CROSSBREEDING EFFECTS ON PREWEANING AND POSTWEANING PERFORMANCE IN SWINE

By

PETER JOHN CUNNINGHAM

Bachelor of Science

Iowa State University

Ames, Iowa

1964

Submitted to the faculty of the Graduate
College of the Oklahoma
State University in partial
fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1967

CROSSBREEDING EFFECTS ON PREWEANING

AND POSTWEANING PERFORMANCE

IN SWINE

Irvin T. Omtvedt

Thesis Adviser

Joe V. Whiteman

R. R. Durham

Dean of the Graduate College

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. Irvin T. Omtvedt, Associate Professor of Animal Science, for his guidance and counsel during the course of this study and in the preparation of this thesis.

The author wishes to thank Dr. Joe V. Whiteman, Professor of Animal Science, and Dr. David L. Weeks, Associate Professor of Mathematics and Statistics, for their assistance in analyzing the data and proofing the manuscript.

The author is indebted to Bob Easterling and Paul Brackelsberg, Graduate Assistants, for their assistance in the analysis of the data.

The author is appreciative of the help and encouragement given by his fellow graduate students, especially Jim Tanner and Fred Thrift.

A special thanks goes to the author's wife Shirley for her understanding and encouragement during the course of this study and for typing the manuscript.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

INTRODUCTION

Crossbreeding has been and is being used extensively in the production of slaughter hogs in the United States. It has been estimated that approximately 85 percent of all slaughter hogs in the United States are crossbreds. Crossbreeding is popular among commercial producers because it permits a producer to combine the desirable traits from several breeds into one line, and to take advantage of the heterosis expressed in certain performance traits.

Heterosis is defined as the amount the offspring of a particular mating differ from the parental average in performance for a particular trait. The questions which arise concerning heterosis are: (1) Which performance traits exhibit heterosis? (2) What is the magnitude of the heterosis for the specific traits? (3) Is the heterosis always positive for performance traits in swine?

The present study was undertaken to seek answers to these questions using data from the Oklahoma swine breeding herds in which three purebred lines of breeding and four line crosses are involved.

REVIEW OF LITERATURE

Heterosis

Crossbreeding experiments in swine have been conducted for over 30 years, and results pertaining to many important traits have been reported, but the results have been quite variable. Much of the early work involved productivity traits, but very limited data are available for traits measuring postweaning performance and carcass merit.

Number of Pigs Farrowed. The reported amount of heterosis exhibited in this trait has ranged as high as 19 percent. Lush et al. (1939), Dickerson et al. (1946), England and Winters (1953), Whatley et al. (1954), Bolick et al. (1956), Gaines and Hazel (1957), Smith et al. (1960), and Smith and King (1964) all reported an advantage in litter size in favor of litters with crossbred pigs. The 19 percent increase in the linecrosses compared to outbred Durocs reported by Whatley et al. (1954) was the largest value reported. However, Robison (1948) reported fewer pigs for the two-breed cross of Berkshire x Duroc compared to purebred Durocs. Likewise, Winters et al. (1935) found fewer pigs for the average of backcross litters involving Polands, Durocs, and Chester Whites compared to the average of the three breeds. Carroll and Roberts (1942) reported that crossbreds were not superior for number of pigs farrowed when compared to the better of the parental breeds.

Litter Birth Weight. Litters composed of crossbred pigs were heavier than straightbred litters in all studies reviewed (Winters et al., 1935; Lush et al., 1939; Dickerson et al., 1946; and Whatley et al., 1954). Whatley et al. (1954) reported an increase of 23 percent in the litter birth weight of linecrossbreds compared to outbred Durocs, and Winters et al. (1935) found a 21 percent increase for the average of the three-breed crosses of Polands, Durocs, and Chester Whites compared to the average of these three breeds.

Pig Birth Weight. Dickerson et al. (1946) found an increase in pig birth weight for single crosses between inbred lines of Poland China swine compared to the average of the inbred parents. The average of backcross litters involving the Poland China, Duroc, and Chester White breeds (Winters et al., 1935) was 15 percent heavier in pig birth weight than the average of the three breeds. Lush et al. (1939) found that crossbreds were heavier than purebreds in six of nine seasons studied. Bolick et al. (1956) found the same general trend but the differences between crossbreds, inbred Tamworths, and outbred Durocs were not statistically significant in his study. When compared to the superior of the parental breeds, Carroll and Roberts (1942) found no advantage for crossbreds.

Number Pigs Weaned per Litter. Winters et al. (1935), Lush et al. (1939), Dickerson et al. (1946), Whatley et al. (1954), Bolick et al. (1956), and Smith and King (1964) all reported a definite heterotic effect for number weaned. The value of 36 percent reported by Winters et al. (1935) for three-breed crosses compared to the average of Polands, Durocs, and Chester Whites was the largest reported.

Litter 56-Day Weight. Since number weaned responds to crossbreeding and the fact that litter weaning weight is a function of number weaned and individual pig weight, heterosis for litter 56-day weight is expected. Winters et al. (1935) reported an advantage of nearly 61 percent for three-breed crosses over the parental purebred average. Whatley et al. (1954) also reported relatively large advantages for crossbreds with a value of 43 percent for linecrossbreds. Smith and King (1964) found the same trend, but obtained only an 11 percent advantage for crossbred sows compared to their purebred parents. Lush et al. (1939), Dickerson et al. (1946), and Bolick et al. (1956) also reported a definite weight advantage for the crossbreds.

Pig Weaning Weight. Winters et al. (1935), Lush et al. (1939), and Dickerson et al. (1946) indicated that crossbreds were from three to seven pounds heavier per pig at weaning than purebreds. In terms of percentage, Sierk and Winters (1951) and England and Winters (1953) reported the advantage for the crossbreds ranged from 6 to 21 percent. Other workers (Robison, 1948; Warren and Dickerson, 1952;

and Bolick *et al*., 1954) also reported in favor of the crossbreds. When Carroll and Roberts (1942) compared the crossbreds to the heavier of the parental breeds, they stated that the crossbreds were not superior.

Survival Percentage. Pig livability is consistently increased by crossbreeding. England and Winters (1953) found a 15 percent increase in survival percentage for rotational crosses over the purebreds. Robison (1948), Bolick *et al*. (1956), and Smith *et al*. (1960) all suggested an advantage for litters with crossbred pigs. Carroll and Roberts (1942) reported crossbreds were superior when compared to the superior parents.

Postweaning Daily Gain. Crossbreds tend to have a more rapid growth rate than purebreds (Lush *et al*. 1939; Carroll and Roberts, 1942; Dickerson *et al*., 1946; Sierk and Winters, 1951; Gregory and Dickerson, 1952; Tucker *et al*., 1952; Warren and Dickerson, 1952; England and Winters, 1953; Gaines and Hazel, 1957; Smith *et al*., 1960; and Whatley *et al*., 1960). The value of nearly 13 percent obtained by England and Winters (1953) for single crosses compared to purebreds was the largest. Smaller values were reported by Whatley *et al*. (1954) where crossbreds were compared to outbred Durocs and by Robison (1948) where two breed crosses were compared to purebreds. These workers found that crossbred pigs gained slightly less per day than did the straightbreds.

Feed Efficiency. Crossbreds appear to be more efficient in the conversion of feed to gain than purebreds. Winters *et al.* (1935) reported nearly a 12 percent saving in feed for backcross pigs compared to the average of the parental breeds. In terms of pounds of feed saved per hundred pounds of gain, Lush *et al.* (1939) and Gregory and Dickerson (1952) obtained feed savings ranging from 20 to 40 pounds for the crosses compared to the purebreds. Robison (1948), Sierk and Winters (1951), Tucker *et al.* (1952), Whatley *et al.* (1954), and Whatley *et al.* (1960) also suggested that crossbreds were more efficient. Two authors (Carroll and Roberts, 1942; and Dickerson *et al.*, 1946) reported no advantage for the crossbreds. England and Winters (1953) indicated that crosses required from three to seven percent more feed. However, they suggested this may have been due to the inability to remove station effects in their analysis.

Carcass Characteristics. Literature pertaining to the amount of heterosis for carcass characteristics is limited. From the small amount of research results available, it appears that most carcass traits show little, if any, response to crossbreeding. Tucker *et al.* (1952) reported that two-breed cross pigs were longer with slightly less average backfat thickness than the average of the purebred parents. Reddy *et al.* (1959) and Whatley *et al.* (1960) also found two-breed crosses to be slightly longer, but the crosses were intermediate between the parents for backfat thickness. When crosses were compared to their inbred parents, Gregory and Dickerson (1958) found the crosses to be slightly fatter and similar in body length. A smaller loin eye area, calculated from width and depth measurements, was suggested by Tucker et al. (1952) for crosses, while Whatley et al. (1960) reported a slight advantage for crossbreds for loin eye area. Dickerson et al. (1946) found no statistically significant differences between inbreds and crosses with respect to carcass length and carcass backfat thickness.

