COMPARISON OF CROSSBRED AND PUREBRED BOARS FOR REPRODUCTIVE PERFORMANCE AND PROGENY GROWTH AND CARCASS MERIT

by

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ABSTRACT

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COMPARISON OF CROSSBRED AND PUREBRED BOARS FOR REPRODUCTIVE PERFORMANCE AND PROGENY GROWTH AND CARCASS MERIT

The effects of breed, sire within breed, and induction of parturition on productive and reproductive traits in swine were investigated using a within-litter evaluation technique. Data from 92 double-mated litters (529 pigs) were analyzed by least-squares and non-parametric methods, as was semen data from 14 sires, representing four breeds (Landrace, Hampshire, Duroc, and Hampshire-Duroc cross).

Breed of sire and sire within breed differences were significant for semen volume (the Hampshire-Durocs being ranked first). Hampshire-Duroc progeny were superior to all other breeds for birth weight and carcass yield, but ranked behind the Hampshires and Durocs, and ahead of the Landrace, for carcass index, backfat depth, days to market, and average daily gain to market. Induction of parturition had a significant effect on birth weight. No significant effects of breed of sire, sire, or treatment were found on sex ratio or per cent survival to weaning.

Maîtrise en Science Zoötechnie

RESUME

Peter Douglas Conlon

COMPARAISON ENTRE LES VERRATS CROISSES ET LES VERRATS DE RACE PURE POUR LEUR PERFORMANCE REPRODUCTIVE, LA CROISSANCE DE LEUR PROGENITURE ET LE RENDEMENT DE LEUR CARCASSE

Les effets de la race, de l'individu à l'intérieur de la race, et de la parturition par induction sur les traits productifs et reproductifs chez les porcs furent étudiés en utilisant la technique d'évaluation à l'intérieur d'une portée. Les données des 92 portées provenant d'accouplements doubles (529 porcs) furent analysées par la méthode des moindres carrés et de méthodes non-paramétriques, ainsi que les données sur la semence de 14 mâles, représentant 4 races (Landrace, Hampshire, Duroc, et le croisement Hampshire-Duroc).

La race du mâle et les différences du mâle à l'intérieur d'une race furent significatives pour le volume de semence (Hampshire-Durocs étant au premier rang).

La progéniture des Hampshire-Durocs fut supérieure à toutes les autres races pour le poids à la naissance et le rendement pour la carcasse, mais se sont classés après les Hampshires et les Durocs, et avant les Landraces, pour l'index de la carcasse, l'épaisseur du gras dorsal, le nombre de jours au marché, et la moyenne de gain par jour jusqu'au marché. La parturition par induction a un effet significatif sur le poids à la naissance. La race du mâle, le mâle ou le traitement n'ont pas influencé le sexe de la portée et le pourcentage de survivants au sevrage.

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I. INTRODUCTION

The improvement of animal populations depends on finding superior individuals or breeds which will upgrade the level of production of the specific population. Animal breeders must experiment with new crosses or breeds to improve the genetic merit of the animals with which they are working. The upgrading of a population can be accomplished either by selecting superior animals from the population itself, or by introducing new animals to the genetic pool.

The detection of superior animals within the population can be carried out either by performance or progeny testing.

In performance testing, an animal's individual merit is assessed by measuring a relevant trait within that animal, and comparing his performance to that of his comtemporaries. This method or testing is often not useful for the evaluation of animals for traits which are only expressed in one sex (e.g. milk yield), or for carcass traits, which must be measured after slaughter of the animal.

Progeny testing removes the drawbacks of performance testing in the evaluation of sex-limited or carcass traits. The progeny of one animal are evaluated against the progeny of his or her contemporaries. Progeny testing can be used to study sex-limited traits (e.g. milk yield of a bull's daughters) or carcass traits (e.g. carcass yields of a boar's progeny).

Once a superior animal is detected, he or she is used in matings within the herd or flock, and the overall value of the specific trait in that population is improved.

If superior animals are to be introduced to the population, they can be either the same as, or different from, the population breed. Animals of the same breed improve its genetic worth if they themselves are superior. The use of animals of a different breed is practised when the new breed possesses characteristics not found in the population. The combination of these new characters with those of the original population should produce superior offspring.

In swine, much use has been made of both systems of upgrading - that is, performance and progeny testing, and the inclusion of new strains or breeds in the population. The Danish Landrace breed has been kept pure for over eighty years but, because of rigid selection practices, has become one of the premier breeds of swine for productive and reproductive characteristics. Many new breeds, such as the Lacombe, and the Minnesota Nos. 1, 2, and 3 have been developed by the crossing of strains or breeds. Thus, both selection and crossing have been extremely useful in improving swine breeds over the years.

Because of the polygymous nature of swine - that is, one male mates with many females, it is easier to upgrade a swine herd by improving the quality of the boars used rather than that of the sows, since many fewer boars are used than sows, even though, genetically, each is equally important in the performance of their offspring. Also, if new breeds are to be brought into the herd, it is more convenient, and less expensive, to import them in the form of one or two boars rather than a large number of sows.

Therefore, the problem facing the animal breeder and the swine producer is how best to upgrade the quality of the animals in a certain population. This study presents one possible method - the use of crossbred boars.

The use of these boars allows the combination of the superior traits of two or more breeds in the boars themselves. Also, since the boars are crossbred, they benefit from heterosis, as will their offspring, when the boars are bred to sows of a different breed.

II. REVIEW OF LITERATURE

1. Heterosis

Crossbreeding has long been of economic importance to agriculture, and is used either to introduce new genes into the population or to take advantage of heterosis. The desirable characteristics of several breeds may be combined by the use of crossbreeding, but its most important use is the production of heterosis in the crossbred progeny or hybrids.

East (1908, 1909), G.H. Shull (1910, 1911), and A.F. Shull (1912) put forward explanations of heterosis which were summarized by G.H. Shull (1952). East (1912) believed that the reduced vigour of inbred members of naturally cross-fertilized species, and the increased vigour due to crossing these species, was due to the same phenomenon, which he believed to be heterozygosis. Keeble and Pellew (1910) analyzed data on the stature and flowering time of peas and found a greater height and vigour in the F_1 generation which, they postulated, was due to the convergence in the zygote of dominant growth factors of more than one allelomorphic pair. Bruce (1910) mathematically proved that fewer homozygous recessives exist at a particular locus in the F_1 population than the mean number of the parent stocks. Although without evidence, he postulated that dominance was positively related to fitness, and concluded that the cross of two pure breeds produces a mean vigour greater than the collective mean vigour of the parents.

Jones (1917) raised criticisms against Keeble and Pellew's "dominance" theory of heterosis. If heterosis was ascribable to dominance of factors, it should have been possible to recombine in a homozygous condition, in generations after the F_2, all of the dominant characters in some individuals and all of the recessives in others. The dominant homozygotes should have equal vigour to the hybrids and should not show a decrease in vigour when inbred. However, no such individuals had been produced. Also, it was believed that, if the correct explanation was dominance, the F_2 population would have an asymetrical distribution, which did not fit with the observation. But, Jones said that, if Morgan's theory of linkage were taken into consideration, the improbability of obtaining completely homozygous dominant individuals and the lack of skewness in the F_2 distribution could be accounted for.

