SOW PRODUCTIVITY COMPARISONS FOR FOUR BREEDS OF SWINE IN THE PRODUCTION OF PUREBRED AND CROSSBRED LITTERS

By

HAROLD RAY GAUGLER

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North Dakota State University

Fargo, North Dakota

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Thesis Approved:

David S. Buchanan
Thesis Adviser

Richard Hintz

Charles V. Maxwell

Norman N. Durham
Dean of Graduate College

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CHAPTER I

INTRODUCTION

Crossbreeding is used extensively in the production of market hogs in the United States. It is estimated that 90 percent of the slaughter pigs in the United States are crossbred (Warwick and Legates, 1979). Crossbreeding makes use of heterosis, which is the improvement in performance of the crossbred progeny relative to the average of the purebred parents, and permits breeders to combine the desirable characteristics of different breeds into the crossbred individual. Heterosis varies, dependent upon the traits involved and the breeds used in the crossing system.

In general, traits associated with sow productivity are lowly heritable and do not respond readily to direct selection. Those traits, which are affected by non-additive sources of variation, should respond well to a crossbreeding system. The existing literature on the effect of crossbreeding on swine production is extensive and covers a wide variety of breeds. However, early crossbreeding investigations with swine involved inbred lines and management conditions quite different from those of today. In addition, breed type has changed considerably in recent years.

The success of a crossbreeding program appears to depend to a large degree upon the choice of breeds that are used and their own inherent productivity. Due to the lack of experiments involving several breeds simultaneously, crossing recommendations are usually based on the performance of purebreds which may not be applicable with crossing (Willham, 1960). Because of the absence of crossbreeding information on modern swine breeds under confinement conditions, data on the performance of purebreds and their crosses is needed in order to develop breeding programs that will maximize production.

The purpose of this study is to compare the sow productivity of four breeds of swine (Duroc, Spot, Yorkshire and Landrace) in the production of purebred and two-breed crossbred litters.

CHAPTER II

LITERATURE REVIEW

Introduction

Sow productivity is an important concept in swine production. An increase in the number of offspring produced per female bred reduces female replacement cost, maintenance feed and fixed costs including the fixed cost of pregnancy and lactation. Dickerson (1978) presented estimates of the net effect, of increasing the number of offspring per female per year, on the economic and biological efficiency of meat production. A twenty percent increase in offspring per female per year would result in approximately a 3.5 percent decrease in feed energy input per kg of meat protein output and approximately an 11 percent decrease in cost input per kg of meat protein output.

Characterization of sow productivity generally includes the number of pigs per litter and the weights of the pigs at various times from birth through weaning. The variation in productivity traits is fairly large. Utilizing the residual mean squares, presented by Young *et al.* (1976), to estimate the standard deviations of sow productivity traits, coefficients of variation ranging from 23.8 to 34.5 were calculated. However, direct selection for these traits has been relatively ineffective so the heritabilities appear to be low.

Reasons for low heritabilities of productivity traits may be small additive genetic variance and large environmental or non-additive genetic variance. If there are large non-additive sources of genetic variance these traits should respond well to crossbreeding.

After summarizing data from a large number of experiments, Carroll and Roberts (1942) felt that the crossbreds approached but did not exceed the performance of the better purebred parent. However, in their study, the crossbred was compared to the best performing purebred separately for each of the six traits studied. In this way the crossbred was compared to a composite purebred that did not exist. Comparing the crossbreds to the average of the purebred parents for all traits indicate crossbred superiority.

Sow productivity was examined by Lush and Molln (1942). They considered the number of pigs farrowed and weaned in a litter and the weaning weight of the litter. However, until very recently, research emphasis has been on carcass and growth characteristics so that only a small number of studies have been published dealing with productivity in the female.

Sow productivity is a composite of several pre- and post-natal traits. They include ovulation rate, conception rate, embryonic mortality, and the sows ability to farrow live pigs, all of which influence litter size at birth. In addition, the sow contributes to the pigs liveability and growth both through direct genetic effects the pig inherits from its dam and the environment she provides for her litter.

Estimates of Heritability and Heterosis

There have been many reports in the literature estimating heritability of sow productivity traits. Relatively fewer estimates have been reported dealing with heterosis of traits under specific two-way crossbreeding systems.

A thorough summary of heritability estimates for litter size and weight at various ages from birth to weaning was presented by Irvin (1975). Heritability estimates for traits associated with sow productivity averaged .13 for litter size at birth, .24 for litter weight at birth, .15 for litter size at weaning and .14 for litter weight at weaning. Individual estimates are quite variable but in general they ranged from near zero to .45 for all of these traits. Fewer estimates are available for heritability of percent survival from birth to weaning. Arganosa et al. (1974, 75) reported estimates of .37 and .34 for heritability of percent survival based on total number born and total number born alive. These numbers were quite similar to the .40 reported by Cummings et al. (1947).

Heterosis depends upon the magnitude of the non-additive gene effects associated with a trait. From several crossbreeding experiments, Sellier (1976) and Johnson (1980) summarized individual heterosis for many traits (Table I).

The figures in Table I are only means: experimental estimates of heterosis are quite variable. Possible origins of this variation could result from: (1) sampling error, (2) various biases in the method of estimation or in the data, (3) failure to properly account for non-random mating and (4) true genetic or environment differences among populations (Irvin, 1975).

Variation in heterosis due to true genetic or environmental differences merits further analysis. In an experiment designed to study the genotype by nutritional environment interaction with the Yorkshire x Poland China cross, Kuhlers et al. (1972) found that heterosis for

TABLE I

INDIVIDUAL HETEROSIS[c,d] FOR SEVERAL TRAITS AS A PERCENTAGE ADVANTAGE OVER PUREBRED MEAN

Trait	A	B
Ovulation Rate	.3	—
Conception Rate	3.8	—
No. of Embryos 30 Days Postbreeding	5.1	—
Litter Size at Birth	1.0	3
Pig Birth Weight	3.1	—
Litter Size at 21 Days	8.0	—
Pig 21 Day Weight	3.1	—
Litter Size at Weaning	10.1	6[e]
Pig Weaning Weight	4.8	5[e]
Litter Weaning Weight	—	12[e]
Post Weaning Average Daily Gain	9.4	6
Age at Slaughter	-6.5	-5
Post Weaning Feed Efficiency (G/F)	2.3	3
Carcass Length	0	—
Carcass Backfat	2.5	—
Longissimus Area	1.8	—
Body Composition and Meat Quality	—	0

[A]From Johnson (1980).
[B]From Sellier (1976).
[c]Heterosis levels apply to breed crosses.
[d]Heterosis estimates obtained from the literature.
[e]Estimated for a six-week weaning age.

fattening traits on ad libitam feeding was not affected by a 20-30 percent reduction of the energy content of the ration. However, in an experiment on criss-crossing between Landrace and Yorkshire breeds (Skarmann, 1965) no superiority of crossbreeding in growth rate and food conversion was evidenced when pigs were fed ad lib., but when fed on a restricted basis, there was an advantage with crossbreeding for average daily gain and age at slaughter. In the study of a Pietrain x Landrace cross (Lean et al., 1972), heterosis for food conversion seemed to be favorable on a restricted basis and unfavorable on an ad lib. feeding regime. Orozco and Bell (1974) in a study of egg production in laying hens found heterosis for egg laying to be less important in an optimum environment than in a stress environment. Although these data suggest that there may be a mating type by environment interaction for some traits, there is little evidence indicating such an interaction in those traits associated with sow productivity.

If real variation exists in heterosis for sow productivity traits it may be partially explained by true differences in the different breeds ability to combine with one another (Specific combining ability). The specific combining ability (SCA) between two-breeds is calculated with the following formula: $SCA_{ij} = H_{ij} - 1/2\ (H_i + H_j)$, where H_{ij} is equal to the heterosis exhibited in the i j crosses and H_i (or H_j) is the average heterosis over all crosses involving the i (or j) breed.

Most indications of specific combining ability has come from work dealing with inbred lines. Sprague and Tatum (1942), working with crosses among inbred lines of corn, found specific combining ability to be a highly significant source of variation. Henderson (1948), in an analysis of litter size and weight at 0, 21, 56 and 154 days of age, presented evidence that between 5 and 15 percent of the variation among crosses of inbred lines of Poland China swine was due to specific combining ability. A relationship between specific combining ability and the amount of heterosis obtained from the cross was suggested by England and Day (1971) and Holtman and Fahmy (1974). Holtman and Fahmy, with non-inbred populations, found specific combining ability to be a highly significant source of variation for litter size and weight at birth and three weeks of age. However, reciprocal crosses were not made so differences in specific combining ability could be partially confounded with maternal differences. Hetzer et al. (1959) found little indication of differences among crosses of inbred lines.

Experimental design data from specific crosses was compiled from the literature. Heterosis for sow productivity traits, as a percentage of the parental purebred average, are presented in Table II. From this table of various experiments with specific breed crosses, the conclusion seems to be that certain combinations exhibit more heterosis than others. Genetic diversity of the breeds is a possible explanation.

In contrast to crossbreeding, heterozygosis is decreased with inbreeding. Much of the early work in sow productivity dealt with inbred lines and the effect of inbreeding. A study by Steward (1945a) on the effects of inbreeding of the dam and litter showed that as inbreeding of the dam increased by 10 percent, litter size was decreased by .6 pig while litter size was unaffected by inbreeding of the litter. Bereskin et al. (1968) reported that inbreeding of the litter had no significant effect on litter size at farrowing but did show significant depression on litter birth weight. Also, inbreeding of the dam and litter significantly affected number weaned per litter and litter weight at weaning.