MATERIALS AND METHODS

Data

The data for this investigation were obtained from the experimental swine breeding herds maintained at Stillwater and Ft. Reno in the Oklahoma project of the Regional Swine Breeding Laboratory. The data included litter and individual pig records from the seven lines of breeding described in Table I, and the study extended over a period of 23 seasons (fall 1954 through fall 1965). Since the herds are a part of a reciprocal recurrent selection experiment now in progress, all lines are not represented in all seasons. Tables II - VI give the distribution of lines by season for each trait studied.

The preweaning traits studied were total number of pigs farrowed, number of pigs farrowed alive, number of pigs born dead, pig birth weight, litter birth weight, number of pigs weaned, number of pigs dying after birth, survival rate, pig 56-day weight, and litter 56-day weight. Survival rate is the ratio of number of pigs weaned to total number of pigs farrowed (including stillborn pigs) expressed as a percentage. Pig weights represent the average weight for the pigs within a particular litter. Indi-

TABLE I

BREEDING STRUCTURE FOR SEVEN LINES OF BREEDING USED IN THIS STUDY

Litter Designation	Breed Composition of: Sire	Dam	Litter
8	Duroc	Duroc	Duroc
9	Belts. #1	Belts. #1	Belts. #1
14	Hamp.	Hamp.	Hamp.
89	Duroc	Belts. #1	½ Duroc: ½ Belts. #1
98	Belts. #1	Duroc	½ Duroc: ½ Belts. #1
99	Hamp.	Crossbred Dam (89 or 98)	½ Hamp.: ¼ Duroc: ¼ Belts. #1
33	Crossbred Sire (89 or 98)	Hamp.	½ Hamp.: ¼ Duroc: ¼ Belts. #1

TABLE II

DISTRIBUTION OF LITTERS BY LINE OF BREEDING FOR THE 23 SEASONS INCLUDED IN THE ANALYSIS OF PREWEANING TRAITS

Season	Line of Breeding of the Litter						
	8	9	14	89	98	99	33
542	9	6	4	10	11	21	16
551	8	7	7	14	17	12	11
552	12	11	17	15	11	18	7
561	9	10	9	15	15	19	15
562	10	7	8	12	8	20	11
571	10	10	9	16	16	20	11
572	5	10	9	18	13	14	8
581	8	8	10	18	18	17	10
582	13	11	22			18	
591	15	9	18	4	4	16	
592	15	4	17	4		17	
601	12	6	13	15	11	19	
602	9		18	15	11		
611	27	20	21				
612			27			36	
621			27	24	19		
622	19	23	28				
631			27			48	
632			31	25	21		
641	19	25	32				
642			23			36	
651			31	18	20		
652	22	28	37				
TOTAL	222	195	445	223	195	331	89

TABLE III

DISTRIBUTION BY LINE OF BREEDING FOR THE 22 SEASONS INCLUDED IN THE ANALYSIS OF AVERAGE DAILY GAIN

Season	Line of Breeding of the Pigs						
	8	9	14	89	98	99	33
551	39	28	17	43	48	61	81
552	16	10	46	47	36	90	35
561	60	43	29	48	51	141	100
562	43	31	39	34	30	124	74
571	52	29	35	48	60	155	91
572	25	47	33	50	33	76	44
581	49	43	8	34	33	58	34
582	94	34	67	28	12	130	
591	116	56	52	28	17	97	
592	100	39	38	28	29	80	
601	30	21	48	29	29	100	
602	11		29	92	58		
611	131	87	116				
612			114			213	
621			74	130	138		
622	88	129	105				
631			108			271	
632			128	189	147		
641	118	109	144				
642			118			211	
651			93	90	139		
652	114	144	100				
TOTAL	1086	850	1541	918	859	1807	459

TABLE IV

DISTRIBUTION BY LINE OF BREEDING FOR THE 14 SEASONS INCLUDED IN THE ANALYSIS OF FEED EFFICIENCY

Season	Line of Breeding of the Pigs					
	8	9	14	89	98	99
551				42	46	
552				23	36	
561				45	45	
562				30	27	
571				38	53	
572	11	14		43	32	
581	17	13		34	31	
582	31	12	66	25	11	125
591	32	13	52	28	14	95
592	18	8	11	28	28	12
611			22			
642			47			114
651			18	60	87	
652	93	120	22			
TOTAL	202	180	238	396	409	346

TABLE V

DISTRIBUTION BY LINE OF BREEDING FOR THE 19 SEASONS INCLUDED IN THE ANALYSIS OF CARCASS DATA

Season	Line of Breeding of the Pigs						
	8	9	14	89	98	99	33
551				20	22		
561				21	21	30	20
562			3	16	16	28	17
571				15	17	20	12
572	7	7	5	26	21	19	11
581	9	5		22	22	8	
582	10	8	9	17	9	29	
591	11	10	10	19	10	30	
592	16	6	5	18	18	22	
601			8			8	
602				12	9		
611	23	14	18				
612			10			45	
621				27	24		
631						54	
641			39				
642			16			32	
651			27	30	29		
652	23	30	27				
TOTAL	99	80	177	243	218	325	60

TABLE VI

DISTRIBUTION BY LINE OF BREEDING FOR THE 21 SEASONS INCLUDED IN THE ANALYSIS OF PROBED BACKFAT THICKNESS

Season	Line of Breeding of the Pigs						
	8	9	14	89	98	99	33
552			24			24	28
561	25	29	4				
562	30	27	6				
571	34	22	17			77	86
572	7	19	24			32	30
581	26	22	15			34	34
582	56	16	42			69	
591	61	35	32			50	
592	52	18	24			34	
601	14	11	35	9	8	60	
602	11		24	53	24		
611	84	58	55				
612			45				
621			50	52	55		
622	59	58	67				
631			46			104	
632			84	82	56		
641	71	75	82				
642			64			108	
651			90	40	76		
652	78	100	128				
TOTAL	608	490	958	236	219	592	178

vidual weaning weights were obtained at approximately 56 days of age except for 1961 fall through 1965 fall at Ft. Reno and 1965 spring and fall at Stillwater when pigs were weaned at 42 days of age. However, all individual pig weaning weights were adjusted to a 56-day equivalent by procedures developed by Whatley and Quaife (1937) for calculation of 56-day pig and litter weights.

All pigs were self-fed during the postweaning period. Postweaning traits studied were average daily gain, probed backfat thickness, feed efficiency, carcass length, carcass backfat thickness, and loin eye area. The average daily gain from weaning to market weight represented postweaning average daily gain. Probed backfat thickness data during the period 1955 fall through 1964 fall represented the average of four readings taken at approximately two inches on each side of the mid-dorsal line over the first rib and the mid-loin regions. In 1965, three readings were taken on each side of the mid-line at the first rib, the last rib, and the last lumbar vertebra and the average of these six was used. All probed backfat measurements were taken at the conclusion of the postweaning feeding period and were converted to a 200-pound equivalent by methods described by Durham and Zeller (1955). Gilt probes were adjusted to a barrow equivalent by adding 0.13 inch to their probe at 200 pounds (Enfield, 1957). The ratio of pounds of feed consumed to pounds of gain produced was used as the measure of feed efficiency. Feed records were based on pen averages. Carcass length was obtained on the cold carcass and represented the distance from the forward edge of the first rib to the anterior edge of the aitch bone. Carcass backfat thickness represents the average of six measurements taken from both sides of the cold carcass over the first rib, the last rib, and the last lumbar vertebra. Loin eye area was the area of the longissimus dorsi muscle measured between the tenth and eleventh ribs.

Over-all Analysis

The method of fitting constants was used to estimate the independent effect of each of the variables on the various traits. This was performed by least squares procedures. The procedure was similar to that outlined by Harvey (1960) except for the construction of the observation matrix. The procedure is outlined in detail in the Appendix. Estimates of the least squares constants were computed by

$$[\hat{\beta}] = [X'X]^{-1} [X'Y]$$

The standard errors of the estimated constants were obtained by

$$s_{\hat{\beta}_i} = \sqrt{C^{ii}\sigma_e^{2}}$$

where C^{ii} was the corresponding diagonal inverse element for a particular constant and $\hat{\sigma}_e^{2}$ was the error mean squares. The standard errors of the sum of two estimated constants were obtained by

$$s_{\hat{\beta}_i - \hat{\beta}_j} = \sqrt{(C^{ii} + C^{jj} + 2C^{ij})\ \sigma_e^{2}}$$

where C^{ii} and C^{jj} were the corresponding diagonal inverse elements for the two constants, C^{ij} was the off diagonal element corresponding to the two constants, and $\hat{\sigma}_e^2$ was the error mean square. The error mean square, $\hat{\sigma}_e^2$, was the total sum of squares minus the sums of squares due to fitting all constants divided by the error degrees of freedom. The standard errors of the mean differences were calculated under the assumption the means were independent.