Singleton (1943), Jones (1945), and Rendel (1953) favoured the idea of heterosis from intralocular interaction, and Hull (1945), through research in corn, concluded that non-additive interaction between genes at different loci was very small, if present at all. Hull believed that interaction between genes at the same locus caused heterosis and he termed this "overdominance". However, Jinks (1955) found, in plants, evidence for the simultaneous presence of overdominance and non-allelic interaction. The likelihood of intra- and interlocular interaction both being involved in heterosis cannot be excluded.

Lambert (1940) defined heterosis as the superiority of the crossbred progeny over the better parent. If net merit can be defined as a single value, this definition may be useful, but, when each trait has to be considered separately, the appraisal of heterosis for the individual's total performance causes the hybrid to be expected to excel the performance of a composite parent which does not exist. Caroll and Roberts (1942) described this problem.

Stern (1948) differentiated "hybrid vigour" and "hybrid disvigour" and referred to positive heterosis, where the cross produces an increase in vigour or some other characteristic, and to negative heterosis, where a cross results in a decrease in comparison with both parents.

Manwell and Baker (1970) state that the detection of whether or not heterosis occurs in a particular cross can be done by two different approaches. Firstly, measurement of specific characteristics may be done. Secondly, comparisons may be carried out of the observed number of heterozygotes in relation to the number which would be expected in the absence of any selective advantage (or disadvantage) to the heterozygote.

Mather (1949), Lerner (1958), Falconer (1960) and others have indicated that heterosis should be measured by combining deviations measured from the average of the means for the two parental lines - i.e. the mid-parental value. Brewbaker (1964) stated: "It is conventional to regard heterosis as any excess in vigour of a hybrid over the midpoint between its parents". However, Herskowitz (1967) indicates a superiority over a value below the midparent point. "Hybrid vigour is due to the adaptive superiority of the heterozygote over one or both types of homozygote.... Hybrid vigour or heterosis, is the condition in which the heterozygote is superior to one homozygote or both".

Manwell and Baker (1970) gave several theories for the presence of heterosis which have been suggested in the past:

1. 'The dominance theory'. This theory considers that the hybrid combines suitable dominance of genes from both parents. If this theory were correct it should be quite simple to fix heterosis by a combination of crossing, followed by selection. This is not the case since heterosis is reduced rapidly in successive generations of decendants from the F_1 crossbred.
2. 'Inbreeding depression as the opposite of (positive) heterosis'. The crossing of different inbred lines reverses inbreeding depression.

Lerner (1958), Falconer (1960) and others have equated heterosis with the reverse of inbreeding depression. Therefore, the main point of the theory is that heterozygosity *per se* rather than dominance is involved. However, Sentz, Robinson, and Comstock (1954) found that in hybrid maize a marked decline in yield occurs as heterozygosity decreases from 100% to 75%, but no further decline occurs until the heterozygosity is below 25%.

3. 'Overdominance'. The term 'overdominance' and single gene heterosis have been used to describe the condition where a heterozygote at a particular locus is superior to both homozygotes. Overdominance at several different loci then add up to produce positive heterosis.
4. 'Epistasis'. The influence of one genetic locus on the expression of another is known as epistasis and has been given as a theory for heterosis.
5. 'Complementation'. An excellent example of complementation is heterokaryon formation in fungi. When two strains, each of which is deficient in a different enzyme needed in a metabolic pathway, combine so that each cell contains nuclei from both strains, the metabolic pathway is restored with each strain complementing the deficiency of the other.

The mechanism of complementation provides a possible explanation for heterosis and links genotype to phenotype with a number of different molecular mechanisms, involving fundamentally complementation of proteins or their subunits, forming explanations for overdominance, epistasis and heterosis.

Childers and Bennett (1961), and Childers (1967) have shown a gene-environment interaction on heterosis in hybrid sunfish. It is clear that many cases of heterosis are only expressed in certain environments.

It appears that heterosis is greatest for traits expressed early in life and becomes less important as the animal develops (Fredeen, 1957). In crossbred animals there is an increased rate of pre-weaning growth and greater viability, but, beyond the age of weaning, there is little to show that crossbreds survive better than their purebred contemporaries. In swine, hybrids produce only modest increases in average daily gain and feed efficiency, and carcass traits appear to show little or no heterosis (Fredeen, 1957). Shaw and MacEwan (1936), Hutton and Russell (1939), Whatley et al. (1955), and Craft (1953) have shown a crossbred advantage in carcass quality which may have been due to specific cross combinations rather than heterosis.

Dickerson (1952) postulated that overdominance may be the most important factor in viability traits and litter size, and simple dominance with epistasis may produce the heterotic effects found in post-weaning traits. Lerner (1954) found greater stability towards environmental variables in hybrids, which could raise crossbred performance above the purebred level for traits which are much affected by environmental variation. Sang (1956) stated that this effect is probably related to developmental physiology.

Certain breed crosses seem to show greater heterosis than others. Genetic diversity of the breeds (Sierk and Winters, 1951) and the relative degree of homozygosity of the different breeds (England and Winters, 1953) are possible causes. To utilize the heterotic effects obtained in characteristics such as fertility, vigour, and health, crossbreeding programs have been developed (King, 1971). How to utilize heterotic effects was discussed by Bradford et al. (1958), and Hetzer et al. (1961). A survey of the literature was given by Fredeen (1958).

Skarman (1965) reported on extensive 2-breed crossing experiments involving the Swedish Landrace and Swedish Yorkshire. Bichard and Smith (1972) gave a survey of crossbreeding and genetic improvement.

2. Crossbreeding

Crossbreeding can be defined as outbreeding relative to a species, a process which tends to produce heterozygosity in the species. Within pure breeds a slow but measurable amount of inbreeding occurs. When breeds are crossed the genetic purity caused by this inbreeding is lost and heterozygosity is promoted at all loci for which the breeds differ. This will mainly occur in the first generation of crossbreeding, and following generations of crossing may only maintain the level of heterozygosity reached initially.

Fredeen (1957) gave two main advantages resulting from crossbreeding - the introduction of new genetic variability into an existing gene pool, and the utilization of heterosis.

Craft (1958), reviewing fifty years of progress in swine breeding, reported that little meaningful research in crossbreeding swine had been carried out before 1920. He indicated that early trials were with small numbers of animals and were of poor design. Only after 1920 were large enough trials carried out to indicate the superiority of crossbreds for certain traits.

During a ten year study of British show records, Hammond (1922) compared twelve single crosses from eight British breeds with parental means for growth. He found that, in many cases, crossbreds were heavier than the parental mean and noted only one case where the parental mean exceeded the crossbred for body weight.

Shaw and MacEwan (1936) compared six breeds and their reciprocal crosses for rate and economy of gain. When compared to one parental breed, crossbreds gained more rapidly and consumed less feed.

Winters et al. (1935) compared the performance of backcrosses, three-breed crosses, and single crosses to purebreds. It was found that three-breed crosses generally performed best. Almost two more pigs were farrowed in each litter and crossbred litters averaged 96 lbs heavier at weaning than did purebreds. Backcross litters were 63 lbs heavier at weaning, but there was no superiority over purebreds for number of pigs farrowed. Single cross litters averaged one additional pig and were 37 lbs heavier at weaning. After weaning, backcross pigs gained more rapidly and reached a weight of 220 lbs 22 days before the purebreds. Both three-breed and single crosses reached this weight 17 days before the purebreds.

