backfat thickness, some measure of length, economy of gain on
a litter basis and a measure of sow productivity.

As shown in Table VII there are differences between
breeds and it seems reasonable that these may be the result
of concentrations of favorable genes for different traits as
the product of selection emphasis in different directions. If
the gene frequencies affecting carcass composition and those
affecting rate and economy of gain between breeds are not the
same then the progeny resulting from the crossing of these
breeds might be superior and respond more favorably to se-
lection. It has been shown that heterosis in growth rate does
not increase, and may reduce, the fatness of carcasses,
Dickerson, et al. (1946). There is much evidence that might
be cited to indicate the superiority of crossbreds over their

parental lines in carcass composition, not because their total yield of primal cuts was higher than the superior parent but because they combined the desirable carcass traits of both parents. Craft (1953) states "over-all results in projects of the laboratory show that, through crossing of selected inbred lines, it is possible to produce carcasses with approximately the characteristics desired; further, that this can be done without sacrificing growth rate or economy of gain."

SUMMARY AND CONCLUSIONS

The main purpose of this study was to determine the heritability of and the correlation between carcass characters of swine bred at the Oklahoma Agricultural Experiment Station. Also a preliminary investigation was made of the use of the probe as a measure of carcass composition.

The carcass data analyzed were those from 341 barrows raised at the Fort Reno station and 547 pigs from the Stillwater station slaughtered in connection with the performance testing of breeds and lines in a project of the Regional Swine Breeding Laboratory.

The Stillwater gilts were adjusted to a barrow basis prior to the analysis of variance. Barrows were found to be .60 inch shorter, to have .20 inch thicker backfat, .55 square inch smaller loin lean area, 1.58 percent less lean cuts, 1.14 percent less primal cuts and .76 unit lower carcass index than gilts.

Heritability estimates of the differences between contemporary pigs, of populations assumed to be mating at random, computed from an analysis of variance technique were as follows:

	Fort Reno Barrows	Stillwater Adjusted data
carcass length	.67	.89
backfat thickness	.76	.22
loin lean area	––	.71
specific gravity	––	.14
percent lean cuts	.04	.00
percent primal cuts	.00	.47

percent ham	.91	.85
percent loin	.16	1.31
percent shoulder	.59	.16
percent belly	.44	.74
carcass index	.24	.75
average daily gain	1.11	.09

Possible sources of bias in the estimates discussed were; within breeding group selection of the Fort Reno pigs for carcass test on the basis of their attaining market weight earliest, the progeny being produced by only one sire in some breeding groups , clerical errors and random errors multiplied by four as a consequence of the paternal half-sib method of estimating heritability.

Phenotypic and genetic correlations were computed between carcass length, backfat thickness, percent lean cuts, carcass index and average daily gain for the 341 Fort Reno barrows. Significant correlations were found between measures of fatness and leanness. Fatness and leanness showed opposite relationships to rate of gain, but of about equal magnitude.

Correlations of backfat probe measurements with such carcass items as percent primal cuts, carcass index, specific gravity, and loin lean area indicate that the live animal probe is as good an indicator of carcass composition as carcass backfat thickness. Probe measurements taken at about 210 pounds had the highest predictive value of those studied. Measuring backfat thickness behind the shoulder and over the loin on both sides of the pig was the most useful combination of probe sites studied.

