MATERNAL HETEROSIS FOR DAM PRODUCTIVITY AND POSTWEANING FEEDLOT PERFORMANCE IN SWINE

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CHAPTER I

INTRODUCTION

Crossbreeding is a common and recommended practice in commercial swine production. It has been estimated that about 90% of all swine marketed in the United States today are of crossbred origin. By crossbreeding, swine producers are able to combine the desirable characteristics of different breeds as well as to utilize the genetic phenomena of heterosis.

Crossbred females are recommended in commercial swine production to take advantage of the maternal heterosis of the crossbred dam. However, most commercial swine operations use a crossbred dam in a rotational crossbreeding program. This system maintains only about two-thirds of the heterosis for both individual and maternal performance. Perhaps a specific crossing sequence using a boar of a third breed on a crossbred female would increase overall production efficiency.

Dickerson (1969) states that choice of the most efficient breed for a specific type of production requires reliable estimates of relative performance for the more promising pure breeds, two-breed crosses and three-breed crosses. Several studies have shown there to be important differences for many traits among the most common breeds of swine in the United States. Recent work at the Oklahoma Agricultural Experiment Station (Johnson, Omtvedt and Walters, 1973; Johnson and Omtvedt, 1973) has demonstrated which traits exhibit heterosis from crossing and the relative advantage of two-breed crosses compared to purebreds. In general two-breed cross litters are larger and the crossbred pigs grow faster and reach market weight at an earlier age than purebreds.

However, there is almost a total lack of information evaluating the maternal heterosis of crossbred dams or comparing relative differences of specific three-breed and two-breed crosses. Willham (1968) defined maternal heterosis and designed specific experimental approaches to evaluating the maternal heterosis of the crossbred female. A project was initiated in 1969 at the Oklahoma Agricultural Experiment Station to utilize one of these designs and involved pigs of Duroc, Hampshire and Yorkshire breeding. The objectives of the present study were:

1. To compare the performance of two-breed cross gilts with three-breed cross litters to purebred gilts with two-breed cross litters for ovulation rate, early embryo development and dam productivity through weaning.

2. To evaluate three-breed and two-breed crosses for postweaning feedlot performance to include average daily gain, feed efficiency, daily feed consumption and probe backfat.

CHAPTER II

REVIEW OF LITERATURE

Maternal Influence

Heterosis is defined as the difference between the average performance of a cross between two groups and the average performance of the two parent groups. Willham (1968) defined heterosis in maternal performance as the average performance of progeny from crossbred dams less the average performance of the progeny from parents of the dam. Livestock producers have long recognized the importance of maternal influence on growth of young animals. Recently investigations concerning the maternal influence on traits expressed late in life and the genetic relationships among direct and maternal effects have become of increasing interest.

Cox and Willham (1962) crossfostered 21 Duroc and 12 Hampshire litters and reported that postnatal maternal influences controlled over 20% of the variance in body weight at 21, 42 and 98 days rising to a maximum of 26% at 42 days and declining to 5% at 154 days. They also observed a rather large prenatal by postnatal interaction that became apparent late in the growing period after weaning. This interaction indicated that the performance of two full-sibs, whether raised by their own dam or not, depends partly on the manner of the pen not predictable from the performance of their sibs in other pens.

Ahlschwede and Robison (1971a) crossfostered 62 Duroc and Yorkshire litters and Ahlschwede and Robison (1971b) studied family covariance relationships between 922 Durocs and 1726 Yorkshire pigs and found postnatal maternal variance to range from 13 to 23% of the total variance for weights to 56 days. Important maternal influences on postweaning growth and probe backfat were also observed with maternal sources of variation being larger than direct genetic effects for 140-day weight in both breeds. Negative genetic covariances between direct genetic and maternal genetic effects for weights at birth, 56 days, 140 days and for probe backfat were also found.

Johnson, Omtvedt and Walters (1973) studied the feedlot performance of 941 purebred and crossbred pigs of Duroc, Hampshire and Yorkshire breeding. Reciprocal differences in crosses between Durocs and Hampshires were small and non-significant. However, most reciprocal differences in crosses involving Yorkshires were significant for postweaning growth rate, probe backfat thickness and feed efficiency indicating a difference in the maternal influence of dams of the three breeds for postweaning performance.

These recent studies plus a comprehensive review of the subject by Robison (1972) provide substantial evidence that maternal effects account for a significant portion of the variance for most traits, including those that are manifest rather late in life. Since the role of the dam is so important in swine production, it becomes readily apparent that the maternal influence of crossbred females must be evaluated in order to be able to construct breeding programs that make maximum use of heterosis.

Heterosis: Two-Breed Crosses

In order to compare the performance of specific three-breed and two-breed crosses, it is first necessary to establish which traits have exhibited heterosis in two-breed crosses and the amount of heterosis observed for these traits. With this information one can make relative comparisons of three-breed cross, two-breed cross and purebred swine breeding programs.

Dam Productivity

Most of the results available are based on early investigations with inbred lines and breeding stock typical of that time under management systems quite different from today. Also, many of the results provide data for only one of the parental breeds involved in the cross.

Winters *et al.* (1935) found that two-breed cross litters of the Poland China, Duroc, Chester White and Yorkshire breeds were 0.93 and 0.33 pigs per litter larger than purebred litters at birth and 56 days, respectively. However the survival rate for crossbred pigs from birth to 56 days was 4% less than for purebreds. Lush, Shearer and Culbertson (1939) using double-mated Duroc and Poland sows found a lower percentage of stillborn pigs among crossbreds than among purebreds and observed that crossbred pigs were 2.5% heavier at birth, 10.7% heavier at weaning and had a 15.4% higher survival rate from birth to weaning than did purebred littermates. However, in a review of the early crossbreeding work involving over 50,000 pigs, Carroll and Roberts (1942) reported that litter size and birth weight of crossbred pigs was intermediate to the parental purebred average and that survival rate from birth to weaning for crossbred pigs was equal to the best parent involved in the cross.

Beginning about 1945 much of the swine crossbreeding work involved estimating the combining ability of inbred lines. In crosses among inbred Poland China lines, Dickerson, Lush and Culbertson (1946) found litter size in crosses exceeded that of inbreds by from 0.6 to 1.8 pigs per litter at birth, 24 and 56 days of age. Pig weights were nearly the same at birth and 21 days but crosses exceeded inbreds by 3.4 lbs at 56 days. Chambers and Whatley (1951) found similar results in crosses among inbred Duroc lines. Linecross litters had 0.48, 0.74, and 0.88 more pigs per litter at birth, 21 and 56 days of age, respectively, than inbreds. Linecross litters were also 1.68, 8.76 and 30.21 lbs heavier at birth, 21 and 56 days, respectively, than inbreds. Hetzer, Hankins and Zeller (1951) studied 218 litters representing all reciprocal crosses among 6 inbred lines formed from various single crosses among Landrace, Duroc, Poland, Chester White, Yorkshire and Large Black breeds of swine. Linecrosses had litters with 1.2, 1.7 and 1.7 more pigs per litter than inbreds at 0, 21 and 56 days, respectively. Linecross pigs weighed 0.05 lbs less than inbreds at birth but were 0.3 and 2.6 lbs heavier at 21 and 56 days, respectively. In a more detailed analyses of these same data Hetzer et al. (1961) indicated that specific combining effects, however, were not significant for any of these traits. Studying crosses among inbred lines from various stations involved in the inbreeding project of the Regional Swine Breeding Laboratory, Dickerson et al. (1954) found that the mean superiority of line crosses over inbreds was 0.56, 1.01 and 1.13 pigs per litter for litter size at 0, 21 and 56 days, respectively, and -.06, -.17 and -.22 lbs for pig weight at 0, 21 and 56 days, respectively. O'Ferrall et al. (1968) made further crosses among inbred lines of Landrace, Duroc, Poland, Chester White and Large Black breeding. Crossbred litters (327 litters) were produced from inbred dams mated to a non-inbred boar of another breed while 229 inbred litters were produced.' There was no difference in the litter size at birth of linecrosses and inbreds but pigs from crossbred litters had an 11.6% higher survival rate to 56 days than inbreds. Crossbred pigs weighed 0.07, 0.67 and 3.31 lbs more at 0, 21 and 56 days of age.

In all of the combining ability studies with inbred lines the inbreeding of the dams ranged from 21 to 45 percent. In a review of this work, Craft (1953) concluded that lines and breeds differ in their specific combining ability. Crosses of two lines showed increases ranging from 0 to 20% in number farrowed and from 6 to 40% in numbers weaned as compared with litters of parent lines. Also crosses of lines from different breeds generally have shown considerably more hybrid vigor than linecrosses within a breed.

Research results of crossing outbred individuals of two different breeds are in general difficult to interpret due to lack of sufficient numbers involved or inadequate controls for proper comparisons. Results of these studies have ranged from a reduction in litter size for crossbreds compared to purebreds (Robison, 1948; Cunningham, 1967) to no difference in litter size (Bradford Chapman and Grummer, 1953) to an 11% increase in litter size at birth (Smith, Moorman and McLaren, 1960; Smith and McLaren, 1967). These studies agree, however, that survival rates of crossbred pigs from birth to weaning are higher than for purebred pigs resulting in crossbred litters being larger and heavier at weaning than purebred litters.

Results from 128 purebred and 241 two-breed cross litters of Duroc, Hampshire and Yorkshire breeding from the first phase of the Oklahoma swine crossbreeding study indicate that the primary advantage of two-breed crosses is a greater early embryonic survival rate and a greater survival rate of pigs from birth to weaning (Johnson and Omtvedt, 1973). A total of 39 purebred gilts with purebred litters and 80 purebred gilts with crossbred litters were slaughtered 30-days postbreeding while 89 purebred and 161 crossbred litters were produced. Gilts with crossbred litters averaged 6.3% more embryos at 30-days postbreeding, 8.7% more pigs at farrowing and 17.9% more pigs at weaning than gilts with purebred litters. The response to crossing also appeared to depend on the breeds involved as survival rate of crossbred pigs compared to purebred pigs was 7.6% higher for Duroc dams and 17.9% higher for Hampshire dams compared to no difference for Yorkshire dams. There was little evidence for differences in average pig weight per litter between purebreds and crossbreds.

Feedlot Performance

The results of crossbreeding studies involving postweaning performance are quite variable. Winters *et al*. (1935) and Lush *et al*. (1939) found that two-breed crosses gained 0.09 to 0.12 lbs per day faster and required about 12 lbs less feed per 100 lbs gain than purebreds. Carroll and Roberts (1942) however concluded crossbreds gained about the same and were as efficient as the best parent breed making up the cross. Dickerson *et al*. (1946) also found inbred Poland China linecrosses to be 25 lbs heavier than inbreds at 154 days of age but observed no significant heterosis for feed efficiency. However, Robison (1948) compared two-breed crosses to purebreds and Whatley, Chambers and Stephens (1954) compared linecrosses to outbred Durocs and found that crossbred pigs gained slightly less per day than did straightbreds.

In general crosses among inbred lines have been found to grow from

4 to 20% faster and to be from 1 to 6% more efficient in feed utilization than inbreds (Hetzer et al., 1951; Gregory and Dickerson, 1952; England and Winters, 1953). However, Bradford, Chapman and Grummer (1958) and Hetzer et al. (1961) found an almost total absence of specific combining effects for postweaning growth among crosses of inbred lines.

