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The relationship of body length to economically important swine production and carcass traits

Frank David Kirkpatrick

To the Graduate Council:

I am submitting herewith a dissertation written by Frank David Kirkpatrick entitled "The relationship of body length to economically important swine production and carcass traits." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

R.R. Shrode, Major Professor

We have read this dissertation and recommend its acceptance:

R.L. Murphee, Don O. Richardson, R.D. Sanders

Accepted for the Council:

Carolyn R. Hodges

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(Original signatures are on file with official student records.)

150

May 20, 1971

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Robert R. Shrode
Major Professor

We have read this dissertation and recommend its acceptance:

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Vice Chancellor for Graduate Studies and Research

THE RELATIONSHIP OF BODY LENGTH TO ECONOMICALLY IMPORTANT SWINE PRODUCTION AND CARCASS TRAITS

A Dissertation

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

Frank David Kirkpatrick

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ABSTRACT

A total of 1,062 purebred Duroc pigs of 168 litters by 14 sires provided data from five farrowing seasons at Ames Plantation (November, 1968, through November, 1969). Analyses were conducted to determine the phenotypic and genetic relationships of body length and various productivity and carcass traits and to estimate heritability of body length in order to assess the possible effectiveness of including this trait in a selection program.

Phenotypic correlations among individual traits indicate that heavier weaning pigs reach 200 pounds at an earlier age, are longer and have less backfat and higher muscle scores than lighter weaning pigs. Body length was significantly ($P < .01$) correlated with backfat ($r = -.318$). Also, pigs born with higher nipple counts tend to be longer at 200 pounds than pigs with fewer nipples.

Phenotypically, dam body length was not significantly related to any litter production traits with the exception of litter average body length. Longer dams tended to produce longer litters at 200 pounds than shorter dams. Litter size at birth accounted for 60 percent of the variation in litter birth weight while litter size at weaning accounted for 79 percent of the variation in litter weaning weight.

Genetic correlations among litter traits were very erratic with many of the standard errors larger than the estimates. Heritability estimates obtained from paternal half-sib correlations for litter averages of days to 200, body length and backfat were 0.51 ± 0.29,

0.51 ± 0.28 and 0.11 ± 0.18, respectively. The estimate of heritability of litter average body length computed by intra-sire regression of offspring on dam was 0.06 ± 0.01 which was interpreted as a possible consequence of appreciable maternal influence on body length.

These data indicate that increasing dam body length would not significantly influence any pre-weaning or weaning traits.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

The swine industry has for many years used carcass length as a criterion for determining market grade, and as a major criterion in meat-hog certification programs. The relationship of carcass length to other carcass traits has been studied thoroughly. However, little information has been published concerning the relationship of carcass length to various other important traits of individual animals.

Recently, swine breeders have assigned increasing economic value to subjective measures of length in prospective breeding herd replacements. Most breeders have used an independent culling level with respect to length, prior to the utilization of a selection index or other selection methods. There is little information relating carcass or body length of the individual gilt to her own productivity or to the length, carcass characteristics or performance of her offspring.

Estimates of the heritability of carcass length range from 0.5 to 0.6. Selection programs based on sibling carcass length indicate realized heritability also to be in this range. If these estimates of heritability are valid, progress should be rapid when selection is based on individual measurements of carcass length.

The use of carcass length in mass selection has been limited to subjective estimates due to the necessity of sacrifice of the animal to obtain more accurate measures. However, Fogleman (1966) and Spears

(1967) found that certain measurements of body length in the live animal were highly correlated with carcass length. Further investigation of the relationship of body length to individual performance, carcass traits and future productivity could provide guides to more effective utilization of individual body length in selection programs.

The objectives of the present study were to:

1. Estimate heritability of body length and thus further assess the effectiveness of including this trait in a selection program.

2. Determine the phenotypic and genetic relationships of body length to various productivity and carcass traits.

CHAPTER II

REVIEW OF LITERATURE

An extensive review of all published swine research through 1966 was made by Topel (1967). Only research that has been published later than the above review will be reported and/or any other research which may have been omitted from that review.

I. INDIVIDUAL TRAITS

The literature is very abundant on studies of carcass length and its relationship to other carcass traits, but there is very little on its relationship to production traits. The primary reason for this has been the inability to measure accurately carcass length in the live animal.

Body length. Early researchers tried to measure body length of the live animal and relate it to carcass length by restraining the live pig with a wire loop around the mandible and measuring the distance down the midline between the head and tail. This technique left much to be desired because of the low repeatability of the measurement. The body length measurement obtained varied according to the placement of the pigs' legs.

Fogleman (1966) found a highly significant ($P < .01$) correlation of 0.78 between carcass length and length from the tuber spina to the tuber coxa taken on the hog's left side with a steel tape. These measurements were taken with the pig in a relaxed, suspended position in a restraining crate. By restraining pigs in a similar manner, Spears (1967) obtained a simple correlation of 0.87 between carcass length and length measured from the poll to the root of the tail of the live hog. Jones (1970), using the same technique as Spears, obtained correlations of 0.37 and 0.63 between body length and carcass length of pigs measured at 225 pounds and 300 pounds, respectively. These correlations were much lower than those of Fogleman (1966) and Spears (1967) probably because of the small number of animals involved and the small varition in body length of the animals measured.

Another method of estimating carcass length in the live animal is by slaughtering littermates and obtaining their actual carcass length. Duckworth and Holmes (1968) selected for increased carcass length in large white pigs with the selection criterion being average carcass length of the full-sib group of which the individual in question was a member. An increase of 20.7 mm in carcass length was attained in five generations of selection. Table I shows the results of that experiment with respect to production traits. Their work resulted in an average estimate of heritability of carcass length of 0.53 $\pm$ 0.02.