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APPENDIX

TABLE XVI BREEDING GROUP CLASSIFICATION OF CARCASSES

STILLWATER		FORT RENO	
Durocs	number of carcasses	Durocs	number of carcasses
Line 3	33	T-3 x C-S	8
Line T	21	T x N 10-5	11
Line 5	24	N 10	11
Line 7	17	Line 3	9
Line 8	28	Line 5	23
Line 10	2	Line 8 x T-3	15
Line 11	2	N 12 x T-3	4
Line 12	6	N 12 x 5	22
T x 3 and 3 x T	66	Outbreds	41
Outbred Duroc x 3	27	Outbreds x T-3	5
C x 3 and S x 3	12	Total	163
5 x 3 and 3 x 5	18		
5 x 7 and 7 x 5	10		
3 x 7 and 7 x 3	12	Landrace x Duroc	
S and C	16	Line 3 x Landrace-Poland	9
C x S	4	Landrace-Poland x T-3	13
T-3 x C-S	4	Landrace-Poland x 3	10
S x 5-3	6	Landrace x T-3	12
N 10 x 5	6	Montana No. 1 x T-3	16
T x 3-5	6	Minnesota No. 1 x T-3	11
C x 3-5	6	Landrace x 8-9	14
Outbreds	10	Total	85
Total	339		
		Poland x Duroc	
Duroc x Landrace-Poland		Poland x Duroc	28
Line 8 x line 9	79	Grandee Poland x T-3	13
Line 9 x line 8	86	Outbred Poland x T-3	7
Outbred Duroc x line 9	2	Minnesota Poland x T-3	16
T x Line 9	4	Uark x T-3	13
Outbred Poland x Duroc	6	Missouri Poland x 8-9	12
Total	177	Total	89
Landrace-Poland		Chester x Duroc	
Line 9	31	Chester x Duroc	10
Total	31	Chester x Poland-Duroc	13
		Total	23
FORT RENO			
		Minnesota No. 2 x Durocs	
White King x 8-9	12	Minnesota No. 2 x T-3	5
		Minnesota No. 2 x 3-T	10
S. D. Hampshire x T-3	15	Minnesota No. 2 x 8-9	14
		Total	29

The model chosen for the genetic analysis of the Stillwater data is given by

$$Y_{rijkmp} = \mu + S_r + T_i + B_{ij} + F_{ijk} + D_{ijkm} + E_{ijkmp} \tag{1}$$

where the effects are as previously defined.

To simplify the procedure, let

$$d_{ijkm} = \mu + T_i + B_{ij} + F_{ijk} + D_{ijkm} \tag{3}$$

then $y_{rijkmp} = S_r + d_{ijkm}$. $\tag{4}$

The values of S and d which minimize the sums of squares are given by the so-called normal equations.

The normal equations are

$$n_{o....} S_o + \sum n_{oijkm} d_{ijkm} = Y_{o.....} \tag{5}$$

$$n_{1....} S_1 + \sum n_{1ijkm.} d_{ijkm} = Y_{1.....} \tag{6}$$

$$n_{oijkm} S_o + n_{1ijkm} S_1 + n_{.ijkm} d_{ijkm} = Y_{.ijkm.} \tag{7}$$

Dots (.) in the subscripts denote summation.

Multiplying (7) by $\dfrac{n_{oijkm}}{n_{.ijkm}}$ and summing gives

$$S_o \sum \frac{n_{oijkm}^2}{n_{.ijkm}} + S_1 \sum \frac{n_{oijkm} n_{1ijkm}}{n_{.ijkm}} + \sum n_{oijkm} d_{ijkm} = \sum \frac{n_{oijkm} Y_{.ijkm}}{n_{.ijkm}} \tag{8}$$

Subtracting from (5) leaves

$$S_o \left[n_{o....} - \sum \frac{n_{oijkm}^2}{n_{.ijkm}} \right] - S_1 \sum \frac{n_{oijkm} n_{1ijkm}}{n_{.ijkm}} = - \sum \frac{n_{oijkm} Y_{.ijkm}}{n_{.ijkm}} + Y_{o.....} \tag{9}$$

Similarly

$$- S_o \sum \frac{n_{oijkm} n_{1ijkm}}{n_{.ijkm}} + S_1 \left[n_{1....} - \sum \frac{n_{1ijkm}^2}{n_{.ijkm}} \right] = - \frac{n_{1ijkm.} Y_{.ijkm}}{n_{.ijkm}} + Y_{1.....} \tag{10}$$

Since the two equations are independent, we may choose $S_1 = 0$.

Then from (10) the correction becomes

$$S_o = \frac{\dfrac{n_{1ijkm}\, Y_{.ijkm}}{n_{.ijkm}} - Y_{1.....}}{\dfrac{n_{oijkm}\, Y_{1ijkm}}{n_{.ijkm}}} \tag{11}$$

Then the adjusted dam totals are given by

$$aY_{.ijkm.} = Y_{.ijkm.} - S_o\, n_{oijkm} \tag{12}$$

Hereafter the analysis follows the pattern of a regular hierarchical classification with unequal numbers except for the error sums of squares which were obtained by subtracting from the uncorrected total sums of squares the reduction in sums of squares due to fitting all constants. The following corrections for error components were used to solve for the components of variance.