In general breed crosses involving outbred pigs of two breeds tend to gain more rapidly than purebreds but usually show little or no significant heterosis for feed efficiency. Tucker, Dickerson and Lasley (1952) found that crosses of Landrace with Durocs, Poland Chinas and Hampshires gained 7% faster and reached final weight 10 days earlier, but consumed 6% more feed daily and were no more efficient than parental breeds. In a study involving 2827 litters from 628 Wisconsin farms, Bradford et al. (1953) found virtually no difference in growth rate between purebreds and two-breed crosses. However, Gaines and Hazel (1957) found that Landrace-Poland China crossbreds were superior in growth rate to pigs of the two pure breeds and Whatley, Wilson and Omtvedt (1960) found that Duroc-Beltsville crossbreds gained significantly faster than purebreds but had almost no difference in feed efficiency. Significant heterosis for postweaning growth rate in crosses involving Durocs, Hampshires, Landrace, Poland China and Yorkshires was also found by Louca and Robison (1967) and Smith and McLaren (1967).

Kuhlers, Chapman and First (1972) found that crossbred Poland-Yorkshire pigs gained significantly faster than purebreds from 56 days of age to 200 lbs but no significant differences in daily feed intake or in feed efficiency were observed. Lean et al. (1972), utilizing 338 purebred and two-breed crosses of Pietrain and Landrace breeding, found significant heterosis for growth rate but that crossbred feed efficiency was intermediate to purebreds. Johnson et al. (1973) also observed significant heterosis for postweaning growth rate (10.2%) and age at 220 lbs. (5.2%) in 941 barrows and gilts of Duroc, Hampshire and Yorkshire breeding. No heterosis was observed for feed efficiency; however, crossbreds consumed 5.9% more feed daily than purebreds.

Three-Breed vs. Two-Breed Crosses

Since primary emphasis was placed on estimating heterosis in most of the previous crossbreeding studies, the maternal heterosis of crossbred females or the specific combining ability of breeds in three-breed crosses were seldom considered. Few good studies designed specifically with this objective have been reported.

One of the first studies comparing the added advantage of using a crossbred female in three-breed crosses to two-breed crosses among purebreds was done by Winters et al. (1935). They found that three-breed cross litters involving Durocs, Poland Chinas, Chester Whites and Yorkshires had litters with 0.7 more pigs at birth and 1.7 more pigs at weaning than two-breed cross litters. There was virtually no difference in pig weights at birth or 56 days or in average postweaning daily gain or feed efficiency between two-breed and three-breed crosses. In studies with small numbers and inadequate controls Lush et al. (1939) and Robison (1948) found crossbred females of Poland China, Duroc and Yorkshire breeding when mated to a boar of a third breed had litters with about 1.0 more pigs per litter than purebreds, backcross and two-breed cross litters.

Chambers and Whatley (1951) compared three-line crosses among inbred

Duroc lines to two-line crosses and to outbred Durocs. Three-line cross litters were significantly larger and heavier at birth (1.36 pigs and 2.94 lbs), at 21 days (1.15 pigs and 9.55 lbs) at 56 days (1.20 pigs and 29.68 lbs) and at 180 days (1.66 pigs and 298 lbs) than two-line crosses. Although three-line crosses consistently exceeded outbred Durocs for these traits, only differences in number of pigs per litter at birth (1.17 pigs) and litter birth weight (2.75 lbs) were significant.

Very little information is available on the heterosis of a crossbred female for ovulation rate or for embryo development early in the gestation period. Squires, Dickerson and Mayer (1952) slaughtered 278 purebred and crossbred gilts and 72 sows from inbred Poland China and Hampshire lines and outbred Durocs. One-half of the females were slaughtered at the end of estrus and ovulation points counted. The remainder were slaughtered 25-days postbreeding. Inbred lines did not differ significantly among themselves or from Durocs in ovulation rate or number of embryos recovered at 25-days. Crossbred females, however, had 1.19 ($P < .01$) more ova and 1.85 ($P < .01$) more pigs per litter than purebreds.

Robison (1972) cited work done by Rio (1957) who reported that Yorkshire-Hampshire crosses revealed no heterosis for number of eggs ovulated while the reciprocal cross showed significant negative heterosis. Further crisscrossing and backcrossing these breeds resulted in gilts that expressed alternate low and high heterosis suggesting an interaction exists between the Hampshire chromosomes and the Yorkshire cytoplasm. Gilts of Y(HxY) breeding had 3.78 more eggs than those of H(HxY) breeding. Pani _et al._ (1963) found Landrace-Poland crossbred sows from Poland dams to have larger litters and heavier pigs than crossbred sows from Landrace dams although the differences were not significant. Numbers involved in these studies were small but it is evident that the area of maternal effects due to cytoplasmic inheritance needs further examination.

Observations on 2827 litters on 628 Wisconsin forms led Bradford *et al.* (1953) to conclude that litters from crossbred dams had a lower mortality rate than litters from purebred dams, but that crossbred females had no other marked advantage over purebreds. However, England and Winters (1953) and Whatley *et al.* (1954) found linecross gilts farrowed 6 to 16% larger litters and weaned 2 to 13% more pigs per litter than inbred lines and outbred Durocs. Gaines (1957) also found Landrace-Poland China sows to be superior to purebred sows in litter size at all ages.

Magee and Hazel (1959) analyzed 154-day weight of 2137 pigs produced by mating 12 inbred lines of Poland China swine. Each pig had an inbred sire and a crossline mother. Differences in general combining ability were highly significant and comprised the most important genetic source of variation but accounted for only 4% of the total variation. General maternal effects were small.

Smith and McLaren (1967) obtained data from 531 litters in each of two seasons of two years. Purebred, two-breed, three-breed and four-breed cross litters of Duroc, Hampshire, Landrace and Poland breeding were produced. However, within any season specific comparisons involved few numbers and consequently meaningful conclusions are difficult to make. In general there was little difference in litter size at birth between two, and three-breed crosses; however, at 56-days the three-breed crosses had about 1.0 more pigs per litter than two-breed crosses.

Three-way cross pigs were somewhat heavier at birth but there appeared to be no difference in postweaning growth rate or probe backfat thickness of two and three-breed crosses.

Curran et al. (1972) studied growth rate and feed consumption in two trials with a total of 384 pigs. In Trial 1, offspring of Large White boars mated to Landrace-Pietrain cross females were compared to purebred Landrace. Three-breed cross pigs gained 0.11 lbs more per day from weaning to 200 lbs, were 5 days younger at 200 lbs, and required 0.27 lbs less feed per pound of gain than purebred Landrace ($P < .01$). In Trial 2, three-way cross pigs were produced by mating Large White boars to Landrace-Pietrain sows, Hampshire-Pietrain boars to Large White sows and Hampshire-Pietrain boars to Landrace sows and the performance of all crossbreds was compared to purebred Landrace performance. All three crossbred types grew significantly faster and consumed less feed per pound of gain than Landrace. Crossbreds did not differ significantly from each other in efficiency but LW(LxP) pigs grew more rapidly than (HxP)L pigs.

Summary

This review indicates that the primary advantage of two-breed crosses compared to purebreds is in increased litter size at birth, a greater survival rate of crossbred pigs and in increased postweaning growth rate. However, differences in preweaning pig weights or efficiency of feed utilization have been relatively small. There are some indications that use of a crossbred female should result in litters larger than two-breed cross litters primarily due to the hybrid vigor of the crossbred female. There is essentially no information available with present breeds under present-day confinement management systems on how to best utilize crossbred females in specific crossing sequences to maximize production. Data on ovulation rates of crossbred females and differences in intrauterine environment provided by straightbred and crossbred females and comparisons of specific two-breed and three-breed crosses for measures of postweaning feedlot performance are also lacking. Consequently, this study was conducted to provide some information on these questions for three of the more popular swine breeds in the United States, the Duroc, Hampshire and Yorkshire breeds.

CHAPTER III

MATERIALS AND METHODS

This study involves the productivity of 385 purebred and two-breed cross gilts of Duroc (D), Hampshire (H) and Yorkshire (Y) breeding. Of these gilts, 193 were slaughtered 30-days postbreeding and 192 were carried full term and farrowed. Of the purebred gilts with two-breed cross litters, 87 were slaughtered and 94 farrowed and of the two-breed cross gilts with three-breed cross litters 106 were slaughtered and 98 were farrowed. A total of 456 two-breed and 539 three-breed cross pigs were evaluated for postweaning feedlot performance. Abbreviations will be used to designate the specific crossbred breeding groups. In all cases the letter designating sire breed will be first and letters designating the dam breeding last. For example, the mating of a Duroc boar to a Hampshire-Yorkshire female will be abbreviated D(HxY) and the mating of a Duroc boar to a Yorkshire-Hampshire female will be D(YxH).

The data comes from the second phase of the Oklahoma swine crossbreeding project (Project 1444) conducted at the Ft. Reno Experiment Station. The overall objectives of the project were 1) to evaluate the purebred performance and the combining ability of the three breeds of swine in two-breed and in three-breed crosses; and 2) to investigate the importance of maternal influence in terms of crossbred sow productivity and pig performance.

The seedstock for the project were maintained in three purebred herds at Stillwater. Foundation Duroc and Yorkshire herds were assembled in 1969 by sampling boars and gilts from several purebred herds. The Hampshire herd was formed by purchasing boars from several sources and mating them to females from the existing OK 14 purebred research herd. Each foundation herd consists of about five boars and 30 sows and is maintained on a twice-a-year confinement farrowing system. Each year new boars are introduced into each herd in order to maintain a broad genetic base. Replacement gilts are selected from within the herd. Boars and gilts are selected primarily on growth rate, probe backfat thickness and soundness.

In Phase I of this project purebreds from the seedstock herds were mated in all possible combinations to produce purebred and two-breed cross litters. Approximately 20 litters of each of the nine breeding groups were produced at Ft. Reno in the 1971 spring and fall farrowing seasons. Each season litters were produced by mating each of approximately six boars of each breed to two gilts of each breed. A random sample of gilts of each of the nine breeding groups were saved each season and mated to boars of the other breeds. This mating structure constitutes Phase II and the pigs produced in 1972 spring and fall farrowing seasons from these matings constitute the body of data for the present study.

The general design of Phase II of the experiment is illustrated in Figure 1. Approximately six purebred boars of each breed that were produced in the Stillwater seedstock herds were used to produce the two-breed and three-breed crosses in each season. The basic mating scheme used each season was to mate each boar to approximately 12 gilts (three of each breed type not represented in the boar). At the time of breed-

Boars	Gilts		Mating[a] Type	Slaughter Postbreeding	Farrow
6 Duroc	18 Hamp	______	DxH	8	10
	18 York	______	DxY	8	10
	18 HxY	______	D(HxY)	8	10
	18 YxH	______	D(YxH)	8	10
6 Hamp	18 Duroc	______	HxD	8	10
	18 York	______	HxY	8	10
	18 DxY	______	H(DxY)	8	10
	18 YxD	______	H(YxD)	8	10
6 York	18 Duroc	______	YxD	8	10
	18 Hamp	______	YxH	8	10
	18 DxH	______	Y(DxH)	8	10
	18 HxD	______	Y(HxD)	8	10
18	216			96	120

[a]First letter designates breeding of sire and second breeding of dam; D = Duroc, H = Hampshire and Y = Yorkshire.