TABLE II

LITERATURE ESTIMATES OF HETEROSIS[a,b] FOR SOW PRODUCTIVITY TRAITS

Source	No. of Litters		LSB	LWB	LSW	LWW	SUR	Purebred Controls	
	Crossbred	Purebred						♂	♀
Young et al. 1976	52	111	-4.1	-1.9	14.5	25.0	23.8	Duroc	Hamp
	45	111	4.4	7.8	14.6	15.9	12.6	Hamp	Duroc
	46	105	13.5	-3.6	26.6	23.4	13.2	Duroc	York
	50	105	12.7	20.5	13.0	18.1	4.9	York	Duroc
	40	106	6.6	2.3	3.7	5.9	1.0	Hamp	York
	56	106	-8.9	2.7	4.4	6.1	19.6	York	Hamp
Cunningham et al. 1967	223	417	-14.6	-1.9	.7	7.9	22.6	Duroc	Belts #1
	195	417	-5.2	-1.2	4.9	4.7	15.4	Belts #1	Duroc
Smith and McLaren 1967	46	186	14.1	6.1	15.3	21.1	.8	Hamp	Duroc
	36	186	-1.8	2.2	6.7	17.7	8.8	Duroc	Hamp
	31	139	4.6	7.3	12.4	27.9	7.6	Land	Hamp
	33	161	-.2	.6	6.6	13.0	8.6	Land	Duroc
	11	83	2.0	-5.8	15.6	24.5	12.6	Land	Pol. China
	7	108	.9	-4.5	11.7	-.3	11.1	Hamp	Pol. China
	9	130	-15.6	-4.1	-2.4	12.1	15.9	Duroc	Pol. China
Hutten & Russel 1939	58	74	-2.0	1.0	8.0	20.0	8.0	York	Ch. White
Lush et al. 1939	29	74	-2.9	1.1	4.2	14.5	7.5	York	Ch. White
	29	74	-1.0	.2	12.7	24.1	14.5	Ch. White	York

[a]Heterosis expressed a percent advantage of the crossbred over the purebreed mean.
[b]Heterosis expressed by specific crosses, not the average of reciprocal crosses.

Factors Associated with Sow Productivity

Breed of Dam

Differences among breeds in maternal performance are important for many traits. The results of Fahmy et al. (1971) indicated that Yorkshire, Landrace and Lacombe females were generally superior to the Hampshire, Duroc, Berkshire and Large Black females for most traits associated with sow productivity. They produced larger and heavier litters with relatively lower pre-weaning mortality rates. Comparable work has been reported by Willham (1960). In both studies, a higher general combining ability of the Yorkshire and Landrace breeds was found.

Reports by Johnson et al. (1972), Omtvedt et al. (1973) and Young et al. (1976) showed the breed of dam effect to be large for all traits evaluated from early embryonic development through weaning. This would indicate that the breed of dam used in a crossbreeding program is of considerable importance for productivity traits. For these studies Duroc, Hampshire and Yorkshire breeds were utilized to produce all possible pure-breds and two-breed combinations. Results indicated that the relative advantage of crossbreeding is highly dependent on the breed of dam involved. Crossbred pigs showed little superiority to purebred pigs if the dams were Yorkshire. However, crossbred pigs had much higher survival rates when compared to purebred pigs from Duroc and Hampshire dams. Their findings also showed that Yorkshire dams raised 13 percent more of their pigs from birth to weaning and although pigs from Yorkshire dams weighed less at birth than those of Duroc and Hampshire, they were the heaviest at 21 days of age even though they were from larger litters. This suggests that Yorkshire dams were not only better mothers in terms of keeping their pigs alive but also provided a larger supply of milk per pig than did the other breeds of dam. Similar differences in productivity among breeds of dam are reported by Nelson and Robison (1975a). In the production of specific two-breed crosses in swine, they found the productivity of Hampshire females to be significantly less than Duroc and Yorkshire females. In contrast to the previous data presented, Leigh (1977) found that pigs from Large White females showed the highest preweaning death rate while pigs from Hampshire dams had the least. Total weight of surviving pigs at weaning was highest for the Hampshire litters while Large White litters were larger and heavier at birth.

Utilization of breed complimentarity and heterosis, through crossbreeding, are two methods of attaining a higher level of efficiency in commercial swine production. Much attention has been devoted to performance characteristics of breeds and breed crosses. Such emphasis is natural because breed differences are an important source of genetic variation. Breed differences in maternal effects may be turned to an advantage by using the appropriate cross. That difference is the basis of complimentarity (Sellier, 1976). Superiority in traits known to be maternally controlled will identify breeds suitable as female parents in crossing (Dickerson, 1969).

Sire and Breed of Sire Effects

The importance of the sire and breed of sire in the expression of sow productivity traits has been examined in several studies. Based on early reports by Krallinger and Schott (1934), Mussen (1946) and Reddy *et al*. (1958) it was concluded that sire and breed of sire have little effect on sow productivity. However, Baker *et al*. (1958) found breed of sire differences in embryo mortality between the 25th and 70th day of gestation.

Recent studies by O'Ferral *et al.* (1968) and Johnson and Omtvedt (1972, 1973a) reported that breed of sire was not a significant source of variation for number of pigs in the litter at birth, litter weight at birth, 21 or 56 days. Johnson and Omtvedt (1973a) deleted sire effects from the model because they were not significant and in the resulting analysis breed of sire effects were found to be significant for number of pigs and litter weight at 21 and 42 days of age, but not at birth. However, Ilancic and Pandza (1973) reported that sire had a significant effect on litter size and weight at birth, litter size and weight at weaning and mortality to weaning. Studies by Johnson and Omtvedt (1973a, 1974) indicated that sire effects were either significant or approaching significance for litter size at birth, 21 days and at 42 days.

Johnson and Omtvedt (1975), in the production of 2- and 3-breed cross litters, reported significant sire differences for number of embryos at 30 day post breeding and embryo survival to 30-days but not for productivity traits measured at birth or weaning. Young *et al.* (1976) in an analysis involving 672 gilts and 76 boars mated to produce purebred and 2-breed cross litters found no significant differences between sires within breed of sire for number of embryos measured at 30-days postbreeding, but relatively large differences between sires were found when measured at birth and weaning. Breed of sire differences were small for embryo livability to 30-days post breeding, however when measured at birth and weaning breed of sire differences were large. Yorkshire boars sired litters that were heavier at all ages than litters sired by either Hampshire or Durocs. Yorkshire sired litters also contained more pigs at all ages than litters sired by the other two breeds and their advantage became larger as the pigs grew older due to the greater survival rate of the Yorkshire sired pigs. Duroc sired litters held a similar advantage over those by Hampshire boars with differences in litter size being significant at 21 and 42 days of age and the differences in litter weight were significant at 42 days. No significant breed of sire effects were found for average pig weight at any age. Duroc gilts farrowed 1.78 more pigs per litter when mated to Yorkshire boars than when mated to Hampshire boars and Yorkshire gilts farrowed 1.50 more pigs per litter when mated to Duroc boars than when mated to Hampshire boars. Within Hampshire dams, there were no significant differences between size of litters sired by Duroc and Yorkshire boars, although all averages favored the latter. DuFour and Fahmy (1975) also found that litter size measured at 23, 42 or 63 days post breeding was 7.8 percent larger when Yorkshire sires were used than when Hampshire or Landrace sires were used. These data suggest that the breed of the service sire does affect litter size and pre-weaning pig livability, contrary to results reported previously.

Other Effects on Productivity

The heritability for sow productivity traits are generally considered to be low. Therefore, environmental sources of variation and interactions of genotype with the environment should account for much of the variation observed in the individual traits.

The influences of age of dam and parity on sow productivity have been evaluated in several studies. In the study by Lush and Molln (1942) average litter size increased by about .5 pig from first to second litter, by another pig at two years of age, but was then relatively stable until the sow was 4.5 to 5 years of age when the litter size began to decline. For litter size at weaning, a sows first litter averaged .5 pig smaller and her sixth litter averaged .5 pig larger than the average of all six litters. For litter weaning weight, Lush and Molln indicated that maximum weight was reached for litters from two year old sows with weaning weights 25 percent lighter for one year old sows and litter weights from older sows, three years of age and over, were lighter.

Steward (1945a) reported that gilts farrowing at 320 days of age averaged one pig fewer per litter and those farrowing at 410 days of age averaged one half pig more per litter than gilts farrowing at one year of age. Bereskin et al. (1968) found litter traits at birth and weaning were significantly increased as age of dam increased. Smith and McLaren (1967) found litters from one year old sows were significantly lighter at all ages than litters from older sows.

Omtvedt et al. (1966) discussed some of the production factors associated with weaning records in swine. Their results showed that age of dam differences were significant for number of pigs farrowed per litter, litter weaning weight and survival rate. Sow litters contained an average of 1.1 more pigs per litter than gilt litters at farrowing and weighed an average of 14.9 kg more at 42 days of age. Gilts farrowed smaller litters, but lost fewer pigs prior to weaning, thus litter size at weaning was essentially the same for both sows and gilts.

Leigh (1977) found that only litter size at birth, average pig weight at eight weeks and mortality from three to eight weeks were significantly affected by parity of the dam. Death losses were much higher in the first five parities than later. The general pattern agrees with

Strang (1970) particularly for litter size and pre-weaning mortality. Fahmy et al. (1971) found third parity litters had heavier pig weights and higher survival rates than the first two parities. Although in this study first parity litters were larger at birth than subsequent parities, they were smaller at weaning and lighter at all ages. Bereskin et al. (1973) also found survival rates rose significantly with higher birth weights. The largest single source of variation reported by Lush and Molln (1942), in litter size at birth was the temporary environmental influences. In this study the effects of station, breeds and the interaction of station and breeds were evaluated after the data were corrected for age of dam. Significant differences among stations and among breeds were reported but not a significant interaction of the two. After partitioning the intra-breed and intra-station variance into differences among years, seasons and contemporary sows and among litters of the same sow, Lush and Molln found differences between years. These were thought to be too small to be important and were considered to be due to genetic trends leading to changes in average sow productivity in various years or to time trends in management or environment. Significant differences among contemporary sows were found and were thought to be due to genetic differences or to permanent environmental differences.

