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Heterosis and Breed Effects in Swine

R. K. Johnson

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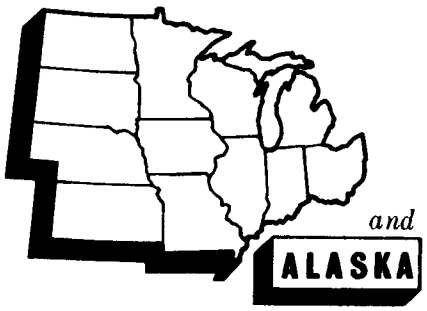
by R. K. Johnson



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Heterosis and Breed Effects in Swine

R. K. Johnson[1]

Introduction

An objective of the NC-103 regional swine breeding project is to evaluate inter-population and intra-population performance of domestic and exotic strains of swine. Several cooperating stations have conducted experiments relative to this objective. Projects were not exact replicates, but sufficient overlap allowed combining the information to yield more precise estimates of heterosis and breed effects than was possible from the analyses of data from any single experiment.

This publication summarizes data available from NC-103 cooperating stations on breed and heterosis effects in swine. An extensive crossbreeding experiment has been conducted and results published by Canadian researchers Fahmy and Bernard, 1971 (8); Fahmy *et al.*, 1971 (9); Fahmy *et al.*, 1975 (10); Fahmy *et al.*, 1976 (11); Holtmann *et al.*, 1975 (13). Several of the breeds were U.S. breeds and many crosses were similar to those in projects contributing to NC-103. To provide additional information on breeds and crosses, the Canadian data were also utilized. These data provided comparisons with breeds found primarily in Canada. For a summary of the Canadian study, see the report of Fahmy and Holtmann, 1977 (12).

Materials and Methods

Data used were individual experiment breed group means obtained from scientific publications, NC-103 annual reports, or personal communication with project leaders. Breed group means were subjected to a weighted least squares analysis where each mean was weighted by the number of observations in the mean.

For each trait, the data were grouped and several analyses were conducted so that each analysis contained the largest possible subset of the data. For example, some experiments included purebreds and crossbreds whereas others compared several crossbred combinations. Breed and heterosis effects were estimated only from experiments

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that included both purebreds and crossbreds. Purebreds were then deleted and breed effects were estimated from analyses utilizing all two-breed cross means. A third analysis of each trait was made utilizing only those experiments that included purebred and crossbred females mated in such a way that heterosis for maternal effects could be estimated. For sow productivity traits, a fourth analysis was conducted on all three-breed cross means (crossbred female and purebred boars) to compare the performance of various combinations of crossbred females.

The same breeds were not used in each experiment. However, most studies included Yorkshire and Duroc-Yorkshire crosses. Therefore, to insure a connected design for each analysis, only experiments that included Yorkshire or Duroc-Yorkshire crosses were included.

A description of the traits analyzed, the experiment stations from which data were obtained and the reference for each source of the data are presented in Table 1.

Adjustments

In the Iowa and North Carolina experiments, postweaning performance was measured to a constant age (154 days at Iowa and 140 days at North Carolina). In these experiments postweaning average daily gain is the average gain for the breed group from weaning to 154 or 140 days. Postweaning average daily gain and 154 or 140 day weight were used to calculate age at 100 kg for breed groups in these experiments. In the North Carolina experiment, breed group backfat means were adjusted to 72.7 kg body weight. These means were adjusted to 100 kg by adding .612 cm (.0224 cm/kg) to each mean.

Weaning age varied among experiments from 42 to 56 days. Variables analyzed were number of pigs per litter and pig weight at weaning, regardless of weaning age. This increases the variation among experiments and may increase the variation among means, but should not contribute appreciably to variation among breed groups.

Carcass data were measured at either 90 or 100 kg in different experiments. Since means had been adjusted, within experiments, to a constant weight, no further weight adjustments were made.

Statistical Analyses

Several models were used to make the comparisons of interest, therefore all models will not be presented here. Analyses of variance are contained in the Appendix. However, the general form of each analysis was similar.

For most experiments, breed group means and number of observations and not individual observations were available. Therefore, analyses of breed group means weighted by the number of observations were conducted. The general form of the model was:

Table 1. Description of traits, total number of observations and reference from which data were obtained for each trait.

Trait	n	References
1. Conception rate — % of those designated for breeding that conceived	3,942	5, 6, 9, 13, 17, 18, 22, 26
2. Total no. of pigs/litter at birth[a]	3,961	4, 5, 7, 9, 14, 17, 18, 21, 22, 26
3. Avg. pig weight/litter at birth-weights taken within 24 hours of birth	3,587	4, 9, 14, 17, 18, 21, 22, 26
4. No. pigs/litter at 21 days	2,787	4, 9, 13, 14, 17, 22, 26
5. Avg. pig weight/litter at 21 days	2,787	4, 9, 13, 14, 17, 22, 26
6. No. pigs/litter at weaning — varied between 42 and 56 days	2,937	5, 7, 9, 14, 17, 18, 21, 22, 26
7. Avg. pig weight/litter at weaning	2,653	4, 5, 7, 9, 14, 17, 18, 21, 22, 26
8. Postweaning average daily gain, kg[b]	12,486	4, 14, 17, 18, 19, 20, 21, 22, 23
9. Age at 100 kg	12,486	4, 14, 17, 18, 19, 20, 21, 22, 23
10. Postweaning feed efficiency, G/F	489 pens	17, 18, 19, 20, 25
11. Carcass length/cm[c]	2,697	3, 14, 19, 20, 22, 25, 4, 17, 21
12. Carcass backfat, cm[c]	5,602	3, 14, 19, 20, 22, 25, 4, 17, 21
13. Carcass loin-eye area, cm^2[c]	2,697	2, 14, 19, 20, 22, 25, 4, 17, 21

[a]Reported as number of live pigs in some studies and total number of fully formed pigs in other studies.

[b]Measured as gain from weaning to 154 days in some studies and from 8 or 9 weeks of age to 90 or 100 kg in other studies.

[c]In each experiment, means were adjusted to either 90 or 100 kg.

$$w \# y = (X \# N)\beta + e$$

where y=n x 1 vector of breed group means

w=n x 1 vector of number of observations per mean

X=n x p input matrix of 0, 1 and −1. The X matrix has been re-parameterized so that $\sum_{i=1}^{n} \hat{\alpha}_i = 0$. The sum of the estimates of least squares constants for each main effect is zero.

N=n x p matrix of numbers of observation where the i^{th} column of N=w.

β=n x 1 vector of fixed effects

e=n x 1 vector of deviations that represent the failure of the model to predict w#y.

The operation # means elementwise multiplication of two matrices. To do this, the matrices must have the same dimensions.

Least squares solutions to the model were obtained from:

$\hat{\beta}=[X^1(X\#N)]^{-1}X^1(w\#y)$.

Sums of squares removed by each effect in the model were obtained from:

$\hat{\beta}_j^1 Z_j^{-1} \hat{\beta}_j$

where β_j are the j least squares estimates of the effects of interest and Z_j is the jxj submatrix of $[X^1(X\#N)]^{-1}$ corresponding to the main effect of interest. Standard errors of least squares estimates were obtained by multiplying the residual mean square times the appropriate diagonal element of $[X^1(X \#N)]^{-1}$.

This model gives the same RHS and LHS, and consequently the same solution that would be obtained as if individual observations rather than breed group means were used in the analyses. The reduction in sum of squares due to fitting each effect in the model is also the same; however, the residual sum of squares will include all interactions that are not in the model. Therefore, tests of significance for main effects with the residual mean square assumes that interactions are not important. Literature estimates of within breed group variances are presented to assist in evaluating the importance of interactions.

Results and Discussion

Conception Rate

The average percent conception rate and number of observations

per mean for females of eight breeds in five experiments is presented in Appendix Table 1. The weighted least squares model included the effects of experiment and breed. Mean squares and degrees of freedom are presented in Appendix Table 2 and estimates of breed constants and standard errors are presented in Table 2.

Experiment and breed effects were significant ($P<.01$). No estimates of within breed variance are available; however, assuming conception rate has a binomial distribution, with $p=.82$, the variance of individual observations expressed in percentage is approximately $[100^2p\ (1 - p)]$ or 1,476. This is very similar to the residual mean square of 1,517.0 obtained from the data. This suggests breed by experiment interactions are not important. Differences among breeds were similar across experiments, also indicating negligible breed by experiment interactions.

Conception rates for Chester White, Hampshire and Berkshire were from 8.2 to 8.8% above average whereas those for Yorkshire, Landrace, and Large Black were from 6.3 to 8.5% below average. Lacombe and Duroc were intermediate in conception rate.

Experiment means reported by Johnson *et al.* (1978) and Schneider (1978) comparing conception rate of purebred and crossbred females are presented in Table 2. Although not significant (AOV in Appendix Table 2) crossbred females had a $3.2\pm2.8\%$ higher mean conception rate than the purebreds. The overall mean for all crossbreds (third column, Table 2) is 5.2% greater than the overall mean for all purebreds (first column, Table 2).

The analysis of variance from the model that compared the mean conception rate of 31 different two-breed cross females is presented in Appendix Table 2 and estimates of constants and standard errors for each breed cross are presented in Table 2. Experiment by breed cross means are presented in Appendix Table 3. Experiments were a significant source of variation ($P<.01$); however, differences among breed cross means were not significant even though the conception rate for various crossbred groups ranged from 13.7% below average to 12.8% above average. Tests of significance were made, however, with a residual mean square that had only nine degrees of freedom.

Sow Productivity Traits

Heterosis. Breed and breed cross means from experiments that included both purebred and crossbred litters from purebred dams were analyzed using a model that included the effects of experiments, breed of dam, and mating type (purebred *vs* crossbred). Means and number of observations per mean are presented in Appendix Tables 4 and 5 for number of pigs and average pig weight per litter at birth, 21 days and at weaning.

Degrees of freedom and mean squares from these analyses are presented in Appendix Table 6, and least squares constants and stan-

Table 2. Least squares constants or means from weighted analyses comparing the conception rate of purebred and crossbred females.