Figure 1. Phase II Mating Scheme for Each Replication in the Oklahoma Swine Crossbreeding Project

ing, two gilts from each mating type for each boar were randomly selected to be carried full term to farrowing and the remaining gilts were designated for slaughter 30-days postbreeding to evaluate ovulation rates and early embryo development. All litters were farrowed and raised in confinement with their dams until weaned at 42 days of age. The pigs were placed by breed group on a postweaning feedlot performance test and pen feed efficiency and individual performance measured until they reached 220 pounds. The number of sires used of each breed, number of gilts of each breeding group slaughtered and farrowed and the number of pigs of each breeding group evaluated for postweaning feedlot performance is shown in Table I. It will be noted from this table that more boars and gilts were used each season than planned for by the design. A few boars produced litters only from gilts that were slaughtered, however, all boars that produced litters at farrowing also produced litters from slaughtered gilts. The number of gilts farrowed each season was approximately as designed and all extra gilts mated were slaughtered.

Husbandry of Animals and Data Collection

Estrus was detected with the assistance of a teaser boar and hand matings were used in each season. Physiological age of the gilts was not determined, however all were at least 220 days of age at the beginning of the breeding season and most were thought to be in their second or third estrus cycle at the time of first exposure to a boar. The gilts were limit fed throughout gestation in dry lots equipped with individual feeding stalls in groups of 16 head per lot. Approximately 30-days postbreeding the gilts designated for slaughter were slaughtered on a weekly basis and the entire reproductive tract recovered. The

TABLE I

TOTAL NUMBER OF SIRES, NUMBER OF GILTS SLAUGHTERED 30-DAYS POSTBREEDING, NUMBER OF GILTS FARROWED AND NUMBER OF PIGS EVALUATED FOR POSTWEANING FEEDLOT PERFORMANCE FOR EACH BREED GROUP

Breed of Sire	Number of Sires[a]	Breeding Group[b]	Number of Gilts Slaughtered 30-Days Postbreeding	Number of Gilts Farrowed	Number of Pigs Evaluated, Feedlot Performance
		DxH	14	15	72
Duroc	13(11)	DxY	16	13	67
		D(HxY)	12	15	82
		D(YxH)	23	17	98
		HxD	12	17	77
Hampshire	14(11)	HxY	9	16	85
		H(DxY)	18	18	81
		H(YxD)	20	15	82
		YxD	19	18	94
Yorkshire	16(12)	YxH	17	15	61
		Y(DxH)	21	16	93
		Y(HxD)	12	17	103
Two-Breed Crosses			87	94	456
Three-Breed Crosses			106	98	539
Total			193	192	995

[a]First number designates the number of sires that were mated to gilts slaughtered and second the number of sires of each breed that produced a litter.

[b]First letter designates the breed of sire and second the breeding of the dam.

ovaries were removed and the number of corpora lutea counted. The embryos were removed, counted and crown-rump measurements made while the embryos were still enclosed in the amnion. Measurements analyzed on gilts slaughtered 30-days postbreeding were number of corpora lutea, number of embryos, average embryo length per litter in millimeters and the percentage of corpora lutea existing as live embryos.

The gilts that were farrowed were brought to the farrowing barn 110 days postbreeding and farrowed in crates. They were moved with their litters to a nursery barn 3 to 7 days after farrowing. Gilts and litters were maintained in the nursery, one litter per pen, until the pigs were weaned at 42 days of age. The pigs were given free access to creep feed and all male pigs were castrated after 21-day weights were taken. The data collected on pigs and litters from birth to weaning included number of pigs per litter and individual pig weights at birth, 21 and 42 days. Data analyzed for this period were litter size, total litter weight and average pig weight per litter at each age. Survival rate, expressed as the percentage of pigs born per litter that were weaned, was also analyzed.

The sows were removed from their litters when the pigs reached 42-days of age. Each litter remained in its pen in the nursery for two more weeks and then the pigs were moved to the confinement finishing floor and allotted by breed group in groups of about 15 pigs per pen. The pigs were given a one-week adjustment period in the finishing barn before being weighed on test. The pigs were self-fed a 16% protein milo-soybean meal ration from nine weeks of age to 220 pounds. As they reached 220 lbs the pigs were weighed off test on a weekly basis and all gilts were probed for backfat thickness.

Postweaning feedlot performance data analyzed was average daily gain from nine weeks of age to 220 lbs, age at 220 lbs, pen feed efficiency expressed in terms of pounds of gain per pound of feed and pen average daily pounds of feed consumed per pig. Actual off test weights and ages were adjusted to a 220 lb live weight basis with an additive adjustment factor of two pounds of gain per day. (Conversion factors approved by National Association of Swine Records, Jan. 1, 1970). Probed backfat thickness of the gilts was measured approximately 4 cm from the midline at the area of the first rib, last rib and last lumbar vertebrae and the average of the three probes was analyzed. The average probe was adjusted to a 220 lb live weight basis with an adjustment factor of 0.004 in per pound live weight.

Only litters meeting the arbitrary standard of at least one live pig at farrowing, no unusual environmental conditions and no serious parturition complications, serious illness, disease or injury of the dam prior to weaning her litter were included in the analyses of dam productivity from birth to weaning. Approximately two-thirds of the way through the postweaning feeding period in the 1972 fall season, a disease thought to be Salmonellosis but of uncertain diagnosis struck in the finishing barn. Pigs that were afflicted lost weight or did not gain at all for several weeks. Each breed group was affected in approximately equal numbers. The postweaning performance for these pigs (approximately 75 pigs) were not included in the analyses. The pen feed efficiency for four pens was also deleted from analyses. It is not felt that this biased the results in any manner.

Statistical Treatment of the Data

Number of Corpora Lutea Per Gilt

The number of ovulations per gilt was assumed not to depend on the sire or breed of sire to which she was mated. The model assumed for this trait was:

$$Y_{ijk} = \mu + R_i + B_j + (RB)_{ij} + e_{ijk}$$

where Y_{ijk} represents the number of corpora lutea for the kth gilt of the jth breed group and the ith repetition (season), R_i and B_j are fixed cross classified effects that represent season (i = 1 or 2) and breeding of gilt (j = 1 to 6), $(RB)_{ij}$ is the season by breed of gilt interaction and e_{ijk} is a random variable assumed to be independently, normally distributed with mean 0 and variance σ^2. Constants for the effects in the model were estimated by least squares and specific comparisons of interest were made by linear functions of least squares constants. The standard errors of specific comparisons were estimated by summing the appropriate elements of the $(X'X)^{-1}$ matrix and multiplying times $\hat{\sigma}^2$, the error mean square of the analysis of variance.

Litter Traits of Gilts Slaughtered and Farrowed

For all other 30-day postbreeding traits and litter traits from birth to weaning, the mating scheme shown in Figure 1 involved the mating of sires of each breed to gilts of breeding not represented in the sire. This mating scheme allowed the variance components for the random effects of sires and sires by breeding of dam interaction to be evaluated. The full model assumed for each of these traits was:

$$Y_{ijklm} = \mu+R_i+A_j+(RA)_{ij}+s_{k(j)}+B_{l(j)}+(sB)_{kl(j)}+(RB)_{il(j)}+e_{ijklm}.$$

In this model R_i, A_j and $(RA)_{ij}$ are fixed effects representing season ($i = 1,2$) breed of sire ($j = 1,2,3$) and their interaction, respectively, $s_{k(j)}$ is the random effect of sires nested within breed of sire, $B_{l(j)}$ is the nested fixed effect of breeding of dam within the jth breed of sire ($l = 1$ to 4), $(sB)_{kl(j)}$ is the random effect representing the interaction of the kth sire with the lth breed of dam within the jth breed of sire, $(RB)_{il(j)}$ is the fixed interaction of the ith season and lth breed of dam within the jth breed of sire and e_{ijklm} is the random normal deviate that represents the failure of the other effects in the model to predict Y_{ijklm} the observed value for any trait. The $s_{k(j)}$, $(sB)_{kl(j)}$ and e_{ijklm} are random variables assumed to have zero mean. The e_{ijklm}' are assumed independent and normally distributed with variance σ^2; the e_{ijklm} are assumed independent of the $s_{k(j)}$ and the $sB_{kl(j)}$; the $s_{k(j)}$ are assumed independent and normally distributed with variance σ_s^2 and are assumed independent of the $(sB)_{kl(j)}$; the $(sB)_{kl(j)}$ are assumed normally distributed with variance $\frac{3}{4}\sigma_{sb}^2$ and:

$$E[(sB)_{kl(j)}\ (sB)_{kl'(j)}] = -\tfrac{1}{4}\sigma_{sb}^2 \text{ if } l \neq l',$$

$$E[(sB)_{kl(j)}\ (sB)_{k'l'(j')} = 0 \text{ if } j \neq j' \text{ or } k \neq k',$$

$\sum_{\ell}(sB)_{kl(j)} = 0$ for all k and j, where E is the expected operator. This model and associated assumptions are an expansion of the two-way classification model with interaction and with fixed and random effects as given by Graybill (1961).

This is a complex mixed model and would be desirable to simplify, if possible. Because of unequal subclass numbers and missing cells in some sire by breed of dam subclasses, however, it was impossible to fit the full model and the data had to be broken down into smaller subsets of data to test certain hypotheses. Six data subsets were formed, each consisting of the observations for a breed of sire by season subclass. Within each data subset the mixed linear model

$$Y_{ijk} = \mu + s_i + B_j + (sB)_{ij} + e_{ijk}$$

was fit with the effects and assumptions defined above. The sums of squares derived from least squares procedures were pooled over the six data sets and from these pooled sums of squares the hypotheses that $\sigma^2_{sb} = 0$ was tested. The reduced X'X matrix for each of these models was not of full rank and therefore the only hypotheses that can be validly tested is the null hypothesis that σ^2_{sb} equals zero. The error sum of squares from an analysis of variance for each of these data subsets is the pooled within sire-breed of dam subclass sum of squares and is the residual sum of squares due to fitting the full model. The interaction sum of squares is the difference in residual sum of squares due to the reduced (no interaction) model minus the residual sum of squares due to fitting the full model. The ratio of these mean squares has a central F distribution under normal theory if σ^2_{sb} equals zero (Graybill, 1961). Also, each of these sums of squares when divided by their appropriate degrees of freedom and variance can be shown to have a chi-square distribution and assuming independence of these sums of squares from each data set the ratio of the pooled mean squares also has a central F distribution if σ^2_{sb} equals zero.

As will be discussed later, sire by breeding of dam interactions within breed of sire were found to be nonsignificant for all traits. The six subsets of data were then combined and the full model as described above was fit but the $(sB)_{kl(j)}$ random effect was deleted from the model. All other effects and assumptions were as defined above. From these analyses the null hypothesis that σ_s^2 equals zero was tested and found to be non-significant for all traits. At the same time the interactions of season by breed of sire, $(RA)_{ij}$, and season by breeding of dam within sire breed were evaluated. Mean squares for these effects (obtained by least squares procedures) were generally smaller than the error mean square and thus interactions were assumed non-existent.

From these analyses it was concluded that the model that best described these data was

$$Y_{ijkl} = \mu + R_i + A_j + B_{k(j)} + e_{ijkl}$$

with all effects as defined above. Constants for each effect were again obtained by least squares and linear functions and standard errors of linear functions calculated as described for the trait number of corpora lutea. From Figure 1 it can be seen that breed of dam is not really nested within breed of sire and that one degree of freedom exists for evaluating breed of sire by breed of dam interaction. However, since this interaction can be estimated only for breed of sire and purebred dams and all comparisons of interest in this study are made within breed of sire, it was decided to do the within breed of sire analysis.