Omtvedt et al. (1966) found season of birth to be an important source of variation for all litter productivity traits and Bereskin et al. (1973) found a significant year season interaction for survival rate. Leigh (1977) reported a significant breed of dam by season of birth interaction for litter size and weight at birth and for percent mortality from birth to eight weeks and from three to eight weeks of age. Leigh, in the production of purebred and crossbred pigs in the wet and dry seasons of southwestern Nigeria, stated that overall the crossbred pigs were least affected by season of birth.

CHAPTER III

MATERIALS AND METHODS

Description of Data

Experimental Design

Litters produced in a four breed diallel mating system involving the Duroc, Landrace, Spot and Yorkshire breeds were born during five consecutive (fall and spring) farrowing seasons beginning in the fall of 1976. Each season, boars were mated at random to at least one female of each breed group (Appendix, Table XX). A total of 366 litters were produced, however only 345 litters had complete records at weaning time. A summary of the number of litters produced for each of the 16 breed group combinations and the numbers of litters produced in each of the five consecutive farrowing seasons is presented in the Appendix (Table XXI). The number of litters produced in each parity group were not uniform for the different breed group combinations (Appendix Table XXII). For these analyses, parity is divided into three catagories, first parity gilts, second parity sows and all sow parities greater than two.

In the spring of 1976, 25 gilts and four boars of each of the Landrace and Spot breeds were purchased from breeders to establish herds at the Stillwater Experimental Swine Farm. Landrace gilts were purchased from two breeders and were primarily of American Landrace breeding. The Landrace boars, two unrelated Canadian Landrace and two unrelated Swedish

Landrace, were purchased from two different sources. Spot boars and gilts originated from nine different breeders, two of which provided both gilts and an unrelated boar. Duroc and Yorkshire herds had been maintained in Stillwater for several years with a broad genetic base with semi-annual introduction of at least one new boar per breed. In order to sample and maintain a broad genetic base of all four breeds, one or more boars of each breed were replaced each season.

Purebred females of each breed were maintained by within herd selection of replacement gilts. Selection was based primarily upon an index of growth and backfat (Appendix Table XXIII). The total number of sires and dams representing each breed group is presented in Table III.

TABLE III

THE NUMBER OF SIRES AND DAMS UTILIZED FROM EACH BREED[a]

Breed	Sires	Dams
Duroc	10	41
Spot	11	40
Yorkshire	10	46
Landrace	10	43
Total	41	170

[a]Total number of sires and dams utilized to produce litters in fall 1976 and spring and fall of 1977 and 1978.

Husbandry and Data Collection

Each season, females were hand mated during an eight week breeding period. Gestating females were maintained in pasture lots and hand-fed a daily ration of 1.8 to 2.2 kg of a 15 percent crude protein corn or milo based diet. Litters were farrowed in a central confinement building. Spring litters were farrowed during March and April and fall litters were farrowed in September and October. Individual pig weights on all fully formed piglets were recorded within 12 hours of birth.

When the pigs were one to two weeks of age, litters were moved to pasture lots with three to four litters per lot or to an open front, solid concrete floor confinment building with one litter per pen. Litters were provided access to creep feed between two and three weeks of age and were weaned at approximately six weeks of age. Individual pig weights on all surviving pigs were recorded at approximately 42 days of age and adjusted to a 42-day weight (Appendix Table XXIII).

At approximately eight weeks of age, pigs were allotted to pens for gain test. All pigs were self-fed a 14% crude protein corn or milo based diet during the test period. Gilts were removed from the gain test when reaching a weight of 90.7 kg, boars and barrows remained on test until 100 kg. After being removed from the gain test, all pigs were probed for backfat. Replacement gilts were selected and returned to the breeding herd after an estrus detection study had been completed.

Statistical Analyses

Estimation of Variance Components

An objective of this study was to estimate variance components for the following traits: litter size at birth (LSB), litter weight at birth (LWB), litter size at weaning (LSW), litter weight at weaning (LWW) and survival percentage from birth to weaning (SUR).

Hendersons Method 3 (1953) was utilized to obtain unbiased estimates of the following variance components for each of the five traits:

V_s = estimated sire component of variance for trait X,

V_{ds} = estimated breed of dam by sire within breed of sire interaction component of variance for trait X and

V_e = estimated environmental component of variance for trait X.

The following linear model was assumed for the sow productivity traits outlined at the beginning of this section:

$$\tilde{y} = \tilde{X}\,\tilde{\beta} + \tilde{Z}_1\,\tilde{s} + \tilde{Z}_2\,\tilde{ds} + \tilde{e}$$

where,

$\tilde{y}$ is an observation vector;

$\tilde{X}$ is a known design matrix of fixed effects;

$\tilde{\beta}$ is an unknown vector of fixed effects (all levels of breed of sire, breed of dam, parity, year, season, year x season, season x parity, breed of dam x season, breed of dam x parity, breed of sire x breed of dam and a common constant μ);

$\tilde{Z}_1$ is a known design matrix for sires;

$\tilde{Z}_2$ is a known design matrix for the breed of dam by sire within breed of sire interaction;

$\tilde{s}$ is a random vector of one-half the additive genetic effect of the sires having a multivariate distribution with mean zero and a non-singular variance-covariance matrix $\tilde{G}_1$;

$\tilde{ds}$ is a random vector of the breed of dam by sire within breed of sire interaction effect having a multivariate distribution with mean zero and a non-singular variance-covariance matrix $\tilde{G}_2$;

$\tilde{e}$ is a random vector of residual effects including environmental and other genetic effects having a multivariate distribution with mean zero and a non-singular variance-covariance matrix R; and $\tilde{s}$ $\tilde{ds}$ and $\tilde{e}$ are mutally uncorrelated.

Earlier analyses were conducted in which the vector of fixed effects ($\tilde{\beta}$) also included the interactions of breed of sire with season and parity and also two three-way interactions involving breed of sire, breed of dam and either season or parity. From these analyses it was determined that these fixed effects did not remove significant amounts of variation and were therefore removed from any further analyses.

For the class of linear models assumed, the solutions of the equations:

$$\begin{bmatrix} \tilde{X}'\tilde{R}^{-1}\tilde{X} & \tilde{X}'\tilde{R}^{-1}\tilde{Z}_1 & \tilde{X}'\tilde{R}^{-1}\tilde{Z}_2 \\ \tilde{Z}_1'\tilde{R}^{-1}\tilde{X} & \tilde{Z}_1'\tilde{R}^{-1}\tilde{Z}_1 + \tilde{G}_1^{-1} & \tilde{Z}_1'\tilde{R}^{-1}\tilde{Z}_2 \\ \tilde{Z}_2'\tilde{R}^{-1}\tilde{X} & Z_2'\tilde{R}^{-1}\tilde{Z}_1 & \tilde{Z}_2'\tilde{R}^{-1}\tilde{Z}_2 + \tilde{G}_2^{-1} \end{bmatrix} \begin{bmatrix} \hat{\tilde{\beta}} \\ \hat{\tilde{s}} \\ \tilde{d\hat{s}} \end{bmatrix} \begin{bmatrix} \tilde{X}'\tilde{R}^{-1}\tilde{y} \\ \tilde{Z}_1'\tilde{R}^{-1}\tilde{y} \\ \tilde{Z}_2\tilde{R}^{-1}\tilde{y} \end{bmatrix}$$

where $\hat{\tilde{\beta}}$ are best linear unbiased estimates (BLUE) of functions of the fixed effects (Henderson <u>et al</u>., 1959; Henderson, 1973) and $\hat{\tilde{s}}$ and $\hat{\tilde{s}}d$ are best linear unbiased predictors (BLUP) of the random effects (Henderson, 1963, 1973) for sire and breed of dam x sire (breed of sire), respectively.

It was assumed that the variance-covariance matrix $R = IV_e$ where I is an identity matrix with order equal to the number of records, which implies that the elements of e are uncorrelated and that all records have a common variance, V_e. The variance-covariance matrix G_1 was assumed to be IV_s, where I is an identity matrix with order equal to the number of sires. The variance-covariance matrix G_2 was assumed to be

IV_{ds} where I is an identity matrix with order equal to the number of breed of dam by sire subclasses and V_{ds} is equal to the variance component for the breed of dam by sire interaction.

These assumptions allow the equations to be simplified to:

$$\begin{bmatrix} \underset{\sim}{X}'\underset{\sim}{X} & \underset{\sim}{X}'\underset{\sim}{Z}_1 & \underset{\sim}{X}'\underset{\sim}{Z}_2 \\ \underset{\sim}{Z}_2'\underset{\sim}{X} & \underset{\sim}{Z}_2'\underset{\sim}{Z}_1 + I\frac{V_e}{V_s} & \underset{\sim}{Z}_1'\underset{\sim}{Z}_2 \\ \underset{\sim}{X}_2'\underset{\sim}{X} & \underset{\sim}{Z}_2'\underset{\sim}{Z}_1 & \underset{\sim}{Z}_2'\underset{\sim}{Z}_2 + I\frac{V_e}{V_{ds}} \end{bmatrix} \begin{bmatrix} \hat{\underset{\sim}{\beta}} \\ \hat{\underset{\sim}{s}} \\ \hat{\underset{\sim}{ds}} \end{bmatrix} \begin{bmatrix} \underset{\sim}{X}'\underset{\sim}{y} \\ \underset{\sim}{Z}_1'\underset{\sim}{y} \\ \underset{\sim}{Z}_2'\underset{\sim}{y} \end{bmatrix}$$

where knowledge of $\frac{V_e}{V_{ds}}$ and $\frac{V_e}{V_s}$ are required. Although these parameters are never really known, estimates of these ratios can be obtained from variance component estimates reported in the literature. Few, and in some cases no, estimates were available. Since variance components of both sire and the breed of dam by sire interaction were available from the analyses of these data, these estimates were used to obtain appropriate ratios to be added to the diagonal of the respective equations.