Purebred females[a]			Purebred and crossbred females[b]			Crossbred females[c]		
Breed	n	$\bar{x}$	Breed	n	$\bar{x}$	Breed	n	$\bar{x}$
$\hat{\mu}$	2346	82.0± .88**	*Oklahoma: 2- and 3-breed matings*			μ	2351	87.2±1.32
Lacombe (La)	99	−3.4± 4.33				B-La	38	.4±3.24
Berkshire (B)	22	8.8± 7.67	μ	835	80.3	B-D	39	−2.4±3.20
Duroc (D)	627	−.8± 2.85	D	141	81.6	B-H	36	−2.5±3.33
Hampshire (H)	601	8.2± 2.84	H	131	86.0	B-L	37	3.6±3.28
Lage Black (LB)	10	−8.5±11.0	Y	134	70.9	B-Y	33	−9.6±3.47
Landrace (L)	117	−6.3± 4.07	D-H	146	77.9	La-L	38	−4.3±3.24
Yorkshire (Y)	706	−6.5± 2.64	D-Y	145	83.5	La-Y	36	−2.4±3.33
Chester White (C)	164	8.5± 3.04	H-Y	138	82.4	D-La	39	−4.0±3.20
			Crossbreds		81.1	D-H	321	−3.5±1.13
			Purebreds		78.1	D-L	38	−6.6±3.24
			Heterosis		3%	D-Y	435	.9± .97
			% Heterosis		3.8%	H-La	38	−13.6±3.24
						H-L	38	−6.2±3.24
			Iowa: back-cross matings			H-Y	416	−2.9±1.00
						LB-B	37	2.3±3.28
			μ	646	85.8	LB-D	38	−.2±3.24
			C	76	85.9	LB-H	33	10.0±3.47
			D	70	90.4	Pi-La	35	2.9±3.37
			H	76	79.8	Pi-L	34	−4.7±3.42
			Y	76	77.9	Pi-Y	38	4.3±3.24
			C-D	61	96.9	L-Y	125	−1.6±2.26
			C-H	58	88.5	T-B	39	.7±3.20
			C-Y	54	92.8	T-La	36	−2.5±3.33
			D-H	64	86.9	T-D	34	5.9±3.42
			D-Y	56	86.1	T-H	36	1.9±3.33
			H-Y	55	72.7	T-LB	38	−13.7±3.24

Crossbreds	87.1	T-L	37	−.9±3.28
Purebreds	83.5	T-Y	36	2.9±3.33
Heterosis	3.6%	C-D	61	12.8±6.77
% Heterosis	4.3%	C-H	58	4.4±7.12
		C-Y	54	8.6±7.65

[a]Breed x experiment means are in Appendix Table 1 and analysis of variance in Appendix Table 2.

[b]Means from Johnson *et al.*, 1978 (Okla) and Schneider, 1978 (Iowa).

[c]Breed x experiment means in Appendix Table 3. Abbreviaitons not shown in column 1: Pi=Pietrian, T=Tamworth, P=Poland.

**Breed effects significant (P<.01).

Table 3. Estimates of within breed variances.

	Trait										
	Litter size			Avg pig wt, kg					Carcass, cm		
Reference	Birth	21 days	Weaning	Birth	21 days	Weaning	Avg daily gain, kg	Days to 100 kg	Length	Backfat	Longissimus muscle area
15	6.72	4.68	4.64	.04	.66	3.02					
16							.005	187	2.01	.096	12.2
19									4.0	.16	8.41
20							.003		1.6	.60	5.4
3									2.7	.17	7.3
10								262		.46	
9	6.86	5.10	5.15	.05		2.34					
1	10.6	7.73	7.63	.046	.80	4.45	.006				
2	8.27	5.29	5.29	.041	.62	3.13	.004		3.1	.41	16.5
24	8.76	7.62	7.29		.98	4.62					

dard errors are in Table 4. Residual mean squares for number of pigs per litter at birth, 21 days, and at weaning are 9.5, 13.8 and 11.1, respectively. These are somewhat larger than most literature estimates of the variance of these traits which have ranged from 6.72 to 10.6 for number at birth and from 4.64 to 7.63 for number at weaning (Table 3).

Perhaps a more complete model that included the effects of breed of sire and breed of sire by breed of dam would have significantly reduced the residual mean square as breed of sire effects on litter size and pig livability have been reported by Young *et al.* (1976). The residual mean square would also be inflated if the heterosis expressed by different breed crosses is not the same since the model used only tests for average heterosis. The means in Appendix Table 5 show that the difference between purebred and crossbred litters from Yorkshire and Landrace dams at 21 days and at weaning is not as large as the difference expressed by other breeds. Further, in the Iowa experiment, Chester White dams ranked very high when producing crossbred litters, but were well below average when producing purebred litters (Appendix Table 5). Breed by experiment interactions, if they exist, also would contribute to the magnitude of the residual variance.

Residual mean squares for average pig weight per litter at birth and 21 days are similar to within breed estimates of the variance of these traits (Table 3), but the residual mean square for average pig weight at weaning is higher than most estimates of variance in the literature. In addition to factors mentioned above, the fact that this includes weights at 42 or 56 days in different experiments may be a contributing factor.

The primary purpose of these analyses was to estimate average heterosis. Estimates are presented in Table 4. Least squares constants for breed of dam effects also are presented, but breed effects will be discussed later from other analyses.

Heterosis was significant for number of pigs at weaning and for average pig weight per litter at each age. Crossbred litters averaged .10, .56, and .70 pigs per litter more than purebred litters at birth, 21 days, and at weaning, respectively. Crossbred pigs also averaged .04, .16, and .64 kg heavier at birth, 21 days, and at weaning. These differences suggest that the primary advantages of crossbred pigs over purebred pigs are increased preweaning livability and growth rate.

Breed Effects. All breed cross means from experiments that included purebred dams mated to produce crossbred litters were subjected to a weighted least squares analysis that included the effects of experiment and breed of dam. Experiment by breed of dam means and number of observations are presented in Appendix Table 7 for litter size and average pig weight per litter at birth and in Appendix

Table 4. Least squares constants for litter traits from birth to weaning from the weighted means analysis comparing purebred dams with purebred and crossbred litters. [a]

	Birth			21 days			Weaning		
Breed group[b]	n	No. born	Pig wt, kg	n	No./litter	Pig wt, kg	n	No./litter	Pig wt, kg
$\hat{\mu}$	1042	9.80±.14	1.31±.01	706	7.27±.17	5.28±.04	1029	7.28±.15	13.63±.18
B	46	−.54±.59					46	.0 ±.61	1.07±.74
D	276	.38±.22	.10±.02	213	−.48±.24	.00±.06	272	−.56±.24	−.12±.29
H	232	−.76±.26	.06±.02	224	−.74±.24	.20±.06	224	−.80±.27	−.46±.33
L	62	−.63±.42	.11±.03				62	.36±.46	.49±.56
Y	299	1.01±.20	−.13±.02	198	.53±.25	.09±.06	298	.45±.22	−.31±.26
S	56	−1.26±.43	.06±.04				56	−.53±.54	−.23±.65
C	71	1.81±.38	−.20±.03	71	.69±.38	−.29±.15	71	1.08±.43	−.44±.52
CB Litter	702	.05±.10	.02±.01	485	.28±.15	.08±.04	699	.35±.11	.32±.13
PB Litter	340	−.05±.10	−.02±.01	221	−.28±.15	−.08±.04	330	−.35±.11	−.32±.13
Heterosis		.10	.04*		.56*	.16*		.70**	.64*
% Heterosis		1.0%	3.1%		8.0%	3.1%		10.1%	4.8%

[a]Breed x experiment means are in Appendix Table 4 and analyses of variance are in Appendix Table 6.

[b]See Table 2 for abbreviation of breeds.

*P<.05.

**P<.01.

Table 8 for traits at 21 days and at weaning.

Residual mean squares from these analyses (Appendix Table 9) are somewhat larger than those found in the literature, but are similar to those from the previous model with the exception of number weaned for which the residual mean square was 6.03 from this model compared to 11.1 from the previous analysis. Several factors could be responsible, including an experiment station by breed of dam interaction. Differences among breeds of dam were not the same in each experiment; however, breeds tended to rank similarly in each experiment (Appendix Tables 7 and 8) with the exception of average pig weight per litter at 21 days. There appears to be some evidence for experiment by breed of dam interaction for this trait.

Experiment was a significant source of variation for all traits except number of pigs per litter at birth and breed of dam effects were significant for number of pigs per litter at birth and weaning and for average pig weight per litter at birth (Appendix Table 9).

Least squares constants and standard errors for each breed of dam are presented in Table 5.

Correlations among breed of dam effects for traits measured from birth to weaning are in Table 6. Correlations among measures of litter size were very high. With the exception of Duroc, breeds ranked about the same for litter size regardless of the age when measured. Duroc dams had litters with .26 pigs more than average at birth, but litter size was .14 pigs below average by weaning. Chester White, Lacombe, and Yorkshire consistently ranked high for number of pigs per litter with Chester Whites having litters that were 2.10, 1.52, and 1.38 pigs above average at birth, 21, and 42 days, respectively. Berkshire, Hampshire, Large Black, and Spot sows were consistently below average in litter size at each age.

Differences among breeds of dam were not as consistent for average pig weight per litter. Correlations ranged from .49 to .63 (Table 6). In most experiments pigs were allowed creep feed at three weeks of age. Thus, pigs from breeds of dam that were below average at birth and 21 days but above average at weaning may reflect pigs with above average genetic merit for growth that were nursed by dams that are below average in milking ability. This is also confounded with litter size. Correlations among litter size and pig weights ranged from -.13 to -.62. Pigs from large litters may be expected to be lighter than pigs from small litters during the period when they are completely dependent on the dam for nutrition. Litters from Yorkshire dams, however, were above average in litter size at all ages and the pigs were below average in weight at birth, but well above average in weight by 21 days. At 42 days, pigs from Yorkshire dams were below average.