Nipple count. Swine breeders have attached considerable importance to number of nipples when selecting breeding stock. It is apparent that the only need for using teat number as a selection criterion is to insure that females have an adequate number of functional teats to raise the young pigs.

Enfield and Rempel (1961) obtained a phenotypic correlation of 0.44 between total teat number at birth and functional teat number.

TABLE I

SELECTION FOR CARCASS LENGTH IN LARGE WHITE PIGS
BY DUCKWORTH AND HOLMES (1968)

	P_1	F_1	F_2	F_3	F_4
Number of litters	39	39	37	28	28
Litter size, birth	13.5	10.7	10.6	10.1	10.7
Litter birth weight		24.8	24.9	29.2	30.9
Avg. litter size, weaned	10.5	9.1	9.0	8.9	10.3
Litter weaning weight	411.7	355.9	351.0	338.7	425.0
Age at 210 lbs.	182.7	178.0	175.8	182.5	178.1
Mean litter carcass length (mm)*	804.9	805.7	823.0	825.4	825.6
Depth of backfat, shoulder (mm)	49.2	48.5	47.0	45.5	45.2
Depth of backfat, mid-back (mm)	22.7	22.4	21.7	21.2	20.5
Depth of backfat, loin (mm)	34.5	34.5	33.0	32.6	31.9
Weighted selection differential of carcass length of male parents (mm)	17.0	19.5	14.4	7.6	
Weighted selection differential of carcass length of female parents (mm)	11.9	15.0	7.1	6.8	

*(2 castrates and 1 female).

This indicates that total teat number at birth might not be a good indication of the number of teats that will be functional at the time of farrowing. Their estimates of heritability of total teat number were 0.10 ± 0.04 estimated from a dam-offspring regression analysis and 0.23 ± 0.20 estimated from the paternal half-sib correlation.

II. AGE OF DAM

It is generally agreed that first litter gilts farrow fewer pigs, on the average, than mature sows. McLaren (1967) found that age of dam had a significant ($P < .05$) effect on litter and production traits. Mature sows produced larger and heavier litters at birth, weaning and market age than first litter gilts. Also, pigs from mature sows produced pigs that had higher post-weaning gains than those from first-litter gilts, and litter size at birth increased by an average of 1.8 pigs from the first to the second litter.

III. SEX

Marked differences in performance and carcass traits have been noted among boars, barrows and gilts. Burgess (1965) found that boars gained faster than gilts and barrows, but there was practically no difference in gain between barrows and gilts. Also, boars and gilts had longer carcasses with less backfat than barrows. Jones (1970) obtained similar results with the exception that barrows gained significantly faster than gilts. Results of other findings included in Topel's (1967) review are referred to in the discussion section of this dissertation.

IV. PRESENT STATUS OF KNOWLEDGE IN THIS PROBLEM AREA

There has been no research, to the author's knowledge, on the relationship of body length with sow productivity traits. The only research that approaches the problem is the experiment by Duckworth and Holmes (1968). Their study was by sib selection and not on the individual herself. Also, they did not remove the effects of inbreeding, and it certainly must have increased appreciably within their small closed herd and could have influenced their results.

CHAPTER III

EXPERIMENTAL PROCEDURE

I. SOURCE OF DATA

The data for this study were collected in a swine breeding project conducted at Ames Plantation, Grand Junction, Tennessee, by the Animal-Husbandry-Veterinary Science Department, University of Tennessee.

This study includes data from five farrowing seasons from November, 1968, through November, 1969.

Data were obtained on the following individual pig traits:

Nipple count

Weaning weight

Market weight

Market age

Days to 200 pounds

Body length

Backfat

Muscle score

Litter traits recorded were:

Litter birth weight

Litter size at birth

Litter weaning weight

Litter size at weaning

Litter average market weight

Litter average market age

Litter average days to 200 pounds

Litter average body length

Litter average backfat

Litter average body length, days to 200 and backfat were adjusted to a gilt basis by a least-squares procedure.

II. EXPERIMENTAL ANIMALS

The animals used were from the Ames Plantation Duroc herd. The herd was divided into two groups in order to facilitate a four-season farrowing operation. Each group farrowed twice a year and consisted of only first and second-litter gilts which had been measured for body length, backfat and muscle score when they were of market age. One group farrowed in February and August and the other group in May and November. Each group was selected for maximum variation in body length. In order to shorten the generation interval; females were removed from the herd after they had farrowed twice, and were replaced by gilts that were selected for maximum variation in body length. Distribution of litters born in various seasons and by age of dam is shown in Table II.

Boars of varying body length were purchased from outside pure-bred Duroc herds or selected from within the herd and used on both groups of gilts. Planned matings were used in an attempt to increase variation in body length and to prevent inbreeding. The longest boar in each breeding season was always mated to the longest replacement

TABLE II

DISTRIBUTION OF LITTERS BORN BY SEASON AND AGE OF DAM

Season	Age of dam		Total
	1st Litter	2nd Litter	
1	22	0	22
2	17	12	29
3	27	17	44
4	26	11	37
5	16	20	36
Total	108	60	168

gilt and to the longest first-litter gilt. Also, the shortest boar was mated to the shortest replacement gilt and to the shortest first-litter gilt. After these restrictions, a negative-assortive mating system was followed. Distribution of pigs and litters by sire and season is shown in Tables III and IV.

III. HERD MANAGEMENT AND FEEDING

With the exception of dividing the herd into two groups, one-half farrowing in February and August and the other half farrowing in May and November, management and feeding practices were the same as those described by McLaren (1967).

IV. SELECTION PRACTICES

Prospective herd boars from within the herd were selected at approximately four to five weeks of age. Two or three boar pigs from each litter produced by matings of extremes and a random sample from litters produced by matings between males and females deviating in opposite directions from the mean length, representing all sire groups in a season, were saved for potential breeding stock.