Error $\quad S_o$ (number of S_o) + dams

$$\text{Dams} \qquad \frac{1}{\text{denominator of } S_o} \sum \frac{n_{oijkm}^2}{n_{.ijkm}}$$

$$\text{Sires} \qquad \frac{1}{\text{denominator of } S_o} \sum \frac{n_{oijk.}^2}{n_{.ijk.}}$$

$$\begin{array}{l}\text{Breeding} \\ \text{group}\end{array} \qquad \frac{1}{\text{denominator of } S_o} \sum \frac{n_{oij..}^2}{n_{.ij..}}$$

$$\text{Seasons} \qquad \frac{1}{\text{denominator of } S_o} \sum \frac{n_{oi...}^2}{n_{.i...}}$$

$$\text{C.F.} \qquad \frac{1}{\text{denominator of } S_o} \frac{n_{o....}^2}{n_{.1...}}$$

The components of variance were found by equating the expected to the observed sums of squares of the model given in the following table.

TABLE XVII EQUATING EXPECTED AND OBSERVED SUMS OF SQUARES

Y

Sex

$$\sum_{r} \frac{Y_{r\cdots}^2}{n_{r\cdots}}$$

Seasons

$$\sum_{i} \frac{Y_{\cdot i\cdots}^2}{n_{\cdot i\cdots}}$$

Breeding group in season

$$\sum_{ij} \frac{Y_{\cdot ij\cdots}^2}{n_{\cdot ij\cdots}}$$

Sires in Breeding group

$$\sum_{ijk} \frac{Y_{\cdot ijk\cdot}^2}{n_{\cdot ijk\cdot}}$$

Dams in Sires

$$\sum_{ijkm} \frac{Y_{\cdot ijkm\cdot}^2}{n_{\cdot ijkm}}$$

Total

$$\sum_{rijkmp} Y_{rijkmp}^2$$

C.F.

$$\frac{Y_{\cdots}^2}{n_{\cdots}}$$

$$=$$

$$
\begin{array}{ccccccc}
n_{\cdots} & n_{\cdots} & \displaystyle\sum_{ri}\frac{n_{ri\cdots}^2}{n_{r\cdots}} & \displaystyle\sum_{rij}\frac{n_{rij\cdots}^2}{n_{r\cdots}} & \displaystyle\sum_{rijk}\frac{n_{rijk\cdot}^2}{n_{r\cdots}} & \displaystyle\sum_{rijkm}\frac{n_{rijkm}^2}{n_{r\cdots}} & u \\[3ex]
n_{\cdots} & \displaystyle\sum_{ri}\frac{n_{r\cdots}^2}{n_{\cdot i\cdots}} & n_{\cdots} & \displaystyle\sum_{ij}\frac{n_{\cdot ij\cdots}^2}{n_{\cdot i\cdots}} & \displaystyle\sum_{ijk}\frac{n_{\cdot ijk\cdot}^2}{n_{\cdot i\cdots}} & \displaystyle\sum_{ijkm}\frac{n_{\cdot ijkm}^2}{n_{\cdot i\cdots}} & v \\[3ex]
n_{\cdots} & \displaystyle\sum_{rij}\frac{n_{rij\cdots}^2}{n_{\cdot ij\cdots}} & n_{\cdots} & n_{\cdots} & \displaystyle\sum_{ijk}\frac{n_{\cdot ijk\cdot}^2}{n_{\cdot ij\cdots}} & \dfrac{n_{\cdot ijkm}^2}{n_{\cdot ij\cdots}} & w \\[3ex]
n_{\cdots} & \displaystyle\sum_{rijk}\frac{n_{rijk\cdot}^2}{n_{\cdot ijk\cdot}} & n_{\cdots} & n_{\cdots} & n_{\cdots} & \displaystyle\sum_{ijkm}\frac{n_{\cdot ijkm}^2}{n_{\cdot ijk\cdot}} & x \\[3ex]
n_{\cdots} & \displaystyle\sum_{rijkm}\frac{n_{rijkm}^2}{n_{\cdot ijkm}} & n_{\cdots} & n_{\cdots} & n_{\cdots} & n_{\cdots} & y \\[3ex]
n_{\cdots} & n_{\cdots} & n_{\cdots} & n_{\cdots} & n_{\cdots} & n_{\cdots} & n_{\cdots} \\[3ex]
n_{\cdots} & \displaystyle\sum_{r}\frac{n_{r\cdots}^2}{n_{\cdots}} & \displaystyle\sum_{i}\frac{n_{\cdot i\cdots}^2}{n_{\cdots}} & \displaystyle\sum_{ij}\frac{n_{\cdot ij\cdots}^2}{n_{\cdots}} & \displaystyle\sum_{ijk}\frac{n_{\cdot ijk\cdot}^2}{n_{\cdots}} & \displaystyle\sum_{ijkm}\frac{n_{\cdot ijkm}^2}{n_{\cdots}} & 1
\end{array}
$$