Purebred vs Crossbred Dams. To estimate heterosis for maternal effects for litter traits measured from birth to weaning, breed group means from experiments where purebred and crossbred dams were

Table 5. Least squares constants for litter traits from birth to weaning from the weighted means analyses comparing the performance of purebred dams with crossbred litters. [a]

	Birth			21 days			Weaning		
Breed of dam	n	No. born	Pig wt, kg	n	No./litter	Pig wt, kg	n	No./litter	Pig wt, kg
$\hat{\mu}$	1416	9.67±.18**	1.39±.01**	1025	7.36±.19*	5.19±.07**	1410	7.55±.14**	13.3 ± .23
La	67	.62±.42	.09±.05	67	.81±.39	.05±.15	67	.94±.33	−.16± .55
B	50	−.66±.51	−.07±.07	27	−.74±.56	−.55±.21	50	−.43±.41	−.22± .67
D	346	.26±.24	.04±.03	247	−.01±.27	−.02±.10	343	−.14±.20	−.32± .33
H	338	−.74±.25	.04±.03	274	−.35±.26	.20±.10	335	−.34±.20	−.29± .33
LB	12	−1.49±.89	.10±.09	12	−1.54±.81	.70±.31	12	−1.51±.70	1.69±1.15
L	117	−.08±.33	.14±.04	73	−.29±.38	−.12±.14	117	−.03±.26	.52± .44
Y	391	.80±.22	−.14±.03	272	.60±.25	.08±.09	391	.54±.18	−.60± .30
S	42	−.81±.55	.02±.06	—	—	—	42	−.41±.44	−.38± .73
C	53	2.10±.51	−.23±.05	53	1.52±.48	−.36±.18	53	1.38±.41	−.24± .68

[a]Breed x experiment means are in Appendix Tables 7 and 8 and analyses of variance are in Appendix Table 9.

[b]See Table 2 for abbreviations of breeds.

*Breed of dam effects significant (P<.05).

**Breed of dam effects significant (P<.01).

Table 6. Correlations[a] among breed of dam effects for traits measured from birth to weaning.

Trait	2	3	4	5	6
1. Litter size, birth	.97	.95	−.65	−.45	−.13
2. Litter size, 21 days		.99	−.59	−.46	−.45
3. Litter size, weaning			−.55	−.55	−.62
4. Pig weight, birth				.51	.51
5. Pig weight, 21 days					.63
6. Pig weight, weaning					

[a]Calculated from least squares constants in Table 5.

mated to produce 2-breed cross and 3-breed cross litters, respectively, (Appendix Tables 10 and 11) were analyzed. They were analyzed with a model that included the effects of experiments, variation among purebred dams, variation among crossbred dams and the effect of crossbred *vs* purebred dams. Degrees of freedom and mean squares are presented in Appendix Table 12 and least squares constants in Table 7.

With the exception of average pig weight per litter at weaning, residual mean squares for each trait are very similar to estimates of within breed group variances reported in the literature (Table 3). Based on this, and from inspection of means (Appendix Tables 10 and 11), it appears that differences among breed groups and between purebred and crossbred dams were similar in each experiment. Pig weaning weight may be expected to have a larger residual mean square partly because weights were taken at either 42 or 56 days.

Differences between purebred and crossbred dams were significant for litter size at each age and for average pig weight per litter at weaning. Crossbred dams had .46, .64, and .58 more pigs per litter at birth, 21 days, and weaning, respectively, than purebred dams. In addition, pigs nursed by crossbred dams were heavier at each age than pigs nursed by purebred dams. This difference was 1.2 kg per pig at weaning.

Comparison Among Crossbred Dams. The mean litter size and pig weight at each age for crossbred dams in each experiment were subjected to a weighted least squares analysis that included the effects of experiment and breeding of dam. Breed of sire was ignored in the analyses, however, all crossbred dams were mated to produce 3-breed cross litters. The mean performance for each breed group in each experiment is presented in Appendix Tables 13 and 14. Degrees of freedom and mean squares are presented in Appendix Table 15 and least squares breed group constants are presented in Table 8.

Because the Canadian study, which provided the only data on several breed crosses, did not report litter size or pig weights beyond 21 days, only litter size and pig weight at birth and 21 days were analyzed.

Table 7. Least squares constants for litter traits from birth to weaning from the weighted means analyses comparing the performance of purebred and crossbred dams.[a]

		Birth		21 Days		Weaning	
Breed of Dam[b]	n[c]	No. born	Pig wt, kg	No./litter	Pig wt, kg	No./litter	Pig wt, kg
$\hat{\mu}$	1052 (788)	10.0±.09	1.33±.01	7.67±.11	5.56±.04	7.87±.10	15.12± .28
			Purebred dams				
D	168 (113)	−.46±.18	.11±.03	−.41±.24	−.05±.10	−.59±.20	.04± .53
H	170 (109)	−1.04±.18	.10±.03	−.56±.24	.21±.10	−.56±.10	−.08± .53
Y	158 (103)	.05±.18	−.05±.03	−.24±.24	.18±.10	.04±.20	−.10± .53
C	44	1.45±.29	−.16±.05	1.21±.39	−.34±.15	1.11±.32	.14± .88
			Crossbred dams				
D-H	139 (109)	−.21±.21	.07±.03	−.17±.27	.16±.11	−.05±.23	.51± .64
D-Y	131 (101)	−.10±.22	.01±.03	−.10±.27	−.15±.11	−.17±24	.12± .65
D-C	41	−.79±.33	.14+.05	−.42±.38	.18±.15	−.46±.36	.38± .98
H-Y	128 (95)	.04±.22	−.07±.03	.47±.28	−.13±.11	.38±.24	−.06± .66
H-C	36	.25±.35	−.10±.05	−.20±.40	−.09±.16	−.14±.38	−.67±1.04
Y-C	37	.81±.35	−.05±.03	.42±.40	.03±.16	.44±.38	−.28±1.04
Crosses	540 (419)	.23±.09	.01±.01	.32±.11	.10±.04	.29±.10	.60± .26
Pure	512 (369)	−.23±.09	−.01±.01	−.32±.11	−.10±.04	−.29±.10	−.60± .26
Heterosis		.46*	.02	.64*	.20	.58*	1.20*
% Heterosis		4.7%	1.5%	8.7%	3.7%	7.7%	8.2%

[a]Breed x experiment means are in Appendix Tables 10 and 11 and analyses of variance are in Appendix Table 12.
[b]See Table 2 for abbreviation of breeds.
[c]Numbers in parentheses are number of litters at weaning. The large discrepancy is because one experiment did not report performance at weaning.
*P<.05.
**P<.01.

Table 8. Least squares constants for litter traits at birth and 21 days from the weighted means analyses comparing the performance of crossbred dams.[a]

Breed of dam[a]	n	Birth		21 Days	
		No./litter	Pig wt, kg	No./litter	Pig wt, kg
$\hat{\mu}$		9.94± .27	1.36±.02**	7.92± .29	5.30±.04**
B-La	38	−.18± .73	.00±.05	−.39± .76	−.07±.11
B-D	39	.42± .72	−.05±.05	−.09± .75	−.27±.11
B-H	36	−.88± .75	−.02±.05	−.59± .78	−.11±.11
B-L	37	.32± .74	.02±.05	.61± .77	−.17±.11
B-Y	33	.12± .78	−.06±.05	.11± .82	−.11±.11
La-L	38	.42± .73	.07±.05	−.29± .76	−.09±.11
La-Y	36	−.18± .75	−.03±.05	−.09± .78	.15±.11
D-La	39	.52± .72	−.26±.05	.91± .75	−.21±.11
D-H	269	−.06± .41	.04±.03	−.25± .43	.06±.06
D-L	55	.16± .62	.11±.04	−.02± .65	.10±.09
D-Y	389	.51± .37	−.03±.03	.32± .39	−.19±.05
H-La	38	.82± .73	−.02±.05	.41± .76	−.24±.11
H-L	38	1.22± .73	.06±.05	1.11± .76	−.04±.11
H-Y	354	.28± .38	−.08±.03	−.06± .40	−.04±.06
LB-B	37	−1.18± .74	.11±.05	−.79± .77	.36±.11
LB-D	38	−.18± .73	.10±.05	−.19± .76	.30±.11
LB-H	33	−1.28± .78	.05±.05	−.49± .82	.39±.11
Pi-La	35	.22± .76	.09±.05	.41± .79	.41±.11
Pi-L	34	.02± .77	.13±.05	.21± .80	.38±.11
Pi-Y	38	−.98± .73	−.02±.05	−.39± .76	.35±.11
L-Y	130	.08± .46	−.04±.03	.73± .49	−.04±.07
T-B	39	−.48± .72	−.06±.05	−.59± .75	−.42±.11
T-La	36	.72± .75	−.03±.05	.61± .78	−.16±.11
T-D	34	−.18± .77	−.03±.05	−.29± .80	−.22±.11
T-H	36	−.18± .75	.02±.05	.41± .78	−.04±.11
T-LB	38	−1.08± .73	−.04±.05	−.49± .76	−.10±.11
T-L	37	−.68± .74	.07±.05	−.19± .77	.12±.11
T-Y	36	.32± .75	−.07±.05	.41± .78	.13±.11
L-S	17	−.14±1.25	.03±.08	.33±1.31	−.09±.18
Y-S	19	.17±1.20	−.06±.08	−.98±1.26	−.02±.18
D-S	15	.12±1.31	.04±.08	−.64±1.37	−.00±.19
C-Y	37	1.15± .88	−.06±.06	.57± .92	−.02±.13
C-H	36	.58± .89	−.12±.06	−.06± .93	−.14±.13
C-D	41	−.51± .90	.14±.06	.27± .89	.04±.13

[a]Breed cross x experiment means are in Appendix Tables 13 and 14 and analyses of variance are in Appendix Table 15.

[b]See Table 2 for abbreviation of breeds.

**Breed cross of dam effects significant (P<.01).

Residual means squares for number of pigs per litter at birth and at 21 days were considerably larger than those from previous analyses and are larger than within breed estimates of variances in the literature (Table 3). This would suggest some breeding of dam by experiment interaction. Part of this appears to be the difference in rank of

Landrace x Yorkshire cross dams in the various experiments. They ranked first in litter size at birth in the Canadian and Oklahoma experiments and last in the Purdue experiment (Appendix Table 13). Duroc-Yorkshire dams also ranked high in all experiments except the North Carolina experiment where they ranked last compared to Hampshire x Yorkshire and Duroc x Hampshire dams.

Differences among crossbred dam groups were large, but were significant only for average pig weight per litter at birth and 21 days, due primarily to the large residual mean square for litter size. Averaged overall, litter size at birth was highest for Hampshire-Landrace cross sows (+1.22 pigs), followed closely by Chester White-Yorkshire crosses (+1.15 pigs).

In general, dams that were half Chester White, Yorkshire, and Lacombe ranked high in litter size at birth while dams that were half Large Black, Berkshire, Pietrain, and Tamworth were below average.

Hampshire-Landrace cross dams also had the largest litters at 21 days (+1.11 pigs), followed by Duroc-Lacombe (+.91) and Yorkshire-Landrace (+.73). Averaged overall, dams that were half Landrace ranked highest in litter size at 21 days. Chester White, Yorkshire, and Lacombe cross dams also ranked high while those that were half Large Black, Berkshire, and Spot ranked lowest.