Hutton and Russell (1939) and Lush et al. (1939) found that, in single crosses, the crossbred litters at birth were intermediate in size to those from the parent breeds. However, the litter size at market age frequently was greater than that of the better purebred parent due to a greater survival percentage of the crossbred pigs. Average pig weight at birth was intermediate to that of the parent breeds, but the crossbreds exceeded the parental average by 8 to 18% at weaning and later. The crossbreds were slightly superior in feed efficiency to the parents' average by 3-4%.

Similar relative superiority of backcross and three-breed cross pigs for growth and survival was reported by Lush et al. (1939). They also noted the superiority of crossbred dams for maternal ability.

Roberts and Caroll (1939) compared single crossbreds with purebred Duroc-Jersey and Poland Chinas. A small, but non-significant, advantage of the crossbreds for rate of gain, feed efficiency, and age at market was found.

The Illinois Agricultural Experimental Station Annual Report of 1928 questioned the importance of hybrid vigour in swine in comments on the work of Carroll and Roberts, by noting that there was no crossbred advantage for rate of economy of gain. Carroll and Roberts (1942) in a study of over 50,000 animals concluded that heterosis cannot be expected in the majority of crosses. However, the superiority of crossbreds, especially those from crossbred dams, has been established for survival and growth characteristics.

Bradford et al. (1953) showed that litters from crossbred dams had a significantly lower mortality to 154 days than litters from straightbred dams. Gaines and Hazel (1957) investigated the merits of crossbred sows and found that crossbred Landrace-Poland China sows were superior to purebred sows for litter size at all ages.

Most crossbreeding experiments utilizing three-breed crosses have involved crossbred dams. Smith and King (1964) found the Landrace x Large White cross or its reciprocal to have the best performance. After mating five different breeds to Large Whites to produce crossbred gilts, King (1968) found that the Landrace x Large White had the best reproductive performance. Schlote et al. (1974), in Germany, found the Large White x German Landrace sow the most productive of four types of crossbred sows which were examined. The Landrace x Yorkshire cross was found by Holtmann et al. (1975) to have the earliest sexual maturity, and to farrow and wean the largest number of offspring from 28 crosses which were tested. Jensen (1975, cited by King, 1975b) found improvements in litter size, litter weight, and piglet weight at birth, 3 weeks, and 8 weeks in litters from Large White x Danish Landrace sows crossed with Danish Landrace, Swedish Landrace, or Large White boars.

The crossbred sow provides a more suitable intra-uterine environment for the fetuses, which results in larger litters, and generally she has increased milk production.

Hazel (1963) presented the following summary of the merits of three mating systems - purebred, single cross and three-breed cross relative to survival and growth traits. The size and weight figures are given in terms of 100 per cent for purebreds.

Table 1: Mating System Summary

Characteristic	Pure-Bred	Single Cross	3-Breed Cross
Litter size at birth	100	101	111
Litter size at 8 wks.	100	107	125
Pig weight at 8 wks.	100	108	110
Pig weight at 154 days	100	114	113
Pork produced per litter	100	122	141

3. Crossbred Boars

Although the literature on the use of crossbred boars is not extensive, several authors have conducted experiments to evaluate the hybrid's value as a sire.

King (1975) stated that, since the presence of hybrid vigour in an animal is generally expressed in characters associated with the overall "fitness" of the species, it has been difficult to evaluate the crossbred boar due to the difficulty of measuring male reproductive performance. In the boar, the characters which might be studied are earliness of sexual maturity, libido, number of females that can be successfully mated, length of breeding life, and numbers of viable offspring produced. Also, it would be relevant to evaluate semen production and characteristics.

The contrast between inbred and crossbred boars can be extrapolated to provide an estimate of the differences between purebred and crossbred boars, which indicates that crossbreeding increases the rate of growth of the testes, increases the earliness of sexual maturity and increases sperm production (King, 1975).

Crossbred boars could provide a means of increasing the numbers of genetically good sires from a given number of tested purebred stock with little extra cost, and could also be an economic method of using exotic breeds when they are superior to native breeds in some traits (King, 1975).

There is some evidence that crossbred sires produce an increase in litter size. King (1975) reported a significant increase in litter size of litters sired by Pietrain-Hampshire boars in comparison to Large Whites or Landrace when mated to a variety of crossbred females. This advantage of litter size persisted to weaning. The explanation of this phenomenon may be a reduction in embryonic mortality due to heterosis in the embryos.

In studies of the progeny of crossbred boars, it has been found that their average performance reflects quite closely that to be expected from the average performance of the two parental breeds of the crossbred boar.

King (1975) observed that the variability in performance of the offspring of crossbred boars should also be examined. A suspected increase in variability of these progeny has been used as a strong argument against the use of these boars. This increased variability is only to be expected in characters which are determined by a small number of gene pairs such as coat colour or ear carriage, but not to characters such as growth rate and fatness. All results from using crossbred boars indicate no increased variability in body weights and growth rate over purebreds.

He indicated that in using crossbred boars the main problems are the choice of breeds and the cost of producing the boars. Ideally, one should use two parent breeds for the crossbred boar that are genetically distinct from the sow to be used. If competitive perfotmance in terms of growth rate, efficiency of food conversion, and carcass characteristics has to be maintained it may be difficult to choose two additional breeds. Specific requirements in the carcass, such as minimum length, may preclude the use of certain breeds.

It may be difficult to produce crossbred boars in commercial numbers since it entails the keeping of two purebreds to be used in the crossing. These two breeds must be selected intensively to ensure a competitive performance level in their crossbred offspring.

In crosses utilizing Minnesota No. 1, Minnesota No. 2, and Minnesota No. 3, "purebred" boars and a combination of these breeds as hybrid boars on Minnesota No. 1 sows, Remple et al. (1964) found that the progeny of purebred sires were superior for backfat thickness and daily gain. The authors explained the superiority of the purebred sires by indicating greater selection was practiced for this trait in these boars. The difference in backfat thickness was not entirely explained. It was found that the variances of progeny performance were similar for purebred and crossbred sires, which was concluded to mean that the use of crossbred sires in systematic crossing systems need not result in increased variation among the progeny. Rempel stated that, in general, the progeny of crossbred boars will perform at an equal level to the average performance of progeny of the parent breeds of the crossbred sires.

Curran et al. (1972) studied growth, feed consumption per unit weight gain, carcass characteristics and some aspects of meat quality in trials with crosses of the Landrace, Pietrain, Hampshire, and Large White breeds. Landrace, Large White x Landrace-Pietrain, Large White x Pietrain-Landrace, Hampshire-Pietrain x Landrace, and Hampshire-Pietrain x Large White pigs were compared to 91 kg live weight. It was found that all crossbred types provided better economy of production than Landrace when assessed by live-weight gain and feed consumption per unit weight gain. Crossbred carcasses had larger quantities of lean meat than, and similar amount of rind, bone, and fat to Landrace at comparable weights, but they showed a variable tendency to poorer meat quality. Hampshire-Pietrain x Large White and Hampshire-Pietrain x Landrace carcasses at 91 kg were much shorter than Landrace; 34% and 38% respectively were less than the given acceptable bacon length of 775 mm.

Sellier (1973) found no significant differences for ADG, carcass length, backfat thickness or three meat quality parameters in the progeny of Blanc de l'Ouest-Pietrain and Pietrain boars, although differences for age at slaughter and chest weight were highly significant (P<0.01), and differences for age on test and ham weight were very highly significant (P<0.001). Age at slaughter favoured the purebred Pietrain progeny as did chest weight, age on test, and ham weight.