$$
x
\begin{array}{c}
\mu^2 \\[2ex]
\sigma_s^2 \\[2ex]
\sigma_t^2 \\[2ex]
\sigma_B^2 \\[2ex]
\sigma_F^2 \\[2ex]
\sigma_D^2 \\[2ex]
\sigma^2
\end{array}
$$

Where
- u = number of sexes
- v = number of seasons
- w = number of breeding groups
- x = number of sires
- y = number of dams

TABLE XVIII EQUATING EXPECTED AND ADJUSTED SUMS OF SQUARES
(In terms of the adjusted totals)

$$
\begin{bmatrix}
\sum\limits_{i} \dfrac{aY^2_{\cdot\cdot i\cdots}}{n_{\cdot\cdot i\cdots}} \\[2ex]
\sum\limits_{ij} \dfrac{aY^2_{\cdot\cdot ij\cdots}}{n_{\cdot\cdot ij\cdots}} \\[2ex]
\sum\limits_{ijk} \dfrac{aY^2_{\cdot\cdot ijk\cdot}}{n_{\cdot\cdot ijk\cdot}} \\[2ex]
\sum\limits_{ijkm} \dfrac{aY^2_{\cdot\cdot ijkm}}{n_{\cdot\cdot ijkm}} \\[2ex]
\dfrac{aY^2_{\cdots\cdots}}{n_{\cdots\cdots}}
\end{bmatrix}
=
\begin{bmatrix}
n_{\cdots\cdots} & n_{\cdots\cdots} & \sum\limits_{ij}\dfrac{n^2_{\cdot\cdot ij\cdots}}{n_{\cdot\cdot i\cdots}} & \sum\limits_{ijk}\dfrac{n^2_{\cdot\cdot ijk\cdot}}{n_{\cdot\cdot i\cdots}} & \sum\limits_{ijkm}\dfrac{n^2_{\cdot\cdot ijkm}}{n_{\cdot\cdot i\cdots}} & K+\dfrac{1}{D}\sum\limits_{i}\dfrac{n^2_{o i\cdots}}{n_{\cdot\cdot i\cdots}} \\[3ex]
n_{\cdots\cdots} & n_{\cdots\cdots} & n_{\cdots\cdots} & \sum\limits_{ijk}\dfrac{n^2_{\cdot\cdot ijk\cdot}}{n_{\cdot\cdot ij\cdots}} & \sum\limits_{ijkm}\dfrac{n^2_{\cdot\cdot ijkm}}{n_{\cdot\cdot ij\cdots}} & W+\dfrac{1}{D}\sum\limits_{ij}\dfrac{n^2_{o ij\cdots}}{n_{\cdot\cdot ij\cdots}} \\[3ex]
n_{\cdots\cdots} & n_{\cdots\cdots} & n_{\cdots\cdots} & n_{\cdots\cdots} & \sum\limits_{ijkm}\dfrac{n^2_{\cdot\cdot ijkm}}{n_{\cdot\cdot ijk\cdot}} & X+\dfrac{1}{D}\sum\limits_{ijk}\dfrac{n^2_{o ijk\cdot}}{n_{\cdot\cdot ijk\cdot}} \\[3ex]
n_{\cdots\cdots} & n_{\cdots\cdots} & n_{\cdots\cdots} & n_{\cdots\cdots} & n_{\cdots\cdots} & Y+\dfrac{1}{D}\sum\limits_{ijkm}\dfrac{n^2_{o ijkm}}{n_{\cdot\cdot ijkm}} \\[3ex]
n_{\cdots\cdots} & \sum\limits_{i}\dfrac{n^2_{\cdot\cdot i\cdots}}{n_{\cdots\cdots}} & \sum\limits_{ij}\dfrac{n^2_{\cdot\cdot ij\cdots}}{n_{\cdots\cdots}} & \sum\limits_{ijk}\dfrac{n^2_{\cdot\cdot ijk\cdot}}{n_{\cdots\cdots}} & \sum\limits_{ijkm}\dfrac{n^2_{\cdot\cdot ijkm}}{n_{\cdots\cdots}} & 1+\dfrac{1}{D}\dfrac{n^2_{o\cdots\cdots}}{n_{\cdots\cdots}}
\end{bmatrix}
\begin{bmatrix}
\mu^2 \\[2ex]
\sigma_t^2 \\[2ex]
\sigma_B^2 \\[2ex]
\sigma_F^2 \\[2ex]
\sigma_D^2 \\[2ex]
\sigma^2
\end{bmatrix}
$$