In order to obtain a non-singular matrix, the last equation within each fixed class was set to zero. In obtaining the direct inverse, the breed of dam by sire within breed of sire interaction equations were absorbed to save computer time.

Fixed effects were examined by the use of reduction sums of squares. The effect of adding one fixed effect to the model over and above having the remaining fixed effects in it was tested by the F test, where the sums of squares for the added fixed effects were calculated by the difference in reductions of the total model and of the total model excluding the fixed effect of interest. Differences among means were tested utilizing the t test. This procedure is called the least significant difference (LSD) procedure (Steel and Torrie, 1960).

CHAPTER IV

RESULTS AND DISCUSSION

Variance Components

The variance components for sire within breed of sire and its interaction with breed of dam on sow productivity traits are presented in Table IV along with error components of variance. In all cases the sire component is less than the interaction and both are less than the error variance. The ratio of sire to error variance is largest for litter weight at birth.

Heritability estimates for these traits, calculated from the sire component are as follows: .25 for LSB, .31 for LWB, .28 for LSW, .21 for LWW and .04 for SUR. Approximate standard errors, which ranged from .68 to .72, were obtained for these estimates using an approximation formula (Swiger et al., 1964). Since litter characteristics are considered to be traits of the dam, paternal half-sib heritability estimates could be more accurately described as the proportion of variation in these traits due to the additive genetic effects of the sire. The estimates indicate that for these data the sire of the litter does account for a substantial portion of the variation of all traits with the exception of survival rate.

The breed of dam by sire within breed of sire interaction components for these traits suggest that the individual sire effect varies dependent upon the breed of dam. For all traits considered the error variance

TABLE IV

VARIANCE COMPONENTS FOR SOW PRODUCTIVITY TRAITS

Trait	V_s[a]	V_{ds}[b]	V_e[c]
Litter Size at Birth (N)	.5620	1.2115	6.9654
Litter Weight at Birth (Kg)	1.1707	2.8500	11.0899
Litter Size at Weaning (N)	.4518	.8699	5.0382
Litter Weight at Weaning (Kg)	41.3845	48.1042	682.1891
Survival Birth-Weaning (%)	3.8991	34.5737	344.0610

[a]Sire within Breed of Sire component.
[b]Breed of Dam x Sire within Breed of Sire interaction component.
[c]Residual error component.

accounted for a large proportion of the observed variation.

Analyses of Variance and Least Squares Means

The analyses of variance for the sow productivity traits are presented in Table V. Environmental factors, including year and season, failed to reach significance for both litter weight at birth and survival rate while parity was important ($P<.05$) for all traits except survival rate. There were no significant breed of sire or breed of sire by breed of dam interaction effects for any traits although, the interaction term approached significance ($P<.10$) for both litter weight at weaning and percent survival to weaning. The breed of dam term was important ($P<.05$) for all traits except litter size at weaning.

Genetic Differences

The primary interest of this study was to evaluate purebred performance and the combining ability of the Duroc, Spot, Yorkshire and Landrace breeds for sow productivity traits. The mating structure utilized allowed the estimation of individual breed performance as well as the importance of heterosis. Since these are the main objectives in this study, purebred and reciprocal cross as well as overall breed of dam and breed of sire least squares means are presented for the sow productivity traits (Tables VI, VII, VIII, IX, X).

It should be remembered that, for these analyses, litter size at birth includes all fully formed pigs born, not just those born alive. There were also instances of problem records after the birth information was collected; in most cases these records involved crossfostering for various reasons. These litters were included in the analyses of litter

TABLE V

LEAST SQUARES ANALYSES OF VARIANCE FOR SOW PRODUCTIVITY TRAITS

Source	df	Mean Squares				
		LSB (N)	LWB (Kg)	LSW (N)	LWW (Kg)	SUR (%)
Year (Y)	2	26.60*	13.13	26.66**	6135.52**	800.17
Season (S)	1	57.31**	25.97	44.11**	7603.73**	65.19
Parity (P)	2	99.61**	264.12**	25.98**	7554.47**	618.17
BOS	3	6.09	22.11	3.33	530.75	110.85
BOD	3	46.81**	100.08**	9.15	1988.59*	1075.47*
Y X S	1	33.02*	17.53	4.53	784.67	455.14
P X S	2	8.69	8.68	3.69	426.17	553.00
BOS X BOD	9	5.36	9.92	8.13	1301.10+	640.77+
BOD X S	3	13.60	42.79*	10.04	882.90	201.24
BOD X P	6	7.26	22.05+	6.17	690.49	792.78+
Error	333(312)[a]	7.12	11.55	5.32	722.43	379.09

+P<.10.
*P<.05.
**P<.01.
[a]Error degrees of freedom for weaning traits (LSW, LWW and SUR).

TABLE VI

PUREBRED AND RECIPROCAL CROSS LEAST SQUARES MEANS FOR LITTER SIZE AT BIRTH (N)

Breed of Dam (BOD)	Breed of Sire (BOS) Duroc	Spot	York	Landrace	BOD Means
Duroc	10.44 ± .73	11.62 ± .76	10.32 ± .76	11.60 ± .80	10.99 ± .42[a]
Spot	9.44 ± .76	9.40 ± .74	9.57 ± .80	9.10 ± .78	9.38 ± .41[b]
York	11.41 ± .81	12.40 ± .77	11.52 ± .77	9.97 ± .83	11.34 ± .42[a]
Landrace	10.06 ± .77	11.43 ± .80	10.43 ± .74	10.74 ± .73	10.67 ± .41[a]
BOS Means[c]	10.34 ± .46	11.21 ± .45	10.46 ± .46	10.35 ± .47	

[a,b]Breed of Dam means with different superscripts are significantly different (P<.05).

[c]Overall F test not significant (P>.05) for Breed of Sire.

TABLE VII

PUREBRED AND RECIPROCAL CROSS LEAST SQUARES
MEANS FOR LITTER WEIGHT AT BIRTH (KG)

Breed of Dam (BOD)	Breed of Sire (BOS)				BOD Means
	Duroc	Spot	York	Landrace	
Duroc	14.65 ± 1.00	16.80 ± 1.05	14.26 ± 1.05	16.18 ± 1.09	15.47 ± .57[a]
Spot	13.39 ± 1.05	12.80 ± 1.03	12.80 ± 1.10	12.28 ± 1.07	12.82 ± .56[b]
York	13.30 ± 1.1	15.56 ± 1.06	13.34 ± 1.07	11.79 ± 1.14	13.50 ± .58[b]
Landrace	15.58 ± 1.06	16.81 ± 1.09	14.27 ± 1.02	14.61 ± 1.01	15.31 ± .56[a]
BOS Means[c]	14.23 ± .63	15.49 ± .63	13.66 ± .64	13.72 ± .65	

[a,b]Breed of Dam means with different superscripts are significantly different ($P<.05$).

[c]Overall F test not significant ($P>.05$) for Breed of Sire.

TABLE VIII

PUREBRED AND RECIPROCAL CROSS LEAST SQUARES MEANS FOR LITTER SIZE AT WEANING (N)

Breed of Dam (BOD)	Breed of Sire (BOS)				BOD Means[c]
	Duroc	Spot	York	Landrace	
Duroc	6.29 ± .65	8.57 ± .69	7.09 ± .68	8.24 ± .71	7.55 ± .37
Spot	7.37 ± .70	6.85 ± .65	7.29 ± .71	7.25 ± .69	7.19 ± .37
York	8.06 ± .72	9.31 ± .68	7.25 ± .69	7.31 ± .77	7.99 ± .38
Landrace	8.09 ± .68	7.60 ± .71	8.18 ± .66	7.88 ± .65	7.94 ± .36
BOS Means[c]	7.45 ± .42	8.08 ± .40	7.45 ± .41	7.67 ± .42	

[c] Overall F test not significant ($P>.05$) for Breed of Dam or Breed of Sire.

TABLE IX

PUREBRED AND RECIPROCAL CROSS LEAST SQUARES MEANS FOR LITTER WEIGHT AT WEANING (KG)

Breed of Dam (BOD)	Breed of Sire (BOS)				BOD Means
	Duroc	Spot	York	Landrace	
Duroc	70.30 ± 6.76	94.24 ± 7.25	79.18 ± 7.01	90.63 ± 7.39	83.34 ± 3.94[a]
Spot	85.51 ± 7.27	74.26 ± 6.76	83.85 ± 7.39	83.50 ± 7.17	81.78 ± 3.82[a]
York	87.41 ± 7.62	97.90 ± 7.15	73.53 ± 7.13	80.66 ± 8.00	84.88 ± 4.01[a,b]
Landrace	97.99 ± 7.13	93.72 ± 7.40	90.59 ± 6.84	89.79 ± 6.64	93.02 ± 3.83[b]
BOS Means[c]	85.30 ± 4.30	90.03 ± 4.19	81.54 ± 4.21	86.14 ± 4.26	

[a,b]Breed of Dam means with different superscripts are significantly different ($P<.05$).