King and Thorpe (1973), in an experiment utilizing Pietrain-Hampshire crossbred boars, studied the mean performance and variability of the progeny of these boars under two systems of feeding. The Pietrain-Hampshire boars were compared with Large White (the majority) and Landrace boars. The gilts and sows used in the study were of a variety of crosses. Progeny were fed either ad libitum or on a scale feeding plan. The Pietrain-Hampshire boars produced slightly slower growing progeny, having the same feed conversion efficiency; but their daily feed intake was lower than that of the progeny of the Large White boars. Carcasses of progeny of the crossbred boars were heavier, although all pigs were slaughtered at the same weight. The Pietrain-Hampshire progeny carcasses were over 3 cm shorter but had about the same shoulder fat and eye muscle fat measurement, with significantly less fat over the loin and more at the middle of the back. These carcasses had more than 4 cm^2 greater area of eye muscle. The authors state that, on the whole, the Pietrain-Hampshire crossbred boar compares favourably with the Large White for the production of market pigs, especially if carcass length is not included in the grading system of the carcasses.

Smith and Lishman (1974) also compared the performance of Pietrain-Hampshire and Large White boars. Although their data may be faulted for small numbers (the use of only 4 boars and 24 sows), they found that breed of sire did not effect litter size or total weight at birth or weaning. It was found that crossbred pigs grew more slowly to slaughter by 5% but had equal efficiency of live-weight gain. The crossbreds had higher carcass yields (3%), shorter carcasses (3%), and larger eye-muscle areas (18%). Traits not affected were fat depths, joint proportions and cut out values. In the crossbreds, 'eye-muscles' were paler in colour and had a lower water-binding capacity than those of the purebreds, but pH values and transmission percentages were similar.

Large White, Landrace, Large White-Landrace, Landrace-Large White, Hampshire-Large White, and Hampshire-Landrace boars were evaluated by Lishman et al. (1975). They found that breeding of the boars did not effect the level or variability of litter performance. Differences in performance and carcass traits between the progeny of purebred and whitecross boars were found for 'eye-muscle' area and fat depth over the 'eye muscle'. Progeny of Hampshire-cross boars had carcasses which were 2% shorter than those from white boars.

4. Double-Mating

Double-mating can be considered to be the most efficient sire evaluation system, producing a litter consisting of progeny from two boars.

A typical double-mating plan was outlined by Roberts and Carroll (1939) as shown below.

Table 2: Double Mating Plan

Sows		Boars
Duroc Jersey	x	(Duroc Jersey (Poland China
Poland China	x	(Duroc Jersey (Poland China

Fredeen (1957) stated that double-mating provides comparative data on two sires by controlling dam differences in pre- and post-natal maternal environments. After carrying out early experiments in double-mating swine, Hays (1919) concluded that crossbreds were superior to purebreds for the production of feeder hogs. Shaw and MacEwan (1936) found that reliable test results could be obtained with a small number of litters using double-matings.

Lush et al. (1939) double-mated Duroc, Poland China, and Yorkshires and their crosses to evaluate the progeny of purebred, single cross, backcross, and three-breed cross matings. They found that crossbred pigs were more vigourous at birth, showed greater survival to weaning and gained more rapidly after weaning.

The determination of paternity in double-mated litters has been established through the use of colour markers. Sumption (1961) outlined the inheritance of colour patterns for six breeds, when crossed with the Duroc, and Searle (1968) examined the genetic basis of coat colour in swine and other mammals. Using solely colour markers for determining sire identification has limited the use of double-matings to the comparison of breeds of contrasting colours. However, the advent of blood-group markers for paternity determination (Buschmann, 1964; Widdowson and Newton, 1964; Newton and Widdowson, 1965; Saison and Moxley, 1966) has removed this restriction and has allowed wider application of double-mating.

The determination of paternity is usually established on the basis of blood group factor inheritance within one or more closed systems, which is one in which all animals in a population react to one or more of the known antisera for that system. Saison and Moxley (1966) presented a method for sire identification using the L system as follows:

Table 3: Double Mating Sire Identification Plan

(L SYSTEM)

Sow Genetype		Boar Genotype	Progeny Phenotype From Each Boar
L^a/L^a	x	Boar 1 L^a/L^a	L (a+ b-)
		Boar 2 L^b/L^b	L (a+ b+)
L^b/L^b	x	Boar 1 L^b/L^b	L (a - b+)
		Boar 2 L^a/L^a	L (a+ b+)

Paternity identification is possible in double matings when one boar is homozygous for any factor not found in the second boar nor the sow.

Howard (1968) stated that, on the basis of double matings using both colour and blood group markers, mating systems and sire comparisons can be made more efficiently on a within-litter basis than on a between-litter basis. Kennedy, Moxley, and Saison (1974) compared double-mating, sequential-mating, and random-mating to evaluate sires and breeding plans. They found that double-mating was the most efficient breeding plan of the three studied.

Multiple sire mating has been used in the development of new breeds of swine, such as the Minnesota No. 3 (Sumption et al., 1959). The authors concluded that, in a random mating situation, the possibility exists for natural selection to favour more active sires which are capable of production of viable sperm.

Roberts and Carroll (1939) suggested that the simultaneous introduction of semen of two boars into a sow could increase the frequency of mixed litters and produce a balanced proportion of progeny attributable to each sire. This is possible through the use of artificial insemination of mixed semen.

It was noted by Lush et al. (1939) that certain boars sire more progeny than others in double mated litters and this appeared to be independent of order of service or breed of sow or boar. Saison and Moxley (1966) presented additional evidence for preferential fertilization in natural matings and mixed artificial inseminations.

Other interesting consequences of double mating have been reported. Roberts and Carroll (1939) noted an average of two more pigs per litter in double matings compared to single matings. Sokolovskaja et al. (1964) observed higher conception rates and lower embryonic mortality with mixed inseminations. Hlebov (1965) similarly found that conception rate, embryo weight and litter size all increased when mixed inseminations were used. Contrarily, Sokolovskaja et al. (1966) stated that mixed inseminations increased embryo survival without increasing conception rate.

In Yugoslavia, Cerne and Salehar (1964) found that the number of pigs born alive was significantly decreased when mixed insemination was used, which conflicts with the previous evidence.

III. MATERIALS AND METHODS

The experiment was designed to evaluate the productive and reproductive performances of Hampshire-Duroc boars in relation to Hampshire, Duroc, and Landrace boars. Boars in the study were selected on the basis of their value as possible herd sires in overall characteristics such as size, conformation, strength of feet and legs, and state of health. Production characteristics such as backfat depth, age to 200 pounds, and efficiency of food conversion were not of paramount importance in the selection of the boars, since it was desired not to bias the study by choosing extremely superior boars of one breed over poorer boars of another breed, based on the above three production traits.

In order to reduce maternal influences on the progeny tests of the boars, double-matings were carried out, thus producing progeny of two boars within a litter for comparison purposes.

Fourteen sires, 118 dams and 529 market pigs were involved in this study. All market pigs were farrowed from September, 1974 to February, 1976.

Landrace sows of the Macdonald College breeding herd were housed either in group pens or in single stalls, while all boars were housed in individual pens. All were fed a commercial, pelleted ration of 15% protein: boars, 3.64 kg/day; non-lactating sows, 2.27 kg/day; and lactating sows, 4.55 kg/day. The sows and boars used in the study ranged in age from 1 to 4 years. All sows and several of the Landrace boars were farrowed and raised in the Macdonald College herd, while the Duroc, Hampshire, Hampshire-Duroc, and remaining Landrace boars were bought from producers in Nova Scotia, Quebec, and Ontario.