Since all gilts were not slaughtered exactly 30-days postbreeding, the observation for each gilt for average embryo length per litter was adjusted to 30 days of age before being subjected to the above analyses. An adjustment factor was obtained from fitting the following model:

$$Y_{ij} = \mu + G_i + bx_{ij} + e_{ij}$$

where

Y_{ij} is the observed average embryo length per litter;

μ is a constant;

G_i is the ith breed group constant (i = 1 to 12);

x_{ij} is the actual days pregnant for the jth gilt of the ith breed group;

b is the regression coefficient; and

e_{ij} are unobserved normal variables that are independent with means zero and variances σ^2.

The quadratic regression coefficient was also estimated but it was very small and non-significant and not used in the adjustment.

Feedlot Performance

Since the pigs were fed in pens and feed efficiency and average daily feed consumption were measured on a pen basis, the individual pens were the experimental unit for analyses of these data. The model assumed was:

$$Y_{ijkl} = \mu + R_i + A_j + (RA)_{ij} + B_{k(j)} + (RB)_{ik(j)} + e_{ijkl}$$

where Y_{ijkl} is the response of the lth pen from the kth breed of dam in the jth breed of sire and ith season. Effects of the model are as defined above and estimates of constants, linear functions and standard errors were made by least squares procedures as defined above for other traits.

The traits of average daily gain, age at 220 lbs and probe backfat thickness of gilts were first subjected to the same analyses described earlier to test the importance of sire by breed of dam interaction. Results of these analyses suggest this source of variation to be very small if it exists at all. These traits are moderately heritable and therefore sire and dam variance components are greater than zero. These variance components as well as the within litter variance become a part of variances of breed group means and estimates of maternal heterosis. Attempts at fitting a full model by least squares with the effects of season, breed of sire, sires within breed of sire, breeding of dam within breed of sire and dams within sire and all possible interactions resulted in an input matrix too large to be handled by available computer facilities. When this model was fit within each season the missing cells in sire-breed of dam subclasses resulted in an X'X matrix that was not of full rank. A generalized inverse and solution to the system of equations was obtained but exact tests of significance for effects in the model could not be made because of the unbalanced data. Least squares estimates of maternal heterosis could be obtained but the variance of these estimates was difficult to obtain.

Therefore, breed group means were obtained in the following manner. Let Y_{ijk} represent the observation on the kth pig of the jth litter from the ith sire and

$$Y_{ijk} = \mu_p + s_i + d_{ij} + e_{ijk}$$

where μ_p is the true mean for the pth breed group (p = 1 to 12). The s_i, d_{ij} and e_{ijk} are random variables with mean 0 and variance σ_s^2, σ_d^2 and σ^2, respectively. These random variables are also assumed to be uncorrelated. Assuming this model litter means, $\bar{Y}_{ij.}$, were obtained and averaged to obtain sire means, $\bar{Y}_{i..}$, which were averaged, $\bar{Y}...$, to estimate μ_p. Under this model these means have the following variances:

$$V(\bar{Y}_{ij.}) = \sigma_s^2 + \sigma_d^2 + \sigma_e^2/n_{ij}$$

$$V(\bar{Y}_{i..}) = \sigma_s^2 + \sigma_d^2/n_i + \sigma_e^2(\sum_j \frac{1}{n_{ij}})$$

$$V(\bar{Y}\cdots) = \sigma_s^2/s + \sigma_d^2 \; (\sum_i \frac{1}{n_i}) + \sigma_e^2 \; (\sum_i \sum_j \frac{1}{n_{ij}})$$

where n_{ij} is the number of pigs in the jth litter of the ith sire, n_i is the number of dams mated to the ith sire and s is the number of sires with litters in the pth breed group. Estimates of these variances can then be found simply by replacing the variance components with their estimates. Estimates of maternal heterosis are then obtained simply by taking the proper linear function of the estimates of the breed group means and estimates of variances of these estimates are found by replacing the estimates of the variance components in the above formulas. Generally each sire of a breed produced litters from each breeding of dam mated to that breed of sire. When this happens sire effects are removed from estimates of maternal heterosis and estimates of variances of maternal heterosis involve only $\hat{\sigma}_d^2$ and $\hat{\sigma}^2$. However, in some instances sire-breed of dam subclasses were empty thus $\hat{\sigma}_s^2$ also is a part of some estimates of variances of maternal heterosis.

Estimates of variance components were obtained by assuming a nested design, and finding the reduction in sum of squares for the effects of season, breed of sire in season, sires in breed of sire, dams in sires and pigs in dams. Expected values of mean squares were computed assuming an all random effects model and mean squares were equated to expected values and solved for estimates of variance components. Estimates of breed group means and maternal heterosis obtained in this manner have the property of being unbiased and estimates of variances are also unbiased. These statistics are not Best Linear Unbiased Estimates which would be difficult to obtain for these traits.

Statistics were computed with the Statistical Analysis System computer program of Barr and Goodnight (1971).

CHAPTER IV

RESULTS AND DISCUSSION

Theoretical Considerations

The following discussion is taken directly from information presented by Willham (1968) and Dickerson (1970). This information is included here because it is pertinent in making genetic interpretations of the results presented.

The primary interest in this study is the evaluation of the maternal heterosis expressed by the crossbred female and the comparison of two-breed and three-breed crosses. The basic problem in estimating maternal heterosis is that the expression of maternal performance is measured in offspring values and involves the confounding of maternal performance with the genes of the dam transmitted to the offspring. To separate maternal from genetic influence contributed by the dam to the offspring and consequently allow an estimate of maternal heterosis involves the production of comparable progeny from crossbred and straightbred gilts.

A model depicting the phenotypic value of a trait is

$$P = S + D + SD + E$$

where P is the phenotypic value as a deviation from the mean, S is the sire effect, D is the dam effect, SD is the interaction of the sire and the dam and E is the environmental deviation. If it is assumed that this phenotypic value is influenced by the maternal performance of the dam and D is the sum of the genetic contribution g_d and a maternal contribution m_d, then

$$P = g_s + g_d + m_d + gg_{sd} + gm_{sd} + e$$

where g_s is the genetic contribution of the sire, gg_{sd} is the interaction of the genetic contribution of the sire and the genetic contribution of the dam and gm_{sd} is the interaction of the genetic contribution of the sire and the maternal contribution of the dam.

Willham (1968) used this model to depict the phenotypic value of two-breed and three-breed crosses and derived estimates of maternal heterosis from these phenotypic values. He also gave the assumptions necessary for these estimates to be unbiased. These models are used here to illustrate how maternal heterosis was estimated in the present study. A specific example is given for estimating the maternal heterosis of a Duroc-Yorkshire crossbred gilt and the assumptions necessary for this estimate to be unbiased.

The phenotypic value of a cross between a Hampshire boar and a Duroc gilt is:

$$P_{HH \cdot DD} = g_{HH} + g_{DD} + m_{DD} + gg_{HHDD} + gm_{HHDD} + e$$

where $P_{HH \cdot DD}$ denotes the phenotypic value of the cross, g_{HH} is the genetic effect of Hampshire boars, g_{DD} is the genetic effect of Duroc gilts, gg_{HHDD} is the interaction of the genetic effect of Hampshire boars and Duroc gilts and gm_{HHDD} is the interaction of the genetic effect of Hampshire boars and the maternal effect of Duroc gilts. In the same notation the phenotypic value of a cross between a Hampshire boar and a Yorkshire gilt is:

$$P_{HH \cdot YY} = g_{HH} + g_{YY} + m_{YY} + gg_{HHYY} + gm_{HHYY} + e.$$

A three-way cross phenotypic value for a DxY crossbred female mated to a Hampshire boar is:

$$P_{HH \cdot DY} = g_{HH} + g_{DY} + m_{DY} + gg_{HHDY} + gm_{HHDY} + e$$

and the three-way cross of a Hampshire boar mated to a YxD gilt is:

$$P_{HH \cdot YD} = g_{HH} + g_{YD} + m_{YD} + gg_{HHYD} + gm_{YD} + e.$$

An estimate of the maternal heterosis of the Duroc-Yorkshire crossbred female is:

$$\tfrac{1}{2}(P_{HH \cdot DY} + P_{HH \cdot YD} - P_{HH \cdot DD} - P_{HH \cdot YY}) .$$

This quantity equals

$$\tfrac{1}{2}(g_{HH} + g_{DY} + m_{DY} + gg_{HHDY} + gm_{HHDY} + e + g_{HH} + g_{YD} + m_{YD} + gg_{HHYD}$$

$$+ gm_{HHYD} + e - g_{HH} - g_{DD} - m_{DD} - gg_{HHDD} - gm_{HHDD} - e - g_{HH} - g_{YY} - m_{YY}$$

$$- gg_{HHYY} - gm_{HHYY} - e).$$

However for this comparison to equal $\tfrac{1}{2}(m_{DY} + m_{YD} - m_{DD} - m_{YY})$ the following assumptions are made.

1. There is no important non-allelic interaction in the crossbred DxY or YxD gamete compared with the straightbred gametes, or $g_{DY} = g_{YD} = \tfrac{1}{2}(g_{DD} + g_{YY})$.

2. The specific combining ability of a triple cross is simply the average of the two single cross combining abilities, or $gg_{HHDY} = gg_{HHYD} = \tfrac{1}{2}(gg_{HHDD} + gg_{HHYY})$.

3. There is no interaction between the sire contribution and the maternal effect of the dam, or $gm_{HHDY} = gm_{HHYD} = gm_{HHDD} = gm_{HHYY} = 0$.

In the present study comparable progeny from the same sire were produced by straightbred and crossbred dams allowing the interaction of sires and breed of dam to be evaluated. Since reciprocal crossbred females were used in the present study, the difference between reciprocally produced crossbred females can also be evaluated. Estimates of the maternal heterosis of crossbred gilts of each breed group are made as described above for Duroc-Yorkshire gilts.

Dickerson (1969) further defined the genetic parameters involved in breed utilization. The components he defined in comparing two-breed and three-breed crosses are presented and defined in Table II for the same specific comparisons described above. The information in this table and the foregoing discussion will assist in making genetic interpretations of the following comparisons. From Table II it can be seen that estimates of maternal heterosis of the D-Y gilts by the above method are estimates of the quantity h^M_{DY} but that r^I_{DY} also gets involved in these comparisons. This is the quantity assumed zero in Assumption No. 1 above. Also comparisons of reciprocally produced crossbred females ($P_{HH \cdot DY} - P_{HH \cdot YD}$) will evaluate the importance of $g^{M'}_Y$ minus $g^{M'}_D$.

The pooled within season-breed of sire mean squares for the tests of significance of the interaction of sires by breed of dam within breed of sire are presented for traits of gilts slaughtered 30-days postbreeding in Table III and for dam productivity traits from birth to weaning in Table IV. The interaction of sires by breeding of dam within breed of sire was not significant for any trait (P > .20). This suggests Assumption No. 3 above concerning the interaction of the sire contribu-

TABLE II

EXPECTED RELATIVE PERFORMANCE FOR TWO-BREED AND THREE-BREED CROSSES

Mating		Parameters					
Type	Breed	g^I	h^I	r^I	g^M	h^M	g^{M^I}
Two-way	HxD	(H+D)/2	HxD		D		D
Two-way	HxY	(H+Y)/2	HxY		Y		Y
Three-way	H(DxY)	(2H+D+Y)/4	(HxD+HxY)/2	DY	(D+Y)/2	DY	Y
Three-way	H(YxD)	(2H+Y+D)/4	(HxY+HxD)/2	DY	(Y+D)/2	DY	D

g_H^I = deviation due to average direct effects of the individuals own genes for breed H.

g_D^M = deviation due to average effects through maternal environment, for genes of breed D dams.