Due to the unequal distribution of lines within seasons, all analyses were done on a within line basis. Previous work at this station using similar data (Stanislaw, 1966) indicated the variables for which adjustments needed to be made. The least squares model for lines 14, 89, 98, and 33 for total number of pigs farrowed, number of pigs farrowed alive, number of pigs born dead, litter birth weight, number of pigs weaned, litter 56-day weight, death loss from birth to weaning and percent survival was

$$Y_{ijk} = \mu + s_i + a_j + e_{ijk}$$

where:

Y_{ijk} is an observation on one of the traits listed above.

μ is an effect common to all litters.

s_i is the effect of the ith season and the number of seasons depends on the line involved.

a_j is the effect of the jth age of dam and j=1,2,...5 for line 14 and j=1,2 for lines 89, 98, and 33.
a_1 = 1.0 years, a_2 = 1.5 years, ... a_5 = 3.0 years

e_{ijk} is a random error unique for each litter.

The model for lines 8, 9, and 99 for the above variables was similar to the above model except that age of dam was not included in the model. Since small numbers of litters in the various age classifications were present in lines 8 and 9, the line 14 constants were used to adjust these two lines for age of dam (Table VII). A multicross control line maintained at Ft. Reno was used to adjust line 99 for age of dam (Table VIII). The control line was composed of crossbred sows and were mated to the same boar for both the first and second litter, and it was felt that this line most nearly resembled line 99.

The model for pig birth weight and pig 56-day weight was

$$Y_{ijkl} = \mu + s_i + a_j + n_k + e_{ijkl}$$

where:

Y_{ijkl} is pig birth weight and pig 56-day weight.

n_k is the effect of the kth number of pigs farrowed and the kth number of pigs weaned, respectively, for the two models and k=1,2,...,5.

n_1 = 0-3 pigs, n_2 = 4-6 pigs, n_3 = 7-9 pigs, n_4 = 10-13 pigs, and n_5 = 13 or more pigs

and all remaining terms are defined as in the previous model. As before, lines 8 and 9 were adjusted for age of dam using line 14 constants, and line 99 was adjusted using constants determined from the multicross control line.

All preweaning traits were adjusted to a second litter equivalent (1.5 years) using constants determined from the models, line 14 constants for lines 8 and 9 (Table VII), or control line constants (Table VIII) for line 99. In the case of lines 8, 9, and 99, the constants were added to the observations before the least squares analysis was conducted.

The model for postweaning daily gain for lines 8, 9, 89, 98, 99, and 33 was

$$Y_{ijk} = \mu + s_i + x_j + e_{ijk}$$

where:

Y_{ijk} is postweaning daily gain.

μ is an effect common to all individuals.

s_i is the effect of the ith season.

x_j is the effect of the jth sex and $j = 1,3$. x_1 = gilts and x_3 = barrows.

e_{ijk} is a random error unique for each pig.

The model for line 14 is similar except that treatment t_k, k=1,2,; t_1 = pasture before weaning and pasture after weaning, t_2 = pasture before weaning and confinement after weaning) was added to the model. The adjusted means used for comparison were on a treatment 2 equivalent. All the observations in the other lines were from treatment 2, and line 14 was adjusted to treatment 2 using the calculated constant.

The feed efficiency model was the same as the model for postweaning daily gain. All observations were from treatment 2. No feed efficiency data was available on line 33.

The model for the carcass traits was

$$Y_{ijk} = \mu + s_i + e_{ij}$$

where:

Y_{ijk} is carcass length, carcass backfat, or loin eye area.

μ is an effect common to all individuals.

s_i is the effect of the ith season.

e_{ij} is a random error unique for each pig.

Only barrows were involved in the carcass study, and treatment was not included in the model because its effects were confounded with the effects of season.

The model for probed backfat adjusted to a 200-pound barrow equivalent was the same as the model for carcass data for line 8, 9, 14, 89, 98, and 99. Only gilts were involved in the probed backfat study for these lines. Both barrows and gilts were used for line 33 so sex was added to the above model. Only the seasons after 1959 were used to determine heterosis for probed backfat thickness.

All models were constructed under the assumption that no interactions existed among the effects and that all errors were normally and independently distributed about a mean of zero and had a common variance σ^2.

TABLE VII

LINE 14 CONSTANTS USED TO ADJUST LINES 8 AND 9 FOR AGE OF DAM

Trait	Age of Dam 1	2	3	4	5
Total pigs farrowed	0.85	0	- .40	- 1.63	- .57
Pigs farrowed alive	0.83	0	- .23	- .87	- .04
Pigs born dead	0.03	0	- .15	- .80	- .55
Pig birth weight, lb.	0.33	0	- .15	- .01	- .02
Litter birth weight, lb.	4.51	0	-2.08	- 4.07	- 1.61
Pigs weaned per litter	0.45	0	0.42	0.37	1.03
Pig 56-day weight, lb.	6.78	0	-1.02	- 1.26	- .38
Litter 56-day weight, lb.	53.0	0	8.3	12.3	36.6
Pigs dying before weaning	0.42	0	- .51	- 1.35	- .96
Percent survival	- .14	0	3.09	10.00	- 1.83

TABLE VIII

MULTICROSS CONTROL LINE CONSTANTS USED TO ADJUST LINE 99 FOR AGE OF DAM

Trait	Age of Dam	
	1	2
Total pigs farrowed	1.24	0
Pigs farrowed alive	1.42	0
Pigs born dead	- .18	0
Pig birth weight	0.31	0
Litter birth weight, lb.	6.84	0
Pigs weaned per litter	1.00	0
Pig 56-day weight	5.02	0
Litter 56-day weight, lb.	80.4	0
Pigs dying after birth	0.44	0
Percent survival	0.29	0

RESULTS AND DISCUSSION

Data

Means, standard deviations, and standard errors for the traits studied are given for each line of breeding in Tables IX throught XXIV.

No line was consistently superior to all other lines. Line 8 (Duroc) was superior to the other two purebred lines for all the preweaning traits studied. Line 99 (crossbred sow) was superior to the other lines for all traits involving number of pigs except number of pigs dying after birth. Pig weights were largest for line 89, while litter weights were the largest for line 99. This might be explained by the fact that litter size was generally smaller for line 89 than the other lines and line 99 had the largest litter size at birth and weaning. The fact that line 89 had the fewest pigs dying after birth may be partially the result of fewer pigs farrowed per litter and the larger size of the pigs farrowed.

The magnitudes of the standard deviations indicates that all the lines studied were relatively uniform. Also, crossbreds did not appear to be any more, or less, variable

TABLE IX

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR TOTAL NUMBER OF PIGS FARROWED PER LITTER

Line of Litter	Number of Litters	Pigs Farrowed per Litter	Standard Error	Standard Deviation
8	222	10.8	0.2	2.9
9	195	10.3	0.2	3.0
14	445	9.6	0.3	2.8
89	223	9.0	0.3	3.0
98	195	10.0	0.3	3.0
99	331	10.9	0.2	3.0

TABLE X

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR NUMBER OF PIGS FARROWED ALIVE PER LITTER

Line of Litter	Number of Litters	Pigs Farrowed per Litter	Standard Error	Standard Deviation
8	222	10.6	0.2	2.8
9	195	9.9	0.2	2.8
14	445	9.3	0.3	2.7
89	223	8.7	0.3	3.0
98	195	9.7	0.3	3.0
99	331	10.7	0.2	3.0

TABLE XI

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR NUMBER OF PIGS BORN DEAD PER LITTER

Line of Litter	Number of Litters	Stillborn Pigs per Litter	Standard Error	Standard Deviation
8	222	0.21	0.06	0.75
9	195	0.43	0.08	0.97
14	445	0.33	0.10	0.95
89	223	0.36	0.07	0.75
98	195	0.27	0.09	1.00
99	331	0.21	0.06	1.11

TABLE XII

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR NUMBER OF PIGS WEANED PER LITTER

Line of Litter	Number of Litters	Pigs Weaned per Litter	Standard Error	Standard Deviation
8	222	7.8	0.2	2.5
9	195	6.5	0.2	2.8
14	445	6.5	0.3	2.4
89	223	7.2	0.3	2.9
98	195	7.5	0.2	2.6
99	331	7.9	0.2	2.8