The semen from up to three ejaculations from each boar was evaluated grossly for volume, and microscopically for concentration, motility, morphology, and live-dead rate of the sperm.

The sows were checked for the presence of "standing heat" every morning by putting pressure manually on their backs in the presence of a boar. Sows were generally bred on the first and second days of "standing heat". If a sow was to be bred, semen was collected from two appropriate boars with the use of a dummy sow on which the boars mounted. After collection, according to the gloved-hand technique of Herrick and Self (1962), the semen was strained through cheesecloth to remove the gel fraction and measured in a graduated cylinder. Eighty ml of semen was used from each boar regardless of variation in sperm concentration. Previous work had established that equal volumes of semen was as effective as equal concentrations in producing split litters having both boars represented (Howard, 1968). The sows were bred with the 160 ml of mixed semen in the morning of each day of "standing heat". Table 4 shows the number of sows bred to each combination of boars.

Table 4: Mating Distribution

		Landrace Boars					
		149-E	2749-C	267-C	1043-D	1500X-E	Total
1-F	(H)[a]	2	1	3	3	2	11
136-F	(H)	0	4	6	2	1	13
547-F	(H)	5	1	0	4	2	12
71-E	(D)[a]	3	2	2	3	3	13
459-F	(D)	1	1	6	2	2	12
54-F	(D)	6	1	2	1	3	13
15-E	(HD)[a]	2	3	4	1	1	11
16-E	(HD)	10	2	5	3	1	21
2702-F	(HD)	2	4	0	6	0	12
Total		31	19	28	25	15	118

[a](H) = Hampshire
(D) = Duroc
(HD) = Hampshire-Duroc

The sows were moved to individual farrowing crates 5 to 7 days before the expected date of farrowing. Twenty-eight of the sows were induced to farrow from 2 to 3 days early by the intramuscular injection of an analogue of Prostaglandin F2 α which was being used in a separate, simultaneous study (Downey et al., 1976). Each Thursday morning, sows to be induced were given a single intramuscular injection of 50 mg AY24,655[1] as the sodium salt. If farrowing appeared to be imminent, an animal was left as a control. Sows were observed continuously for approximately two hours post-injection for evidence of side-effects, and then, occasionally, until onset of parturition.

Identification of the sire of each piglet was based on blood-typing of the sows, boars and piglets or by phenotypic identification of the offspring. Blood samples for typing were drawn from an ear vein of mature pigs, and from the anterior vena cava of young pigs, into an equal volume of sterile Alsever's solution, and refigerated until bloodtyping could be carried out.

The pigs were typed for up to 36 blood group factors in 17 systems. As outlined by Saison and Moxley (1966), the system found most effective in identifying the piglets was the N system, which is composed of three factors; a, b, and c. The a and b factors are complementary characters and form a closed system. The c factor is a subgroup of the b factor and is not found if the b factor is not present. Sire identification could be especially easily made if one boar was homozygous positive for either the a, b, or bc factor and the second boar and sow homozygous negative for the same factor.

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[1] Ayerst Research Laboratories,
Montreal, Quebec

Direct Agglutination (Saison, 1958), Indirect Agglutination (Coombs), as outlined by Saison (1958), Capillary, Capillary Papain (Lewis et al., 1958), and Hemolytic (Stormont et al., 1950) tests were used to type the blood group systems. In combination with phenotypic methods (i.e. identification of the piglet's sire by the piglet's colour or appearance) it was possible to identify most of the piglets. Any piglet whose sire was not identified was discarded from the study.

Piglets were weaned at 3 weeks of age, housed in group pens and fed a ration containing 18% protein ad libitum until they reached 23 kg or greater in weight. At this point they were moved to smaller pens containing 6 to 8 animals and fed, ad libitum, a ration containing 15% protein. They remained in these pens until reaching a market weight of 80 to 90 kg. The pigs were slaughtered at a commercial packing plant and the carcasses weighed, measured for depth of backfat and given an overall carcass index by Agriculture Canada graders.

IV. SEMEN EVALUATION

1. Method of Analysis

Two or three ejaculates from each of the five Landrace, three Hampshire, three Duroc and three Hampshire-Duroc boars in the study were evaluated for seven semen characteristics: volume in ml, concentration in millions of sperm/ml, concentration as a score, motility as a score, morphology as a score, live-dead rate as a score, and total semen score. Scores were assigned according to Herrick and Self (1962). The ejaculations were obtained by the gloved-hand technique of Herrick and Self (1962).

Table 5: Details of Scoring

Concentration	Top Score 20
Motility (Degree of Vigour)	Top Score 40
Morphology (Per Cent of Normal and Abnormal Sperm)	Top Score 30
Live-Dead Rate (Per Cent of Motile Sperm)	Top Score 10
Semen Score	Top Score 100

Although the ratings are somewhat subjective and each individual technician tends to establish his own standards, all ratings were done by the author and were measured as objectively as possible for all ejaculations.

Least squares analyses to estimate the effects of breed and sire within breed, and the linear and quadratic effects of age of boar at collection (months) were performed (Harvey, 1960).

The model used is given below:

$$y_{ijk} = \mu + b_i + s_{ij} + c_1 a_{ijk} + c_2 a^2_{ijk} + e_{ijk}$$

where y_{ijk} = an observed semen trait

μ = the population mean

b_i = the effect of i^{th} breed

s_{ij} = the effect of the j^{th} sire within the i^{th} breed

c_1 = the regression of y_{ijk} on age at collection

a_{ijk} = the age at collection of the ijk^{th} ejaculate

c_2 = the regression of y_{ijk} on age^2 at collection

a^2_{ijk} = the age^2 at collection of the ijk^{th} ejaculate

e_{ijk} = the random error associated with the k^{th} ejaculate of the j^{th} sire within the i^{th} breed $\sim (0, \sigma^2)$.

All effects, other than the error term, were treated as fixed.

2. Results and Discussion

Estimates of breed and sire effects and their standard errors are given in Table 6. Breed effects were expressed as deviations from the Hampshire-Duroc cross. Sire effects were expressed as deviations from crossbred boar 2702-F. Analysis of variance tables, based on transformed data (square root) are in Appendix Table A.

No significant linear or quadratic effect of age was found. A significant effect ($P < 0.01$) of breed and sire was found for semen volume only.

Hampshire-Duroc cross boars were superior for semen volume. Although differences were not significant, Landrace boars appeared to be superior for live-dead rate, Hampshire boars for motility and overall score, Duroc boars for concentration and morphology. Hampshire-Duroc boars appeared superior to the Landrace boars in all characteristics except live-dead rate. The advantages of the crossbred boars over the Landrace standard are evident, especially in total semen score, where the Landrace ranked fourth and the crossbred second. The semen score of the crossbreds closely approached that of the value of their best parent breed, the Hampshires, indicating a possible heterotic effect may be acting over all the semen characteristics. If semen score can be taken as an overall indicator of the "fertilizing ability" of the sperm, then, in relation to the Landrace standard, the crossbred boars appear superior, although the differences were not significant.

The evidence for a heterotic effect of the crossbred boars on semen volume is more concrete as, in this case, breed differences were significant. A negative heterotic effect may be contributing to the lack of superiority of these boars for concentration. Semen volume may be negatively correlated with sperm concentration (Swierstra and Rahnefeld, 1967).