TABLE XIX VARIANCE COMPONENT EQUATIONS

Where $D = \sum\limits_{ijkm} \dfrac{n_{oijkm}\, n_{1ijkm}}{n_{.ijkm}}$

$$\sigma^2_{sibs} = \frac{\sum\limits_{rijkmp} Y^2_{rijkmp} - \sum\limits_{ijkm} \dfrac{Y^2_{.ijkm.}}{n_{.ijkm}} - \left[\dfrac{\left[\sum\limits_{1ijkm}\dfrac{n_{1ijkm}\, Y_{.ijkm.}}{n_{.ijkm}} - Y_{1.....}\right]^2}{\sum\limits_{ijkm}\dfrac{n_{oijkm}\, n_{1ijkm}}{n_{.ijkm}}}\right]}{n_{.....}}$$

$$n_{.....} - \text{No. of dams in sires}$$

$$\sigma^2_{dams} = \frac{\left[\sum\limits_{ijk}\dfrac{aY^2_{.ijk.}}{n_{.ijk.}} - \sigma^2\left(X + \dfrac{1}{D}\sum\limits_{ijk}\dfrac{n^2_{oijk.}}{n_{.ijk.}}\right)\right] - \left[\sum\limits_{ijkm}\dfrac{aY^2_{.ijkm.}}{n_{.ijkm}} - \sigma^2\left(Y + \dfrac{1}{D}\sum\limits_{ijkm}\dfrac{n^2_{oijkm}}{n_{.ijkm}}\right)\right]}{\sum\limits_{ijkm}\dfrac{n^2_{.ijkm}}{n_{.ijk.}} - n_{.....}}$$

$$\sigma^2_{sire} = \frac{\left[\sum\limits_{ij}\dfrac{aY^2_{.ij..}}{n_{.ij..}} - \sigma^2\left(W + \dfrac{1}{D}\sum\limits_{ij}\dfrac{n^2_{oij..}}{n_{.ij..}}\right)\right] - \left[\sum\limits_{ijk}\dfrac{aY^2_{.ijk.}}{n_{.ijk.}} - \sigma^2\left(X + \dfrac{1}{D}\sum\limits_{ijk}\dfrac{n^2_{oijk.}}{n_{.ijk.}}\right)\right] - \left[\sum\limits_{ijkm}\dfrac{n^2_{.ijkm}}{n_{.ij..}} - \sum\limits_{ijkm}\dfrac{n^2_{.ijkm}}{n_{.ijk.}}\right]\sigma^2_D}{\sum\limits_{ijk}\dfrac{n^2_{.ijk.}}{n_{.ij..}} - n_{.....}}$$

where X = No. of sires, Y = No. of dams, and W = No. of breeding groups.