Gilts to be used as replacements were selected at or near 200 pounds of weight after measurement for body length, backfat and muscle score. Selection of gilts was based entirely on body length with the exception of an independent culling level established for structural soundness. The longest and shortest gilts of each season were saved along with a representative sample of gilts of intermediate lengths representing all sire groups in that season.

TABLE III

DISTRIBUTION OF PIGS BY SIRE AND SEASON

Season	Sires														Total
	1-9	2-7	110-9	7-3	7-6	7-7	8-4	8-7	9-7	75-6	80-4	84-8	86-6	89-2	
1											49		50	17	116
2					31	44	15		39				16	53	198
3	56	46		43	41			43	39				73		341
4		64		49		54		41					36		244
5		33	31			21				32		31	15		163
Total	56	143	31	92	72	119	15	84	78	32	49	31	190	70	1,062

TABLE IV

DISTRIBUTION OF PIGS BY YEAR, SEASON, SEX AND AGE OF DAM

	Sex			Age of dam		
Season	Boars	Gilts	Barrows	1st Litter	2nd Litter	Total
1	6	53	57	116	0	116
2	5	99	94	101	97	198
3	16	156	169	215	126	341
4	34	124	86	163	81	244
5	20	83	60	71	92	163
Total	81	515	466	666	396	1,062

Measurements of body length were taken by the procedures described by Fogleman (1966), Spears (1967) and Jones (1970). Recorded backfat was the average thickness at three probing sites, viz; 1-1/2 inches lateral to the dorsal midline at point of shoulder, at last rib and at point of hip. These locations correspond in position to the first rib, last rib and last lumbar vertebra which are the locations of sites for backfat measurements on pork carcasses.

Muscle score was an average of subjective evaluations of muscling in the live pig made independently by two experienced individuals in live hog evaluation.

V. METHODS AND ANALYSIS

Weight records were kept on all pigs in this study. The weights were adjusted to a 56-day basis to permit comparison of litter means. Market weights were adjusted to a comparable basis by calculating the number of days required to reach 200 pounds. The following linear formulas were used for adjusting individual pig weights and days to 200 pounds:

$$\text{Adjusted 56-day weight} = 56\,\frac{W_W - W_B}{A_W} + W_B$$

$$\text{Days to 200 pounds} = A_M - \frac{W_m - 200}{1.8}$$

when:

W_B = Birth weight

W_W = Weaning weight

A_W = Weaning age

A_M = Market age

W_M = Market weight

1.8 = regression coefficient of market weight on market age calculated from the population in this study.

Backfat probes taken on pigs at market weight were adjusted to a 200-pound basis by use of the conversion factor adopted by the National Association of Swine Records. Their conversion factor is $\pm$ 0.004 inches per pound deviation from 200 pounds. The adjustment factor for body length was determined by calculating the coefficient of regression of body length on market weight. This value was $\pm$ 0.0527 inches per pound deviation from 200 pounds. All pigs farrowed, whether alive or stillborn, were included in litter size and litter weight data collected at birth. All pigs at weaning were included in weaning data, and only those pigs measured at market age were included in litter averages which were adjusted to a gilt basis.

The dependent variables used in this study were:

Litter size at birth weaning

Birth and weaning weight of litter

Individual nipple count

Individual pig weaning and market weight

Litter average market weight and age

Litter average and individual days to 200 pounds

Litter average and individual body length

Litter average and individual backfat

Individual muscle score

Dam's body length, backfat and muscle score

Litter traits and individual traits were analyzed separately. Least-squares constants were fitted by methods described by Harvey (1960) as a means of studying the effects of season, sire, sex and age of dam. Since litter averages were adjusted to a gilt basis, the effect of sex was not fitted in the model for litter traits.

The following linear additive models were assumed for the least-squares analysis of the dependent variables. These models were:

(1) $Y_{ijkln} = \mu + y_i + s_j + d_k + a_l + e_{ijkln}$

where Y_{ijkln} = Individual nipple count, weaning weight, market weight, market age, days to 200 pounds, backfat, body length or muscle score for the n^{th} pig, of the l^{th} sex, of the k^{th} age of dam from the j^{th} season by the i^{th} sire.

(2) $Y_{ijkm} = \mu + y_i + s_j + d_k + e_{ijkm}$

where:

Y_{ijkm} = The litter size at birth or weaning, litter weight at birth or weaning, litter average market weight, age, days to 200 pounds, body length or backfat of the m^{th} litter of the k^{th} age of dam, from the j^{th} season by the i^{th} sire.

The dam's body measurements were included as dependent variables in these models in order to obtain phenotypic and genetic correlations between her measurements and traits of her offspring.

(3) $Y_{ijkm} = \mu + y_i + s_j + d_k + b_1(X_1 - \overline{X}_1) + e_{ijkm}$

where:

Y_{ijkm} = The litter size at birth or weaning, litter weight at birth or weaning, litter average market weight, age, days to 200 pounds, body length or backfat, with dam body length held constant, for the m^{th} litter of the k^{th} age of dam, in the j^{th} season by the i^{th} sire.

The dam's backfat and muscle score also were dependent variables in the above model in order to determine the effect of these traits on pigs' performance traits with the effect of dam's body length removed.

(4) $Y_{ijkm} = \mu + y_i + s_j + d_k + b_2(X_2 - \overline{X}_2) + e_{ijkm}$

where:

Y_{ijkm} = The litter size at birth or weaning, litter weight at birth or weaning, litter average market weight, age, days to 200 pounds, body length or backfat, with dam backfat thickness held constant, for the m^{th} litter of the k^{th} age of dam, in the j^{th} season, by the i^{th} sire.

The dam's body length and muscle score were included also as independent variables in the above model.