It is interesting to compare the overall means for all crossbred dams with three-way cross litters (Table 8) to the overall means for all crossbred dams with crossbred litters (Table 5). Crossbred dams had litters that were 3 and 8% larger at birth and 21 days, respectively, and pigs that were 21% lighter at birth and 2% heavier at 21 days. These comparisons are not strictly correct, but are similar to estimates of maternal heterosis in Table 7.

Growth

Heterosis and Breed Effects. Appendix Table 16 contains the mean average daily gain and age at 100 kg for purebred and crossbred pigs in five experiments. The weighted least squares model included the effects of experiment, breed of sire, breed of dam, and purebreds *vs* crossbreds. Degrees of freedom and mean squares from the analyses are presented in Appendix Table 17 and least squares constants are in Table 9.

The residual mean squares for average daily gain and age at 100 kg are larger than estimates of within breed variances from the literature (Table 3). Perhaps this is because growth was measured over different age and weight intervals. It may also reflect true differences in breed samples between experiments. This appears to be differences in magnitude rather than rank as breeds and crosses ranked similarly in most experiments (Appendix Table 16).

Breed of sire, breed of dam and differences between purebreds and crossbreds were significant for both average daily gain and age at

Table 9. Least squares constants from the weighted means analyses of purebred and crossbred pigs for average daily gain (ADG) and age at 100 kg (AGE).

	ADG[c]		AGE[c]	
Breed[b]	No.	Constant, kg	No.	Constant, days
$\hat{\mu}$	5050	.67±.007	4906	179.7± .82
Breed of sire				
D	1443	.02±.006	1443	−3.2±1.0
H	1053	−.00±.007	1053	2.1±1.0
Y	1610	.00±.006	1538	−1.0±1.0
C	481	−.03±.009	481	7.7±1.7
P	72	−.01±.023	--	
L	193	.00±.012	193	−1.6±2.3
S	198	.01±.012	198	−4.0±2.1
Breed of dam				
D	1348	.02±.006	1348	−3.2±1.1
H	1210	−.01±.007	1210	2.1±1.2
Y	1452	.01±.006	1380	−2.0±1.1
C	570	−.03±.008	570	5.5±1.6
P	72	−.00±.023	--	
L	213	−.00±.012	213	.1±2.3
S	185	.02±.012	185	−2.4±2.3
Crossbreds	3697	.03±.003	3721	−6.0± .54
Purebreds	1353	−.03±.003	1218	6.0± .54
Heterosis		.06		12
% Heterosis		9.4%		6.5%

[a]Breed by experiment means are in Appendix Table 16; analyses of variance are in Appendix Table 17.
[b]See Table 2 for abbreviations of breeds.
[c]Breed of sire, breed of dam and heterosis effects were significant (P<.01) for each trait.

100 kg (Appendix Table 17). Averaged overall, crossbreds gained .06 kg per day faster and reached 100 kg 12 days sooner than purebreds (Table 9). Pigs by Duroc sires gained .02 kg per day faster and reached market weight 3.2 days sooner than the overall average. In contrast, pigs by Chester White sires gained .03 kg per day less and were 7.7 days older at market weight than average. In general, pigs by other sire breeds were similar in growth.

Breed of dam differences for growth are similar to breed of sire differences. The correlation between breed of sire and breed of dam effects for average daily gain is .90. Pigs from Duroc dams gained faster and reached market weight earlier than pigs from all other breeds of dam, whereas pigs from Chester White dams were well below average.

Two and Three-Breed Crosses. The mean average daily gain and age at 100 kg for two-and three-breed crosses are presented in Table 10. These means were not analyzed. Of importance is the difference between crossbred pigs from crossbred dams and crossbred pigs from

Table 10. Mean postweaning average daily gain (ADG) and age at 100 kilograms (AGE) for two-breed and three-breed crosses.

	Reference											
	17			21			4[b]			18		
Breed group[a]	n	ADG	AGE	n	ADG	AGE	n	ADG	AGE	n	ADG	AGE
DxH	193	.73	177.7	210	.655	184.1						
DxY	210	.73	175.8	292	.699	177.5						
HxD	210	.73	197.4	187	.617	193.3						
HxY	192	.70	182.5	205	.635	190.4						
YxD	232	.74	174.2	283	.644	187.5						
YxH	209	.73	178.6	334	.627	190.7						
D (HxY)	270	.72	177.5	95	.636	184.3				310	.699	185.7
D (YxH)	252	.71	182.3	190	.657	178.7						
H (DxY)	247	.74	175.4	112	.681	175.7				307	.693	188.4
H (YxD)	234	.72	178.8	128	.657	180.2						
Y (DxH)	296	.73	177.4	147	.646	180.4				315	.696	186.9
Y (HxD)	300	.74	174.2	118	.629	186.7						
P (DxH)				209	.635	182.3						
P (DxY)				190	.642	181.3						
P (HxY)				205	.634	182.5						
Cross ♂ x Pure ♀							329	.601	174.7			
Pure ♂ x Cross ♀							425	.600	174.8			
3-breed Crosses	1599	.727	177.6	790	.651[c]	181.0[c]						
2-breed Crosses	1246	.727	178.0	1511	.646[c]	187.3[c]						

[a]See Table 2 for abbreviation of breeds, breed of sire first.
[b]Individual breed group means were unavailable.
[c]Includes only the average of Duroc, Hampshire and Yorkshire crosses.

purebred dams when each progeny group is expressing the same level of heterosis. This difference estimates the heterosis for maternal effects on postweaning growth. Averaged overall, 2,814 pigs from crossbred dams gained .686 kg per day and were 178.1 days of age at 100 kg compared to 3,086 pigs from purebred dams that gained .674 kg per day and were 182.2 days of age at 100 kilograms. The difference in age at 100 kg is about what would be expected based on the difference in weaning weight between two-and three-breed cross pigs. This suggests that heterosis for maternal effects for postweaning growth is small and unimportant.

Efficiency of Growth

Postweaning feed efficiencies for various breed groups in different experiments are presented in Table 11. Because of the lack of

Table 11. Feed efficiency for purebred and crossbred pigs.

	Reference									
	25		17		18		19		20	
Breed Group[a]	n[b]	G/F	n[b]	G/F	n[b]	G/F	n[c]	G/F	n[c]	G/F
DxD	17	.3049								
DxH	17	.3106	12	.3215						
DxY	15	.3298	10	.3333						
HxD	11	.3216	13	.3266						
HxH	16	.3071								
HxY	12	.3302	12	.3372						
YxD	17	.3104	12	.3110						
YxH	14	.3013	12	.3080						
YxY	23	.3181					24	.28	12	.27
D (HxY)			17	.3273	4	.3390				
D (YxH)			15	.3280						
H (DxY)			13	.3302	4	.3300				
H (YxD)			14	.3335						
Y (DxH)			18	.3039	4	.3210				
Y (HxD)			19	.3128						
D (DxY)					4	.3200				
D (HxD)					4	.3150				
H (DxH)					4	.3130				
H (HxY)					4	.3250				
Y (DxY)					4	.3170				
Y (HxY)					4	.3140				
PxP							24	.27	12	.27
PxY							24	.30	12	.27
YxP							24	.29	12	.31
Heterosis		.0072				.025		.02		.02

[a]See Table 2 for abbreviation of means. Breed of sire first.
[b]n = number of pens with 12 to 18 pigs per pen.
[c]Individually fed pigs.

similar designs in the various experiments, these data were not analyzed. Four experiments provide estimates of heterosis. The comparison of backcrosses and three-breed crosses from the Oklahoma experiment (18) estimates half of the heterosis. This difference was doubled and averaged with the difference between purebreds and crossbreds (25, 19, and 20).

The estimate of heterosis for postweaning efficiency of growth is .018 kg of gain per kg of feed. The four different estimates are quite consistent. The two Oklahoma estimates (18, 25) were significant. The two Wisconsin estimates were not. Although not large, these results indicate that postweaning growth is more efficient for crossbreds than purebreds.

Table 11 also contains the means from the Oklahoma study that utilized two-breed and three-breed cross matings. Postweaning feed efficiency for two-breed and three-breed crosses was nearly identical, suggesting heterosis for maternal effects is unimportant.

From the means presented in Table 11, it is difficult to compare breeds averaged over experiments for feed efficiency. Young *et al.* (1976) in the Oklahoma study (25) found significant breed of sire and breed of dam effects on feed efficiency. Hampshire sired pigs were more efficient than Duroc or Yorkshire sired pigs; however, pigs out of Yorkshire dams were more efficient than pigs out of Duroc or Hampshire dams. Similar differences were found by Johnson *et al.* (1978) shown in Table 11 (17). The relatively large direct maternal effect on postweaning feed efficiency is evident by comparing the means for reciprocal crosses involving Yorkshire in Table 11.

Carcass Traits

The mean carcass length, backfat, and *longissimus* muscle area for purebred and crossbred barrows of several breed groups are presented in Appendix Table 18. These means were subjected to a weighted least squares analysis that included the effects of experiment, breed of sire, breed of dam, and purebred *vs* crossbreds. Mean squares are presented in Appendix Table 19 and least squares constants are in Table 12.

Residual mean squares for each carcass trait are somewhat larger than those reported in the literature (Table 4). This could be caused by significant interactions among effects in the model. Differences between reciprocal crosses have been reported by Young *et al.* (1976) and Bereskin *et al.* (1971) for carcass traits. In addition, differences between the sample of breeds used in each experiment could result in experiment by breed group interactions. Inspection of the means in Appendix Table 18 suggests some evidence for breed group by experiment interaction. Differences between barrows by each breed of sire are not the same in each experiment, however, in some cases differences between reciprocal crosses are also quite large. Perhaps

Table 12. Least squares constants for carcass traits from the weighted means analyses comparing the performance of purebred and crossbred pigs. [a]

Breed group[b]	n	Length cm	Backfat cm	Longissimus area cm^2
$\hat{\mu}$	1382	76.8±.16	3.27±.16	29.08±.33
		Breed of Sire[c]		
D	412	−.21±.20	.02±.04	.55±.41
H	260	.52±.23	−.23±.05	1.84±.48
Y	456	.64±.19	.14±.04	−.33±.39
C	131	−.11±.29	.01±.06	−.83±.59
L	38	.62±.45	.02±.10	−1.28±.93
S	37	−.65±.46	.15±.10	−.97±.94
P	48	−.81±.40	−.11±.08	1.02±.82
		Breed of Dam[c]		
D	406	.01±.19	.09±.04	−1.44±.40
H	253	.36±.23	−.12±.05	.74±.48
Y	472	.66±.18	−.03±.04	1.02±.38
C	125	−.66±.29	.01±.06	.06±.59
L	45	.52±.43	.23±.09	−.90±.90
S	33	.38±.48	−.05±.10	−.11±.82
P	48	−1.27±.40	−.13±.08	.64±.82
Crossbreds	920	.02±.08	.04±.02	.26±.17
Purebreds	462	−.02±.08	−.04±.02	−.26±.17
Heterosis		.04	.08	.52
% Heterosis		0	2.5%	1.8%

[a]Breed x experiment means are in Appendix Table 18 and analyses of variance are in Appendix Table 19.
[b]See Table 2 for abbreviations of breeds.
[c]Breed of sire and breed of dam effects were significant ($P<.01$) for each trait.

both factors contribute to the large residual mean squares.