Table 6: Least Squares Estimates of the Effects of Breed of Sire, Sire, Age, And Age² on Semen Traits

		Volume (ml)	Conc. (10^6/ml)	Concentration	Motility	Morphology	Live-Dead Rate	Score
Breed of Sire								
Landrace		- 81.23± 32.269	- 71.54 ± 38.543	- 2.94 ± 1.675	-0.52 ± 1.888	- 3.50 ± 1.211	0.78 ±0.264	- 6.18 ± 2.581
Hampshire		- 86.70± 30.671	12.15 ± 36.634	0.13 ± 1.592	2.32 ± 1.794	- 2.79 ± 1.151	0.48 ±0.250	0.13 ± 2.453
Duroc		-135.75± 23.680	27.87 ± 28.284	0.80 ± 1.229	0.20 ± 1.385	- 2.99 ± 0.889	-0.10 ±0.193	- 2.47 ± 1.894
Hamp-Duroc		0	0	0	0	0	0	0
Regressions								
$\hat{b}_1$ (Age in Months)		23.11± 10.454	11.396± 12.486	0.708± 0.543	0.759± 0.612	0.091± 0.392	-0.130±0.085	1.429± 0.836
$\hat{b}_2$ (Age² in Months²)		- 0.348± 0.208	- 0.239± 0.248	- 0.016± 0.011	-0.018± 0.012	- 0.002± 0.008	0.002±0.002	- 0.035± 0.017
Sire								
267-C	(L)[a]	-232.45±422.308	-994.58 ±504.415	-58.13 ±21.924	2.01 ±24.703	-13.18 ±15.853	-0.39 ±3.449	-69.68 ±33.777
2749-C	(L)	84.10±265.106	-532.32 ±316.649	-35.45 ±13.763	5.50 ±15.508	- 7.45 ± 9.952	-0.93 ±2.165	-38.33 ±21.204
1043-D	(L)	-240.38±327.889	-621.79 ±391.639	-37.79 ±17.022	7.28 ±19.180	-13.91 ±12.309	-0.24 ±2.678	-44.17 ±26.225
149-E	(L)	- 8.10± 87.639	- 90.34 ±104.678	-13.60 ± 4.550	6.75 ± 5.127	4.01 ± 3.290	1.08 ±0.716	-15.26 ± 7.010
1500X-E	(L)	- 14.75±104.430	31.50 ±124.734	- 1.31 ± 5.422	0.43 ± 6.109	- 2.21 ± 3.920	1.59 ±0.853	- 1.49 ± 8.353
1-F	(H)	- 21.80±113.405	- 69.96 ±135.454	- 5.42 ± 5.887	3.99 ± 6.634	- 6.86 ± 4.257	0.62 ±0.926	- 7.66 ± 9.070
136-F	(H)	- 57.39±109.777	100.36 ±131.120	0.94 ± 5.699	2.60 ± 6.422	- 1.49 ± 4.121	1.79 ±0.896	3.83 ± 8.780
547-F	(H)	- 78.25±108.328	45.93 ±129.390	0.27 ± 5.624	1.18 ± 6.337	- 1.97 ± 4.066	0.21 ±0.885	- 0.31 ± 8.664
71-E	(D)	- 62.80±109.705	194.52 ±131.034	0.91 ± 5.695	0.19 ± 6.417	- 4.08 ± 4.118	0.13 ±0.896	- 2.85 ± 8.774
54-F	(D)	- 94.86±110.080	62.35 ±131.482	- 0.13 ± 5.715	0.76 ± 6.439	1.34 ± 4.132	0.28 ±0.899	0.74 ± 8.804
459-F	(D)	- 66.67±110.624	42.35 ±132.132	0.92 ± 5.743	-2.72 ± 6.471	- 0.13 ± 4.153	0.84 ±0.903	- 1.10 ± 8.848
15-E	(HD)	167.41±113.473	-103.76 ±135.535	- 0.85 ± 5.891	-2.81 ± 6.638	4.98 ± 4.260	-0.10 ±0.927	1.22 ± 9.076
16-E	(HD)	57.41±113.473	150.43 ±135.535	- 0.51 ± 5.891	-1.48 ± 6.638	4.98 ± 4.260	1.57 ±0.927	4.55 ± 9.076
2702-F	(HD)	0	0	0	0	0	0	0

[a] L = Landrace, H = Hampshire, D = Duroc, HD = Hampshire-Duroc

Sires within breeds were also ranked, in comparison to crossbred boar 2702-F. The large standard errors obtained for volume and concentration (in 10^6 sperm/ml) in Landrace boars 267-C, 2749-C, and 1043-D were probably due to variation in the frequency of collection. Semen volume and sperm concentration depend on frequency of collection, and boars which are not used with the same frequency will tend to vary in their semen volumes and sperm concentrations.

Regressions of semen characteristic on age in months and on age^2 indicated that all seven traits except live-dead score increased as age increased, but at a diminishing rate. Nonetheless, none of the effects of age was significant. A decreased live-dead rate as the boars became older may have been due to infrequent collection which resulted in in vivo death of the sperm.

Wilson et al. (1976) in a study of Hampshire, Duroc, and Hampshire-Duroc boars, found no significant differences between Duroc and Hampshire boars for testes weight, testes sperm, or number of sperm per gm of testes tissue. However, the crossbred boars' testes weighed 16% more than the average of the purebreds, and had 27.8% more sperm numbers. It was concluded that, since there was no difference between purebreds and crossbreds for sperm numbers per gm testes tissue, the increased sperm numbers in the crossbred boars is a function of heterosis for testes growth and the greater testes weight of crossbreds. The authors indicated that other research shows that testes weight is a good indicator of daily sperm production and total sperm output by the testes. The heavier testes and more testes sperm found in the crossbred boars at 7.5 months (castration age) indicated that they are more sexually mature than the purebred boars at the same age and have the capacity for greater sperm production.

These findings agree with those of this study, where Hampshire-Duroc boars were found to have greater semen volume and were superior to the Durocs for sperm motility, live-dead rate and overall score, and superior to the Hampshire for sperm morphology.

V. REPRODUCTIVE PERFORMANCE

1. Method of Analysis

The total number of progeny sired by each boar, the dominance of the boars in each double-mating, the conception rate of the sows bred to each boar, the sex-ratio of the litters from each boar, and piglet survival rate from birth to weaning were examined. Raw means are given in Appendix Table B.

To evaluate the dominance of boars in double matings, boars were given a score based on each litter in which they were a potential sire. If a boar sired less than 1/3 of the pigs in the litter, he was considered to be the dominated boar and allocated 0 points. A boar that sired 1/3 to 2/3 of the pigs in the litter was given 1 point, and considered to be a neutral boar. If the boar sired more than 2/3 of the pigs in the litter, he was allocated 2 points, and classified as the dominant boar. A theoretical maximum dominance rating was calculated for each boar, and a percentage value determined, based on the theoretical and actual ratings.

Boars were simply ranked for number of progeny sired, dominance, and conception rate. Differences between breeds in boar rankings were tested by the Kruskal-Wallis Test (Kruskal and Wallis, 1952).

Least squares procedures (Harvey, 1960) were used to evaluate breed of sire, sire, and treatment effects on survival from birth to weaning and on sex ratio of the litters.