Where:

μ = The theoretical population mean when equal numbers exist in subclasses

y_i = The effect of sire with i classification, when i = 1, 2, ...,14.

s_j = The effect of season of birth with j classification, when j = 1,2,3,4,5 as follows:

1. November, 1968

2. February, 1969

3. May, 1969

4. August, 1969

5. November, 1969

d_k = The effect of age of dam with k classification, when

k = 1,2 as follows:

1. First-litter gilt

2. Second-litter gilt

a_l = The effect of sex with l classification, when

l = 1,2,3 as follows:

1. Boar

2. Gilt

3. Barrow

$b_1 (X_1 - \bar{X}_1)$ = Term for regression of the dependent variables on dam's body length (X_1 = dam's body length).

$b_2 (X_2 - \bar{X}_2)$ = Term for regression of the dependent variables on dam's backfat (X_2 = dam's backfat).

e_{ijkln} and e_{ijkm} = random errors.

The term for regression of the dependent variables on dam's body length was added also, in another analysis, to model 1 in order to obtain an estimate of heritability of body length by intra-sire regression of offspring's body length on dam's body length.

Duncan's Multiple Range Test (1955) as modified by Kramer (1957) was used for mean separation when significant differences were detected.

Heritability estimates were obtained for the dependent variables from paternal half-sib correlations and from intra-sire regressions of off-spring on dam as described by Falconer (1960). This was facilitated by the ability to include in a model more than one dependent variable with the analysis being performed independently for each dependent variable in the Least-Squares and Maximum Likelihood General Purpose Program prepared by Harvey (1968).

CHAPTER IV

RESULTS AND DISCUSSION

Included in the analyses reported here were data from 1,062 pigs born in 168 litters sired by 14 different boars. The dependent variables in the mathematical models fitted were various tratis of individual pigs and various litter traits. The main effects considered in the models were sire, season, sex and age of dam. In preliminary analyses the first-order interactions of the main effects were found to be non-significant and neglible and, hence, were deleted from the models in subsequent analyses.

I. INDIVIDUAL TRAITS

Age of dam. Pigs farrowed by first-litter gilts had significantly ($P < .01$) higher nipple counts and lighter weaning weights than pigs from second-litter gilts. Age of dam had a significant ($P < .01$) effect also upon days to 200 pounds and backfat thickness. There was no significant age-of-dam effect upon the other traits studied. Least-squares means of dependent variables for the two age-of-dam classes are shown in Table V. These results, with the exception of nipple count, concur with Hetzer et al. (1961) and with McLaren (1967) who found that second-litter and older females produce pigs that gain faster but with no associated difference in backfat. However, a tremendous number of reported studies have shown an increase in gain to be associated with an increase in backfat as is indicated in the present results.

TABLE V

LEAST-SQUARES MEANS OF INDIVIDUAL PIG TRAITS BY AGE OF DAM

	Age of dam	
	1	2
Nipple count	12.31 ± .05	12.16 ± .06
Weaning weight (lbs.)	35.23 ± .40	36.72 ± .48
Days to 200 pounds	186.66 ± .82	183.37 ± .99
Backfat (in.)	1.10 ± .006	1.12 ± .008
Body length (in.)	42.06 ± .05	42.08 ± .06
Muscle score	2.81 ± .03	2.75 ± .03

Season. There was a highly significant ($P < .01$) effect of season upon weaning weight, days to 200 pounds, backfat, body length and muscle score. Reddy et al. (1959) also found season to have a significant effect upon rate of gain and backfat. Fitting season in the model permits assessment of the data as though the analysis had been done on a within-season basis. Least-squares means for the seasons are shown in Table VI.

Sex. Boar pigs were heavier at weaning than barrows or gilts which is in partial agreement with results reported by Craig et al. (1956). However, they did not include barrows in their study. One would expect boars to be heavier at weaning than barrows because of the stress which castration imposes on barrows.

The effects of sex were noted also on days to 200 pounds. Boars and barrows reached 200 pounds at a significantly ($P < .01$) younger age than gilts, which is in accord with the work of Lacy (1932), Bruner et al. (1958), Mulholland et al. (1960), Omtvedt, et al. (1962), Cox (1963) and Magee (1964). However, Wagner, et al. (1963) found that gilts gained slightly faster than boars which disagrees with results of the present study.

Significant ($P < .01$) differences in backfat thickness between sexes at 200 pounds were observed, with boars the leanest followed by gilts and then barrows. These results are well in agreement with the work of Hammond and Murray (1937), Hetzer et al. (1956), Zobrisky (1960) and Wagner et al. (1963). Burgess (1965) and Moore (1966) failed to find a significant difference in backfat thickness between boars and

TABLE VI

LEAST-SQUARES MEANS OF INDIVIDUAL TRAITS BY SEASON

	Season				
	1	2	3	4	5
Nipple count	12.13 ± 0.13	12.14 ± 0.09	12.23 ± 0.08	12.36 ± 0.08	12.07 ± 0.10
Weaning weight	34.80 ± 1.04	37.89 ± 0.71	37.46 ± 0.59	36.57 ± 0.63	33.17 ± 0.80
Days to 200	186.44 ± 2.11	179.69 ± 1.45	167.31 ± 1.19	206.84 ± 1.29	184.81 ± 1.62
Backfat	1.12 ± 0.02	1.14 ± 0.01	1.16 ± 0.01	1.08 ± 0.01	1.06 ± 0.01
Body length	42.45 ± 0.14	41.91 ± 0.09	42.10 ± 0.08	41.82 ± 0.08	42.08 ± 0.11
Muscle score	2.72 ± 0.08	2.72 ± 0.05	2.74 ± 0.04	2.66 ± 0.05	3.09 ± 0.06

gilts, but both had significantly ($P < .01$) less backfat than barrows.