TABLE XX SUMS OF SQUARES FOR THE STILLWATER ADJUSTED DATA

Trait[1]	Total Y^2_{rijkmp}	Sex $\dfrac{Y^2_{.ijkm.}}{n_{.ijkm}}$	Station $\dfrac{aY^2_{......}}{n_{.....}}$	Season $\dfrac{aY^2_{.i....}}{n_{.i...}}$	Breed $\dfrac{aY^2_{.ij...}}{n_{.ij..}}$	Sire $\dfrac{aY^2_{.ijk..}}{n_{.ijk.}}$	Dam $\dfrac{aY^2_{.ijkm.}}{n_{.ijkm}}$
1	461489.17	461338.73	453628.80	453709.31	453786.04	453930.85	454010.62
2	1767.5851	1757.7329	1884.7829	1892.8391	1897.5003	1903.4725	1908.7667
3	11886.0831	11777.4566	10422.1664	10581.0767	10663.1035	10751.1968	10805.4302
4	439.372149	439.364742	437.408355	437.435052	437.437685	437.444367	437.444327
5	2909266.30	2908804.05	2925864.77	2926357.16	2926372.66	2926673.71	2927002.59
6	656430.65	655674.86	640935.87	645737.50	646107.40	646628.54	646931.25
7	1158778.88	1158157.57	1133082.04	1135612.75	1136007.70	1136488.95	1136845.49
8	83418.48	83271.31	78059.20	78903.77	79031.19	79138.46	79199.16
9	59944.20	59810.61	56141.37	56934.59	56974.94	57079.02	57156.11
10	77410.98	77332.89	75848.37	76172.54	76178.80	76259.28	76333.16
11	73448.42	73243.77	75026.32	75925.63	75932.30	76148.71	76280.30
12	1140556.7202	1140149.9790	1123674.9649	1124730.7462	1124949.9898	1125335.9318	1125570.3492
13	815730.	810155.	764760.	787873.	788713.	799007.	810192.
14	1248.7299	1242.3594	1307.8310	1319.1614	1320.3099	1325.7588	1331.0021
15	12702170.	12693522.	12797074.	12813455.	12813580.	12818209	12822668.
16	365.5297	362.5314	407.5122	407.5731	409.0472	409.7693	410.7465

[1]Numbers refer to traits given in Table VI, page 56.

TABLE XXI SUMS OF SQUARES FOR FORT RENO MALES

Trait[1]	Total	Dam	Sire	Breed	Season	Station
	Y^2_{lijkmp}	$\dfrac{Y^2_{lijkm.}}{n_{lijkm}}$	$\dfrac{Y^2_{lijk..}}{n_{lijk.}}$	$\dfrac{Y^2_{lij...}}{n_{lij..}}$	$\dfrac{Y^2_{li....}}{n_{li...}}$	$\dfrac{Y^2_{l.....}}{n_{l....}}$
1	279365.75	279307.18	279268.22	279209.13	279081.57	279067.38
2	1166.8816	1163.1736	1160.8714	1157.1086	1150.0856	1148.0219
5	1779695.56	1779351.20	1779124.61	1778938.22	1778779.49	1778502.72
6	455208.57	454984.43	454820.30	454666.66	454427.73	454341.05
7	853730.34	853475.55	853244.71	853081.29	852961.47	852840.03
8	61347.26	61298.06	61267.66	61212.29	61153.12	61117.45
9	41932.09	41878.82	41843.78	41807.57	41727.73	41660.16
10	49796.21	49746.67	49722.23	49686.25	49657.68	49606.88
11	62745.90	62641.49	62564.97	62497.08	62421.58	62247.19
12	646731.3863	646487.5859	646307.6308	646136.0049	646012.7587	645914.2672
13	966174.	947606.	947615.	930839.	924653.	886431.
14	867.3123	866.0508	865.0812	863.1116	861.4190	854.5303
15	7392726.	7386613.	7382731.	7380149.	7378072.	7370727.
16	184.0021	183.5296	183.2549	182.7376	182.7269	182.7269

[1]Numbers refer to traits given in Table VI, page 56.