$g_D^{M^I}$ = deviation due to average effects of genotype for breed D maternal granddams, through modification of (i.e., interaction with) direct maternal effects.

h_{HxD}^I = deviation due to increased average heterozygosity of F_1 crossbreds from H males x D females, or reciprocals, including any non-allelic interaction of H with D gametes.

h_{DxY}^M = same as h^I, but for maternal environment effects of F_1 crossbred dams.

r_{DxY}^I = deviation due to change in non-allelic gene interactions effects in F_2 individuals, relative to those of the F_1, from gametic recombinations between chromosomes of the parent breeds D and Y.

Source: Dickerson *et al.* (1970).

TABLE III

POOLED WITHIN SEASON-BREED OF SIRE MEAN SQUARES AND TESTS OF SIGNIFICANCE FOR SIRE BY BREED OF DAM INTERACTION FOR LITTER TRAITS OF GILTS SLAUGHTERED 30-DAYS POSTBREEDING

Source	df	Trait: No. of Embryos	Trait: Avg. Embryo Length, mm	Trait: Embryo Survival Rate, %
Sires	37	10.94	2.598	545.0
Breed of Dam	18	11.19	2.595	482.0
Sires x Breed of Dam[a]	65	9.34	2.428	418.0
Residual	67	7.21	2.147	366.0

[a]The sire x breeding of dam interaction was not significant for any trait ($P > .20$).

TABLE IV

POOLED WITHIN SEASON-BREED OF SIRE MEAN SQUARES AND TESTS OF SIGNIFICANCE FOR SIRE BY BREED OF DAM INTERACTION FOR LITTER TRAITS FROM BIRTH TO 42-DAYS

Source	df	Birth No. Per Litter	Birth Avg. Pig Wgt./ Litter	Birth Litter Weight	21-Days No. Per Litter	21-Days Avg. Pig Wgt./ Litter	21-Days Litter Weight	42-Days No. Per Litter	42-Days Avg. Pig Wgt./ Litter	42-Days Litter Weight	Pig Survival Rate to 42-Days, %
Sires	28	8.60	0.1943	49.55	4.82	1.98	511.35	4.96	10.12	2310.3	255.61
Breeding of Dam	18	7.95	0.3916	39.25	5.19	1.64	674.93	4.94	15.82	2380.9	179.62
Sires x Breeding of Dam[a]	65	8.80	0.1945	65.49	6.77	2.72	782.41	6.47	11.67	3317.1	249.31
Residual[b]	75	9.26	0.1999	55.51	6.08	2.00	643.59	5.70	9.52	2830.3	225.58

[a]The sire x breeding of dam interaction was not significant for any trait (P > .20).

[b]Residual degrees of freedom for 21 and 42-day traits equals 73.

tion and the maternal effect of the dam is valid for these traits and the breed groups involved. A significant interaction between sires and breed of dam would provide evidence for specific combining effects at the level of crosses between individual boars. These data provide statistical evidence that specific combining effects are not important at this level.

The effect of sires on traits of gilts slaughtered 30-days post-breeding and on dam productivity from birth to weaning can be evaluated from the mean squares presented in Tables V and VI, respectively. The effect of sires within breed of sire was significant ($P < .05$) for number of embryos and embryo survival rate to 30-days postbreeding but the sires mean squares were of the same magnitude or smaller than error mean square for all other traits. This provides some evidence that individual sires may be important in determining early embryo liveability. However, if this is true, individual sires should also be important sources of variation for litter size at birth since it is generally accepted that the early life of the embryo is the most critical period. This is borne out in the present study where the overall number of ovulations, number of embryos 30-days postbreeding and number of pigs per litter at birth were 13.2, 10.3 and 9.5, respectively. Results from the first phase of this project (Johnson and Omtvedt, 1973) with 119 gilts slaughtered and 250 litters farrowed showed ovulation rate, number of embryos and litter size at birth to be 13.2, 10.5 and 9.9, respectively. Also, contrary to the results reported here, unpublished data utilizing all two-way cross litters produced in the first two phases of this project (all two-way litters in the present study were included) with 67 boars, 167 gilts slaughtered and 176 gilts farrowed resulted in a nonsignificant

TABLE V

MEAN SQUARES AND TESTS OF SIGNIFICANCE FOR SIRE EFFECTS FOR LITTER TRAITS OF GILTS SLAUGHTERED 30-DAYS POSTBREEDING

Source	df	Trait		
		No. Embryos	Avg. Embryo Length,mm	Embryo Survival Rate, %
Season (S)	1	41.59	38.07	830.7
Breed of Sire (BOS)	2	1.46	0.18	43.5
S x BOS	2	9.22	1.42	121.9
Sire in BOS	37	13.10*	2.31	584.5*
Breed of Dam in BOS	9	13.21	1.36	813.5
S x Breed of Dam in BOS	9	8.53	1.51	180.8
Residual[a]	132	8.25	2.31	391.9

[a]Error term used to test the effect of sires.

*P<.05.

TABLE VI

MEAN SQUARES AND TESTS OF SIGNIFICANCE FOR SIRE EFFECTS FOR LITTER TRAITS FROM BIRTH TO WEANING

		Birth			21-Days			42-Days			
Source	df	No. Per Litter	Avg. Pig Wt./ Litter	Litter Wt.	No. Per Litter	Avg. Pig Wt./ Per Litter	Litter Wt.	No. Per Litter	Avg. Pig Wt./ Per Litter	Litter Wt.	Survival %
Season (S)	1	38.01	1.40	43.9	0.08	13.66	641.4	0.30	120.1	8754.4	5692.5
Breed of Sire (BOS)	2	9.67	2.08	145.5	8.70	7.43	2260.5	10.82	9.6	5552.0	2287.1
S x BOS	2	11.40	0.43	32.9	2.85	3.87	50.4	4.51	5.2	1556.3	313.1
Sire in BOS[b]	28	5.45	0.21	36.8	4.00	2.17	532.9	4.09	11.3	2420.6	336.9
Dam Breeding in BOS	9	8.63	0.43	25.1	7.87	1.53	1238.2	7.15	7.6	3604.0	234.2
Sires x Dam Breeding in BOS	9	8.34	0.16	60.7	6.21	1.58	860.2	6.08	16.7	3845.0	229.2
Residual[a]	140	8.93	0.20	59.4	6.40	2.33	709.0	6.06	10.5	3055.0	289.2

[a]Resudual degrees of freedom for 21-day and 42-day traits equals 138.

[a]Error term used to test the effect of sires.

[b]Sire effects were not significant for any trait (P > .20).

sires effect for number of embryos and number of pigs per litter. Reddy, Lasley and Mayer (1958) also demonstrated that the boar does not influence prenatal death loss. Because the effect of sires was so different for number of embryos 30-days postbreeding and litter size at birth and the conflicting evidence from other similar studies it was decided to delete the effect of sires from the model for all dam productivity traits; however, it appears obvious that the influence of boars on litter size and embryo survival needs further investigation. If the sire component of variance is in fact not zero for number of embryos 30-days postbreeding, then variances of maternal heterosis estimates for this trait are biased upwards since this variance component now becomes a part of the error variance and all estimates of maternal heterosis are made from mean differences of dams within sires.

Maternal Heterosis for Dam Productivity

Thirty-Days Postbreeding

The mean squares and degrees of freedom for number of corpora lutea per gilt slaughtered 30-days postbreeding are presented in Table VII.

TABLE VII

MEAN SQUARES AND DEGREES OF FREEDOM FOR NUMBER OF CORPORA LUTEA PER GILT SLAUGHTERED 30-DAYS POSTBREEDING

Source	df	MS
Season	1	18.59*
Breeding of Gilt	8	5.21
Season x Breeding of Gilt	8	6.99
Remainder	175	5.86

*P < .05.

The effect of season was significant as gilts mated in the summer to produce fall pigs had 0.68 more ovulations per gilt than gilts mated in the winter. There was no evidence for season by breeding of gilt interaction or for differences in ovulation rate of gilts of the various breed groups.

Least squares breed group means and estimates of heterosis for ovulation rate are presented in Table VIII. All crossbred groups had lower ovulation rates than the purebreds making up the cross with the largest difference being 1.03 ± .51 corpora lutea per gilt between Hampshire-Yorkshire crosses and the average ovulation rate for purebred Hampshires and Yorkshires. Overall, purebreds had 0.45 ± .35 more corpora lutea per gilt than crossbreds.

The D x H cross gilts had 1.40 more ovulations than H x D gilts, D x Y gilts had 0.59 more than Y x D gilts and Y x H gilts had 0.20 more than H x Y. Differences between reciprocally produced Hampshire-Yorkshire crosses are not as large but are in the same direction as the difference of 2.06 corpora lutea reported by Robison (1972). These data do not strongly support his hypothesis of an interaction between the Hampshire chromosomes and Yorkshire cytoplasm which affects ovulation rate of reciprocal Hampshire-Yorkshire crosses. Some of these differences are quite large; however, one must keep in mind the size of the standard errors of the means when making these comparisons. No conclusions can be made from these data but they do suggest the effects due to environmental deviations caused by the maternal and grandmaternal genetic make-up (g^M and g^{M^1}, Table II) need further study.

The mean squares in Table V for number of embryos, average embryo length and percent of corpora lutea found as live embryos 30-days post-

TABLE VIII

LEAST SQUARES BREED GROUP MEANS AND ESTIMATES OF HETEROSIS FOR NUMBER OF CORPORA LUTEA PER GILT SLAUGHTERED 30-DAYS POSTBREEDING

Breed Group[a]	No. of gilts	Mean	S.E.
	Breed Group Means		
D	31	13.31	0.44
DxH	21	13.77	0.54
DxY	18	13.78	0.57
HxD	12	12.37	0.71
H	31	13.34	0.47
HxY	12	12.44	0.74
YxD	20	13.19	0.55
YxH	23	12.64	0.51
Y	25	13.79	0.48
	Heterosis		
DxH & HxD	33	13.07	
D & H	62	13.33	
Difference		-.26	0.55
DxY & YxD	38	13.49	
D & Y	56	13.55	
Difference		-.06	0.51
HxY & YxH	35	12.54	
H & Y	56	13.57	
Difference		-1.03	0.51
Crossbreds	106	13.03	
Straightbreds	87	13.48	
Difference		-.45	0.35

[a]First letter represents breed of sire and second breed of dam of gilts parents.

breeding provide no evidence for interactions of season by breed of sire or season by breeding of dam within breed of sire for any trait. Consequently, interaction terms were deleted from the model and the mean squares derived by fitting the reduced model for these traits are presented in Table IX. Season effects were significant for number of embryos ($P < .05$) and average embryo length ($P < .01$). Gilts mated in the winter for spring litters had 1.06 fewer embryos per litter and average embryo length was 0.92 mm less than those mated in the summer for fall pigs. Breed of sire effects were not significant for any trait, however breeding of dam within breed of sire approached significance for number of embryos and for percent embryo survival rate ($P < .20$).