TABLE XIII

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR PIGS BIRTH WEIGHT

Line of Litter	Number of Litters	Avg. Pig Birth Weight, lbs.	Standard Error	Standard Deviation
8	222	3.08	0.06	0.46
9	195	2.85	0.06	0.54
14	445	3.05	0.05	0.45
89	223	3.30	0.06	0.56
98	195	2.80	0.06	0.52
99	331	3.10	0.04	0.62

TABLE XIV

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR LITTER BIRTH WEIGHT

Line of Litter	Number of Litters	Avg. Litter Birth Weight, lbs.	Standard Error	Standard Deviation
8	222	31.5	0.6	7.9
9	195	26.2	0.7	8.0
14	445	28.0	0.8	7.6
89	223	28.3	0.8	8.1
98	195	28.5	0.8	8.2
99	331	32.6	0.5	7.8

TABLE XV

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR DEATH LOSS AFTER BIRTH

Line of Litter	Number of Litters	Pigs Dying after Birth/Litter	Standard Error	Standard Deviation
8	222	2.6	0.2	2.6
9	195	2.9	0.2	2.5
14	445	2.7	0.2	2.4
89	223	1.4	0.2	2.0
98	195	2.2	0.2	2.1
99	331	2.7	0.1	2.1

TABLE XVI

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR SURVIVAL RATE

Line of Litter	Number of Litters	Percent Survival	Standard Error	Standard Deviation
8	222	71.9	1.6	22.6
9	195	62.4	1.9	22.7
14	445	68.8	3.2	30.3
89	223	82.3	2.0	21.4
98	195	77.5	2.0	22.1
99	331	73.9	1.3	22.0

TABLE XVII

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR PIG 56-DAY WEIGHT

Line of Litter	Number of Litters	Pig 56-Day Weight, lbs.	Standard Error	Standard Deviation
8	222	40.2	0.6	8.4
9	195	38.6	1.0	10.4
14	445	38.6	0.8	7.4
89	223	45.7	1.4	8.5
98	195	42.6	1.1	7.9
99	331	40.4	0.5	7.9

TABLE XVIII

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR LITTER 56-DAY WEIGHT

Line of Litter	Number of Litters	Litter 56-Day Wt., lbs.	Standard Error	Standard Deviation
8	222	319.8	7.4	100.9
9	195	279.9	9.7	117.2
14	445	254.6	10.0	95.9
89	223	323.6	10.8	115.8
98	195	314.0	9.1	97.8
99	331	331.9	6.0	101.6

TABLE XIX

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR POSTWEANING AVERAGE DAILY GAIN

Line of Pigs	Number of Pigs	Avg. Daily Gain, lbs.	Standard Error	Standard Deviation
8	1086	1.65	0.01	0.20
9	850	1.50	0.01	0.19
14	1541	1.37	0.01	0.15
89	918	1.67	0.01	0.19
98	859	1.68	0.01	0.18
99	1807	1.46	0.01	0.18

TABLE XX

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR FEED EFFICIENCY

Line of Pigs	Number of Pigs	Lbs. Feed/Lb. Gain	Standard Error	Standard Deviation
8	202	3.43	0.02	0.21
9	180	3.43	0.02	0.16
14	238	3.35	0.02	0.22
89	396	3.43	0.01	0.18
98	409	3.43	0.01	0.20
99	346	3.45	0.02	0.19

TABLE XXI

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR CARCASS LENGTH

Line of Breeding	Number of Carcasses	Carcass Length, In.	Standard Error	Standard Deviation
8	99	28.8	0.1	0.8
9	80	30.0	0.1	0.8
14	177	29.5	0.1	0.8
89	243	29.8	0.1	0.8
98	218	29.8	0.1	0.8
99	325	29.9	0.1	0.8

TABLE XXII

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR CARCASS BACKFAT THICKNESS

Line of Breeding	Number of Carcasses	Backfat Thickness, In.	Standard Error	Standard Deviation
8	99	1.69	0.02	0.20
9	80	1.45	0.02	0.14
14	177	1.42	0.01	0.14
89	243	1.55	0.01	0.17
98	218	1.57	0.01	0.15
99	325	1.50	0.01	0.14

TABLE XXIII

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR LOIN EYE AREA

Line of Breeding	Number of Carcasses	Loin Area, sq. in.	Standard Error	Standard Deviation
8	99	3.23	0.05	0.47
9	80	3.98	0.05	0.40
14	177	3.85	0.05	0.51
89	243	3.85	0.03	0.48
98	218	3.61	0.03	0.42
99	325	3.54	0.03	0.49

TABLE XXIV

LINE MEANS, STANDARD ERRORS, AND STANDARD DEVIATIONS FOR PROBED BACKFAT THICKNESS

Line of Pigs	Number of Pigs	Probed Backfat Thickness, in.	Standard Error	Standard Deviation
8	317	1.62	0.01	0.16
9	302	1.50	0.01	0.12
14	770	1.46	0.01	0.13
89	236	1.51	0.01	0.15
98	219	1.57	0.01	0.12
99	272	1.52	0.01	0.16

than the purebreds. The variances for each trait studied were nearly the same for each of the lines of breeding.

Line 8 had the fastest average daily gain of the purebred lines, but was inferior to the other purebred lines for the other postweaning traits studied. Line 9 was the superior purebred line for carcass length and loin eye area, while line 14 was superior with respect to feed efficiency and backfat thickness measurements. The crossbred lines tended to be intermediate between the extremes of the purebred lines for backfat thickness measurements. Only for average daily gain was any crossbred line superior to all purebred lines for a specific trait (Table XIX). The two-line cross pigs were superior to all other lines for average daily gain. Similar to the preweaning traits, no line was consistently more uniform, and the variances of the lines were similar.

Heterosis is defined as the amount the offspring of a particular mating differ from the parental average in performance for a particular trait. The estimated amount of heterosis in the three-line cross pigs was calculated by two methods. First, it was estimated by comparing the three-line cross to the average of the parental lines making up the cross. The parental lines were line 14 and the average of the two-line crosses (89 and 98). Secondly, the comparison was based on the average of the three purebred lines which served as the foundation stock for the three-line cross (average for lines 8, 9, and 14).

Preweaning Traits

The performance of crosses and parental lines are summarized for preweaning traits in Tables XXV, XXVI, and XXVII.

Number of Pigs Farrowed. Using a boar of different breeding did not increase litter size for purebred dams. Negative estimates of heterosis were obtained for total number of pigs farrowed per litter (-10.38 percent) and number of pigs farrowed alive per litter (-9.80 percent) for the two-line cross. Winters *et al*. (1935) also obtained negative heterosis estimates for these two traits when backcross litters were compared to the average of the three parental purebred breeds. However, they found the estimates to be positive for the average of two-breed crosses. Robison (1948) found 1.3 fewer total pigs and 1.1 fewer live pigs at birth for Duroc-Berkshire crosses compared to purebred Durocs. In a review (Carroll and Roberts, 1942), three of 11 experiments showed crossbred litters were larger than the purebred line with the largest litters, while in four of the 11 experiments, crossbred litters were smaller than the purebred line with the smallest litters. The failure to obtain positive heterosis for the two-line cross may have been due to the already large litter size of the two purebreds or the lack of genetic diversity between lines 8 and 9 for these traits.

The superiority of the crossbred sow for litter size is clearly shown in Tables XXVI and XXVII and agree with results obtained by other workers. Smith and King (1964)

TABLE XXV

COMPARISON BETWEEN TWO-LINE CROSSES AND PARENTAL PUREBREDS FOR PREWEANING TRAITS

TRAIT	Crossbred Avg. (89 & 98)	Purebred Avg. (8 & 9)	Difference Crossbred-Purebred	S.E.	Percentage
Total pigs farrowed per litter	9.5	10.6	-1.1	0.2	-10.38
Live pigs farrowed per litter	9.2	10.2	-1.0	0.2	- 9.80
Pigs born dead per litter	0.32	0.32	0.00	0.08	0.00
Pig birth weight, lb.	3.05	2.96	0.09	0.06	3.04
Litter birth weight, lb.	28.4	28.8	- .4	0.7	- 1.38
Pigs weaned per litter	7.3	7.1	0.2	0.2	2.82
Pigs dying per litter after birth	1.8	2.8	-1.0	0.2	-35.71
Survival rate, %	79.9	67.2	12.7	1.9	18.90
Pig 56-day weight, lb.	44.2	39.4	4.8	1.1	12.18
Litter 56-day weight, lb.	318.8	299.9	18.9	9.2	6.30