TABLE XXII DEGREES OF FREEDOM AND VARIANCE COMPONENT COEFFICIENTS

Trait[1]	STILLWATER[2]						FORT RENO-MALES[2]	
	1	3	4	13	14	16	1	16
$n_{.....}$	547	488	413	538	478	131	341	53
$n_{1....}$	336	305	258	327	285	67	341	53
$n_{o....}$	211	183	155	211	193	64	0	0
number of sexes	2	2	2	2	2	2	1	1
number of seasons	13	12	10	13	11	2	8	1
number of breeding groups	22	21	19	22	19	5	34	4
number of sires	149	137	119	148	125	27	98	12
number of dams	285	259	210	281	240	51	172	23
$n_{.i...}^2 / n_{.....}$	46.12	44.50	45.61	45.77	47.74	66.36	47.45	53.00
$n_{.ij..}^2 / n_{.....}$	36.43	33.76	33.31	35.92	37.20	43.00	13.24	14.66
$n_{.ijk.}^2 / n_{.....}$	4.85	4.82	4.53	4.72	4.80	5.41	4.51	6.17
$n_{.ijkm}^2 / n_{.....}$	2.18	2.15	2.19	2.17	2.22	2.85	2.27	2.55
$n_{.ijkm}^2 / n_{.i...}$	27.31	24.91	21.17	27.21	23.54	5.59	17.67	2.55
$n_{.ijkm}^2 / n_{.ij..}$	47.77	45.34	41.38	47.67	41.88	16.30	71.79	10.11
$n_{.ijkm}^2 / n_{.ijk.}$	300.81	272.35	242.96	298.60	262.73	75.32	204.69	29.80
$n_{.ijk.}^2 / n_{.i...}$	60.70	55.66	42.90	59.04	50.81	10.74	33.30	6.17
$n_{.ijk.}^2 / n_{.ij..}$	93.68	88.60	75.50	92.02	79.24	24.68	132.14	22.80
$n_{.ij..}^2 / n_{.i...}$	443.70	384.94	311.66	434.70	383.09	89.08	97.37	14.66
$n_{oijkm}^2 / n_{.ijkm}$	116.96	103.47	81.57	117.63	102.05	31.65		
$n_{oijk.}^2 / n_{.ijk.}$	105.09	91.69	76.60	106.32	94.07	31.53		
$n_{oij..}^2 / n_{.ij..}$	94.79	81.53	69.99	97.43	86.26	31.29		
$n_{oi...}^2 / n_{.i...}$	93.69	80.42	68.89	96.33	85.16	31.27		
$n_{o....}^2 / n_{.....}$	81.39	68.63	58.17	82.75	77.93	31.27		

[1] Numbers refer to traits given in Table VI, page 56.

[2] Other traits not listed have the same n's and coefficients as No. 1.

TABLE XXIII   NUMBER OF SIRES BY SEASON AND BREEDING

GROUP AT FORT RENO

Season	Duroc	Land. x Duroc	Poland x Duroc	Chester x Duroc	White King x 8-9	Minn.No. 2 x Duroc	So.Dak. Hamp. x T-3
1953 F	4	3	3	2	--	--	--
1953 S	3	4	3	2	--	--	--
1952 F	3	2	3	--	2	1	--
1952 S	5	2	3	--	2	2	--
1951 F	4	4	4	--	--	--	2
1951 S	4	5	4	--	--	--	2
1950 F	5	2	--	1	--	1	--
1950 S	6	1	2	--	--	2	--
Totals	34	23	22	5	4	6	4
Degrees freedom	26	15	15	2	2	2	2

Number of sire by season-breeding group subclasses = 98.

Number of sires actually different animals = 61.

Number of degrees of freedom for sires = 64.

BREEDS		1953 F Gain	No.	1953 S Gain	No.	1952 F Gain	No.	1952 S Gain	No.	1951 F Gain	No.	1951 S Gain	No.	1950 F Gain	No.	1950 S Gain	No.
Duroc	Test pigs	1.71	19	1.59	20	1.70	10	1.51	23	1.77	14	1.47	16	1.56	9	1.40	19
	All pigs	1.68	77	1.53	87	1.43	70	1.45	63	1.59	76	1.31	86	1.53	51	1.33	85
	Difference	.03		-.06		-.27		-.06		.18		.16		.03		.07	
Land.x Duroc	Test pigs	1.60	13	1.79	12	1.50	4	1.49	6	1.96	12	1.49	15	1.55	5	1.41	8
	All pigs	1.56	44	1.73	34	1.37	29	1.37	22	1.71	46	1.39	71	1.49	22	1.24	50
	Difference	.04		.06		.13		.12		.25		.10		.06		.17	
Pol. x Duroc	Test pigs	1.73	16	1.74	13	1.68	6	1.39	14	1.77	12	1.45	15			1.46	3
	All pigs	1.67	50	1.65	40	1.43	35	1.31	65	1.61	46	1.36	73			1.31	29
	Difference	.06		.09		.25		.08		.16		.09				.15	
Ch. x Duroc	Test pigs	1.70	5	1.49	8									1.49	2		
	All pigs	1.61	16	1.40	47									1.36	18		
	Difference	.09		.09										.13			
W.K. x 8-9	Test pigs					1.68	2	1.39	8								
	All pigs					1.52	17	1.34	46								
	Difference					.16		.05									
M #2 x Duroc	Test pigs					1.48	3	1.29	8					1.48	1	1.86	5
	All pigs					1.23	23	1.28	30					1.46	10	1.36	23
	Difference					.25		.01						.02		.50	
S.D.H. x T-3	Test pigs									1.86	7	1.38	8				
	All pigs									1.58	30	1.31	41				
	Difference									.28		.07					
Average difference within season		.05		.11		.24		.09		.21		.12		.05		.16	