Gilts were significantly ($P < .01$) longer at 200 pounds than boars and barrows. Boars and barrows did not differ significantly in body length, but boars tended to be longer than barrows. Charette (1961) and Bratzler et al. (1954) found boars to be significantly ($P < .05$) longer than barrows which is in disagreement with this study. However, Brunner et al. (1958), Cahill et al. (1960), Charette (1961), Kropf (1962) and Emmerson et al. (1964) all found gilts to be longer than barrows. Burgess (1965) and Moore (1966) also reported gilts and boars to be longer than barrows.

Boars received the highest muscle score followed by gilts and then barrows. Sex means for this variable have the same rank as backfat thickness means of the respective sexes. These results would be intuitively expected since muscling is a relationship of fat and lean. Least-squares means of individual traits by sex are shown in Table VII.

II. LITTER TRAITS

Age of dam. Second-litter gilts farrowed significantly ($P < .01$) larger and heavier litters than first-litter gilts. These results are well in agreement with McLaren (1967). Second-litter gilts also weaned significantly ($P < .01$) heavier litters than first-litter gilts, but there was no significant difference in litter size at weaning between the two ages of dam. Sinclair and Syrotuck (1928) and Nordskog et al. (1944) also reported that first-litter gilts weaned lighter litters than older sows. This common observation is to be expected since sows are known to produce more milk than first-litter gilts.

TABLE VII

LEAST-SQUARES MEANS OF INDIVIDUAL TRAITS BY SEX

	Boar	Barrow	Gilt
Nipple count	12.36 ± 0.11	12.15 ± 0.05	12.21 ± 0.05
Weaning weight	39.51 ± 0.85	33.87 ± 0.40	34.55 ± 0.38
Days to 200	183.48 ± 1.72	184.26 ± 0.80	187.32 ± 0.77
Backfat	0.98 ± 0.01	1.22 ± 0.01	1.14 ± 0.01
Body length	42.03 ± 0.11	41.90 ± 0.05	42.28 ± 0.05
Muscle score	3.03 ± 0.06	2.59 ± 0.03	2.74 ± 0.03

Pigs farrowed by second-litter gilts were significantly (P < .05) younger at 200 pounds than pigs of first-litter gilts. Least-squares means of litter traits by age-of-dam classes are presented in Table VIII.

Season. There were significant (P < .01) differences between seasons in litter weight at birth and at weaning and in litter averages for market weight, length and backfat. Least-squares means of litter traits by season are shown in Table IX.

III. CORRELATIONS AMONG INDIVIDUAL TRAITS

For convenient comparison, a partial summary of published phenotypic and genetic correlations among individual traits are presented in Table X. In most cases in Table X, only the signs of the significant correlations are shown.

Phenotypic correlations of individual traits are shown in Table XI. Actual body length was included in the correlations as well as body length adjusted to 200 pounds. In all previous and subsequent discussion body length adjusted to 200 pounds is denoted as body length. Likewise, backfat adjusted to 200 pounds will be and has been referred to as backfat.

Phenotypic correlations. Pigs born with higher nipple counts at birth were significantly longer (P < .01) at 200 pounds and had significantly (P < .05) higher muscle scores.

Pigs heavier at weaning reached 200 pounds at a significantly (P < .01) earlier age than did lighter-weaning pigs. Weaning weight accounted for 29 percent of the variation in days to 200 pounds. These

TABLE VIII

LEAST-SQUARES MEANS OF LITTER TRAITS BY AGE OF DAM

	Age of dam	
	1	2
Litter size, birth	8.71 ± 0.31	9.95 ± 0.43
Litter birth weight	29.74 ± 0.93	34.53 ± 1.27
Litter size, weaning	7.24 ± 0.30	7.86 ± 0.41
Litter weaning weight	237.33 ± 9.83	269.24 ± 13.46
Litter average market weight	201.31 ± 0.97	204.93 ± 1.32
Litter average market age	188.45 ± 0.98	187.22 ± 1.35
Litter average days to 200	189.70 ± 1.04	185.98 ± 1.43
Litter average body length	42.22 ± 0.06	42.29 ± 0.09
Litter average backfat	1.13 ± 0.01	1.14 ± 0.01

TABLE IX

LEAST-SQUARES MEANS OF LITTER TRAITS BY SEASON

	Season				
	1	2	3	4	5
Litter size, birth	9.72 ± 0.91	9.63 ± 0.65	9.61 ± 0.54	9.11 ± 0.60	8.59 ± 0.67
Litter birth wt.	39.82 ± 2.72	34.36 ± 1.95	31.53 ± 1.63	28.20 ± 1.80	26.76 ± 2.00
Litter size, wean.	7.67 ± 0.88	8.40 ± 0.63	8.46 ± 0.52	7.42 ± 0.58	5.80 ± 0.64
Litter wean. wt.	226.58 ± 28.83	295.84 ± 20.63	299.06 ± 17.25	264.78 ± 19.05	180.17 ± 21.21
Litter avg. mkt. wt.	196.72 ± 2.83	208.64 ± 2.03	198.04 ± 1.70	211.07 ± 1.87	201.13 ± 2.09
Litter avg. mkt. age	187.25 ± 2.89	184.39 ± 2.07	167.53 ± 1.73	212.94 ± 1.91	187.08 ± 2.13
Litter avg. days - 200	189.96 ± 3.06	180.96 ± 2.19	170.12 ± 1.83	209.04 ± 2.02	189.12 ± 2.25
Litter avg. body length	42.67 ± 0.19	42.11 ± 0.14	42.36 ± 0.12	41.92 ± 0.13	42.22 ± 0.14
Litter avg. backfat	1.14 ± 0.02	1.16 ± 0.01	1.18 ± 0.01	1.10 ± 0.01	1.08 ± 0.02