TABLE XXVI

COMPARISON OF THREE-LINE CROSSES WITH THE PARENTAL LINES FOR PREWEANING TRAITS

Trait	3-Line Cross Avg.	Parental Avg.	Difference 3-Line cross Parental	S.E.	Percentage
Total pigs farrowed per litter	10.9	9.6	1.3	0.3	13.54
Live pigs farrowed per litter	10.7	9.2	1.5	0.3	16.30
Pigs born dead per litter	0.21	0.32	- .11	0.08	-34.38
Pig birth weight, lb.	3.09	3.05	0.04	0.06	1.31
Litter birth weight, lb.	32.6	28.2	4.4	0.8	15.60
Pigs weaned per litter	7.9	6.9	1.0	0.3	14.49
Pigs dying per litter after birth	2.7	2.2	0.5	0.2	22.73
Survival rate, %	73.9	74.4	- .5	1.9	- .67
Pig 56-day weight, lb.	40.3	41.4	-1.1	0.9	- 2.65
Litter 56-day weight, lb.	331.9	286.7	45.2	9.1	15.76

TABLE XXVII

COMPARISON OF THE THREE-LINE CROSS WITH THE PUREBRED LINES FOR PREWEANING TRAITS

Trait	3-Line Cross Avg.	Purebred Avg.	Difference 3-Line Cross - Purebred	S.E.	Percentage
Total pigs farrowed per litter	10.9	10.2	0.7	0.2	6.86
Live pigs farrowed per litter	10.7	9.9	0.8	0.2	8.08
Pigs born dead per litter	0.21	0.32	- .11	0.08	-34.38
Pig birth weight, lb.	3.09	2.99	0.10	0.05	3.34
Litter birth weight, lb.	32.6	28.6	4.0	0.6	13.98
Pigs weaned per litter	7.9	6.9	1.0	0.2	14.49
Pigs dying per litter after birth	2.7	2.7	0.0	0.2	0.00
Survival rate, %	73.9	67.7	6.2	1.9	9.16
Pig 56-day weight, lb.	40.3	39.1	1.2	0.7	3.07
Litter 56-day weight, lb.	331.9	284.8	47.1	7.9	16.54

found a 5.2 percent superiority for crossbred sows compared to the average of the parental purebred sows for number of pigs born alive.

Number of Pigs Born Dead per Litter. Fewer pigs were born dead in litters from crossbred sows. This was in agreement with results reported by Lush et al. (1939) and Winters et al. (1935). Crossbred litters from straightbred sows showed no advantage over straightbred litters.

Birth Weights. Crossbred pigs from straightbred dams were, on the average, heavier at birth than straightbred pigs. However, litter birth weights were slightly heavier for litters containing straightbred pigs. Crossbred pigs from crossbred sows were heavier at birth, and litter birth weights were heavier for crossbred sows than from either straightbred dams with crossbred pigs or with straightbred pigs.

Heterosis estimates for pigs birth weight were 3.04 percent for the two-line cross, 1.31 percent and 3.34 percent for the three-line cross based on the parental and purebred averages, respectively. The increase of 0.09 pound in pigs birth weight for the two-line cross was similar to the 0.08 pound advantage reported by Dickerson et al. (1946) for crosses of inbred lines of Poland China swine. The percentage superiority of crosses (1.97 for two-breed and 0.39 for three-breed) for pig birth weight obtained by Winters et al. (1935) was slightly lower than the values obtained in this study.

Although crossbred pigs were heavier at birth, litter weights for the two-line cross pigs were smaller. This was contrary to other studies reviewed. Using similar data, Omtvedt et al. (1966) found that litter size accounted for 67 percent of the variation in litter birth weight; therefore, the smaller litter size for the two-line cross could account for the decreased litter birth weight.

In the present study, litter birth weight was increased approximately 4.0 pounds when a crossbred dam was used. Lush et al. (1939) reported a 4.7 pound advantage for crossbred sows compared to purebred sows. Similarly, Winters et al. (1935) obtained an increase of 4.4 pounds for crossbred sows. Studies with cattle have revealed similar results. Gregory et al. (1965), in a study involving the British breeds of cattle, reported a 2.7 pound advantage for the average of all crossbreds (two-breed and three-breed) over the average of the straightbreds.

Pigs Weaned per Litter. The smaller number of pigs farrowed alive undoubtedly suppressed the heterosis for the two-line cross for number weaned. The increase of 2.82 percent (0.2 pig) shown in Table XXV was smaller than the value of 5.87 percent reported by Winters et al. (1935) or the 1.3 pigs increase reported by Dickerson et al. (1946). In both of these studies, an increased litter size at birth was reported for the crosses. Smith and King (1964) also found a somewhat higher result with a value of 4.8 percent for two-breed crosses. The value of 14.49 percent given in

Table XXVII for the heterosis of the three-line cross was larger than the value of 8.2 percent stated by Smith and King (1964), but less than the value of 36.2 percent found by Winters _et al_. (1935). However, it was quite similar to the value of 16 percent reported by Whatley _et al_. (1954) for linecrosses compared to outbred Durocs. In terms of number of pigs, Lush _et al_. (1939) found crossbred sows weaned 2.15 more pigs than purebred sows. This was over twice as large as the increase of 1.0 pigs obtained in this study.

Death Loss After Birth. The mortality rate after birth was less for crossbred pigs resulting in a greater survival rate for crossbred pigs compared to straightbred pigs. Approximately one pig less was lost after birth in the two-line cross litters compared to the average of the parental purebreds. This resulted in a 19 percent increase in survival rate of two-line cross pigs. Heterosis was probably not entirely responsible for the decreased death loss or increased survival rate in this study since part of what was measured as heterosis may be due to the smaller litter size for the two-line crosses. However, England and Winters (1953) reported a 10.2 percent increase in survival rate for single crosses within the Poland China breed when number of pigs farrowed per litter favored the crosses. The increased death loss of the three-line cross compared to the parental average may partially have been due to the smaller litter size for the two-line crosses and line 14. This may be indicated by the fact that the death loss was the same for the three-line cross and the average of the purebred lines which are more like line 99 with respect to litter size.

Weaning Weights. Crossbred pigs were heavier than straightbred pigs both for pig 56-day weight and litter 56-day weight. Crossing two purebred lines increased pig 56-day weight 12.18 percent (4.8 pounds) and litter 56-day weight 6.30 percent (18.9 pounds). The estimate for pig 56-day weight agreed fairly closely with several other studies reviewed. Winters *et al.* (1935) reported a 5 pound advantage for the average of first cross litters of the Poland, Duroc, and Chester White breeds compared to the average of the three breeds. Likewise, Lush *et al.* (1939) found a 3 to 4 pound increase for crossbred pigs compared to purebred pigs. Dickerson *et al.* (1946) reported a 12 percent increase for crosses over inbred lines of Poland Chinas.

The positive heterosis for litter 56-day weight in the two-line cross was expected since positive heterotic effects were obtained for number weaned and pig 56-day weight. However, the estimates from this study were smaller than those of other studies. Whatley *et al.* (1954) reported estimates ranging from 30 percent for linecrosses to 43 percent for linecrossbreds compared to outbred Durocs. Winters *et al.* (1935) found an increase of 39 pounds for first cross litters compared to straightbreds. Smith and King (1964) obtained a value more nearly like this study with a 10.0 percent increase reported for two-breed crosses.

Since pig 56-day weight was adjusted for number of pigs in the litter, the negative estimate (-2.65 percent) for pig 56-day weight of the three-line cross compared to the parental average was difficult to understand. It appears that maximum heterosis was obtained in the first cross or that the adjustment did not remove all the effects of number weaned. Omtvedt _et al_. (1966) found that as litter size increased individual pig weaning weight decreased; therefore, the failure to completely remove the effect of number weaned is a possible explanation. A positive estimate was obtained (3.07 percent) when line 99 was compared to the average of the three purebred lines. The estimate was smaller than the estimate of 15.0 percent reported by England and Winters (1953) for rotational crosses, involving the Minnesota #1, #2, and Poland China lines, compared to the average of these three lines.

The estimates of 15.76 percent (45.2 pounds) and 16.54 percent (47.1 pounds) for the heterosis of litter 56-day weight for the three-line cross (Tables XXVI and XXVII) compared to the parental and purebred averages, respectively, were intermediate to other studies reviewed. Smith and King (1964) reported a 11.2 percent increase for litters from crossbred sows compared to litters from purebred sows, while Winters _et al_. (1935) obtained an increase of 96 pounds for three-breed crosses compared to straightbreds. In cattle, Gregory _et al_. (1965) reported the average weaning weight of all crossbreds was 19.4 pounds greater than the average of all straightbreds.

Postweaning Traits

The postweaning performance of the crossbred and straightbred pigs is summarized in Tables XXVIII, XXIX, and XXX.