[c]Overall F test not significant ($P>.05$) for Breed of Sire.

TABLE X

PUREBRED AND RECIPROCAL CROSS LEAST SQUARES MEANS FOR PERCENT SURVIVAL FROM BIRTH TO WEANING (%)

Breed of Dam (BOD)	Breed of Sire (BOS)				BOD Means[a]
	Duroc	Spot	York	Landrace	
Duroc	67.80 ± 4.31	78.34 ± 4.63	72.04 ± 4.37	72.12 ± 4.74	72.57 ± 2.54
Spot	79.52 ± 4.60	74.25 ± 4.21	76.69 ± 4.68	79.96 ± 4.51	77.61 ± 2.42
York	68.35 ± 4.93	74.45 ± 4.57	64.21 ± 4.47	79.35 ± 5.02	71.59 ± 2.57
Landrace	83.71 ± 4.52	70.55 ± 4.71	81.69 ± 4.29	76.97 ± 4.04	78.13 ± 2.43
BOS Means[b]	74.74 ± 2.54	74.40 ± 2.45	73.66 ± 2.43	77.10 ± 2.45	

[a] Overall F test significant however no significant differences were detected between Breed of Dam means.
[b] Overall F test not significant for Breed of Sire.

birth traits but not for the analyses of traits associated with weaning.

Differences Due to Year, Season and Age of Dam

Environmental sources of variation account for much of the variation observed in the individual sow productivity traits (Lush and Molln, 1942; Omtvedt *et al*., 1966). Differences in these traits, over various levels of environmental conditions may be due to genetic differences or to changes in management or the environment.

The general trend is for spring born litters to be larger and heavier at both birth and weaning (Table XI). However, this project started in the fall of 1976 so no spring season was available for that comparison. Another trend was a general decrease in productivity of all traits from fall 1976 to fall 1978. It would be expected that this change is due to a time trend in the management of the swine herd rather than any genetic changes.

Litters from first parity gilts were smaller and lighter at both birth and weaning than subsequent parities ($P<.05$) (Table XII). However, preweaning death losses were lower for litters from first parity gilts than from sow litters. These results are generally consistent with reports in the literature (Stewart, 1945a; Omtvedt *et al*., 1966; Smith and McLaren, 1967; Bereskin *et al*., 1968). It should be noted here that for these data, litters from third parity sows and greater were combined to form the third parity in the analyses.

Discussion

Comparisons Among Purebreds

Extensive studies have been conducted on the performance of the

TABLE XI

LEAST SQUARES MEANS FOR SOW PRODUCTIVITY TRAITS BY YEAR AND SEASON

Trait	Fall 1976	Spring 1977	Fall 1977	Spring 1978	Fall 1978	SE
LSB (N)	10.89	10.20	10.08	10.75	8.91	.43[a]
LWB (Kg)	14.53	13.80	13.81	14.50	13.23	.57[b]
LSW (N)	7.99	7.81	7.10	7.55	6.17	.39[c]
LWW (Kg)	93.24	91.47	74.25	81.16	72.54	4.25[d]
SUR (%)	76.95	79.54	73.94	71.23	71.90	2.79[e]

[a]Standard errors ranged from .40 to .44.
[b]Standard errors ranged from .54 to .59.
[c]Standard errors ranged from .37 to .40.
[d]Standard errors ranged from 4.09 to 4.38.
[e]Standard errors ranged from 2.69 to 2.89.

TABLE XII

LEAST SQUARES MEANS FOR SOW PRODUCTIVITY TRAITS BY PARITY OF THE DAM

Trait	Parity		
	1	2	3
LSB (N)	$9.25^{a} \pm .34$	$11.12^{b} \pm .43$	$11.40^{b} \pm .33$
LWB (Kg)	$12.05^{a} \pm .45$	$15.37^{b} \pm .57$	$15.41^{b} \pm .45$
LSW (N)	$6.98^{a} \pm .30$	$7.99^{b} \pm .40$	$8.01^{b} \pm .30$
LWW (Kg)	$74.37^{a} \pm 3.28$	$91.05^{b} \pm 4.45$	$91.84^{b} \pm 3.16$
SUR (%)	$78.44^{a} \pm 2.14$	$74.19^{a,b} \pm 2.98$	$72.29^{b} \pm 2.00$

[a,b]Numbers within a row with different superscripts are significantly different ($P<.05$).

Duroc and Yorkshire breeds while relatively less information is available on the performance of the Spot and Landrace breeds. A part of these analyses was to compare these four breeds, as purebreds, for sow productivity traits (Table XIII).

Purebred Landrace litters were smaller at birth but larger at weaning when compared to Yorkshire litters, due to a significantly greater survival rate of the Landrace litters. Landrace litters were larger at birth and weaning than Duroc and Spot litters. The difference between Landrace and Duroc litters at weaning time approached significance ($P<.10$), again, due to the higher survival rate of the Landrace pigs. Landrace litters were heavier at weaning than Duroc ($P<.05$), Yorkshire ($P<.10$) and Spot ($P<.10$) litters. In contrast to these results, Smith and McLaren (1967) found litter size in Durocs was larger at all ages than Landrace. This difference was greater at weaning than at birth due to increased survival rate of Duroc pigs. They also found Duroc litters to be heavier at weaning than Landrace litters.

For these analyses, Yorkshire litters were larger in number of pigs at birth than litters from the other three breeds; there was a difference of 2.13 pigs ($P<.05$) between Yorkshire and Spot litters. By weaning age Landrace litters were larger than Yorkshires, and although Yorkshire litters were still larger than Duroc and Spot litters the differences were reduced. This change was due to a lower survival rate of the Yorkshire pigs compared to the Duroc, Spot ($P<.10$) and Landrace ($P<.05$) litters. These results agree with those of Young et al. (1976) who found Yorkshire litters were larger at birth and weaning than Duroc litters. However, in their analyses, these differences increased from birth to weaning due to a higher survival rate of Yorkshire pigs.

TABLE XIII

COMPARISONS AMONG PUREBREDS

Comparison[a]	LSB	LWB	LSW	LWW	SUR
DxD - SxS	1.04 ± 1.03	1.85 ± 1.42	-.56 ± .91	-3.96 ± 9.40	-6.45 ± 5.90
DxD - YxY	-1.08 ± 1.04	1.32 ± 1.44	-.96 ± .92	-3.24 ± 9.56	3.59 ± 6.02
DxD - LxL	-1.30 ± 1.01	.04 ± 1.40	-1.59 ± .90+	-19.49 ± 9.25*	-9.18 ± 5.74
SxS - YxY	-2.13 ± 1.07*	-.53 ± 1.47	-.40 ± .94	.73 ± 9.75	10.04 ± 6.10+
SxS - LxL	-1.34 ± 1.02	-1.81 ± 1.41	-1.03 ± .90	-15.53 ± 9.21	-2.73 ± 5.64
YxY - LxL	.78 ± 1.05	-1.28 ± 1.45	-.63 ± .93	-16.25 ± 9.59+	-12.77 ± 5.93*

[a]D=Duroc, S=Spot, Y=Yorkshire, L=Landrace; first letter indicates breed of sire, second letter indicates breed of dam.
+P<.10.
*P<.05.
**P<.01.

For these analyses no significant differences were detected for litter weight at birth, although the comparisons favored the Duroc litters. Landrace litters were most similar in weight to Durocs. Duroc litters were larger and heavier in comparison to Spot litters at birth, while they were smaller but heavier when compared to Yorkshire and Landrace litters. By weaning time, Duroc litters were smaller and lighter than any of the other three types of purebred litters.

Comparisons Among Breeds of Dam

Differences among breeds in maternal performance were significant for most traits associated with sow productivity (Table XIV). These differences were most apparent in the litter traits at birth. No significant differences were found for litter size at weaning.

Litters from Yorkshire dams were larger at birth than litters from the other three dam breeds. The difference of 1.62 pigs in comparison with litters from Spot dams was significant ($P<.01$), but advantages of .33 and .66 over litters from Duroc and Landrace females failed to be significant. Duroc and Landrace females also produced litters which were larger ($P<.05$) than litters from Spot females. Similar to results reported in the purebred comparisons, Yorkshire dams produced litters which were larger at birth, but litters out of both Duroc and Landrace females were heavier ($P<.01$ and $P<.05$, respectively). These Duroc and Landrace females also produced litters which were heavier at birth than litters from Spot dams. The difference in litter weight between Spot and Yorkshire females was .68 kg.