TABLE X

SUMMARY OF CERTAIN PHENOTYPIC AND GENETIC CORRELATIONS (G) AMONG INDIVIDUAL PRODUCTION AND CARCASS TRAITS

	Rate of gain and backfat	Rate of gain and carcass length	Backfat and carcass length	Weaning weight and rate of gain	Weaning weight and backfat	Weaning weight and carcass length
Scott (1930)		Pos.				
Bull *et al*. (1935)			Neg.			
Callow (1935)						Pos.
Donald (1940)					Neg.	Pos.
Dickerson (1947)	0.6					
Wilford (1948)	0.0	0.0				
Cummings and Winters (1951)	Pos.	Pos.				
Coey (1954)	Pos.					Pos.
Fredeen and Jonsson (1957)	-.17 (G)		-.32 (G)			
Cox (1959)	0.59 (G) 0.28					
Duniec (1960)			Neg.			
Enfield and Whatley (1961)			-.36			

TABLE X (continued)

	Rate of gain and backfat	Rate of gain and carcass length	Backfat and carcass length	Weaning weight and rate of gain	Weaning weight and backfat	Weaning weight and carcass length
Brunner (1962)	0.0	0.0				
Hiner and Thornton (1962)			Neg.			
Nelson and Sumption (1962)	0.07		-.51			
Zoellner *et al.* (1963)	Pos.					
Bennett and Cole (1964)				Pos.		
Nielsen (1964)				Pos.		
Bowland *et al.* (1965)	pos.	pos.	Neg.	Pos.		Pos.
Diswas *et al.* (1966)	Pos. (G) Pos.					
Stanislow *et al.* (1967)	Neg. (G)			Pos. (G)	Pos. (G)	

TABLE XI

PHENOTYPIC CORRELATIONS AMONG INDIVIDUAL PIG TRAITS[a]

	Weaning weight	Days to 200	Actual backfat	Backfat	Actual body length	Body length	Muscle score
Nipple count	-.028	0.039	-.077	-.055	0.053	0.117	0.064
Weaning weight		-.539	-.011	-.112	0.207	0.112	0.161
Days to 200			-.244	-.059	-.197	0.074	-.224
Actual backfat				0.898	0.041	-.272	-.233
Backfat					-.253	-.318	-.295
Actual body length						0.809	0.099
Body length							-.136

[a]Coefficients of 0.062 and 0.081 required for significance ($P < .05$) and ($P < .01$), respectively.

results are in agreement with Bennett and Cole (1964), Nielsen (1964), Bowland et al. (1965) and Edwards and Omtvedt (1971). Also, an increase in weaning weight was significantly associated ($P < .01$) with length and muscling at 200 pounds. Callow (1935), Donald (1940), Coey (1954) and Bowland (1965) found an increase in weaning weight to be associated with longer carcasses. Donald (1940) and Edwards and Omtvedt (1971) found heavier weaning pigs to have less backfat at market weight than lighter pigs at weaning.

A decrease in number of days to 200 pounds was significantly ($P < .01$) associated with an increase in actual backfat, actual body length and muscle score. However, when measurements for actual backfat and actual body length were adjusted to a constant market weight, there was no significant relationship between days to 200 and backfat. Days to 200 accounted for less than 1 percent of the variation in body length. Several workers viz., Dickerson (1947), Cummings and Winters (1951), Coey (1954), Cox (1959), Zoellner et al. (1963), Bowland et al. (1965) and Diswas (1966) found an increase in rate of gain to be associated with increase in backfat. Edwards and Omtvedt (1971) reported a non-significant positive relationship between backfat and rate of gain when backfat was adjusted to a constant weight of 230 pounds which is in agreement with this study. Scott (1930), Cummings and Winters (1951) and Bowland et al. (1965) found also that an increase in carcass length was related to an increase in rate of gain. However, Wilford (1948) and Brunner (1962) reported no significant relationship between rate of gain and carcass length. It is difficult to ascertain which is in agreement with this study since carcass length was not adjusted to a constant weight. The relationship between actual body length and days to 200 is in agreement with the general observation that rate of gain and carcass length are positively related.

A decrease in backfat was associated with greater length ($P < .01$) and higher ($P < .01$) muscle scores. However, an increase in body length was associated ($P < .01$) with a decrease in muscle score. Bull et al. (1935), Duniec (1960), Hiner and Thornton (1962), Nelson and Sumption (1962) and Bowland et al. (1965) reported a negative relationship between carcass length and backfat. Enfield and Whatley (1961) reported carcass length to be negatively associated with backfat thickness and loin eye area which is in agreement with this study.

IV. CORRELATIONS AMONG LITTER TRAITS

Phenotypic and genetic correlations and heritability estimates for litter traits are shown in Tables XII, XIII and XIV, respectively.

Phenotypic correlations. Dam body length was not significantly related to any litter production traits in this study. However, there was a positive significant ($P < .01$) relationship between the dam's body length and her offspring's average body length. This indicated that longer pigs at 200 pounds were produced by longer females at 200 pounds.