TABLE IX

MEAN SQUARES FOR LITTER TRAITS OF GILTS SLAUGHTERED 30-DAYS POSTBREEDING

Source	df	Trait: No. of Embryos	Trait: Avg. Embryo Length, mm	Trait: Embryo Survival Rate %
Season	1	53.03*	39.33**	1109.7
Breed of Sire (BOS)	2	2.01	0.12	36.5
Breeding of Dam in BOS	9	13.66	1.97	695.3
Error	180	9.24	2.23	424.0

*P < .05.

**P < .01.

Least squares breed group means and standard errors for litter traits of gilts slaughtered 30-days postbreeding are presented in Table X while the estimates of maternal heterosis for these traits are presented in Table XI. The maternal heterosis estimates were not signifi-

TABLE X

LEAST SQUARES BREED GROUP MEANS AND STANDARD ERRORS FOR LITTER TRAITS OF GILTS SLAUGHTERED 30-DAYS POSTBREEDING

Breed Group[a]	No.	No. of Embryos Mean	No. of Embryos S.E.	Avg. Embryo Length, mm Mean	Avg. Embryo Length, mm S.E.	Embryo Survival Rate,% Mean	Embryo Survival Rate,% S.E.
DxH	14	8.56	0.82	26.63	0.40	69.51	5.54
D(HxY)	12	10.49	0.88	27.49	0.43	83.61	5.95
D(YxH)	23	10.27	0.64	27.60	0.31	81.88	4.31
DxY	16	11.06	0.76	27.53	0.37	82.61	5.15
HxD	12	10.08	0.88	27.69	0.43	74.59	5.95
H(DxY)	18	10.83	0.72	27.24	0.35	79.39	4.86
H(YxD)	20	10.39	0.68	27.18	0.33	80.10	4.61
HxY	9	10.50	1.01	27.07	0.50	77.84	6.87
YxD	19	11.08	0.70	27.19	0.34	84.12	4.72
Y(DxH)	21	11.40	0.67	27.78	0.33	83.87	4.51
Y(HxD)	12	10.08	0.88	27.45	0.43	83.52	5.95
YxH	17	8.90	0.74	27.09	0.36	65.89	5.01

[a]First letter designates breed of sire and second breeding of dam.

TABLE XI

MATERNAL HETEROSIS OF CROSSBRED GILTS FOR LITTER TRAITS OF GILTS SLAUGHTERED 30-DAYS POSTBREEDING

Comparison[a]	No. of Embryos	Avg. Embryo Length,mm	Embryo Survival Rate, %
D(HxY) + D(YxH)	10.38	27.55	82.75
DxH + DxY	9.81	27.08	76.06
Difference	0.57 ± .78	0.47 ± .38	6.69 ± 5.26
H(DxY) + H(YxD)	10.61	27.21	79.75
HxD + HxY	10.29	27.38	76.22
Difference	0.32 ± .83	-.17 ± .41	3.53 ± 5.64
Y(DxH) + Y(HxD)	10.74	27.62	83.70
YxD + YxH	9.99	27.14	75.01
Difference	0.75 ± .75	0.48 ± .37	8.69 ± 5.07
Three-Breed Crosses	10.58	27.46	82.06
Two-Breed Crosses	10.03	27.20	75.76
Difference	0.55 ± .45	0.26 ± .22	6.30 ± 3.08*

[a]First letter designates breed of sire and second breeding of dam.

*P<.05).

cantly different from zero for any of the breeding groups. However, crossbred gilts mated to a boar of another breed consistently had more embryos, even though they had fewer ovulations, than purebred gilts. There was no consistent difference between the average embryo length of two and three-breed crosses but overall the three-breed cross embryos averaged 0.26 ± .22 mm longer than two-breed crosses. In terms of genetic interpretations of these comparisons presented in Table II, these data do not provide strong statistical evidence that the factor h^M (deviation due to increased average heterozygosity of crossbred females) is large for these traits. However, the consistency of differences between number of embryos and percent embryo survival rate for crossbred and purebred gilts suggests maternal heterosis may be important for these traits.

Birth to Weaning

The mean squares in Table VI provide little evidence for interactions of season with breed of sire or season with breeding of dam within breed of sire for any measure of dam productivity from birth to weaning. Therefore, interaction effects were deleted from the model and mean squares derived from the reduced model for all dam productivity traits from birth to weaning are presented in Table XII.

Season effects were significant ($P < .05$) for number of pigs per litter at birth, average pig weight per litter at birth and 42-days and for pig survival rate from birth to weaning. Spring born litters had 0.86 fewer pigs at birth and a 10.8% higher survival rate from birth to weaning and pigs that weighed 0.18 and 1.54 lbs more at birth and 42-days, respectively. Breed of sire effects were significant for several

TABLE XII

MEAN SQUARES AND DEGREES OF FREEDOM FOR DAM PRODUCTIVITY TRAITS FROM BIRTH TO WEANING

Source	df	Number of Pigs Per Litter			Litter Weight, lbs			Average Pig Weight Per Litter, lbs			Pig Survival Rate to 42-Days, %
		Birth	21-Days	42-Days	Birth	21-Days	42-Days	Birth	21-Days	42-Days	
Season	1	35.2*	0.3	0.6	29.9	799.3	9574.9	1.48**	19.13	111.56**	5568.2**
Breed of Sire (BOS)	2	10.9	7.6	9.5	152.2	2045.6*	4739.9	2.11**	102.06	10.52	2218.7**
Dam Breeding in BOS	9	8.1	8.5	7.9	32.8	1403.5*	4145.3	0.47**	58.41	6.89	297.7
Error[a]	179	8.4	5.9	5.7	55.2	673.0	2950.4	0.19	42.51	10.95	290.7

[a] Error degrees of freedom for 21 and 42 day traits equals 177.

*P ≤ .05.

**P ≤ .01.

traits. A significant breed of sire effect does not mean that sire breeds differ in their effect on these traits, but indicates that the overall effect of breed of sire and the specific combinations of breeding of dams mated to that breed of sire differ. All dam breed groups were not mated to each breed of sire and there are some well established differences in productivity of the three pure breeds of dam used; thus, the effect of this variable will not be discussed but is considered as a source of variation only to get a more precise estimate of the error variance for estimates of maternal heterosis. The effect of breed of dam within breed of sire was significant for litter weight at 21-days ($P < .05$) and average pig weight per litter at birth ($P < .01$) and was approaching significance for number of pigs per litter at 21 and 42-days, litter weight at 42-days and average pig weight per litter at 21-days ($P < .20$). This significance does not provide direct evidence for maternal heterosis, but simply provides evidence that dams of the four breeding types mated to each breed of sire differ in productivity.

Least squares breed group means and standard errors and estimates of maternal heterosis for dam productivity from birth to weaning are presented in Table XIII and Table XIV, respectively.

Duroc-Hampshire crossbred gilts revealed significant ($P < .05$) positive maternal heterosis for number of pigs per litter at 21-days (1.27 ± .61 pigs), number of pigs per litter at 42-days (1.22 ± .59 pigs), litter weight at 21-days (21.99 ± 6.45 lbs) and litter weight at 42-days (33.7 ± 13.5 lbs). Hampshire-Yorkshire cross gilts exhibited significant negative maternal heterosis for average pig birth weight per litter (-.24 ± .11 lbs). No other estimates of maternal heterosis were significant, however crossbred gilts of all breeding consistently had larger

TABLE XIII

LEAST SQUARES BREED GROUP MEANS AND STANDARD ERRORS[a] FOR DAM PRODUCTIVITY TRAITS FROM BIRTH TO WEANING

Breed Group[b]	No.[c]	Number of Pigs Per Litter			Litter Weight, lbs			Average Pig Weight Per Litter, lb			Percent Survival Birth to Weaning
		Birth	21-Days	42-Days	Birth	21-Days	42-Days	Birth	21-Days	42-Days	
DxH	15	9.10	8.06	8.00	23.39	87.3	190.1	2.64	10.94	24.14	89.61
D(HxY)	15	9.83	8.53	8.53	22.14	92.9	190.5	2.25	11.04	22.71	86.15
D(YxH)	17	9.07	8.82	8.70	23.35	92.7	201.2	2.42	10.57	23.06	90.06
DxY	13	8.56 ± .81	7.14 ± .68	7.14 ± .66	20.93 ± 2.06	77.1 ± 7.21	167.0 ± 15.1	2.52 ± .12	10.97 ± .42	23.83 ± .92	87.08 ± 4.74
HxD	17(16)	8.67	6.75	6.62	24.08	69.2	157.1	2.83	10.26	23.82	74.43
H(DxY)	18	9.78 ± .68	7.45 ± .57	7.28 ± .56	26.15 ± 1.75	77.1 ± 6.11	166.7 ± 12.80	2.73 ± .10	10.33 ± .36	23.08 ± .78	78.43 ± 4.02
H(YxD)	15	10.29	8.33	8.25	24.61	83.2	189.8	2.38	9.92	23.09	81.37
HxY	16	11.00	7.94	7.63	26.16	81.6	170.2	2.37	10.21	22.19	70.98
YxD	18	8.78	7.11	7.06	23.81	65.6	160.4	2.74	9.96	22.93	81.89
Y(DxH)	16	9.63	7.75	7.69	27.32	84.3	184.1	2.88	10.92	24.14	83.16
Y(HxD)	17	9.56	8.47	8.29	26.11	92.0	196.0	2.80	11.01	23.99	88.07
YxH	15(14)	8.75	6.56	6.48	23.19	66.8	152.3	2.86	10.63	24.27	74.32

[a]Only the smallest and largest standard error of the mean are presented for each trait.

[b]First letter represents breed of sire and second breeding of dam.

[c]Numbers in parentheses are numbers in these breed groups for 21-day and 42-day traits.

TABLE XIV

MATERNAL HETEROSIS OF CROSSBRED FEMALES FOR DAM PRODUCTIVITY FROM BIRTH TO WEANING

Comparison[a]	No.[b]	No. Pigs Per Litter			Litter Weight, lbs			Average Pig Weight Per Litter, lb			Percent Survival Birth to 42-Days
		Birth	21-Days	42-Days	Birth	21-Days	42-Days	Birth	21-Days	42-Days	
D(HxY) + D(YxH)	32	9.75	8.68	8.62	22.75	92.79	195.8	2.34	10.81	22.89	88.11
DxH + DxY	28	8.83	7.60	7.57	22.16	82.21	178.5	2.58	10.96	23.99	88.35
Difference		0.92±.75	1.08±.63	1.05±.62	0.59±1.93	10.58±6.73	17.3±14.1	-.24±.11*	- .15±.39	-1.10±.86	- .24±4.42
H(DxY) + H(YxD)	33	10.04	7.89	7.77	25.38	80.17	178.2	2.56	10.13	23.09	79.90
HxD + HxY	33(32)	9.84	7.35	7.13	25.12	75.44	163.6	2.60	10.24	23.01	72.71
Difference		0.20±.72	0.54±.61	0.64±.59	0.26±1.83	4.73±6.45	14.6±13.5	-.04±.11	- .11±.38	0.08±.82	7.19±4.21
Y(DxH) + Y(HxD)	33	9.60	8.11	7.99	26.72	88.17	190.0	2.84	10.97	24.07	85.62
YxD + YxH	33(32)	8.77	6.84	6.77	23.50	66.18	156.4	2.80	10.30	23.60	78.11
Difference		0.83±.72	1.27±.61*	1.22±.59*	3.22±1.83	21.99±6.45**	33.7±13.5*	0.04±.11	0.67±.38	0.47±.82	7.51±4.21
Three-breed	98	9.80	8.23	8.13	24.95	87.04	188.0	2.58	10.64	23.35	84.54
Two-breed	94(92)	9.15	7.26	7.16	23.59	74.61	166.2	2.65	10.50	23.53	79.72
Difference		0.65±.42	0.97±.36**	0.97±.35**	1.36±1.08	12.43±3.48**	21.9±7.9**	-.08±.06	0.14±.22	- .18±.48	4.82±2.47

[a] First letter designates breed of sire and second breeding of dam.