There were no significant differences between dam breeds for litter size at weaning. For this trait all comparisons favored the Yorkshire

TABLE XIV

COMPARISONS AMONG BREEDS OF DAM

Comparison[a]	LSB	LWB	LSW	LWW	SUR
D♀ - S♀	1.62 ± .53**	2.65 ± .73	.36 ± .47	1.56 ± 4.96	-5.03 ± 3.27
D♀ - Y♀	-.33 ± .54	1.98 ± .73**	-.44 ± .48	-1.54 ± 5.06	.98 ± 3.35
D♀ - L♀	.33 ± .53	.16 ± .72	-.39 ± .47	-9.68 ± 4.94*	-5.56 ± 3.26[+]
S♀ - Y♀	-1.95 ± .54**	-.68 ± .74	-.80 ± .49	-3.10 ± 5.16	6.02 ± 3.42[+]
S♀ - L♀	-1.29 ± .50	-2.49 ± .69	-.75 ± .44	-11.24 ± 4.61*	-.52 ± 3.01
Y♀ - L♀	.66 ± .54	-1.82 ± .73*	.05 ± .49	-8.15 ± 5.16	-6.54 ± 3.42[+]

[a]D=Duroc, S=Spot, Y=Yorkshire, L=Landrace.
[+]P<.10.
*P<.05.
**P<.01.

dams. However, the advantage which Yorkshire dams expressed for litter size at birth was reduced when measured at weaning due to the decreased survival rate of litters out of Yorkshire females. Litters from Landrace and Spot dams showed greater ($P<.10$) survival rates than litters mothered by Yorkshire females and litters by Landrace females also had a higher ($P<.10$) survival rate than litters from Duroc dams. Because of the higher survival rate of litters from Landrace and Spot females, differences in litter size between Spot and Yorkshire females were reduced from 1.95 pigs at birth to .80 pigs at weaning, and differences in litter size between Landrace and Yorkshire females were reduced from .66 pig to .05 pig by weaning time. Differences between litters from Duroc and Spot females were reduced from 1.62 pigs to .36 pig per litter and litter size differences between Duroc and Landrace dams changed from a .33 pig advantage for Duroc females to a .36 pig advantage for Landrace females at weaning. Litters from Spot females were still smaller than litters from the other three breeds of dam. When considering litter weight at weaning, litters from Landrace females were significantly heavier than either Duroc or Spot mothered litters and 8.15 kg heavier than litters from Yorkshire females. Litters by Spot females were the lightest at weaning. When examining the results of these analyses, it must be remembered that creep feed was made available to the litters of approximately 21 days of age, so that differences in litter weight at weaning would be due to differences in litter size, maternal characteristics of the dam and direct genetic effects for individual pig growth, as well as differences in consumption of creep feed. Of course creep feed consumption is likely to be influenced by each of the other factors also.

These data are in partial agreement with reports in the literature

(Fahmy et al., 1971; Johnson et al., 1972; Omtvedt et al., 1973; Young et al., 1976) on breed of dam comparisons for sow productivity traits. However, Fahmy et al. (1971) indicated that Yorkshire and Landrace females produced larger and heavier litters with lower preweaning mortality rates than did the Duroc females. The other reports also indicated a larger survival rate of pigs from Yorkshire dams. Results from Leigh (1977) are also similar to these analyses. In his study Large White females, which include Yorkshire and Landrace females, showed the highest preweaning mortality rate, however, the litter weight at weaning was highest for litters from Hampshire females.

For this study, it appears that pigs produced by Yorkshire females were considerably lighter in weight at birth than pigs from the other three breeds of dam. This may indicate that the decreased survival rate of litters from Yorkshire females was partially due to a decrease in pig livability for the light weight pigs, rather than an increased percentage of stillborn pigs. Conversely the decreased survival rate of litters from Duroc females seems to have been a result of an increased percentage of pigs born dead. Young et al. (1976), in an analyses which included individual pig weights, found pigs from Yorkshire females were significantly lighter at birth than either Duroc or Hampshire pigs. However, in their analyses litters from Yorkshire females had a significantly higher survival rate than did litters from Duroc females.

No significant differences were detected (P>.10) between breeds of dam for litter size at weaning. This is a result of the decreased survival rate by pigs of the largest litters at birth, those from Yorkshire females, and a higher survival rate of pigs from Spot females, which had the smallest litter size at birth. Survival rate of the litters from Duroc females was intermediate to those litters from Spot and Yorkshire females, while Landrace females produced litters which had the highest survival rate. This resulted in partial equalization of litter size at weaning among the four breeds of dam.

Litter weight at weaning can be utilized as an evaluation of maternal abilities (Ahlshwede and Robison, 1971; Young et al., 1976). Utilizing this evaluation, Landrace females were more productive in terms of keeping their pigs alive and supplying adequate nutrition for them to grow, although creep feed was available. Yorkshire females also produced litters which were larger and heavier at weaning than did Duroc and Spot females, although these differences were not significant. Twenty-one day litter weight would probably be a more accurate measure of maternal abilities in swine, but in these analyses litter weight at weaning (42 days) is the best evaluation available.

Comparisons Among Breeds of Sire

Breed of sire effects on sow productivity traits are compared in Table XV. This comparison evaluates the average performance of a sire breed when mated to all breeds of dam. Differences were not significant for litter size at birth or weaning, litter weight at weaning or survivability. Spot sired litters were .88, .86 and .75 pig larger at birth than Duroc, Landrace and Yorkshire sired litters, respectively. At weaning time Spot sired litters were .63, .63 and .41 pig larger and 4.73, 8.49 and 3.89 kg heavier than Duroc, Yorkshire and Landrace sired litters, respectively. Differences in survival rate were not large.

Breed of sire effects on litter weight at birth were fairly large and significant, with all comparisons involving the Spot sired litters

TABLE XV

COMPARISONS AMONG BREEDS OF SIRE

Comparison[a]	LSB	LWB	LSW	LWW	SUR
D♂ - S♂	-.88 ± .62	-1.26 ± .86	-.63 ± .55	-4.73 ± 5.67	.35 ± 3.26
D♂ - Y♂	-.12 ± .61	.57 ± .85	.00 ± .55	3.76 ± 5.60	1.09 ± 3.18
D♂ - L♂	-.02 ± .62	.52 ± .86	-.22 ± .56	-.84 ± 5.69	-2.36 ± 3.25
S♂ - Y♂	.75 ± .62	1.83 ± .86*	.63 ± .55	8.49 ± 5.64	.74 ± 3.22
S♂ - L♂	.86 ± .62	1.78 ± .87*	.41 ± .56	3.89 ± 5.74	-2.71 ± 3.29
Y♂ - L♂	.11 ± .62	-.05 ± .87	-.22 ± .56	-4.60 ± 5.72	-3.44 ± 3.24

[a]D=Duroc, S=Spot, Y=Yorkshire, L=Landrace.
+P<.10.
*P<.05.

indicating that they were heavier. When compared to Yorkshire and Landrace sired litters, Spot sires produced litters which were 1.83 and 1.78 kg heavier (P<.05) at birth. Spot sired litters were also 1.26 kg heavier (P>.10) than Duroc sired litters. All comparisons that did not involve Spot sires indicated much smaller differences. These data contrast with results reported by Young et al. (1976). Their data suggested that breed of service sire affects litter size and weight, at 0, 21 and 42 days of age, as well as preweaning pig survival.

A comparison of the breed of sire effect on crossbred litter production was made (Table XVI). Since crossbred pigs generally exhibit heterosis for some of the sow productivity traits, it is important to evaluate differences between breeds of sire used to sire these crossbred litters. When mated to Duroc females, Spot boars sired larger and heavier litters at both birth and weaning than Yorkshire and Landrace boars. These differences in litter size and weight increased with age of the litter due to a higher survival rate of Spot sired pigs. Differences in litter weights, at both ages, between Spot and Yorkshire sired litters approached significance (P<.10), differences in litter sizes and survival rate, between these two sire breeds, were rather large but nonsignificant. Yorkshire boars sired crossbred litters which were 12.45 kg heavier at weaning than Landrace sires, although Landrace sired crossbred litters were larger at both birth and weaning and also heavier at birth.

For boars mated to Spot dams, differences among breeds of sire were small and standard errors of these differences were large. Comparisons generally favored Duroc sired litters for litter size and weight traits, while Landrace sired litters had higher survival rates.

When mated to Yorkshire females, Spot boars sired litters were

TABLE XVI

EFFECT OF BREED OF SIRE ON CROSSBRED LITTER PRODUCTION

Comparison[a]	LSB	LWB	LSW	LWW	SUR
SxD - YxD	1.31 ± 1.04	2.54 ± 1.43+	1.48 ± .93	16.06 ± 9.71+	6.30 ± 6.10
SxD - LxD	.02 ± 1.07	.62 ± 1.47	.33 ± .96	3.61 ± 10.08	6.22 ± 6.43
YxD - LxD	-1.28 ± 1.07	-1.915± 1.48	-1.15 ± .95	12.45 ± 9.88	-.08 ± 6.24
DxS - YxS	-.14 ± 1.08	.59 ± 1.49	.08 ± .97	1.66 ± 10.10	2.83 ± 6.36
DxS - LxS	.34 ± 1.06	1.11 ± 1.45	.12 ± .95	2.02 ± 9.86	-.44 ± 6.19
YxS - LxS	.48 ± 1.10	.52 ± 1.52	.04 ± .98	.36 ± 10.18	-3.27 ± 6.42
DxY - SxY	-.99 ± 1.11	-2.26 ± 1.52	-1.25 ± .99	-10.49 ± 10.43	-6.10 ± 6.71
DxY - LxY	1.44 ± 1.10	1.52 ± 1.51	.75 ± 1.01	6.75 ± 10.55	-11.00± 6.68+
SxY - LxY	2.43 ± 1.12*	3.78 ± 1.54*	2.00 ± 1.02*	17.24 ± 10.62	-4.91 ± 6.72
DxL - SxL	-1.36 ± 1.09	-1.22 ± 1.49	.49 ± .96	4.28 ± 9.98	12.76 ± 6.3*
DxL - YxL	-.37 ± 1.04	1.33 ± 1.43	-.09 ± .92	7.40 ± 9.51	1.62 ± 5.97
SxL - YxL	1.00 ± 1.07	2.55 ± 1.47+	-.59 ± .94	3.13 ± 9.78	-11.14 ± 6.15+

[a] D=Duroc, S=Spot, Y=Yorkshire, L=Landrace; first letter indicates breed of sire, second letter indicates breed of dam.

+P<.10.

*P<.05.

**P<.01.

significantly larger and heavier at birth and larger at weaning than Landrace sired litters and the difference in litter weight at weaning was also large. Again Landrace sired litters had higher survival rates, this difference was large ($P<.10$) when compared to Duroc sired litters.