All pre-weaning traits were positively related ($P < .01$) to each other. Increased litter size at birth was associated with heavier litter birth weights, larger litters at weaning and heavier litter weaning weights. Heavier litters at birth were larger and heavier at weaning. Of all pre-weaning traits, litter size at weaning and litter weaning

TABLE XII

PHENOTYPIC CORRELATIONS[a] AMONG LITTER TRAITS

	Litter birth weight	Litter size weaning	Litter weaning weight	Litter avg. mkt. wt.	Litter avg. mkt. age	Litter avg. days 200	Litter avg. body length	Litter avg. backfat	Dam body length	Dam backfat	Dam muscle score
Litter size, birth	0.778	0.767	0.615	-.141	0.131	0.193	-.065	-.015	-.035	-.017	0.048
Litter birth weight		0.688	0.598	-.046	0.136	0.150	0.009	-.071	0.036	0.059	0.032
Litter size, weaning			0.886	-.046	0.096	0.113	-.097	-.010	-.030	-.058	-.012
Litter weaning weight				0.014	-.092	-.085	-.033	-.069	-.027	-.053	-.031
Litter avg. mkt. wt.					-.004	-.500	0.001	0.003	0.057	0.053	-.042
Litter avg. mkt. age						0.801	0.511	-.198	-.115	-.162	-.166
Litter avg. days-200							0.126	-.100	0.068	0.038	0.007
Litter avg. body length								-.336	0.219	0.116	-.051
Litter avg. backfat									-.137	-.049	0.044
Dam body length											
Dam backfat											

[a]Coefficient of 0.159 and 0.199 required for significance ($P < .05$) and ($P < .01$), respectively.

ER TRAITS

vg.	Litter avg. body length	Litter avg. backfat	Dam body length	Dam backfat	Dam muscle score
Lit	0.00	0.00	0.00	0.00	0.41 ± 0.50
Lit	0.00	0.00	0.00	0.00	0.43 ± 0.40
Lit	0.00	0.00	0.00	0.00	0.18 ± 0.24
Lit	0.00	0.00	0.00	0.00	-.20 ± 0.39
Lit .76	-.73 ± 0.54	0.29 ± 0.98	-2.00 ± 1.14	-2.99 ± 3.40	0.00
Lit .31	-.62 ± 0.59	0.54 ± 1.20	1.44 ± 0.92	2.38 ± 2.64	0.00
Lit	-.09 ± 0.46	0.10 ± 0.76	1.31 ± 0.60	2.09 ± 2.07	0.00
Lit		-.29 ± 0.84	0.33 ± 0.58	0.46 ± 0.90	0.00
Lit			-1.19 ± 1.37	-2.05 ± 2.66	0.00
Dam					
Dam					

TABLE XIV

HERITABILITY ESTIMATES OF LITTER TRAITS

Trait	Method of estimation: Paternal half-sib correlation	Method of estimation: Intra-sire regression of offspring on dam
Litter size, birth	-.17 ± 0.09	
Litter birth weight	-.24 ± 0.07	
Litter size, weaning	-.28 ± 0.05	
Litter weaning weight	-.17 ± 0.09	
Litter avg. mkt. weight	0.21 ± 0.21	
Litter avg. mkt. age	0.15 ± 0.19	
Litter avg. days-200	0.51 ± 0.29	
Litter avg. body length	0.51 ± 0.28	0.06 ± 0.01
Litter avg. backfat	0.11 ± 0.18	

weight were the most highly correlated. These results agree with those of Louca and Robison (1967) and Edwards and Omtvedt (1971).

There was a tendency for the faster growing litters to be shorter in body length and fatter at 200 pounds than slower growing litters. These relationships, however, were non-significant. There was a significant tendency ($P < .01$) for longer bodied litters to be leaner at 200 pounds than shorter bodied litters which agrees with the work of Duckworth and Holmes (1968).

Partial phenotypic correlations of dam body length with other litter traits with dam backfat held constant are shown in Table XV. Longer dams tended to produce longer litters at 200 pounds ($P < .05$) than shorter dams. The relationship between dam body length and litter average backfat approached significance ($P < .05$). Partial correlations of dam backfat with litter traits with dam body length held constant are shown in Table XVI. All partial correlations are non-significant ($P < .05$). These results indicate that dam body length is not as important an influence on litter traits as generally believed.

Genetic correlations. The standard errors of the correlations are generally larger than the estimates, and many of the estimates are larger than 1.0. These results could be due to the non-randomness of the mating scheme and the small number of sires represented.

The correlations between dam body length and weaning and pre-weaning traits are practically zero. Also, correlations between dam backfat and weaning and pre-weaning traits are also practically zero while the relationships between dam muscle score and those traits are

TABLE XV

PARTIAL PHENOTYPIC[a] AND GENETIC CORRELATIONS AMONG CERTAIN LITTER TRAITS WITH DAM BACKFAT HELD CONSTANT

	Dam body length		Dam muscle score	
	Phenotypic	Genetic	Phenotypic	Genetic
Litter size, birth	-.026	1.01 ± 1.84	0.055	0.51 ± 0.54
Litter birth weight	-.021	0.31 ± 0.78	0.015	0.59 ± 0.48
Litter size, weaning	0.000	0.42 ± 0.83	0.005	0.28 ± 0.26
Litter weaning weight	-.002	-.65 ± 1.33	-.016	0.02 ± 0.33
Litter avg. mkt. wt.	0.030	0.00	-.059	0.00
Litter avg. mkt. age	0.079	0.00	-.055	0.00
Litter avg. days-200	0.057	0.00	-.005	0.00
Litter avg. body length	0.188	0.00	0.041	0.00
Litter avg. backfat	-.140	0.00	0.079	0.00

[a]Coefficient of 0.159 and 0.199 required for significance ($P < .05$) and ($P < .01$), respectively.