Experiment, breed of sire, and breed of dam were significant for each trait, however, the difference between purebred and crossbred pigs was significant only for carcass backfat. Averaged overall, crossbred pigs were .04 cm longer and had .08 cm more backfat and .52 cm^2 more *longissimus* muscle area than purebreds (Table 12).

Hampshire, Landrace, and Yorkshire sired barrows were well above average in carcass length, whereas Spot and Poland sired barrows were much shorter than average. Barrows by Hampshire sires also had considerably less backfat and larger *longissimus* muscle areas than barrows by all other breeds of sire. Poland sired barrows also were considerably below average in carcass backfat and above average in *logissimus* muscle area. Barrows by Spot and Yorkshire sires were considerably fatter than average, however, barrows by Chester White, Landrace and Spot sires had the smallest *longissimus* muscle area.

Breed of dam effects were not the same as breed of sire effects.

Correlations between breed of sire and breed of dam effects were .69, .36, and .33 for length, backfat and *longissimus* muscle area, respectively. Overall, barrows from Yorkshire and Landrace dams were above average in length, followed closely by barrows from Spot and Hampshire dams. Barrows from Poland dams were well below average in carcass length as were barrows by Chester White dams. Barrows from Hampshire and Poland dams had the least fat and those from Landrace dams were well above average in carcass fat. Similar to sire effects, barrows from Poland and Hampshire dams were well above average in *longissimus* muscle area, but barrows from Yorkshire dams had the largest *longissimus* muscle area and barrows from Duroc dams the least.

The difference in rank for sire and dam effects suggests that maternal effects are important for carcass traits. Assuming that the average genetic merit of sires and dams was similar in each experiment, reciprocal differences are caused by average breed differences for maternal effects. It should be noted from the means in Appendix Table 18 that in every experiment involving Duroc and Yorkshire crosses, D x Y crosses are less fat with larger *longissimus* muscle areas than Y x D crosses. Similarly, H x Y crosses are superior to Y x H crosses. It is difficult to make conclusions regarding other breeds, but it appears that the maternal effect of Yorkshire females is quite large.

The mean carcass characteristics for crossbred barrows from purebred and crossbred dams are presented in Table 13. Averaged overall, barrows from crossbred dams were .16 cm longer, .13 cm fatter and had .12 cm^2 less backfat than barrows from purebred dams. Even though reciprocal differences suggest maternal breed differences are important for carcass traits, it appears that heterosis for maternal effects is quite small.

Summary

Breed and heterosis effects were estimated from results of experiments contributing to the NC-103 regional swine project and from the Canadian crossbreeding study. Data from 20 different experiments conducted at 7 experiment stations involving crosses among 12 different breeds were included.

The deviation due to the average increase of heterozygosity in crossbreds compared to purebreds (individual heterosis) was estimated from the average difference between crossbreds and purebreds, whereas the deviation due to the average increase of heterozygosity of crossbred females compared to purebred females (maternal heterosis) was estimated from the average performance of crossbred and purebred dams when they were mated so that expected average breed effects and individual heterosis effects in the progeny were the same.

Table 13. Mean carcass length, backfat and loin-eye area for two-breed and three-breed crosses.

	Reference										
	25				21			22[c]			
Breed group[a]	n	Lgt	BF	LEA	n	Lgt	BF	LEA	n	Lgt	BF	LEA
DxH	46	77.1	2.95	28.9	210		2.72					
DxY	39	78.5	2.95	31.7	292		2.82					
HxD	45	77.9	2.91	29.7	187		2.64					
HxY	39	78.2	2.87	31.7	205		2.69					
YxD	41	78.0	3.20	28.6	283		2.95					
YxH	42	77.5	3.14	29.3	334		2.90					
D (HxY)	43	77.6	3.06	31.1	95		3.10					
D (YxH)	41	78.2	3.08	31.9	190		3.10					
H (DxY)	43	77.8	2.90	31.2	112		3.20					
H (YxD)	42	78.4	2.84	31.4	128		3.05					
Y (DxH)	45	77.7	3.35	29.1	147		3.20					
Y (HxD)	47	77.6	3.21	29.1	118		3.17					
P (DxH)					103		3.17					
P (HxD)					133		3.10					
P (DxY)					87		3.20					
P (YxD)					86		3.35					
P (HxY)					72		3.33					
P (YxH)					123		3.20					
Cross ♂ x Pure ♀									329	78.5	3.40	36.2
Pure ♂ x Cross ♀									425	78.8	3.38	36.6
Maternal Heterosis		.02	.07	−.65			.35[b]			.3	−.02	.4

[a]See Table 2 for abbreviation of breeds. Breed of sire first.
[b]Difference between two-breed and three-breed crosses involving only Duroc, Hampshire, and Yorkshire.
[c]Breeds involved are Duroc, Hampshire, Yorkshire, and Chester White.

Heterosis, breed of sire, and breed of dam effects were estimated from weighted least squares analyses of breed group means in each experiment. The weighting factor was the number of observations per mean.

Individual and maternal heterosis found for each trait are summarized in Table 14. Heterosis effects are quite large for reproductive and growth traits, but relatively unimportant for carcass traits. When absolute estimates of heterosis for conception rate, litter size at weaning, and pig weaning weight are combined, two-breed crosses weaned 15.4% heavier litters at weaning per female in the breeding herd than purebreds and three-breed crosses were 21% above the average of the two-breed crosses. In addition, two -breed and three-breed crosses are expected to be 6.5 to 7.5% younger at 100 kg and to gain 2.3% more efficiently than the average of the purebreds. Carcass merit for crossbreds, however, is expected to be equal to the average of the purebreds that made up the cross.

Purebred Chester White, Berkshire, and Hampshire females excelled in conception rate, whereas purebred Yorkshire, Landrace, and Large Black were considerably below average. Chester White, Yorkshire, and Lacombe dams excelled in litter size at birth while Large Black, Spot, Berkshire, and Hampshire dams had the smallest litters at birth. At weaning, Chester White and Lacombe dams had the largest litters and the heaviest pigs were raised by Large Black and Landrace dams. Litter size at weaning was well below average for Large Black, Berkshire, Hampshire, and Spot dams also were below average in litter size weaned.

Table 15 presents the weighted average of least squares constants for crossbred sows that are half of each breed for conception rate and for litter size and pig weight at birth and 21 days. Crossbred sows that were 50% of each breed were very similar in conception rate. Females that were half Berkshire were 3.2% above average, whereas sows that were half Lacombe were 2.5% below average. Crossbred sows that were 50% of each breed differed considerably in litter size at birth and at 21 days. Sows that were half Chester White and half Lacombe were .37 and .34 pigs above average in litter size at birth, whereas sows that were half Landrace were superior in litter size at weaning. Sows that were 50% Yorkshire, Chester White, and Lacombe were also above average in litter size at 21 days.

Duroc sired pigs excelled in growth rate, whereas Chester White sired pigs were well below average. Pigs from Duroc and Spot dams were superior for growth and pigs from Chester White dams were considerably below average. Hampshire and Poland sired barrows were superior for carcass backfat and *longissimus* muscle area. Significant maternal effects existed for efficiency of growth and carcass merit. Crosses involving Yorkshire as the dam breed were more efficient and less fat than reciprocal crosses where Yorkshire was the sire breed.

Table 14. Individual and maternal heterosis for each trait expressed in absolute value and as a percentage.

Trait	Individual heterosis[c]		Maternal heterosis[d]	
	Absolute	Percent	Absolute	Percent
Ovulation rate	.04± .24[b]	.3		
Conception rate, %	3.0	3.8		
No. of embryos 30 days postbreeding	.52± .48[a]	5.1	.71±.38[b]	6.8
Litter size at birth	.10± .20	1.0	.46±.18	4.7
Pig birth weight, kg	.04± .02	3.1	.02±.02	1.5
Litter size at 21 days	.56± .30	8.0	.64±.22	8.7
Pig 21 day weight, kg	.16± .08	3.1	.20±.08	3.7
Litter size at weaning	.70± .22	10.1	.58±.20	7.7
Pig weaning weight, kg	.64± .26	4.8	1.20±.52	8.2
Postweaning average daily gain, kg	.06± .006	9.4	.00	0
Age at 100 kg	−12 ±1.08	6.5	−2.2	1.2
Postweaning feed efficiency (G/F)	.02± .007	2.3	−.00	0
Carcass length, cm	.04± .16	0	.16	.2
Carcass backfat, cm	.08± .04	2.5	.13	4.4
Longissimus area, cm^2	.52± .34	1.8	.12	.4

[a]From Young *et al.* (1976).

[b]From Johnson *et al.* (1978).

[c]Absolute difference between two-breed crosses and purebreds and percent increase of crossbreds over purebreds.

[d]Absolute difference between three-breed crosses with crossbred females and two-breed crosses with purebred females and percent increase of three-breed crosses over two-breed crosses.

Table 15. Weighted average of least squares constant for sows that are one-half of each breed.

	Conception rate			Birth		21 days	
Breed[a]	No.	%	No. litters	Litter size	Pg wt, kg	Litter size	Pig wt. kg
B	330	3.2	259	−.27	−.01	−.25	−.12
D	824	−.7	919	.21	.00	.08	−.07
H	799	−2.0	840	.12	−.02	−.07	−.01
L	347	−1.5	386	.17	.04	.40	.01
La	186	−2.5	260	.34	−.03	.22	−.04
Y	593	.7	1072	.31	−.05	.19	−.07
LB	146	.2	146	−.92	.05	−.49	.23
Pi	107	2.0	107	−.27	−.06	−.06	.38
T	256	.1	256	−.23	−.02	−.03	−.10
C			114	.37	−.01	.26	−.04
S			51	.05	−.00	−.44	−.04

[a]See Table 2 for abbreviations of breeds.