Differences in litter size and weight traits were small when comparisons between sire breeds were made on Landrace females. Spot sired litters were larger and heavier at birth but smaller at weaning when compared to Duroc and Yorkshire sired litters. These changes were due to a greater survival rate of Duroc ($P<.05$) and Yorkshire ($P<.10$) sired litters. Duroc boars sired litters which were smaller but heavier at birth than Yorkshire sired litters. At weaning there was essentially no difference in litter size, due to the greater survival rate of Duroc sired litters, but litters by Duroc boars were much heavier. These results are similar to results reported by Kuhlers et al. (1980), when Duroc and Yorkshire boars were mated to Landrace females.

These data indicate that some breed of sire differences may exist for sow productivity traits, although breed of sire did not account for a significant portion of the variation of these traits in the analyses of variance. It would also appear that the response to crossbreeding, for a particular breed of dam, is somewhat dependent upon the sire breed used in the production of the crossbred litter. In the production of crossbred litters, Duroc and Spot sired litters were, in all cases, heavier at both birth and weaning than Yorkshire and Landrace sired litters. This suggests that the breed of sire direct genetic effect is important for these traits.

Comparison of Reciprocal Cross Means and Heterosis Estimation

The breed of sire by breed of dam interaction explained a portion ($P<.10$) of the variation in both litter weight at weaning and survivability. To investigate any heterotic effects on sow productivity traits, comparisons were made between the mean of the reciprocal crosses and the mean of the respective purebred parents. In addition, contrasts were made between reciprocal crosses. Since reciprocal crosses produced would be expected to contain similar gene combinations, any differences between reciprocals would be expected to be due to maternal genetic differences or to an interaction of the maternal genetic effects and the direct genetic effects.

A comparison among reciprocals for sow productivity traits (Table XVII) indicates significant differences do exist for all traits except litter weight at weaning. All differences ($P<.05$) between reciprocal crosses for litter size at birth and weaning and litter weight at birth involved crosses with the Spot breed. The largest differences in litter size at birth (2.83 pigs) and weaning (2.02 pigs) was exhibited by Spot-Yorkshire reciprocals and the difference in litter weight at birth (4.52 kg) involved Spot-Landrace reciprocals. The largest difference between reciprocals for survival rate ($P<.10$) involved Duroc-Landrace reciprocal crosses. Large differences between reciprocal crosses would indicate that the amount of heterosis obtained from crossbreeding is dependent upon the breeds and mating structure utilized. Other reports in the literature which also indicate a heterosis by mating structure dependency was presented in the literature review (Table II).

Reciprocal cross means were combined for the estimationg of heterosis

TABLE XVII

COMPARISON OF RECIPROCAL CROSS MEANS

Comparison[a]	LSB	LWB	LSW	LWW	SUR
DxS - SxD	-2.19 ± 1.06*	-3.41 ± 1.46*	-1.20 ± .96	-8.73 ± 10.02	1.18 ± 6.34
DxY - YxD	1.10 ± 1.10	-.96 ± 1.50	.98 ± .97	9.23 ± 10.19	-3.69 ± 6.48
DxL - LxD	-1.54 ± 1.10	-.59 ± 1.50	-.15 ± .97	7.36 ± 10.13	11.19 ± 6.45+
SxY - YxS	2.83 ± 1.10*	2.76 ± 1.52+	2.02 ± .98	14.05 ± 10.23	-2.25 ± 6.51
SxL - LxS	2.33 ± 1.10*	4.52 ± 1.51**	.35 ± .97	10.22 ± 10.10	-9.41 ± 6.36
YxL - LxY	.46 ± 1.10	2.47 ± 1.51	.87 ± 1.01	9.93 ± 10.51	2.33 ± 6.60

[a]D=Duroc, S=Spot, Y=Yorkshire, L=Landrace; first letter indicates breed of sire, second letter indicates breed of dam.
+P<.10.
*P<.05.
**P<.01.

TABLE XVIII

LEAST SQUARES ESTIMATES OF HETEROSIS[a]
FOR SOW PRODUCTIVITY TRAITS

Reciprocal[b] Crosses	LSB (N)	LWB (Kg)	LSW (N)	LWW (Kg)	SUR (%)
S-D crosses	.61 ± .68	1.37 ± .93	1.39 ± .61*	17.60 ± .36**	7.91 ± .17+
D-Y crosses	-.11 ± .69	-.21 ± .95	.80 ± .61	10.88 ± 6.36+	4.19 ± 4.17
D-L crosses	.24 ± .69	1.25 ± .94	1.08 ± .61+	14.27 ± 6.36*	5.33 ± 4.16
S-Y crosses	.53 ± .72	1.11 ± .98	1.25 ± .63*	16.98 ± 6.58**	6.34 ± 4.31
S-L crosses	.19 ± .70	.84 ± .96	.07 ± .62	6.59 ± 6.42	-.36 ± 4.18
Y-L crosses	-.93 ± .70	-.95 ± .97	.18 ± .63	3.97 ± 6.55	9.93 ± .25*
Overall[c]	.09 ± .40	.57 ± .54	.79 ± .35+	11.72 ± 3.63**	5.56 ± 2.36*

[a]Heterosis expressed as a deviation from the respective purebred average in the same unit as each trait.
[b]D=Duroc, S=Spot, Y=Yorkshire, L=Landrace.
[c]Overall crossbred average minus overall purebred average.
+P<.10.
*P<.05.
**P<.01.

(Table XVIII). Reciprocal crosses involving Yorkshire and Duroc or Landrace failed to perform as well as the average of the respective purebreds on litter size and weight at birth. All other heterosis estimates for these two traits were positive although none were significant. Comparing the average of all crossbreds to the average of all purebreds for these traits resulted in positive, but very small, heterosis estimates.

Specific comparisons among breed crosses and respective purebreds for litter size at weaning indicate both Spot-Duroc and Spot-Yorkshire reciprocal crosses exhibited a substantial ($P<.05$) amount of heterosis. Duroc-Landrace crosses also showed heterosis ($P<.10$) for litter size at weaning. Other comparisons were nonsignificant although all were positive. Overall, crossbred litters were .79 pig larger at weaning than the average of all purebred litters ($P<.10$).

The overall heterosis estimates were significant for litter weight at weaning and survivability which were the traits for which the breed of sire by breed of dam interaction was important. Large amounts of heterosis for litter weight at weaning was exhibited in all crosses except the Spot-Landrace and Yorkshire-Landrace reciprocals. Duroc-Spot and Spot-Yorkshire reciprocal crosses were 17.60 and 16.98 kg heavier than their respective purebred averages ($P<.01$). Duroc-Landrace and Duroc-Yorkshire crosses were 14.27 kg ($P<.05$) and 10.88 kg ($P<.10$) heavier than their respective purebred averages. Overall, the 11.72 kg difference of crossbreds over purebreds was highly significant ($P<.01$). The overall comparison for survival rate favored the crossbred litters where 5.56 percent more crossbred pigs survived until weaning than purebred pigs, however, many of the specific comparisons were not large. The comparison involving Spot-Landrace crosses was small and negative while all others exhibited positive heterosis. Yorkshire-Landrace reciprocal crosses expressed 9.93 percentage units greater survival rate ($P<.05$) than the average of the respective purebreds. Heterosis for survival rate approached significance ($P<.10$) for the Duroc-Spot crosses. The other three comparisons showed heterosis which was not large in comparison with their standard errors.

Few investigations have been made utilizing the same breed combinations which were utilized in this study. In order to make the heterosis estimates comparable to other reports in the literature, heterosis as a percent advantage over the purebred mean is presented (Table XIX). The overall percent heterosis estimates are similar to those presented by Johnson (1980) and Sellier (1976) (Table I), while individual estimates were quite variable.

Percent heterosis for crosses involving Yorkshires and the Landrace or Duroc breeds, which all farrowed similarily large litters, were negative for litter size and weight at birth. However, heterosis was positive when measured at weaning, due to a greater survival rate of the crossbred offspring. Data presented by Young et al. (1976), found heterosis for Yorkshire-Duroc crosses was significantly positive for litter size and weight traits measured at birth and 42 days of age. Survival rate was also higher in crossbred offspring. In contrast to these data, heterosis for Spot-Landrace crosses was positive for all traits except survival rate. Therefore, the crossbred advantage in litter size decreased from birth to weaning, although the crossbred advantage in litter weight increased slightly during the same period. This would suggest that heterosis for growth rate during this period is also positive.

These results are in agreement with most research which has found that crossbred pigs have a higher survival rate and crossbred litters

TABLE XIX

HETEROSIS AS A PERCENTAGE ADVANTAGE OVER THE PUREBRED MEAN

Reciprocal[a] Crosses	LSB	LWB	LSW	LWW	SUR
D - S	6.15	9.98	21.16	24.35	11.14
D - Y	-1.00	-1.50	11.82	15.13	6.35
D - L	2.27	8.54	15.23	17.83	7.36
S - Y	5.07	8.49	17.73	22.98	9.16
S - L	1.89	6.13	.95	8.03	-.48
Y - L	-8.36	-6.80	2.37	4.86	14.07
Overall[b]	.01	4.12	11.17	15.23	7.85

[a]D=Duroc, S=Spot, Y=Yorkshire, L=Landrace, first letter indicates breed of sire, second letter indicates breed of dam.
[b]Overall crossbred average minus overall purebred average.

are larger and heavier at weaning than respective purebreds (Winters et al., 1935; Hutten and Russel, 1939; Lush et al., 1939; Craft, 1953; England and Winters, 1953; Whatley et al., 1954; Smith and McLaren, 1967; Young et al., 1976). However, many of the earlier crossbreeding studies involved inbred lines and breeds which have changed dramatically in recent years, so those estimates may not be valid for todays breed types.