The analyses were performed according to the following model:

$$y_{ijkl} = \mu + b_i + s_{ij} + t_k + e_{ijkl}$$

where y_{ijkl} = an observed reproductive trait

μ = the population mean

b_i = the effect of i^{th} breed of sire

s_{ij} = the effect of the j^{th} sire within the i^{th} breed

t_k = the effect of the k^{th} treatment for induction of parturition

e_{ijkl} = the random error associated with the l^{th} pig $\sim (0, \sigma^2)$

For hypothesis testing, normality of the error term was assumed.

Breed effects were expressed as deviations from the Hampshire-Duroc crossbreds. Sire effects were estimated as the breed plus sire within breed effect, and expressed as deviations from boar 2702-F.

2. Results and Discussion

The number of progeny sired by each boar is given in Table 7. Hampshire-Duroc Boar 15-E sired the highest percentage of pigs (84.93%), while Landrace boar 2749-C sired the lowest (15.79%). It is interesting to note that the Landrace boars occupied the lowest five places in the ranking order. That is, the Landrace boars all sired lower percentages of the litters in which they were involved than any of the other breeds of boars ($P < 0.05$). It may be postulated that a heterotic effect is acting in the embryos sired by the Hampshire, Duroc, and Hampshire-Duroc boars when bred to the Landrace sows, and that there is reduced intrauterine mortality of these embryos in comparison with those sired by the Landrace boars.

Skjervold (1962) discussed different environmental and genetic sources to explain a special boar effect on litter size, and divided the problem into:

1) factors affecting the number of ova fertilized, and
2) factors affecting the number of embryos developing normally until birth.

He concluded that differences in litter size between sires must be due to differences in the genotypes for embryonic viability between progeny groups.

Pigs experience serious prenatal mortality (Crew, 1925; Parkes, 1925). Hammond (1914) reported an overall prenatal mortality of 26.7%. Crew (1925), Burger (1952), and Pomeroy (1960) reported foetal deaths at 26.45, 37.34, and 38.53 per cent respectively. If a heterotic effect is present with respect to survival rate, the crossbred embryos should benefit in that they will have increased vigour and survivability.

Rankings of the Hampshire, Duroc, and Hampshire-Duroc boars only, were examined with respect to number of pigs sired by each boar, but no significant difference was found in the ranking order of these breeds alone; that

Table 7: The Total Number of Progeny Sired
By Each Boar
In the Double-Mated Litters

Boar		No. of Litters	Total No. Progeny	No. Sired By Boar	Per Cent
15-E	(HD)[a]	8	73	62	84.93
136-F	(H)	10	110	88	80.00
459-F	(D)	10	87	67	77.01
54-F	(D)	11	102	70	68.63
16-E	(HD)	14	104	62	59.62
547-F	(H)	7	58	34	58.62
71-E	(D)	10	82	48	58.54
1-F	(H)	10	83	43	51.81
2702-F	(HD)	12	131	65	49.62
1500X-E	(L)	12	122	58	47.54
1043-D	(L)	21	174	77	44.25
149-E	(L)	25	207	82	39.61
267-C	(L)	17	156	47	30.13
2749-C	(L)	17	171	27	15.79
		½ of 184 = 92	½ of 1660 = 830	830	–

[a]L = Landrace.
H = Hampshire
D = Duroc
HD = Hampshire-Duroc

is, with the exclusion of the Landrace from the test. Therefore, it appears that any heterotic effect present is effective in the offspring of all breeds examined excepting the Landrace.

Hill (1971) reported a two per cent increase in the number of pigs born alive in crossbred litters from purebred dams. However, O'Ferrall et al. (1968) found that litter size at birth was practically the same for inbred and crossbred litters, although there were highly significant differences in favour of crossbred pigs at 21 and 56 days of age, probably due to a higher survival rate up to 21 days of the crossbred litters. Winters et al. (1935), Hutton and Russell (1939), and Lush et al. (1939) found that crossbred litters at birth were intermediate in size to those from the parental breeds. Therefore, it appears that, in some work, heterosis is detected in the crossbred offspring and, in others, it is not. This may be a function of the actual breeds used.

Rankings of the boars for dominance in double-matings are in Table 8. Hampshire boar 136-F was highest ranked (85.00%) and Landrace boar 2749-C was lowest (14.71%). The Landrace boars all fell in the bottom half of the ranking order, but breed differences for dominance rankings were not significant. When compared as two groups, there was no significant difference between the Landrace boars and the other three breeds.

Since the dominance rating of a boar is affected by the number of pigs he sired, his position in the two rankings should be similar, as is found for the Landrace. A highly significant ($P < 0.01$) correlation of 0.877 was calculated based on the rankings of the boars for total number of progeny sired and dominance rating.

Ollivier and Legault (1967) demonstrated a highly significant ranking order of boars in respect to litter size at birth. Sumption (1961) presented evidence of selective fertilization in swine as did Libizov (1956).

Table 8: The Dominance Ratings of The Boars In the Double-Mated Litters

Boar		Maximum Dominance Rating Possible	Actual Dominance Rating[b]	Per Cent
136-F	(H)[a]	20	17	85.00
459-F	(D)	20	16	80.00
547-F	(H)	14	11	78.57
15-E	(HD)	16	11	68.75
16-E	(HD)	28	19	67.86
54-F	(D)	22	13	59.09
2702-F	(HD)	24	14	58.33
1500X-E	(L)	24	12	50.00
71-E	(D)	20	8	40.00
149-E	(L)	50	16	32.00
1043-D	(L)	42	11	26.19
1-F	(H)	20	5	25.00
267-C	(L)	34	6	17.65
2749-C	(L)	34	5	14.71

[a] L = Landrace
H = Hampshire
D = Duroc
HD = Hampshire-Duroc

[b] >2/3 of pigs in litter by boar = Dominant = 2
1/3-2/3 of pigs in litter by boar = Neutral = 1
<1/3 of pigs in litter by boar = Dominated = 0

Sumption states that, based on Beatty's (1957) work with rabbits, differences in competitive ability and/or concentration of viable sperm are plausible hypotheses for differential fertilization. In poultry, Allen and Champion (1955) have observed substantial correlations between sperm quality and number of progeny per sire. Skjervold (1962) stated that the differences in boar effects on litter size could be due to a difference in semen quality and quantity. At the present time, a definitive explanation of the phenomenon of preferential fertilization is not available, although Martin et al. (1974) reported, in chickens, a relationship between the ratio of the numbers of competitive spermatazoa and the proportions of offspring sired by the males.

This study found that the Hampshire boars had a superior overall semen score in comparison with the other breeds, while the Landrace had the poorest scores.

A highly significant positive correlation of 0.837 was determined between semen score and dominance rating. This seems to indicate that semen quality has an important effect on the ability of a boar to fertilize the ova of the sow. An identical correlation of 0.837 was found between semen score and number of progeny sired by each boar. Both these correlations agree with the work of Allen and Champion (1955), in poultry, and Skjervold (1962), in swine.

Although many other factors may be important in preferential fertilization, the importance of semen quality cannot be ignored.