APPENDIX

Appendix Table 1. Average percent conception rate and number of observations per mean for each breed group in each experiment.

	Reference									
	9		6		26		22		17	
Breed	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$
Lacombe	52	75.0	47	91.5						
Berkshire	22	86.4								
Duroc	30	70.0			276	83.7	180	70.2	141	81.6
Hampshire	40	85.0			274	92.3	156	82.3	131	86.0
Lage Black	10	70.0								
Landrace	64	68.8	53	92.5						
Yorkshire	75	76.0	53	86.8	268	74.6	176	70.9	134	70.9
Chester White							164	81.7		

Appendix Table 2. Degrees of freedom and mean square from weighted means analyses of conception rate.

	Purebreds[a]		Crossbreds[b]	
Source of variation	df	MS	df	MS
Experiment	4	14323.1**	4	7141.1**
Breed	7	11406.1**	29	1274.8
Residual	8	1517.0	9	413.0
Crossbred and purebred females[c]				
Experiment	1	1243.8		
Among purebreds	3	5708.0		
Among crossbreds	5	2941.0		
Pure *vs* cross	1	6707.4		
Residual	5	2836.2		

[a]The means and number of observations for each breed in each experiment are presented in Appendix Table 1.

[b]The means and number of observations for each breed cross in each experiment are presented in Table 2.

[c]The means and number of observations for each breed cross in each experiment are presented in Appendix Table 3.

**P<.01.

Appendix Table 3. Average percent conception rate for crossbred females in each experiment.

	Reference									
	13		17		18		5		23	
Breed of gilt	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$
B-La	38	84.8								
B-D	39	82.0								
B-H	36	81.9								
B-L	37	88.0								
B-Y	33	94.0								
La-L	38	80.1								
La-Y	36	82.0								
D-La	39	80.4								
D-H	36	79.6	146	78.1	75	85.4				
D-L	38	77.8							64	86.9
D-Y	36	89.4	145	83.5	80	90.0	118	95.3	56	86.1
H-La	38	70.8								
H-L	38	78.2								
H-Y	35	77.1	138	82.4	77	91.1	111	92.0	55	72.7
LB-B	37	86.7								
LB-D	38	84.2								
LB-H	33	94.4								
Pi-La	35	87.3								
Pi-L	34	79.7								
Pi-Y	38	88.7								
L-Y	35	84.1					90	92.3		
T-B	39	85.1								
T-La	36	81.9								
T-D	34	90.3								
T-H	36	86.3								
T-LB	38	70.6								
T-L	37	83.5								
T-Y	36	87.3								
C-D									61	96.9
C-H									58	88.5
C-Y									54	92.8

[a]See Table 2 for abbreviation of breeds.

Appendix Table 4. Average litter size (LSB) and pig weight (PWB) per litter at birth for purebred dams with purebred and crossbred litters by experiment.

	Reference											
	26			22			7			14		
Breed of dam	n	LSB	PWB[a]	n	LSB	PWB[a]	n	LSB	PWB[a]	n	LSB	PWB[a]
Purebred dams with crossbred litters												
Berkshire							23	9.80	——			
Duroc	95	9.93	1.301	48	9.47	1.565				41	11.30	1.429
Hampshire	108	8.37	1.306	51	8.29	1.455						
Landrace										44	9.80	1.488
Yorkshire	86	10.40	1.055	47	10.11	1.331	22	11.70	——	42	10.90	1.247
Spot										42	9.40	1.392
Chester White				53	11.20	1.236						
Purebred dams with purebred litters												
Berkshire							23	9.60	——			
Duroc	55	8.89	1.302	19	8.92	1.474				18	11.50	1.420
Hampshire	56	8.36	1.244	17	9.52	1.329						
Landrace										18	10.60	1.351
Yorkshire	50	10.22	1.079	16	10.47	1.230	22	10.80	——	14	12.60	1.129
Spot										14	9.40	1.401
Chester White				18	10.28	1.161						

[a]Weight in kilograms.

Appendix Table 5. Average litter size and pig weights at 21 (N21 and P21) and 42 (N42 and P42) days for purebred dams with purebred and crossbred litters by experiment.

	Reference									
	26					22				
	n	N21	P21[a]	N42	P42[a]	n	N21	P21[a]	N42	P42[a]
Purebred dams with crossbred litters										
Berkshire										
Duroc	94	6.79	4.801	6.62	10.64	48	7.69	6.02	7.52	18.10
Hampshire	106	6.42	5.019	6.30	10.88	51	7.24	5.97	7.16	16.64
Landrace										
Yorkshire	86	7.55	4.763	7.33	10.52	47	7.73	6.21	7.72	17.78
Spot										
Chester White						53	9.02	5.63	8.83	17.63
Purebred dams with purebred litters										
Berkshire										
Duroc	52	5.63	4.499	5.27	10.25	19	6.93	5.78	6.93	16.77
Hampshire	50	5.39	4.962	5.18	10.35	17	7.62	5.80	7.33	16.22
Landrace										
Yorkshire	49	7.69	4.682	7.42	10.53	16	8.90	5.91	8.88	17.58
Spot										
Chester White						18	7.13	5.55	6.97	14.96

Appendix Table 5 (continued). Average litter size and pig weights at 21 (N21 and P21) and 42 (N42 and P42) days for purebred dams with purebred and crossbred litters by experiment.

	Reference									
	7					14				
	n	N21	P21[a]	N42	P42[a]	n	N21	P21[a]	N42	P42[a]
Purebred dams with crossbred litters										
Berkshire	23	—	—	8.10	17.78					
Duroc						41	—	—	7.60	11.38
Hampshire										
Landrace						44	—	—	7.90	11.88
Yorkshire	22	—	—	8.30	14.78	42	—	—	8.00	10.66
Spot						42	—	—	7.30	11.07
Purebred dams with purebred litters										
Berkshire	23	—	—	6.50	14.74					
Duroc						18	—	—	6.00	11.52
Hampshire										
Landrace						18	—	—	8.20	11.25
Yorkshire	22	—	—	7.20	14.97	14	—	—	8.20	10.20
Spot						14	—	—	6.60	10.79
Chester White										

[a]Weights in kilograms.

Appendix Table 6. Degrees of freedom and mean squares from weighted means analyses comparing the performance of purebred females with purebred and crossbred litters.

		Mean square					
Source of variation	df[a]	No. born[b]	Pig wt, birth[b]	No. 21 days[c]	Pig wt, 21 days[c]	No. weaned[c]	Pig wt, weaned[c]
Experiment	3 (1) (2)	71.7**	2.89**	107.2*	186.6**	53.4*	2212.3**
Breed of dam	6 (3) (5)	118.8**	2.12**	77.1*	4.2**	46.4	14.5
Pure *vs* cross	1	2.3	.46*	48.7	4.2*	104.4**	88.4
Residual	15 (9)(13)	9.5	.073	13.8	.77	11.1	16.1

[a]Numbers in parentheses are degrees of freedom from analyses of 21 and 42 day traits, respectively.

[b]Breed group by experiment means and numbers of observations are presented in Appendix Table 4.

[c]Breed group by experiment means and numbers of observations are presented in Appendix Table 5.

*P<.05.

**P<.01.

Appendix Table 7. Litter size (LSB) and average pig weight (PWB) per litter at birth for purebred dams with crossbred litters. [a]

		Breed of dam								
Reference	Trait	Lacombe	Berkshire	Duroc	Hampshire	Large Black	Landrace	Yorkshire	Spot	Chester White
	n	67	27	38	53	12	73	80		
9	LSB	10.20	9.00	9.70	8.60	7.90	9.75	10.60		
	PWB	1.605	1.450	1.500	1.570	1.620	1.670	1.390		
	n			95	108			86		
26	LSB			9.93	8.37			10.40		
	PWB			1.301	1.306			1.055		
	n			69	65			59		
17	LSB			9.24	8.88			9.86		
	PWB			1.335	1.320			1.210		
	n			48	51			47		53
22	LSB			9.47	8.29			10.11		11.20
	PWB			1.565	1.455			1.331		1.236
	n		23					22		
7	LSB		9.80					11.70		
	PWB		--					--		
	n			55	61			55		
21	LSB			9.41	9.02			9.66		
	PWB			1.431	1.508			1.309		
	n			41			44	42	42	
14	LSB			11.30			9.80	10.90	9.40	
	PWB			1.429			1.488	1.247	1.392	

[a]Pig weights in kilograms.

Appendix Table 8. Litter size and average pig weight per litter at 21 (N21 and P21) and 42 (N42 and P42) days for purebred dams with crossbred litters. [a]

		Breed of dam								
Reference	Trait	Lacombe	Berkshire	Duroc	Hampshire	Large Black	Landrace	Yorkshire	Spot	Chester White
	n	67	27	38	53	12	73	80		
	N21	8.85	7.30	7.90	7.25	6.50	7.75	9.00		
7	P21	5.20	4.60	5.19	5.31	5.85	5.03	5.22		
	N42	8.85	7.16	7.90	7.20	6.40	7.75	8.85		
	P42	8.70	7.55	8.54	8.89	10.55	9.42	8.36		
	n			94	106			86		
	N21			6.79	6.42			7.55		
26	P21			4.80	5.02			4.76		
	N42			6.62	6.30			7.33		
	P42			10.64	10.88			10.52		
	n			67	64			59		
	N21			7.04	7.10			7.29		
17	P21			4.69	5.17			4.94		
	N42			6.89	7.01			7.24		
	P42			10.64	11.02			10.90		
	n			48	51			47		53
	N21			7.69	7.24			7.73		9.02
22	P21			6.02	5.97			6.21		5.63
	N42			7.52	7.16			7.72		8.83
	P42			18.10	16.64			17.78		17.63
	n		23					22		
	N21		--					--		
7	P21		--					--		
	N42		8.10					8.30		
	P42		17.78					14.78		

Appendix Table 8. Litter size and average pig weight per litter at 21 (N21 and P21) and 42 (N42 and P42) days for purebred dams with crossbred litters.[a]

	n	55	61		55	
	N21	--	--		--	
21	P21	--	--		--	
	N42	7.36	7.59		8.63	
	P42	15.30	15.74		14.93	
	n	41		44	42	42
	N21	--		--	--	--
14	P21	--		--	--	--
	N42	7.60		7.90	8.00	7.30
	P42	11.38		11.88	10.66	11.07

[a]Pig weights in kilograms.