[b] Numbers in parentheses are the number of litters for 21-day and 42-day traits.

* $P \leq .05$.

** $P \leq .01$.

litters at all ages than purebreds and consequently heavier litters even though estimates of maternal heterosis for average pig weight per litter were small. With the exception of Yorkshire-Hampshire cross gilts, crossbred gilts also raised a greater percentage of pigs from birth to weaning than purebred gilts. Overall, crossbred gilts had larger and heavier litters than purebreds at all ages with significant average maternal heterosis of crossbred gilts observed for number of pigs per litter at 21 and 42-days (0.97 ± .36 and 0.97 ± .35 pigs, respectively), litter weight at 21 and 42-days (12.43 ± 3.48 and 21.9 ± 7.9 lbs, respectively) and for percent survival rate from birth to weaning (4.82 ± 2.47%). This suggests that the average heterozygosity of crossbred females is an important environmental factor in pig liveability and litter size but not for pig weights. Perhaps the fact that crossbred gilts had more pigs per litter but maintained their pigs at the same weight as those from purebred gilts suggests they did provide a better intrauterine nutritional environment as well as more total milk from birth to 21-days of age.

The results presented here are in general agreement with reports in the literature comparing litter traits for two and three-breed crosses. Crossbred sows have been reported to have litters ranging from 0.0 to 1.20 more pigs at birth and 1.0 to 1.7 more pigs at weaning. (Winters et al., 1935; Robison, 1948; Chambers and Whatley, 1951; Bradford et al., 1953; Whatley et al., 1954, Smith and McLaren, 1967). In general, these studies also reported little difference in pig weights between two and three-breed crosses. No specific comparisons of maternal heterosis are available for comparison purposes.

The means for reciprocally produced crossbred females (Table XIII) are similar and suggest that deviations due to environmental effects of genotypes of the gilts dam (g^{M^1}, Table II) are in general small and unimportant.

Maternal Heterosis for Postweaning Feedlot Performance

Feed Intake and Feed Efficiency

The mean squares for pen average daily feed consumption and feed efficiency are presented in Table XV. Season effects were highly significant for both traits as spring born pigs consumed 0.40 lbs more feed per day and gained 0.021 lbs more per pound of feed consumed than fall born pigs. Breed of sire effects were also significant for both traits, however there was little evidence for breeding of dam within breed of sire effects or for interaction of season with other effects.

TABLE XV

MEANS SQUARES FOR PEN AVERAGE DAILY FEED CONSUMPTION AND FEED EFFICIENCY PER PIG

Source	df	Avg. Daily Feed Intake Per Pig (lbs)	Feed Efficiency, lbs Gain/lb Feed
Season (S)	1	2.463**	0.0076**
Breed of Sire (BOS)	2	1.150**	0.00370**
S x BOS	2	0.014	0.00014
Breeding of Dam in BOS	9	0.229	0.00040
S x Breeding of Dam in BOS	9	0.194	0.00047
Remainder	46	0.156	0.00031

**P < .01.

The least squares breed group means and estimates of maternal heterosis for feed consumption and feed efficiency are presented in Tables XVI and XVII, respectively. Although estimates of maternal heterosis were positive for feed consumption and negative for feed efficiency, these values were in general small and non-significant. Overall three-breed crosses consumed 0.14 ± .10 lbs more feed per day and gained 0.005 lbs less per pound of feed consumed. This suggests that the maternal heterosis of the crossbred female is of little importance for these traits. Mean differences of reciprocally produced crossbred females also were small (Table XVI) suggesting that deviations due to the average effect of genotypes of maternal granddams are small and unimportant for these traits.

The lack of heterosis for feed efficiency reported by Johnson _et al._ (1973) and the results of this study suggest that the performance of crossbreds for this trait can be predicted quite accurately from the average performance of the pure breeds making up the cross. Johnson _et al._ (1973), however did report significant differences between reciprocal 2-breed crosses involving Yorkshires. The differences in the present study between Duroc-Yorkshire and Hampshire-Yorkshire reciprocal crosses always favors the cross being produced by Yorkshire females. This agrees very closely with the results of the first phase of this project and suggest real breed differences in deviation due to average effects in maternal environment (g^M, Table II) of purebred dams, but crossbred gilts appear to express this effect simply as the average of the breeds that made up the cross.

TABLE XVI

LEAST SQUARES BREED GROUP MEANS FOR AVERAGE DAILY FEED CONSUMPTION PER PIG AND FOR PEN FEED EFFICIENCY

Breed Group[a]	No. Pens	Avg. Daily Feed Consumption,Lbs		Feed Efficiency,Lbs Gain Per Lb Feed	
		Mean	S.E.	Mean	S.E.
DxH	4	4.74	0.23	0.318	0.010
D(HxY)	5	4.92	0.18	0.321	0.008
D(YxH)	7	4.80	0.15	0.315	0.007
DxY	5	4.69	0.18	0.335	0.008
HxD	6	4.86	0.16	0.322	0.007
H(DxY)	6	4.50	0.16	0.336	0.007
H(YxD)	6	4.79	0.16	0.319	0.007
HxY	7	4.40	0.15	0.337	0.007
YxD	6	4.92	0.16	0.311	0.007
Y(DxH)	6	5.42	0.16	0.297	0.007
Y(HxD)	7	4.98	0.15	0.307	0.007
YxH	5	4.95	0.18	0.302	0.008

[a]First letter designates breed of sire and second breeding of dam.

TABLE XVII

MATERNAL HETEROSIS OF CROSSBRED FEMALES FOR AVERAGE DAILY FEED CONSUMPTION AND FEED EFFICIENCY

Comparison[a]	No. Pens	Avg. Daily Feed Consumption, Lbs	Feed Efficiency, Lbs Gain Per Lb Feed
D(HxY) + D(YxH)	12	4.86	0.318
DxH + DxY	9	4.72	0.327
Difference		0.14 ± .19	-.009 ± .008
H(DxY) + H(YxD)	12	4.65	0.328
HxD + HxY	13	4.63	0.330
Difference		0.02 ± .16	-.002 ± .007
Y(DxH) + Y(HxD)	13	5.20	0.302
YxD + YxH	11	4.94	0.307
Difference		0.26 ± .16	-.005 ± .007
Three-breed crosses	37	4.90	0.316
Two-breed crosses	33	4.76	0.321
Difference		0.14 ± .10	-.005 ± .004

[a]First letter designated breed of sire and second breeding of dam.

Growth Rate and Probe Backfat

The mean squares, pooled within season-breed of sire, to test the effect of sire by breed of dam interactions are presented in Table XVIII for average daily gain, age at 220 lbs and probe backfat thickness of gilts. The interaction of sires and breed of dam was tested with dams within sire, however due to the unequal subclass numbers, this test is not exact. However, the sire by breed of dam interaction mean square was smaller than the dams within sires mean square for all traits. This again suggests no specific combining effects among these breeds on the individual boar level. Based on this evidence, the sire by breed of dam variance component was assumed zero and this source of variation was deleted from further analyses.

The estimates of variance components obtained from the nested analyses for measures of growth rate and probe backfat thickness are presented in Table XIX. The magnitude of the sire components of variance relative to phenotypic variance for average daily gain and age at 220 lbs is well within the range of the importance of this source of variation reported in the literature. Edwards (1970) reported the heritability of average daily gain from 25 separate studies ranged from 0.14 to 0.77 with a simple average of 0.31. He found a range of -.07 to 0.68 with an average of 0.39 for age at 200 pounds. Based on the sire component of variance in this study, heritability estimates for average daily gain and age at 220 lbs are 0.37 and 0.19, respectively. The very small negative sire component of variance for probe backfat thickness is considerably lower than most reports. Edwards (1970) found a range of 0.15 to 0.87 for heritability estimates for this trait. Louca and Robison (1967), however, found a very small positive sire component of

TABLE XVIII

MEAN SQUARES AND DEGREES OF FREEDOM POOLED WITHIN SEASON-BREED OF SIRE FOR AVERAGE DAILY GAIN, AGE AT 220 POUNDS AND PROBE BACKFAT THICKNESS

		Trait		
Source	df[b]	Avg. Daily Gain, lbs	Age at 220 lbs days	Probe Backfat thickness of Gilts, in
Sires	29	0.147	758.4	0.054
Breeding of Dam	18	0.074	603.4	0.060
Sires x Breeding of Dam	64 (59)	0.044	415.3	0.039
Dams Within Sire[a]	66 (58)	0.054	416.3	0.045
Sex	6	0.669	2407.4	---
Pigs Within Dams Within Sires	806 (326)	0.021	149.3	0.024

[a]Error term used to test sires x breeding of dam.

[b]Numbers in parentheses are degrees of freedom for probe backfat thickness of gilts.

TABLE XIX

ESTIMATES OF SIRE, DAM AND INDIVIDUAL VARIANCE COMPONENTS FOR AVERAGE DAILY GAIN, AGE AT 220 POUNDS AND PROBE BACKFAT

Trait	Variance Component[a]			
	σ_s^2	σ_d^2	σ^2	σ_p^2
Average Daily Gain, Lbs	0.003166	0.005732	0.025003	0.033901
Age at 220 lbs , Days	10.00	52.45	165.44	227.89
Probe Backfat, in	-.000089	0.010287	0.035455	0.045742

[a] σ_s^2, σ_d^2 and σ^2 are estimates of the sire dam and pig components of variance, respectively, and $\sigma_p^2 = \sigma_s^2 + \sigma_d^2 + \sigma^2$.

variance for probe backfat thickness in crossbreds and a considerably higher component in purebreds. They also reported a much higher dam component in crossbreds than in purebreds. They contributed this to a reduction in the additive genetic variance relative to total genetic variance in crossbreds. The large dam component of variance for all traits in this study also suggests non-additive genetic variance and maternal variance are important for these traits. These variance components, with the exception of the sire variance component for probe backfat thickness which was assumed to be zero, were used to estimate the standard errors of the means and maternal heterosis estimates presented in Tables XX and XXI, respectively, for these traits.

Season effects were highly significant for all traits. The pigs born in the spring gained 0.23 lbs per day faster, reached 220 lbs 23.6 days sooner and had 0.11 in less probe backfat than those born in the fall. Although no specific test for interaction was made, the means in Table XX suggest that the differences between some breed groups were not the same in each season. Whether or not this interaction is real is difficult to determine. However, because of the unhealthy pigs in the later part of the feeding period for fall born pigs, it was decided not to average these means and to present estimates of maternal heterosis separate for each season.