Average Daily Gain. Two-line cross pigs gained 0.09 pounds per day faster than the average of the purebred pigs. Lush *et al*. (1939) found crossbreds gained faster and ranged from 0.09 to 0.12 pound more per day. In percentage terms, Tucker *et al*. (1952) reported crosses gained 7 percent faster, which compares with the estimate of 5.7 percent found in this study. Sierk and Winters (1951) and England and Winters (1953) obtained nearly a 13 percent advantage for crosses of the Minnesota #1, #2, and Poland China breeds compared to the average of the three breeds. Whatley *et al*. (1954) found crossbreds and linecrosses gained 0.08 and 0.02 pound per day less, respectively, that outbred Durocs. The estimates were -.06 and -.05 pound per day for the three-line cross compared to the parental and purebred averages, respectively, in this study. Robison (1948) also found Berkshire-Duroc crossbred pigs gained 0.08 pound less per day than purebred Durocs.

In cattle, Gregory *et al* (1966a) found a 0.0022 pound per day advantage for crossbred steers over straightbred steers for average daily gain from weaning to 452 days adjusted for daily TDN.

TABLE XXVIII

COMPARISON OF TWO-LINE CROSSES AND PARENTAL PUREBREDS FOR POSTWEANING TRAITS

Trait	Crossbred Avg.	Purebred Avg.	Difference Crossbred-Purebred	S.E.	Percentage
Avg. daily gain, lb.	1.67	1.58	0.09	0.01	5.70
Probed backfat, in.	1.54	1.56	- .02	0.01	-1.28
Lb. feed/lb. gain	3.43	3.43	0.00	0.02	0.00
Carcass length, in.	29.8	29.4	0.4	0.1	1.36
Carcass backfat, in.	1.56	1.57	- .01	0.02	- .64
Loin area, sq. in.	3.73	3.60	0.13	0.04	3.61

TABLE XXIX

COMPARISON OF THE THREE-LINE CROSS WITH THE PARENTAL LINES FOR POSTWEANING TRAITS

Trait	3-Line Cross Avg.	Parental Avg.	Difference 3-Line Cross - Parental	S.E.	Percentage
Avg. daily gain, lb.	1.46	1.53	- .07	0.01	-4.58
Probed backfat, in.	1.52	1.50	0.02	0.01	1.33
Lb. feed/lb. gain	3.45	3.39	0.06	0.02	1.77
Carcass length, in.	29.9	29.6	0.3	0.1	1.01
Carcass backfat, in.	1.50	1.49	0.01	0.01	0.67
Loin area, sq. in.	3.54	3.79	- .25	0.04	-6.60

TABLE XXX

COMPARISON OF THE THREE-LINE CROSS WITH THE PUREBRED LINES FOR POSTWEANING TRAITS

Trait	3-Line Cross Avg.	Purebred Avg.	Difference 3-Line Cross -Purebred	S.E.	Percentage
Avg. daily gain, lb.	1.46	1.51	- .05	0.01	-3.31
Probed backfat, in.	1.52	1.53	- .01	0.01	- .65
Lb. feed/lb. gain	3.45	3.40	0.05	0.02	1.46
Carcass length, in.	29.9	29.4	0.5	0.1	1.70
Carcass backfat, in.	1.50	1.52	- .02	0.01	-1.32
Loin area, sq. in.	3.54	3.69	- .15	0.04	-4.06

Feed Efficiency. The adjusted means for feed efficiency of the lines used in this study were similar. Heterosis estimates indicated the crosses may require slightly more feed per pound of gain than the purebreds. Crosses among inbred lines of Poland China swine (Dickerson _et al_., 1946) showed that crosses required 0.70 more pounds of feed per hundred pounds of gain. Under full feeding, Tucker _et al_. (1952) found crossbreds to be no more efficient than the parental purebreds. Whatley _et al_. (1960) studied Duroc, Beltsville #1, and their crosses and noted that crosses tended to be slightly more efficient but differences between the lines and crosses were not significant.

Carcass Length. Positive estimates of heterosis were obtained for both two and three-line crosses for carcass length. Two-line cross pigs exceeded the average of the parental purebred pigs by 0.4 inch, while three-line cross pigs exceeded the parental and purebred averages by 0.3 and 0.5 inch, respectively. Tucker _et al_. (1952), Reddy _et al_. (1959), and Whatley _et al_. (1960) found crosses to be slightly longer than the purebred parents.

Backfat Thickness. In this study, two-line crosses tended to have slightly less carcass and probed backfat thickness than purebreds, but the magnitudes of the differences were very small. Three-line cross pigs averaged 0.01 inch more carcass backfat than the parental average and 0.02 inch less than the purebred average. Estimates for probed backfat thickness followed the same general pattern.

Tucker et al. (1952) also found crosses had slightly less carcass backfat than straightbreds. Reddy et al. (1959) and Whatley et al. (1960) stated that crosses were intermediate between the parents for carcass backfat, but tended to be closer to the parent with the most fat. No estimates were available in the literature for the heterosis of probed backfat thickness, but results should be the same as for carcass backfat.

Loin Eye Area. The two-line cross pigs averaged 0.13 square inch larger loin eye area than the purebred parental lines, but the three-line cross pigs showed a negative heterosis (-6.60 percent when compared to the parental average and -4.06 percent when compared to the purebred average). The failure of the three-line cross to exhibit a positive heterotic effect may have been due to a negative non-additive gene action for this specific type of cross. Maximum heterosis may have been obtained in the two-line cross resulting in a decrease in the three-line cross compared to the parental average. A smaller loin eye area, calculated from width and depth measurements, was also suggested by Tucker et al. (1952). Dickerson et al. (1946) obtained no significant differences between crosses and inbreds in a study involving 12 inbred lines of Poland China swine. Whatley et al. (1960) found two-line crosses had 0.11 square inch more loin eye area than the purebred average. This compares favorably with the value of 0.13 square inch more loin eye area obtained in this study. Gregory et al.

(1966b) reported the rib eye area of crossbred steers was 0.26 square inch larger than the rib eye area for straightbred steers.

Discussion

The results of this study indicated definite advantages for crossbreeding. Preweaning traits responded greater to crossbreeding than postweaning traits, which should allow for more over-all herd progress to be made. The higher heterotic preweaning traits are traits for which selection is relatively ineffective due to the low heritabilities of the traits. In contrast, the more highly heritable postweaning traits, for which selection can be applied efficiently, are the traits generally exhibiting small heterotic effects. Therefore, selection would probably be a more valuable tool for the improvement of postweaning traits, and crossbreeding can be used effectively to improve preweaning traits. However, crossbreeding is not a substitute for selection. If genetically inferior purebreds are mated, then genetically inferior crossbreds will result. Therefore, selection should be an integral part of any crossbreeding program. As much selection pressure as possible should be applied to the selection of superior purebred or crossbred parents.

In a swine operation, it is doubtful if an individual will maintain more than one type of cross. He is interested in knowing which rotation is the best for crossing the particular breeds used in his breeding program. From this study, it was possible to compare reciprocal combinations for crossing two and three breeds.

The adjusted means for the reciprocal crosses of the Duroc and Beltsville #1 lines are presented in Table XXXI. There appears to be no distinct advantage for one cross over the other. Line 8 dams farrowed and weaned larger litters, but line 9 dams farrowed heavier pigs at birth and weaned heavier litters. Line 98 pigs had slightly more backfat than line 89 pigs, and line 89 pigs averaged 0.24 square inch more loin eye area.

To critically evaluate the advantage of the crossbred dam, the performance for line 99 (three-line cross using Duroc - Belts. #1 cross dam and Hampshire boar) was compared to the performance of line 33 (three-line cross using Duroc - Belts. #1 cross boar and Hampshire dam). Since line 33 litters were available only from 1954 fall to 1958 spring, line 99 data for only these seasons were used to calculate the adjusted means presented in Table XXXII.