Appendix Table 9. Degrees of freedom and mean squares from weighted means analyses comparing the performance of purebred dams with crossbred litters.

		Mean square					
Source of variation	df[a]	No. born[b]	Pig wt, birth[b]	No. 21 days[c]	Pig wt, 21 days[c]	No. weaned[c]	Pig wt, weaned[c]
Experiment	6 (5) (3)	23.8	2.39**	55.8*	51.4**	41.3**	1766.3**
Breed of dam	8 (7)	89.2**	1.56**	43.7*	4.32	41.0**	17.4
Residual	11 (9) (5)	11.2	.13	9.9	1.42	6.03	19.3

[a]Degrees of freedom in parentheses are for traits at 21 days and at weaning, respectively.

[b]Experiment by breed group means are presented in Appendix Table 7.

[c]Experiment by breed group means are presented in Appendix Table 8.

*P<.05.

**P<.01.

Appendix Table 10. Litter size (LSB) and average pig weight (PWB) at birth for litters by purebred and crossbred dams.

	Reference								
	17			4			21		
Breed of dam	n	LSB	PWB[a]	n	LSB	PWB[a]	n	LSB	PWB[a]
Purebred dams with crossbred litters									
Duroc (D)	69	9.24	1.335	44	9.33	1.532	55	9.41	1.431
Hampshire (H)	65	8.88	1.320	44	8.15	1.422	61	9.02	1.508
Yorkshire (Y)	59	9.86	1.210	44	9.97	1.298	55	9.66	1.309
Chester White (C)				44	11.06	1.203			
Crossbred dams with 3-breed cross litters									
D-H	69	10.02	1.375	40	9.57	1.444	30	10.67	1.374
D-Y	64	10.18	1.278	37	10.45	1.385	30	9.68	1.403
D-C				41	9.31	1.530			
H-Y	66	10.49	1.150	29	10.04	1.318	33	10.10	1.415
H-C				36	10.35	1.282			
Y-C				37	10.92	1.342			

[a]Weights in kilograms.

Appendix Table 11. Litter size and average pig weight[a] per litter at 21 (N21 and P21) and 42 (N42 and P42) days for crossbred litters by purebred and crossbred dams

	Reference														
	17					4					21				
Breed of dam	n	N21	P21	N42	P42	n	N21	P21	N42	P42	n	N21	P21	N42	P42
Purebred dams with crossbred litters															
Duroc (D)	67	7.04	4.69	6.89	10.65	44	6.93	6.15	6.81	17.77	55	—	—	7.36	15.30
Hampshire (H)	64	7.10	5.17	7.01	11.02	44	6.48	6.10	6.45	16.31	61	—	—	7.59	15.74
Yorkshire (Y)	59	7.29	4.94	7.24	10.90	44	6.97	6.34	7.01	17.45	55	—	—	8.63	14.93
Chester White (C)						44	8.26	5.76	8.12	17.30					
Crossbred dams with 3-breed cross litters															
D-H	69	8.45	5.22	8.26	11.45	40	6.95	6.39	6.89	19.10	30	—	—	9.15	18.82
D-Y	64	8.01	4.86	7.83	11.02	37	7.89	6.17	7.83	18.71	30	—	—	8.37	18.45
D-C						41	7.27	6.49	7.13	18.75					
H-Y	66	8.85	4.82	8.73	10.90	29	7.94	6.34	7.78	17.50	33	—	—	8.89	19.04
H-C						36	7.49	6.22	7.45	17.70					
Y-C						37	8.12	6.34	8.03	18.09					

[a]Pig weights in kilograms.

Appendix Table 12. Degrees of freedom and mean squares from weighted means analyses comparing the performance of purebred and crossbred dams.

Source of variation	df[a]	Mean square					
		No. born[b]	Pig wt, birth[b]	No. 21 days[c]	Pig wt, 21 days[c]	No. weaned[c]	Pig wt, weaned[c]
Experiment	2 (1)	2.1	1.74**	50.7	244.12**	90.3**	4376.0**
Among pure dams	3	76.8**	1.33**	32.4	3.92	40.3**	1.0
Among cross dams	5	11.6	.51*	8.0	1.61	7.8	10.9
Cross *vs* pure dams	1	39.0*	.13	65.2*	6.99	61.0*	259.1*
Residual	10 (5)	5.5	.13	7.2	1.18	6.6	48.6

[a]Degrees of freedom in parentheses for 21 day traits.

[b]Means for each breed group in each experiment are presented in Table 10.

[c]Means for each breed group in each experiment are presented in Table 11.

*P<.05.

**P<.01.

Appendix Table 13. Average litter size (LSB) and pig weight (PWB) at birth for litters by crossbred dams.

Breed of dam	Reference 13			Reference 17			Reference 18		
	n	LSB	PWB [a]	n	LSB	PWB [a]	n	LSB	PWB [a]
B-La	38	9.60	1.385						
B-D	39	10.20	1.333						
B-H	36	8.90	1.360						
B-L	37	10.10	1.396						
B-Y	33	9.90	1.323						
La-L	38	10.20	1.451						
La-Y	36	9.60	1.354						
D-La	39	10.30	1.117						
D-H	36	8.30	1.446	69	10.02	1.375	62	9.80	1.353
D-L	38	10.10	1.495						
D-Y	36	10.80	1.296	64	10.18	1.278	72	10.22	1.315
H-La	38	10.60	1.368						
H-L	38	11.00	1.436						
H-Y	35	9.70	1.340	66	10.49	1.150	69	10.01	1.286
LB-B	37	8.60	1.488						
LB-D	38	9.60	1.479						
LB-H	33	8.50	1.435						
Pi-La	35	10.00	1.470						
Pi-L	34	9.80	1.510						
Pi-Y	38	8.80	1.364						
L-Y	35	11.00	1.327						
T-B	39	9.30	1.323						
T-La	36	10.50	1.352						
T-D	34	9.60	1.354						
T-H	36	9.60	1.396						
T-LB	38	8.70	1.345						
T-L	37	9.10	1.451						
T-Y	36	10.10	1.307						
L-S									
Y-S									
D-S									
C-Y									
C-H									
C-D									

[a]See Table 2 for abbreviation of breeds.

[b]Weights in kilograms.

Appendix Table 13 (continued). Average litter size (LSB) and pig weight (PWB) at birth for litters by crossbred dams.

Breed of dam	Reference 4 n	4 LSB	4 PWB[b]	Reference 21 n	21 LSB	21 PWB[b]	Reference 14 n	14 LSB	14 PWB[b]
B-La									
B-D									
B-H									
B-L									
B-Y									
La-L									
La-Y									
D-La									
D-H	40	9.57	1.444	30	10.67	1.374			
D-L							17	9.44	1.356
D-Y	37	10.45	1.385	30	9.68	1.403	15	9.71	1.245
H-La									
H-L									
H-Y	29	10.04	1.318	33	10.10	1.415			
LB-B									
LB-D									
LB-H									
Pi-La									
Pi-L									
Pi-Y									
L-Y							16	10.50	1.220
T-B									
T-La									
T-D									
T-H									
T-LB									
T-L									
T-Y									
L-S							17	9.49	1.294
Y-S							19	9.80	1.201
D-S							15	9.75	1.304
C-Y	37	10.92	1.342						
C-H	36	10.35	1.282						
C-D	41	9.31	1.530						

[a]See Table 2 for abbreviations of breeds.

[b]Weights in kilograms.

Appendix Table 13 (continued). Average litter size (LSB) and pig weight (PWB) at birth for litters by crossbred dams.

Breed of dam	Reference					
	5			21		
	n	LSB	PWB[b]	n	LSB	PWB[b]
B-La						
B-D						
B-H						
B-L						
B-Y						
La-L						
La-Y						
D-La						
D-H				28	9.90	1.501
D-L						
D-Y	109	12.27	—	27	9.15	1.418
H-La						
H-L						
H-Y	96	11.63	—	29	9.60	1.337
LB-B						
LB-D						
LB-H						
Pi-La						
Pi-L						
Pi-Y						
L-Y	79	10.73	—			
T-B						
T-La						
T-D						
T-H						
T-LB						
T-L						
T-Y						
L-S						
Y-S						
D-S						
C-Y						
C-H						
C-D						

[a]See Table 2 for abbreviations of breeds.

[b]Weights in kilograms.

Appendix Table 14. Average litter size (N21 and N42) and pig weight (P21 and P42) at 21 and 42 days for litters by crossbred dams.

Breed of dam[a]	Reference									
	13					17				
	n	N21	P21[b]	N42	P42[b]	n	N21	P21[b]	N42	P42[b]
B-La	38	7.70	4.91	—	—					
B-D	39	8.00	4.71	—	—					
B-H	36	7.50	4.87	—	—					
B-L	37	8.70	4.81	—	—					
B-Y	33	8.20	4.87	—	—					
La-L	38	7.80	4.89	—	—					
La-Y	36	8.00	5.13	—	—					
D-La	39	9.00	4.77	—	—					
D-H	36	6.90	4.86	—	—	69	8.45	5.22	8.26	11.45
D-L	38	8.00	5.13	—	—					
D-Y	36	8.50	4.75	—	—	64	8.01	4.86	7.83	11.02
H-La	38	8.50	4.74	—	—					
H-L	38	9.20	4.94	—	—					
H-Y	35	8.10	5.12	—	—	66	8.85	4.82	8.73	10.90
LB-B	37	7.30	5.34	—	—					
LB-D	38	7.90	5.28	—	—					
LB-H	33	7.60	5.37	—	—					
Pi-La	35	8.50	5.39	—	—					
Pi-L	34	8.30	5.36	—	—					
Pi-Y	38	7.70	5.33	—	—					
L-Y	35	9.70	4.94	—	—					
T-B	39	7.50	4.56	—	—					
T-La	36	8.70	4.82	—	—					
T-D	34	7.80	4.76	—	—					
T-H	36	8.50	4.94	—	—					
T-LB	38	7.60	4.88	—	—					
T-L	37	7.90	5.10	—	—					
T-Y	36	8.50	5.11	—	—					
L-S										
Y-S										
D-S										
C-Y										
C-H										
C-D										

[a]See Table 2 for abbreviation of breeds.