Only two of the estimates of maternal heterosis, Table XXI, are significantly different from zero. Spring pigs from Hampshire-Yorkshire crossbred gilts gained 0.10 ± .043 lbs per day less and were 9.90 ± 3.48 days older than the average for DxH and DxY pigs. All other estimates of maternal heterosis for average daily gain and age at 220 lbs were small in comparison to associated standard errors but in all cases pigs

TABLE XX

BREED GROUP MEANS AND STANDARD ERRORS BY SEASON[a] FOR AVERAGE DAILY GAIN, AGE AT 220 POUNDS AND PROBE BACKFAT THICKNESS

Breed Group[b]	No. of Pigs		Average Daily Gain, lbs		Age at 220 lbs, Days		Probe Backfat of Gilts, in	
	S	F	S	F	S	F	S	F
μ			1.66	1.43	171.4	195.0	1.28	1.17
DxH	52	20	1.65±.043	1.31±.058	169.2±3.34	205.8±4.95	1.32±.050	1.16±.087
D(HxY)	46	36	1.55±.044	1.50±.051	181.5±3.39	188.8±4.19	1.30±.066	1.15±.063
D(YxH)	60	38	1.65±.041	1.37±.045	172.2±3.18	202.2±3.59	1.38±.047	1.17±.056
DxY	50	17	1.72±.045	1.49±.057	164.7±3.43	186.3±4.71	1.25±.048	1.11±.081
HxD	43	34	1.65±.045	1.40±.046	168.9±3.49	202.6±3.66	1.19±.051	1.24±.056
H(DxY)	54	27	1.69±.043	1.46±.048	171.8±3.38	189.5±3.91	1.16±.050	1.05±.071
H(YxD)	51	31	1.70±.044	1.36±.049	169.5±3.40	199.9±4.01	1.20±.053	1.10±.062
HxY	45	40	1.65±.043	1.34±.044	174.3±3.39	204.6±3.56	1.18±.051	1.07±.059
YxD	53	41	1.62±.042	1.50±.042	173.9±3.31	187.7±3.40	1.37±.051	1.27±.060
Y(DxH)	52	41	1.75±.043	1.50±.044	167.0±3.43	187.6±3.55	1.31±.053	1.19±.053
Y(HxD)	63	40	1.64±.041	1.46±.043	172.8±3.23	190.3±3.52	1.32±.049	1.29±.056
YxH	37	24	1.67±.048	1.42±.053	171.5±3.80	195.2±4.40	1.34±.058	1.26±.069

[a]S and F represent spring and fall born pigs respectively.

[b]First letter designates breed of sire and second breeding of dam.

TABLE XXI

ESTIMATES OF MATERNAL HETEROSIS BY SEASON[a] FOR AVERAGE DAILY GAIN, AGE AT 220 POUNDS AND PROBE BACKFAT THICKNESS

Comparison[b]	No. Pigs		Average Daily Gain, lbs		Age at 220 lb, Days		Probe Backfat of Gilts, in	
	S	F	S	F	S	F	S	F
D(HxY) + D(YxH)	106	74	1.60	1.44	176.9	195.5	1.34	1.16
DxH + DxY	102	37	1.70	1.40	167.0	196.1	1.29	1.14
Difference			-.10±.043*	0.04±.061	9.90±3.48*	- .6±4.68	0.05±.053	0.02±.073
H(DxY) + H(YxD)	105	58	1.70	1.41	170.7	194.7	1.18	1.08
HxD + HxY	88	74	1.65	1.37	171.6	203.6	1.19	1.16
Difference			0.05±.044	0.04±.082	- .90±3.43	- 8.9±5.47	-.01±.051	-.08±.062
Y(DxH) + Y(HxD)	115	81	1.70	1.48	169.9	190.0	1.32	1.24
YxD + YxH	90	65	1.65	1.46	172.7	191.5	1.36	1.27
Difference			0.05±.048	0.02±.056	- 2.8±3.50	- 1.5±4.14	-.04±.053	-.03±.060
Three-breed crosses	326	213	1.67	1.44	172.5	193.4	1.28	1.16
Two-breed crosses	280	176	1.67	1.41	170.4	197.1	1.28	1.19
Difference			0.00±.026	0.03±.039	2.1±2.00	- 3.7±2.77	0.00±.030	-.03±.038

[a]S and F represent spring and fall born pigs, respectively.

[b]First letter designates breed of sire and second breeding of dam.

*$P < .05$.

from crossbred dams gained slightly faster and were younger at 220 lbs than pigs from purebred dams. Estimates of maternal heterosis for probe backfat did not agree in sign among crosses and in general estimates were smaller than standard errors.

Averaging over seasons and breed groups indicated almost no difference between three and two-breed crosses for these traits. These data provide little evidence for maternal heterosis of crossbred females for measures of feedlot performance. These results agree quite well with overall three-breed and two-breed cross results for growth rate and probe backfat thickness (Winters et al., 1935; Magee and Hazel, 1959; Smith and McLaren, 1967). However, no estimates of maternal heterosis of crossbred females were found in the literature.

The differences in performance of pigs from reciprocally produced crossbred females also are within what might be expected from sampling error. This suggests the environmental deviations caused by differences in genotypes of maternal granddams is not important even though rather large differences in the maternal influence of purebred dams has been shown (Johnson et al., 1973). Pani et al. (1963) also observed a nonsignificant difference in 154 day weight in pigs from reciprocally produced Landrace-Poland sows. This suggests that three-breed cross performance can be predicted from the average effects of the breeds involved, the average individual heterosis and the maternal influence of the crossbred dam which is predicted from the average maternal influence of the dam's parent breeds.

CHAPTER V

SUMMARY

The objectives of this study were to estimate the maternal heterosis of crossbred females and to compare dam productivity and postweaning feedlot performance of two- and three-breed crosses of Durocs, Hampshires and Yorkshires.

The data were collected in the 1972 spring and fall farrowing seasons from Phase II of the Oklahoma swine crossbreeding project. A total of 193 pregnant gilts (106 crossbreds and 87 purebreds) were slaughtered 30-days postbreeding, 192 gilt litters (98 three-breed and 94 two-breed) were farrowed and 539 three-breed and 456 two-breed cross pigs were evaluated for postweaning feedlot performance. In each season six boars of each breed were each mated to six purebred gilts and to six two-breed cross gilts (three gilts of each breed group not represented in the boar). Thirty-days postbreeding one gilt of each mating type for each boar was randomly selected to be slaughtered and evaluated for ovulation rate and early embryo development and the other two gilts of each mating type were carried full term and farrowed.

Heterosis of crossbred females was estimated for ovulation rate and maternal heterosis of crossbred dams was evaluated for number of embryos per litter, average embryo length per litter and embryo survival rate 30-days postbreeding. From birth to weaning maternal heterosis was estimated for litter size, average pig weight per litter and litter weight at birth, 21 and 42 days and for percent pig survival rate from birth to 42-days. Estimates of maternal heterosis for postweaning feedlot performance are given for pounds of feed consumed per day, pounds of gain per pound of feed, average daily gain from nine weeks of age to 220 lbs., age at 220 lbs. and probe backfat thickness of gilts. The mating structure allowed the importance of sires and sire by breed of dam interactions to be evaluated for all traits.

The pooled within breed of sire-season subclass sire by breed of dam interaction mean squares were small and non-significant for all traits. This provides evidence that there is no specific combining effects at the level of individual boars for any trait studied. Sire effects were not significant for any of the measures of dam productivity except number of live embryos per litter 30-days postbreeding and for percent embryo survival from conception to 30-days. This suggests that sire differences exist for early embryo survival rate; but sires were not an important source of variation for litter size.

Although estimates of heterosis for ovulation rate were not significantly different from zero, crossbred gilts of all breed groups consistently had fewer corpora lutea per gilt than purebreds. Overall, purebred gilts had 0.45 ± .35 more corpora lutea per gilt than crossbreds (13.48 vs. 13.03).

Estimates of maternal heterosis of crossbred gilts for traits measured 30-days postbreeding were not significantly different from zero. Even though crossbred gilts had fewer ovulations than purebreds, they consistently had more embryos per litter and consequently had a higher percentage of their ovulations represented as live embryos. Averaged over breed groups crossbred gilts had 0.55 ± .45 more embryos (10.58 vs. 10.03) and 6.30 ± 3.08% more of their ovulations represented as embryos

(82.06 vs. 75.76) than purebreds. Three-breed cross embryos were also 0.26 ± .22 mm longer than two-breed cross embryos but estimates of maternal heterosis for this trait differed in sign and magnitude for the various crosses, none being significant.

Significant estimates of maternal heterosis were found in Duroc-Hampshire crossbred gilts for litter size at 21 and 42 days postfarrowing (1.27 ± .61 and 1.22 ± .59 pigs, respectively) and for litter weight (21.99 ± 6.45 and 33.7 ± 13.5 lbs., respectively). Significant negative maternal heterosis was observed for Hampshire-Yorkshire gilts for average pig birth weight per litter (-.24 ± .11 lbs.). No other estimates of maternal heterosis of crossbred gilts for measures of dam productivity from birth to weaning were significant; however, crossbred gilts with three-breed cross litters had consistently larger and heavier litters at all ages and raised a larger percentage of their pigs from birth to weaning than did purebred gilts with two-breed cross litters. Three-breed cross litters contained 0.65 ± .42, 0.97 ± .36 and 0.97 ± .35 more pigs that weighed 1.36 ± 1.08, 12.43 ± 3.48 and 21.9 ± 7.9 lbs. more than two-breed cross litters at birth, 21 and 42 days, respectively. The survival rate from birth to weaning was 4.82 ± 2.47% higher for three-breed cross pigs than for two-breed cross pigs. There was almost no difference between two- and three-breed cross pigs in average pig weight per litter at any age.

There was virtually no evidence for maternal heterosis for any measure of postweaning feedlot performance. Three-breed cross pigs for all breed groups consistently consumed more feed per day (0.14 ± .10 lbs.) but gained less per pound of feed consumed (-.005 ± .004 lbs. gain per pound feed). Three-breed cross pigs born in the spring from Hampshire-

Yorkshire crossbred gilts gained significantly slower (-.10 ± .043 lbs. per day) and were older at 220 lbs. (9.90 ± 3.48 days) than two-breed cross pigs from purebred Hampshire and Yorkshire gilts. Differences in fall-born pigs were in the opposite direction and not significant and all other differences in growth rate between two- and three-breed crosses were small and non-significant. All estimates of maternal heterosis for probe backfat thickness of gilts were also small and non-significant. Averaged over breed groups and seasons, three-breed cross pigs gained 0.015 ± .023 lbs. per day faster, were 0.8 ± 1.71 days younger at 220 lbs. and had 0.015 ± .024 in less probe backfat than two-breed crosses.

Differences in performance of pigs from reciprocally produced crossbred gilts were small and non-significant for all traits indicating that deviations due to average effects of genotypes of maternal granddams through modification of direct maternal effects are unimportant.

These data provide some evidence that three-breed cross embryos from crossbred dams have a greater early embryonic survival rate. However, the primary advantage of crossbred gilts in a three-breed crossing program appears to be their ability to raise a higher percentage of their pigs from birth to weaning resulting in three-breed cross litters being larger and heavier at weaning than two-breed cross litters. There was little evidence for maternal heterosis for postweaning feedlot performance.

This suggests three-bred cross postweaning feedlot performance can be predicted from estimates of the deviations due to average direct effects and average individual heterosis of the breeds involved plus the deviation due to the maternal effects of the genotype of the crossbred dam. This maternal effect appears to be simply the average of the maternal deviation of the dams' parent breeds.

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