For the 15 traits where a comparison was possible, line 99 was superior to line 33 for 11 of these traits. Litter size was in favor of the crossbred sow by approximately one pig at farrowing and 0.36 pigs at weaning. Line 33 had a lower death loss than line 99, but this may have been due largely to the smaller litter size for line 33. As litters become larger, death loss after birth is expected to increase. Line 33 pigs gained 0.02 pound per day faster during the postweaning period and their loin eye area was 0.10

TABLE XXXI

COMPARISON OF THE TWO-LINE RECIPROCAL CROSSES

	Line 89	Line 98	Difference (89-98)
Number of litters	223	195	
Total pigs farrowed per litter	9.0	10.0	-1.0
Live pigs farrowed per litter	8.7	9.7	-1.0
Pigs born dead per litter	0.36	0.27	0.09
Pig birth weight, lb.	3.30	2.80	0.50
Litter birth weight, lb.	28.3	28.5	- .2
Pigs weaned per litter	7.2	7.5	- .3
Pigs dying/litter after birth	1.4	2.2	- .8
Survival rate, %	82.3	77.5	4.8
Pig 56-day weight, lb.	45.7	42.6	3.1
Litter 56-day weight, lb.	323.6	314.0	9.6
Average daily gain, lb.	1.67	1.68	- .01
Probed backfat, in.	1.51	1.57	- .06
Lbs. feed per lb. gain	3.43	3.43	0.00
Carcass length, in.	29.8	29.8	0.00
Carcass backfat, in.	1.55	1.57	- .02
Loin eye area, sq. in.	3.85	3.61	0.24

TABLE XXXII

COMPARISON OF THE THREE-LINE CROSSES

	Line 99	Line 33	Difference (99-33)
Number of litters	141	89	
Total pigs farrowed/litter	10.7	9.8	0.9
Live pigs farrowed/litter	10.4	9.4	1.0
Pigs born dead	0.29	0.42	- .13
Pig birth weight, lb.	3.07	2.94	0.13
Litter birth weight, lb.	31.8	28.0	3.8
Pigs weaned per litter	7.8	7.4	0.4
Pigs dying per litter after birth	2.6	1.9	0.7
Survival rate, %	74.8	76.4	-1.6
Pig 56-day weight, lb.	39.4	39.3	0.1
Litter 56-day weight, lb.	324.9	283.8	41.1
Average daily gain lb./day	1.37	1.39	- .02
Probed backfat, in.	1.52	1.61	- .09
Carcass length, in.	29.6	29.5	0.1
Carcass backfat, in.	1.55	1.61	- .06
Loin eye area, sq. in.	3.30	3.40	- .10

square inch larger. Although the magnitude of the observed differences were small, there appeared to be a definite advantage for the crossbred sow over the purebred sow when the breed composition of the pigs was the same.

The results of this investigation indicate definite response to crossbreeding for sow productivity traits. Traits measured at weaning are more highly heterotic than traits measured at birth. This is probably due to the increased thriftiness of the crossbred pigs (indicated by the survival rates). Maximum response depends on the use of crossbred dams and the particular breed involved in the cross.

SUMMARY

The swine breeding herds maintained at Stillwater and Ft. Reno in the Oklahoma project of the Regional Swine Breeding Laboratory were the source of the data used in this study. The data included 1700 litters (7520 individual pigs records) from three purebred and four crossbred lines of breeding farrowed during the 23 seasons from 1954 fall through 1965 fall.

The preweaning traits studied were total number of pigs farrowed, number of pigs farrowed alive, number of pigs born dead, pig birth weight, litter birth weight, number of pigs weaned, pig livability, pig 56-day weight, and litter 56-day weight. Postweaning traits included average daily gain, probed backfat thickness, feed efficiency, carcass length, carcass backfat thickness, and loin eye area. Least squares procedures were used to adjust the preweaning traits for season, age of dam, number of pigs farrowed and number of pigs weaned. Postweaning traits were adjusted for season, sex, and management system. All analyses were done on a within line basis.

Purebred dams with crossbred litters farrowed smaller litters than purebred dams with purebred litters but were superior for pig birth weight, pigs weaned per litter, pig

livability, and pig and litter 56-day weight. Pig livability was the most highly heterotic preweaning trait studied for the two-line cross. Two-line cross pigs were superior to purebred pigs for average daily gain, carcass length, and loin eye area with average daily gain being the most heterotic. There was no distinct advantage for using Duroc sows and Beltsville #1 boars over Beltsville #1 sows and Duroc boars.

Crossbred dams with crossbred pigs were superior to the parental average for number of pigs farrowed per litter, pigs born dead per litter, litter birth weight, pigs weaned per litter, and litter 56-day weight. Pigs born dead per litter was the most heterotic, and the positive heterotic effects of the other traits were relatively high and quite similar. Although crossbred sows weaned larger litters, a larger number of three-line cross pigs died after birth compared to the parental average. Carcass length was the only postweaning trait for which the three-line cross was superior to the parental average. Three-line cross pigs had a slower daily gain, required more feed per pound of gain, and had a smaller loin eye area than the parental average.

Crossbred dams with crossbred pigs were superior to purebred dams with purebred pigs for total and live pigs farrowed per litter, pigs born dead per litter, pig birth weight, litter birth weight, pigs weaned per litter, survival rate, and pig and litter 56-day weight. Traits exhibiting the most heterosis were pigs born dead per litter, litter birth weight, pigs weaned per litter, and litter 56-day weight and carcass length. Postweaning growth rate, feed efficiency, or loin eye area were not increased in the three-line cross when compared to the average of the purebreds. The use of a crossbred sow and purebred boar was definitely superior to using a purebred sow and crossbred boar in the production of crossbred pigs.

The over-all analysis of the Duroc, Beltsville #1, and Hampshire lines and four specific crosses of these lines indicated preweaning traits were more heterotic than postweaning traits. Preweaning traits involving weight responded more to crossbreeding than traits concerned with litter size. Traits measured at weaning exhibited more heterosis than traits measured at birth. Carcass length was the only postweaning trait which showed a consistent response to crossbreeding. Traits concerned with litter size and litter weight responded greater to crossbreeding when a crossbred dam was used compared to a purebred dam.

APPENDIX

Least Squares Procedure

The construction of the observation matrix will be illustrated using average daily gain. Two variables, season and sex, are included in the model.

$$Y_{ijk} = \mu + s_i + x_j + e_{ijk}$$

where:

Y_{ijk} is average daily gain.

μ is an effect common to all individuals.

s_i is the effect of the ith season and $i = 1,2,3$.

x_j is the effect of the jth sex and $j=1,2$.

e_{ijk} is a random error.

The restriction, which is imposed in order to make the coefficient matrix (X'X) non-singular or full rank so an inverse can be obtained, is that the sum of the effects for an independent variable equals zero. Therefore, in the construction of the observation matrix (X) the last classification within each independent variable is deleted and a minus one is inserted in all remaining classifications if the particular observation is in the last class. The following example illustrates this:

Y_{111} = 1.50 in season 1 and sex 1.

Y_{122} = 1.00 in season 1 and sex 2.

Y_{313} = 1.30 in season 3 and sex 1.

Y_{224} = 1.20 in season 2 and sex 2.

Y_{315} = 2.00 in season 3 and sex 1.

Y_{116} = 1.60 in season 1 and sex 1.

The example X matrix is as follows:

$$[X] = \begin{bmatrix} \mu & s_1 & s_2 & x_1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & 0 & 1 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & 1 & 0 & 1 \end{bmatrix} \qquad [Y] = \begin{bmatrix} 1.50 \\ 1.00 \\ 1.30 \\ 1.20 \\ 2.00 \\ 1.60 \end{bmatrix}$$

Once the X matrix has been determined, the X'X and X'Y matrices can be obtained. By exchanging the rows and columns of the X matrix, the X' matrix can be obtained.

$$[X'] = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & 0 & -1 & 1 \\ 0 & 0 & -1 & 1 & -1 & 0 \\ 1 & -1 & 1 & -1 & 1 & 1 \end{bmatrix}$$

So,

$$\underset{[X']}{\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & 0 & -1 & 1 \\ 0 & 0 & -1 & 1 & -1 & 0 \\ 1 & -1 & 1 & -1 & 1 & 1 \end{bmatrix}} \times \underset{[X]}{\begin{bmatrix} 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & -1 \\ 1 & -1 & -1 & 1 \\ 1 & 0 & 1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}} = \underset{[X'X]}{\begin{bmatrix} 6 & 1 & -1 & 2 \\ 1 & 5 & 2 & -1 \\ -1 & 2 & 3 & -3 \\ 2 & -1 & -3 & 6 \end{bmatrix}}$$

Similarly,

$$\underset{[X']}{\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & 0 & -1 & 1 \\ 0 & 0 & -1 & 1 & -1 & 0 \\ 1 & -1 & 1 & -1 & 1 & 1 \end{bmatrix}} \times \underset{[Y]}{\begin{bmatrix} 1.50 \\ 1.00 \\ 1.30 \\ 1.20 \\ 2.00 \\ 1.60 \end{bmatrix}} = \underset{[X'Y]}{\begin{bmatrix} 8.60 \\ 0.80 \\ 2.10 \\ 4.20 \end{bmatrix}}$$

The normal equations for a least squares procedure are:

$$[X'] [\hat{\beta}] = [X'Y]$$

with X'X and X'Y being the coefficient matrix and right hand side, respectively, under the restriction imposed, and $[\hat{\beta}]$ being the vector of least squares constants. The $\hat{\beta}$ matrix can be solved for algebraically.