[b]Weights in kilograms.

Appendix Table 14 (continued). Average litter size (N21 and N42) and pig weight (P21 and P42) at 21 and 42 days for litters by crossbred dams.

Breed of dam[a]	Reference									
	18					4				
	n	N21	P21[b]	N42	P42[b]	n	N21	P21[b]	N42	P42[b]
B-La										
B-D										
B-H										
B-L										
B-Y										
La-L										
La-Y										
D-La										
D-H	62	—	—	6.80	9.24	40	6.95	6.39	6.89	19.10
D-L										
D-Y	72	—	—	7.50	9.41	37	7.89	6.17	7.83	18.71
H-La										
H-L										
H-Y	69	—	—	7.03	9.59	29	7.94	6.34	7.78	17.50
LB-B										
LB-D										
LB-H										
Pi-La										
Pi-L										
Pi-Y										
L-Y										
T-B										
T-La										
T-D										
T-H										
T-LB										
T-L										
T-Y										
L-S										
Y-S										
D-S						37	8.12	6.34	8.03	18.09
C-Y										
C-H						36	7.49	6.22	7.45	17.70
C-D						41	7.27	6.49	7.13	18.75

[a]See Table 2 for abbreviation of breeds.

[b]Weights in kilograms.

Appendix Table 14 (continued). Average litter size (N21 and N42) and pig weight (P21 and P42) at 21 and 42 days for litters by crossbred dams.

Breed of dam[a]	Reference									
	21					14				
	n	N21	P21[b]	N42	P42[b]	n	N21	P21[b]	N42	P42[b]
B-La										
B-D										
B-H										
B-L										
B-Y										
La-L										
La-Y										
D-La										
D-H	30	—	—	9.15	18.82					
D-L						17	7.86	4.78	7.78	10.03
D-Y	30	—	—	8.37	18.45	15	7.27	4.68	7.01	10.26
H-La										
H-L										
H-Y	33	—	—	8.89	19.04					
LB-B										
LB-D										
LB-H										
Pi-La										
Pi-L										
Pi-Y										
L-Y						16	9.00	4.77	8.97	10.26
T-B										
T-La										
T-D										
T-H										
T-LB										
T-L										
T-Y										
L-S						17	8.05	4.69	7.94	10.47
Y-S						19	6.74	4.76	6.74	10.12
D-S						15	7.08	4.78	7.08	10.85
C-Y										
C-H										
C-D										

[a]See Table 2 for abbreviation of breeds.

[b]Weights in kilograms.

Appendix Table 14 (continued). Average litter size (N21 and N42) and pig weight (P21 and P42) at 21 and 42 days for litters by crossbred dams.

Breed of dam [a]	Reference 5 n	N21	P21 [b]	N42	P42 [b]	Reference 21 n	N21	P21 [b]	N42	P42 [b]
B-La										
B-D										
B-H										
B-L										
B-Y										
La-L										
La-Y										
D-La										
D-H						28	—	—	7.69	19.77
D-L										
D-Y	109	—	—	9.37	—	27	—	—	7.10	19.58
H-La										
H-L										
H-Y	96	—	—	7.64	—	29	—	—	7.44	19.88
LB-B										
LB-D										
LB-H										
Pi-La										
Pi-L										
Pi-Y										
L-Y	79	—	—	8.46	—					
T-B										
T-La										
T-D										
T-H										
T-LB										
T-L										
T-Y										
L-S										
Y-S										
D-S										
C-Y										
C-H										
C-D										

[a]See Table 2 for abbreviaiton of breeds.

[b]Weights in kilograms.

Appendix Table 15. Degrees of freedom and mean squares from weighted means analyses comparing the performance of crossbred dams.

Source of variation	df	Mean square			
		No. born[a]	Pig wt. birth[a]	No., 21 days[b]	Pig wt, 21 days[b]
Experiment	7	63.7*	.39**	45.9	21.83**
Breed of dam	33	15.1	.30**	10.9	1.89**
Residual	14	20.1	.08	22.1	.43

[a]Means for each breed group in each experiment are presented in Appendix Table 13.

[b]Means for each breed group in each experiment are presented in Appendix Table 14.

*P<.05.

**P<.01.

Appendix Table 16. Mean postweaning average daily gain (ADG) and age at 100 kilograms (age) for purebred and crossbred pigs.

Breed group[a]	Reference											
	25			22			14			19		20	
	n	ADG[b]	Age	n	ADG[b]	Age	n	ADG[b]	Age	n	ADG[b]	n	ADG
DxD	183	.702	184.1	121	.690	176.3	61	.656	184.2				
DxH	260	.757	174.9	109	.754	167.4							
DxY	277	.750	174.9	114	.738	166.7	45	.743	170.3				
DxC				176	.726	168.1							
DxL							54	.711	172.9				
DxS							43	.773	163.4				
HxD	211	.740	178.6	86	.729	167.1							
HxH	172	.674	191.7	146	.635	187.6							
HxY	198	.726	178.0	120	.730	168.4							
HxC				120	.682	178.2							
YxD	290	.747	175.9	129	.735	167.1	51	.766	161.7				
YxH	280	.706	182.2	115	.723	169.1							
YxY	240	.674	186.2	130	.696	174.1	50	.672	181.5	24	.64	12	.59
YxC				161	.704	172.5							
YxL							49	.712	172.1				
YxS							43	.734	171.3				
CxD				128	.727	168.5							
CxH				128	.668	181.2							
CxY				112	.702	173.2							
CxC				113	.596	198.4							
LxD							43	.748	162.6				
LxL							63	.656	184.2				
LxY							40	.708	174.0				
LxS							47	.710	170.7				
SxD							45	.749	163.3				
SxL							47	.728	166.4				
SxY							54	.716	171.5				
SxS							52	.678	179.9				
PxP										24	.61	12	.59
PxY										24	.69	12	.64
YxP										24	.70	12	.62

[a]See Table 2 for abbreviation of means.

[b]Kilograms per day.

Appendix Table 17. Mean squares and degrees of freedom for average daily gain (ADG) and age at 100 kilograms (AGE) from the weighted least squares analyses comparing the performances of purebred and crossbred pigs.

Source of variation	df[a]	Mean square	
		ADG	AGE[b]
Experiment	4 (2)	.059	35368.7**
Breed of sire	6 (5)	.177**	8760.5**
Breed of dam	6 (5)	.134**	7216.4**
Purebred *vs* crossbred	1	3.693**	138743.0**
Residual	31 (28)	.025	1102.0

[a]Degrees of freedom in parentheses are for age.

[b]Breed by experiment station means are presented in Appendix Table 16.

**P<.01.

Appendix Table 18. Mean carcass length (Lgt), backfat (BF), and loin-eye area (LEA) for purebred and crossbred pigs in each experiment.

Breed group	Reference											
	25				22				18			
	n	Lgt	BF	LEA	n	Lgt	BF	LEA	n	Lgt	BF	LEA
DxD	43	75.9	3.21	28.9	32	76.7	3.41	31.7	9	79.5	2.96	31.8
DxH	45	77.5	3.02	30.7	24	77.4	3.11	35.7				
DxY	41	77.7	3.10	31.3	36	77.2	3.31	36.2	8	80.2	2.73	35.2
DxC					34	75.7	3.39	34.9				
DxL									12	79.9	3.23	31.4
DxS									10	80.3	3.03	31.1
HxD	42	77.6	2.96	30.8	30	78.2	3.03	33.5				
HxH	46	77.8	2.78	32.3	30	77.5	2.82	36.3				
HxY	41	78.2	2.86	32.4	34	77.6	3.14	36.3				
HxC					37	76.8	3.08	35.6				
YxD	44	77.8	3.31	29.1	30	78.5	3.36	32.4	11	79.0	3.62	28.5
YxH	46	77.7	3.26	29.1	32	78.0	3.26	34.7				
YxY	44	78.4	3.20	30.0	31	77.7	3.44	32.3	6	81.6	3.11	27.8
YxC					28	77.5	3.35	33.5				
YxL									11	79.8	3.71	26.8
YxS									8	79.9	3.24	31.4
CxD					39	76.9	3.39	31.3				
CxH					30	77.2	3.15	34.2				
CxY					36	77.5	3.30	34.2				
CxC					26	76.2	3.22	31.9				
PxP												
PxY												
LxD									8	81.1	3.12	27.7
LxL									12	80.5	3.23	30.1
LxY									9	79.9	3.12	30.4
LxS									9	79.7	3.12	28.1
SxD									10	79.1	3.39	29.8
SxL									10	79.5	3.38	29.1
SxY									11	78.4	3.29	29.1
SxS									6	79.3	3.02	30.9
YxP												

Appendix Table 18 (continued). Mean carcass length (Lgt), backfat (BF), and loin-eye area (LEA) for purebred and crossbred pigs in each experiment.

Breed group	Reference											
	3				19				20			
	n	Lgt	BF	LEA	n	Lgt	BF	LEA	n	Lgt	BF	LEA
DxD	60	74.4	3.98	22.3								
DxH												
DxY	58	75.3	3.96	25.9								
DxC												
DxL												
DxS												
HxD												
HxH												
HxY												
HxC												
YxD	48	74.7	4.30	22.8								
YxH												
YxY	69	76.2	3.82	26.2	24	77.3	3.03	27.4	12	76.5	3.44	
YxC												
YxL												
YxS												
CxD												
CxH												
CxY												
CxC												
PxP					24	74.5	2.81	28.1	12	73.3	3.15	
PxY					24	75.6	2.88	29.9	12	75.1	3.26	
LxD												
LxL												
LxY												
LxS												
SxD												
SxL												
SxY												
SxS												
YxP					24	75.2	3.03	28.1	12	75.5	2.95	

[a]See Table 2 for abbreviation of means.

Appendix Table 19. Degrees of freedom and mean squares for carcass traits from the weighted least squares analyses comparing the performances of purebred and crossbred pigs.

		Mean square		
Source of variation	df	Length	Backfat	Longissimus muscle area
Experiment	4	295.47**	21.11**	2320.90**
Breed of sire	6	40.90**	3.49**	166.42**
Breed of dam	6	45.05**	1.48**	236.41**
Purebred vs crossbred	1	.71	1.52*	78.08
Residual	31	7.42	.33	31.71

[a]Breed by experiment means are presented in Appendix Table 18.
*P<.05.
**P<.01.

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