It seems apparent that if crossbreeding is to be utilized to its greatest advantage, the choice of breeds to be crossed is still of major importance. The amount of heterosis obtained in crossing varies with the traits and breeds involved so that breed complimentarity may be used in the decision of which breeds to use in a crossbreeding system. Dickerson (1969) in a discussion of utilizing breed resources stated that superiority in traits known to be maternally controlled will identify breeds more suitable as female parents in crossing. Similarily, superiority in traits largely determined by the individual genotype identifies a promising sire breed. Since sow productivity traits are largely determined by the maternal characteristics of the sow, then identification of sow breeds which excel in maternal abilities will aid in determining a female breed for a crossbreeding system. For these analyses, the Landrace females are the most productive in terms of litter weight at weaning and their ability to raise a high percentage of their offspring from birth to weaning. Yorkshire females are also quite productive in terms of their ability to farrow and wean the largest litters. In these analyses Duroc females were intermediate and Spot females were the lowest in maternal ability. The lower maternal ability of Spot females is also indicated by significant differences between reciprocal crosses involving the Spot breed. This suggests that a crossbreeding system should include either Landrace or Yorkshire females in the dam line, rather than Duroc or Spot females.

If we examine the breed of sire effects on sow productivity, it seems logical that direct genetic effects from the sire would most likely influence individual pig weights and growth characteristics, both of which function in litter weight at birth and weaning. For these traits, Spot sired litters were heavier and Yorkshire sired litters were lighter at both ages than litters from the other two breeds of sire. Spot boars also sired larger litters at both birth and weaning than the other three sire breeds. It is not known whether these differences were due to a greater number of fertilized ova or to a lower embryonic mortality rate. Very little experimental evidence is available to make this distinction. From these analyses it appears as though Spot sires should be considered in the design of a crossbreeding system. However, more information is needed on both pre- and postweaning performance of Spot sired pigs before a more conclusive characterization can be made.

CHAPTER V

SUMMARY

Data were collected from 366 litters produced in a four breed diallel mating system. Purebred and crossbred litters were farrowed during five consecutive fall and spring farrowing seasons (Fall 1976 - Fall 1978). Litters were produced by randomly mating boars of each breed to at least one female of each breed.

Litters were farrowed in confinement during March and April of the spring season and during September and October of the fall farrowing season. Litter weights were calculated, including all fully formed piglets, at birth. Litters were moved to either pasture lots, with three to four litters per lot, or to a solid floored confinement building, with one litter pen, at one or two weeks of age. Creep feed was made available to litters between two and three weeks of age and litters were weaned at approximately six weeks of age. Litter weights at weaning were calculated after adjusting individual pig weights to a 42 day weaning age. Percent surviving from birth to weaning was calculated by the ratio of number weaned to number born.

Heritability estimates for sow productivity traits were low to moderate, based on paternal half-sib estimates. Since litter characteristics are traits of the dam, these estimates would be better described as the proportion of the variation in these traits due to the additive genetic effect of the sire. With this definition, these estimates show that the sire of the litter does account for a substantial proportion of the variation in these traits with the exception of survivability. For all traits considered the error variance accounted for a large portion of the observed variation.

There were significant year, season and parity effects for most all traits involved. Spring born litters were generally larger and heavier than fall born litters and a general decrease in all traits over the five year-season periods. In terms of litter size and weight, second and third parity sows were more productive than gilts although gilt litters showed a lower preweaning death loss.

Large breed of dam differences were detected for most sow productivity traits. Litters from Spot females were smaller and lighter at all ages in comparison to litters from the other three breeds of dam. Litters by Yorkshire females were the largest at both birth and weaning but litter weight at both ages was similar to the litters by Spot dams. Landrace females were the most productive in terms of litter weight at weaning, where litters by Landrace females were more than eight kilograms heavier than litters from the other three breeds of dam. Landrace females also raised a higher proportion of their pigs from birth to weaning than did the other three breeds of dam. Duroc females had litters which were the heaviest at birth but were intermediate for all other traits.

Breed of sire differences were not significant for any trait in the analyses of variance, but differences were detected in individual breed of sire comparisons. These differences were generally in favor of Spot sired litters.

The interaction between breed of sire and breed of dam explained a small portion of the variation in litter weight at weaning and survivability.

Reciprocal crosses were combined to allow estimation of heterosis, although differences between reciprocal crosses were detected in some cases. Reciprocal crosses involving Yorkshire and Duroc or Landrace breeds failed to perform as well as the average of their respective purebred means for litter size and weight at birth. Overall, heterosis estimates for these two traits were positive but not significantly so. Significant heterosis estimates were obtained for litter size and weight at weaning and for survivability. Crosses involving the Spot and Duroc or Yorkshire and Duroc with Landrace breeds were consistently high in their heterotic effect of these three traits. Yorkshire-Landrace crosses showed the greatest amount of heterosis for survival rate while Spot-Landrace crosses had a negative heterosis estimate. Overall, crossbred litters were .79 pig larger and 11.72 kg heavier at weaning and had a 5.56 percent higher survival rate than the average of all purebreds.

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APPENDIX

TABLE XX

NUMBER OF LITTERS OF EACH BREED TYPE
TO BE PRODUCED EACH SEASON

Breed of Sire	Number of Sires	Breed of Dam			
		D	S	Y	L
Duroc (D)	4	6	4	4	4
Spot (S)	4	4	6	4	4
York (Y)	4	4	4	6	4
Landrace (L)	4	4	4	4	6

TABLE XXI

NUMBER OF LITTERS PRODUCED BY BREED GROUP IN EACH YEAR SEASON

Breed Group[b]	Fall 1976	Spring 1977	Fall 1977	Spring 1978	Fall 1978	Breed Group Totals
D x D	5	8	5	5	5	28 (1)[a]
D x S	5	5	5	3	5	23 (2)
D x Y	6	4	5	2	4	21 (1)
D x L	4	5	5	4	4	22 (1)
S x D	4	6	4	3	5	22 (2)
S x S	4	5	5	7	4	25 (1)
S x Y	5	6	4	3	4	22 (1)
S x L	5	5	5	3	2	20 (1)
Y x D	6	6	3	5	4	24 (1)
Y x S	5	3	4	5	3	20 (1)
Y x Y	3	6	5	5	4	23 (1)
Y x L	5	5	5	6	4	25 (1)
L x D	5	3	5	3	4	20 (1)
L x S	4	5	5	5	3	22 (1)
L x Y	6	4	3	4	3	20 (3)
L x L	4	7	7	5	6	29 (2)
Year-Season Totals	76	83	75	68	64	366 (21)

[a]Number of litters which were not included in the analysis of weaning traits.

[b]D=Duroc, S=Spot, Y=Yorkshire, L=Landrace; first letter indicates breed of sire, second letter indicates breed of dam.

TABLE XXII

NUMBER OF LITTERS PRODUCED IN EACH BREED GROUP BY PARITY

Breed Group[b]	Parity 1	Parity 2	Parity 3[a]
D x D	5	4	19
D x S	11	7	5
D x Y	5	3	13
D x L	9	6	7
S x D	5	6	11
S x S	7	8	10
S x Y	11	7	4
S x L	7	7	6
Y x D	6	4	14
Y x S	8	4	8
Y x Y	7	6	10
Y x L	9	6	10
L x D	8	4	8
L x S	8	9	5
L x Y	7	3	10
L x L	10	9	10
Overall	123	93	150

[a]Parity three includes all sow parities greater than two.

[b]D=Duroc, S=Spot, Y=Yorkshire, L=Landrace; first letter indicates breed of sire, second letter indicates breed of dam.

TABLE XXIII

INDEX AND ADJUSTMENT FACTORS

1. $I = 550 - 2[\text{age (days)}] - 35.4\,[\text{BF (cm)}]$

   I = Index value for gilt selection
   Age (days) = Adjusted age at 90.7 kg
   BF (cm) = Adjusted backfat at 90.7 kg

2. Age at 90.7 kg

$$\frac{\frac{90.7 - wi}{wi}}{age-31} + \text{age (days)} = \text{Adjusted age at 90.7 kg}$$

3. Probe backfat at 90.7 kg

$$\frac{BFwi}{wi} \times 90.7 \text{ kg} = \text{Adjusted probe backfat (cm)}$$

   wi = Weight when probed (kg)

   BFwi = Probe backfat (cm) at weight wi

4. Adjusted 42-day weight

$$\frac{\text{Actual weight} \times 27.7}{\text{Actual age} - 14.3}$$

VITA

Harold Ray Gaugler

Candidate for the Degree of

Master of Science

Thesis: SOW PRODUCTIVITY COMPARISONS FOR FOUR BREEDS OF SWINE IN THE PRODUCTION OF PUREBRED AND CROSSBRED LITTERS

Major Field: Animal Science

Biographical:

Personal Data: Born in Elgin, North Dakota, October 1, 1955, the son of Raymond and Mary Gaugler.

Education: Graduated from New Leipzig High School, New Leipzig, North Dakota, in May, 1973; received the Bachelor of Science degree from North Dakota State University, Fargo, North Dakota, with a major in Animal Science, in November, 1977; completed the requirements for the Master of Science degree at Oklahoma State University in December, 1980.

Experience: Grew up on a diversified farm and ranch operation in southwestern North Dakota; extensive involvement in student government during high school and college; livestock buyer for the Hormel Company, 1978; performed general and managerial work for the North Dakota State University Nutrition Research Center, 1978; Animal Science Research and Teaching assistant, Oklahoma State University, 1979-1980.