$$[X'X] [\hat{\beta}] = [X'Y]$$

$$[X'X]^{-1} [X'X] [\hat{\beta}] = [X'X]^{-1} [X'Y]$$

but,

$$[X'X]^{-1} [X'X] = [I]$$

so,

$$[\hat{\beta}] = [X'X]^{-1} [X'Y]$$

The inverse of the X'X matrix ($[X'X]^{-1}$) can be determined by the Abbreviated Doolittle Method or any other inversion method. In the example, the inverse is:

$$[X'X]^{-1}$$

$$\begin{bmatrix} 5/24 & -1/12 & 1/12 & -1/24 \\ -1/12 & 1/3 & -1/3 & -1/12 \\ 1/12 & -1/3 & 1 & 5/12 \\ -1/24 & 1/12 & 5/12 & 3/8 \end{bmatrix}$$

The vector of constants can now be determined.

$$[\beta] = [X'X]^{-1} [X'Y]$$

$$\begin{bmatrix} \mu \\ \beta_{s_1} \\ \beta_{s_2} \\ \beta_{x_1} \end{bmatrix} = \begin{bmatrix} 5/24 & -1/12 & 1/12 & -1/24 \\ -1/12 & 1/3 & -1/3 & -1/12 \\ 1/12 & -1/3 & 1 & 5/12 \\ -1/24 & 1/12 & 5/12 & 3/8 \end{bmatrix} \begin{bmatrix} 8.60 \\ 0.80 \\ -2.10 \\ 4.20 \end{bmatrix} = \begin{bmatrix} 1.37 \\ -.10 \\ 0.10 \\ 0.41 \end{bmatrix}$$

From the restrictions that were imposed, $\hat{\beta}_{s_3}$ and $\hat{\beta}_{x_z}$ can be obtained as follows:

$$\hat{\beta}_{s_1} + \hat{\beta}_{s_2} + \hat{\beta}_{s_3} = 0$$
$$-.10 + 0.10 + \hat{\beta}_{s_3} = 0$$
$$\hat{\beta}_{s_3} = 0$$

Similarly,

$$\hat{\beta}_{x_1} + \hat{\beta}_{x_2} = 0$$
$$0.41 + \hat{\beta}_{x_2} = 0$$
$$\hat{\beta}_{x_2} = -.41$$

Now that the constants have been determined, it is possible to estimate the mean for a particular trait within a variable adjusted for all other variables in the model. From the example, the mean for average daily gain for sex one adjusted for season would be:

$$Y = 1.37 + 0.41 = 1.78$$

This can be illustrated mathematically by the following:

$$Y_{ij} = \hat{\mu} + \hat{\beta}_i + \hat{\beta}_j$$

$$\frac{\sum_j Y_{ij}}{n_j} = \frac{\sum_j \hat{\mu}}{n_j} + \frac{\sum_j \hat{\beta}_i}{n_m} + \frac{\sum_j \hat{\beta}_j}{n_j}$$

$$\overline{Y}_i = \frac{n_j \hat{\mu}}{n_j} + \frac{n_j \hat{\beta}_i}{n_j} + \frac{0}{n_j} = \hat{\mu} + \hat{\beta}_1$$

LITERATURE CITED

Bolick, G. M., H. A. Stewart, and E. V. Dillard. 1956. Comparison of a three-breed rotational crossbreeding program with an inbred and an outbred population in swine. J. Animal Sci. 15:1222 (Abstr.).

Carroll, W. E. and E. Roberts. 1942. Crossbreeding in swine. Ill. Agr. Exp. Sta. Bul. 489.

Craft, W. A. 1958. Fifty years of progress in swine breeding. J. Animal Sci. 17:960.

Dickerson, G. E., J. L. Lush, and C. C. Culbertson. 1946. Hybrid vigor in single crosses between inbred lines of Poland China swine. J. Animal Sci. 5:16.

Durham, R. M. and J. H. Zeller. 1955. Using the probing technique in selecting breeding swine on farms. J. Animal Sci. 14:1180. (Abstr.).

Enfield, F. D. 1957. Heritability of carcass length, carcass backfat thickness, and loin lean area in swine. M.S. Thesis, Oklahoma State University.

England, D. C. and L. M. Winters. 1953. The effects of genetic diversity and performance of inbred lines per se on hybrid vigor in swine. J. Animal Sci. 12:836.

Gaines, J. A. and L. N. Hazel. 1957. Differences in litter size and growth rate among purebred and crossbred swine. J. Animal Sci. 16:1066. (Abstr.).

Gregory, K. E. and G. D. Dickerson. 1952. Influence of heterosis and plane of nutrition on rate and economy of gains, digestion and carcass composition of pigs. Mo. Agr. Exp. Sta. Res. Bul. 493.

Gregory K. E., L. A. Swiger, R. M. Koch, L. J. Sumption, W. W. Rowden, and J. E. Ingalls. 1965. Heterosis in preweaning traits of beef cattle. J. Animal Sci. 24:21.

Gregory, K. E., L. A. Swiger, L. J. Sumption, R. M. Koch, J. E. Ingalls, W. W. Rowden, and J. A. Rothlisberger. 1966a. Heterosis effects on growth rate and feed efficiency of beef steers. J. Animal Sci. 25:299.

Gregory, K. E., L. A. Swiger, L. J. Sumption, R. M. Koch, J. E. Ingalls, W. W. Rowden, and J. A. Rothlisberger. 1966b. Heterosis effects on carcass traits of beef steers. J. Animal Sci. 25:311.

Harvey, Walter R. 1960. Least-squares analysis of data with unequal numbers. Agr. Res. Service. U. S. D. A., ARS-20-8.

Lush, J. L., P. S. Shearer, and C. C. Culbertson. 1939. Crossbreeding hogs for pork production. Ia. Agr. Exp. Sta. Bul. 380.

Omtvedt, I. T., J. A. Whatley, Jr., and R. L. Willham. 1966. Some production factors associated with weaning records in swine. J. Animal Sci. 25:372.

Reddy, V. B., J. F. Lasley, and L. F. Tribble. 1959. Heritabilities and heterosis of some economic traits in swine. Mo. Agr. Exp. Sta. Res. Bul. 689.

Robison, W. L. 1948. Crossbreeding for the production of market hogs. Ohio Agr. Exp. Sta. Bul. 675.

Sierk, C. F. and L. M. Winters. 1951. A study of heterosis in swine. J. Animal Sci. 10:104.

Smith, C. and J. W. B. King. 1964. Crossbreeding and litter production in British pigs. An. Prod. 6:265.

Smith, H. J., R. P. Moorman, and J. B. McLaren. 1960. Performance of straightbred and crossbred swine. J. Animal Sci. 19:1227. (Abstr.).

Stanislaw, C. M. 1966. A covariance analysis between purebred and crossbred populations of swine. Ph.D. Thesis, Oklahoma State University.

Tucker, H. F., G. E. Dickerson, and J. F. Lasley. 1952. Crossbreeding effects on growth, digestion, feed utilization and carcass composition in swine under full and equalized feeding, with and without antibiotic. J. Animal Sci. 11:745. (Abstr.).

Warren, W. M. and G. E. Dickerson. 1952. Components of performance in selecting for heterosis in swine. Mo. Agr. Exp. Sta. Res. Bul. 511.

Whatley, J. A., Jr., Doyle Chambers, and D. F. Stephens. 1954. Using hybrid vigor in producing market hogs. Okla. Agr. Exp. Sta. Bul. 415.

Whatley, J. A., Jr. and E. L. Quaife. 1937. Adjusting weights of pigs to a standard age of 56 days. Proc. Am. Soc. Animal Prod. 30:126.

Whatley, J. A., Jr., S. P. Wilson, and I. T. Omtvedt. 1960. Performance tests with purebred and crossbred pigs from two lines of breeding. Okla. Agr. Exp. Sta. Misc. Pub. 57:49.

Winters, L. M., O. M. Kiser, P. S. Jordan, and W. H. Peters. 1935. A six year study of crossbreeding s swine. Minn. Agr. Exp. Sta. Bul. 320.

VITA

Peter John Cunningham

Candidate for the Degree of

Master of Science

Thesis: CROSSBREEDING EFFECTS ON PREWEANING AND POST-WEANING PERFORMANCE IN SWINE

Major Field: Animal Science

Biographical:

Personal Data: Born at Winterset, Iowa, October 27, 1941, the son of Peter J. and Katherine M. Cunningham.

Education: Graduated from Winterset High School in 1960. Received the Bachelor of Science degree from Iowa State University in Ames, with a major in Animal Science, May 1964.

Experience: Graduate Assistant at Oklahoma State University, 1964-1966.

Professional Organizations: American Society of Animal Science.

Date of Final Examination: November, 1966.