Average breed difference: Duroc .10   Land. x Duroc .15   Pol. x Duroc .15

Ch. x Duroc .13   W.K. x 8-9 .06   M #2 x Duroc .19

S.D.Hamp x T-3 .18

TABLE XXV   CODE IDENTIFICATION MASTER SHEET

Column	Item	Code
1	Station	0 Stillwater 1 Fort Reno
2-3	Season	01 1953 Fall 02 1953 Spring 03 1952 Fall 04 1952 Spring 05 1951 Fall 06 1951 Spring 07 1950 Fall 08 1950 Spring 09 1949 Fall 10 1949 Spring 11 1948 Fall 12 1948 Spring 13 1947 Fall
4	Breeding group	1 Stillwater Durocs 2 Duroc x Landrace-Poland 3 Landrace-Poland 4 Durocs (Fort Reno) 5 Landrace x Duroc (Fort Reno) 6 Poland x Duroc (Fort Reno) 7 Chester x Duroc (Fort Reno) 8 White King x 8-9 (Fort Reno) 9 Minn. No. 2 x Duroc (Fort Reno) 0 So. Dak. Hamp. x T-3 (Fort Reno)

Column	Item	Code	
5-6-7	Sires	003-T.J.B.	042-42 Duroc
		004-Square Prince	043-42 Landrace-Poland
		005-Sooner Fancy	403-40x3
		006-Red Liner	541-54x1
		008-RL7	905-905x1
		009-Cherry Wave	990-3482
		010-Black King	991-3583
		034-RL32	

The other sires retain their original number without the letter.

Column	Item	Code		
8-9-10	Dams	013-RL12	192-19x2	699-R699x1
		037-RL36	321-RL322	729-L729x1
		046-P45	349-R349x2	758-RL757
		060-6x1	611-RL612	800-L801
		090-C90	649-649x1	907-906x1
		147-047	651-L652	908-T906
		179-R179x2	692-69x2	

Column	Item	Code	
8-9-10	Dams (continued)	933-L923	001-2874
		935-L925	002-2875
		936-L926	003-3524
		991-99g	004-3703
		999-999x2	
		The other dams retain their original number.	
11-12-13	Pigs	Coded on a within season basis making all numbers read in three digits, dropping all letters, using the actual ear notch number.	
14	Sex	0-gilt	
		1-barrow	
15-16-17	Shrunk live weight		
18-19-20	Carcass length		
21-22-23	Average backfat thickness		
24-25-26-27	Specific gravity		
28-29-30	Loin lean area		
31-32-33	Dressing percentage		
34-45-36	Percent ham		
37-38-39	Percent loin		
40-41-42	Percent shoulder		
43-44-45	Percent belly		
46-47-48	Percent lean cuts		
49-50-51	Percent primal cuts		
52-53-54-55	Carcass index		
56-57	Initial weight		
58-59-60	Average daily gain		
61-62-63	Carcass weight		
64-65-66	Sequence number		

Note - For columns 15 through 63 the actual weight or percent was used with a constant number of digits within each measurement.

Columns 24-25-26-27, specific gravity and columns 28-29-30, loin lean area are blank in the Fort Reno data.

VITA

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Thesis: SWINE CARCASS STUDIES. I. GENETIC VARIATION AND
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