TABLE XVI

PARTIAL PHENOTYPIC[a] AND GENETIC CORRELATIONS AMONG CERTAIN LITTER TRAITS WITH DAM BODY LENGTH HELD CONSTANT

	Dam backfat		Dam muscle score	
	Phenotypic	Genetic	Phenotypic	Genetic
Litter size, birth	0.004	-.66 ± 0.72	0.075	0.38 ± 0.66
Litter birth weight	0.059	-.56 ± 0.57	0.024	0.71 ± 0.74
Litter size, weaning	-.045	-.42 ± 0.38	0.009	0.28 ± 0.38
Litter weaning weight	-.039	-.39 ± 0.52	-.014	0.30 ± 0.55
Litter avg. mkt. wt.	0.021	0.00	-.083	0.00
Litter avg. mkt. age	0.030	0.00	-.105	0.00
Litter avg. days-200	-.007	0.00	-.034	0.00
Litter avg. body length	-.032	0.00	-.049	0.00
Litter avg. backfat	0.053	0.00	0.158	0.00

[a]Coefficient of 0.159 and 0.199 required for significance ($P < .05$) and ($P < .01$), respectively.

greater than zero numerically. However, the reverse is true when dam backfat or dam body length is held constant. No explanation of these results can be given.

Heritability estimates. A partial summary of the average of several published estimates of heritability for various swine traits as reported by Craft (1958) is shown in Table XVII.

Negative heritability estimates were obtained for all pre-weaning and weaning traits due to a negative sire component of variance for these traits. This may be due to large maternal influences on these traits.

Estimates of heritability of days to 200 pounds and body length are generally in agreement with published estimates. The estimates of heritability of backfat thickness is lower than published results, but this is probably due to the small amount of variation in backfat thickness within this population.

The estimate of heritability of body length obtained from the intra-sire regression of offspring on dam differs greatly from the paternal half sib estimate. This is probably due to a negative maternal effect which is included in the regression estimate. The phenotypic correlations indicated that longer dams produced longer offspring with more backfat than shorter dams, but there was a negative relationship between offspring's body length and backfat. This discrepancy could be the cause of the low heritability estimate of body length by the regression method. Of course, in addition to this possible cause, the non-normality of the distribution, mentioned earlier, resulting from non-randomness of the mating system may be involved.

TABLE XVII

PARTIAL SUMMARY OF HERITABILITY ESTIMATES FOR SEVERAL SWINE CHARACTERS BY CRAFT (1958)

	Heritability percent	
	Range	Approx. avg.
Number of pigs farrowed	0 - 24	15
Number of pigs weaned	0 - 32	12
Weight of litter at weaning	3 - 37	17
Weight of pig at approx. 5-6 months	3 - 66	30
Growth rate	14 - 58	29
Carcass length	40 - 81	59
Loin eye area	16 - 79	48
Thickness of backfat	12 - 80	49
Percent of lean cuts (carcass wt.)	14 - 76	31

CHAPTER V

SUMMARY

A total of 1,062 purebred Duroc pigs of 168 litters by 14 sires provided data from five farrowing seasons at Ames Plantation (November, 1968, through November, 1969). Analyses were conducted to determine the phenotypic and genetic relationships of body length and various productivity and carcass traits and to estimate heritability of body length in order to assess the possible effectiveness of including this trait in a selection program.

Phenotypic correlations among individual traits indicate that heavier weaning pigs reach 200 pounds at an earlier age, are longer and have less backfat and higher muscle scores than lighter weaning pigs. Body length was significantly ($P < .01$) correlated with backfat ($r = -.318$). Also, pigs born with higher nipple counts tend to be longer at 200 pounds than pigs with fewer nipples.

Phenotypically, dam body length was not significantly related to any litter production traits with the exception of litter average body length. Longer dams tended to produce longer litters at 200 pounds than shorter dams. Litter size at birth accounted for 60 percent of the variation in litter birth weight while litter size at weaning accounted for 79 percent of the variation in litter weaning weight.

Genetic correlations among litter traits were very erratic with many of the standard errors larger than the estimates. Heritability estimates obtained from paternal half-sib correlations for litter

averages of days to 200, body length and backfat were 0.51 ± 0.29, 0.51 ± 0.28 and 0.11 ± 0.18, respectively. The estimate of heritability of litter average body length computed by intra-sire regression of offspring on dam was 0.06 ± 0.01 which was interpreted as a possible consequence of appreciable maternal influence on body length.

These data indicate that increasing dam body length would not significantly influence any pre-weaning or weaning traits.

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APPENDIX

TABLE XVIII

OVERALL MEANS AND STANDARD DEVIATIONS
OF INDIVIDUAL TRAITS

	Mean	S.D.
Nipple count	12.26	0.93
Weaning weight	34.54	7.59
Market weight	203.39	16.42
Market age	186.80	22.44
Days to 200	184.49	21.72
Actual backfat	1.17	0.16
Backfat	1.16	0.14
Actual body length	42.18	1.30
Body length	42.05	1.04
Muscle score	2.73	0.61

TABLE XIX

OVERALL MEANS AND STANDARD DEVIATIONS
OF LITTER TRAITS

	Mean	S.D.
Litter size, birth	9.15	2.81
Litter birth weight	30.98	8.86
Litter size, weaning	7.51	2.74
Litter weaning weight	250.93	95.62
Litter avg. market weight	203.09	10.73
Litter avg. market age	187.71	18.96
Litter avg. days to 200	187.87	18.22
Litter avg. body length	42.19	0.69
Litter avg. backfat	1.13	0.08
Dam body length	41.62	4.71
Dam backfat	1.19	0.19
Dam muscle score	2.72	0.71

VITA

Frank David Kirkpatrick was born in Oklahoma City, Oklahoma, on January 3, 1943. He was reared in Shattuck, Oklahoma and graduated from Shattuck High School in May, 1961. He enrolled at Oklahoma State University in 1961, majored in Animal Science and received the B. S. degree from that institution in May, 1965. In September, 1965, he entered the Graduate School of New Mexico State University serving as a graduate teaching assistant in Animal Science. He received his M. S. degree in Animal Science from New Mexico State University in July, 1967. In September, 1967, he entered the Graduate School of The University of Tennessee serving as an Assistant in Animal Husbandry. He received his Doctor of Philosophy degree in Animal Science in June, 1971.