The conception rates of the sows bred to each boar are in Table 9. A negative, but non-significant, correlation of -0.332 was calculated between dominance and conception rate rankings. Even though a boar sired a large percentage of the piglets in his litters, which may indicate some superiority of his semen over that of the other boar in the double-mating, the sows to which

Table 9: The Conception Rates of the Sows Bred to Each Boar

Boar		No. of Sows Bred to Listed Boar	No. of Sows Not Returning to Heat	Per Cent
2702-F	(HD)[a]	12	12	100.00
1-F	(H)	11	10	90.91
2749-C	(L)	19	17	89.47
54-F	(D)	13	11	84.62
1043-D	(L)	25	21	84.00
459-F	(D)	12	10	83.33
149-E	(L)	31	25	80.65
1500X-E	(L)	15	12	80.00
136-F	(H)	13	10	76.92
71-E	(D)	13	10	76.92
15-E	(HD)	11	8	72.73
16-E	(HD)	21	14	66.67
267-C	(L)	28	17	60.71
547-F	(H)	12	7	58.33
Total		$\frac{1}{2}$ of 236 = 118	$\frac{1}{2}$ of 184 = 92	-

[a]L = Landrace
H = Hampshire
D = Duroc
HD = Hampshire-Duroc

he was bred did not necessarily stand a good chance of remaining pregnant. Therefore, it appears that conception rate of the sows is influenced most greatly by the sows themselves, while the boars produce the competitive advantages in litter size by means of preferential fertilization.

A negative correlation of -0.244 was determined for the relationship between the rankings of the number of pigs sired by each boar and the conception rate of the sows bred to that boar.

The effects of breed, sire within breed, and treatment on sex ratio (per cent males in the litter) are in Table 10. From the standpoint of breed, the Hampshires produced the greatest number of males, and the Durocs the fewest. Hampshire boar 547-F produced the largest number of males, and Landrace boar 2749-C the fewest. Analysis of variance (Appendix Table C) was performed on the data (arcsin transformation); but no significant differences were present.

The boars were ranked, and a highly significant positive correlation of 0.675 was determined between the rankings for dominance and sex ratio.

Kennedy (1970) found a significant difference ($P < 0.05$) in the number of males sired by dominant (51.4% males) and dominated (63.7% males) boars. These results contradict the present study. Many external factors such as breed of sire and dam, season of year, and natural or artificial service may be involved in this phenomenon. Further work is needed to resolve the question of dominance and sex ratio, and its possible economic use in animal breeding.

The per cent survival rate of the piglets from birth to weaning is given in Table 11. The values were calculated as (number alive at birth/ number alive at weaning) x 100. Analysis of variance tables based on transformed data (arcsin) are in Appendix Table C.

Table 10: Least Squares Estimates of the Effects of Breed of Sire, Sire, and Treatment on the Sex Ratio Of the Double-Mated Litters

		Sex Ratio (%)
Breed of Sire		
Landrace		-10.626± 3.916
Hampshire		2.617± 7.831
Duroc		-11.540± 7.690
Hampshire-Duroc		0
Sire		
267-C	(L)[a]	- 5.260±13.973
2749-C	(L)	-36.879±14.177
1043-D	(L)	- 0.566±10.625
149-E	(L)	4.307±10.496
1500X-E	(L)	- 7.174±13.493
1-F	(H)	- 8.512±13.313
136-F	(H)	- 5.734±21.164
547-F	(H)	40.549±17.751
71-E	(D)	- 5.017±15.021
54-F	(D)	-14.294±16.496
459-F	(D)	7.588±18.885
15-E	(HD)	-12.470±20.440
16-E	(HD)	12.232±11.812
2702-F	(HD)	0
Treatment		
Not Induced		- 0.223± 2.728
Induced		0

[a] L = Landrace
H = Hampshire
D = Duroc
HD = Hampshire-Duroc

Table 11: Least Squares Estimates of the Effects Of Breed of Sire, Sire, and Treatment On Percent Survival From Birth to Weaning

		% Survival
Breed of Sire		
Landrace		- 0.188±1.374
Hampshire		- 2.385±2.748
Duroc		- 6.034±2.698
Hampshire-Duroc		0
Sire		
267-C	(L)[a]	- 3.566±4.902
2749-C	(L)	-12.089±4.974
1043-D	(L)	- 3.938±3.729
149-E	(L)	- 7.960±3.683
1500X-E	(L)	4.009±4.734
1-F	(H)	0.349±4.671
136-F	(H)	-29.419±7.426
547-F	(H)	- 5.295±6.228
71-E	(D)	-13.375±5.270
54-F	(D)	- 5.130±5.788
459-F	(D)	- [illegible].875±6.626
15-E	(HD)	- 7.021±7.171
16-E	(HD)	- 9.802±4.144
2702-F	(HD)	0
Treatment		
Not Induced		- 1.999±0.957
Induced		0

[a] L = Landrace
H = Hampshire
D = Duroc
HD = Hampshire-Duroc

Although breed differences were not significant, the Hampshire-Duroc progeny had the best survival to weaning percentage, which indicates that a heterotic effect may be present for survival.

Induced pigs had a survival advantage of 1.999±0.957% over non-induced pigs. This difference was not significant.

Brekke (1948) reported death losses of 16.6% at 21 days for Norwegian pigs born between 1932 and 1944. Trulsson (1957, cited by Belanger, 1964), observed an average loss of 20.0% at 3 weeks of age in litters of Swedish Landrace sows. Vernon (1948) reported that mortality in pigs to 21 days of age was 30.3% in linecross males, 24.7% in linecross females, 41.5% in inbred males, and 38.2% in inbred females. Cox (1960) stated that the reduced mortality in crossbred pigs was almost three times greater in males as in females, and the difference between male and female mortality was more than twice as large in the purebreds as in the crossbreds.

Among the interesting reproductive phenomena detected in this study were the superiority of the Hampshire, Duroc, and Hampshire-Duroc boars for number of progeny sired, the relationship between semen score and dominance rating, the positive correlation between dominance and sex ratio.

VI. PRODUCTIVE PERFORMANCE

1. Method of Analysis

Least squares procedures (Harvey, 1960) were used to evaluate sex of pig, breed of sire, litter, sire, and treatment effects on ten productive traits - birth weight, weaning weight, eight-week weight, average daily gain to market (from birth, 21 days, and 56 days), age to market, carcass yield, backfat thickness, and carcass index.

The analyses were performed according to the following general model:

$$y_{ijklmn} = \mu + b_i + s_{ij} + t_k + l_{kl} + g_m + cw_{ijklmn} + e_{ijklmn}$$

where y_{ijklmn} = an observed productive trait on the n^{th} pig:

μ = the population mean

b_i = the effect of the i^{th} breed of sire

s_{ij} = the effect of the j^{th} sire within the i^{th} breed

t_k = the effect of the k^{th} treatment for induction of parturition

l_{kl} = the effect of the l^{th} litter within the k^{th} treatment

g_m = the effect of the m^{th} sex of pig

c = the regression of y_{ijklmn} on liveweight at market age

w_{ijklmn} = the liveweight at market of the $ijklmn^{th}$ pig

e_{ijklmn} = the random error associated with the n^{th} pig $\sim (0, \sigma^2)$

For hypothesis testing, normality of the error term was assumed. The treatment for induction of parturition ~~term~~ (t_k) was included in the analyses for birth weight, weaning weight, and eight-week weight, and was omitted for the later growth and carcass traits. The liveweight covariate was included only for age to market and backfat thickness.

Breed effects were expressed as deviations from the Hampshire-Duroc crossbreds. Sire effects were estimated as the breed plus sire within breed effect, and expressed as deviations from boar 2702-F.

2. Results and Discussion

Birth weight, weaning (21 day) weight, and 56 day weight were examined as early growth traits. Raw means are given in Appendix Table D. Analysis of variance tables are found in Appendix Table E. Least squares estimates with their standard errors are in Table 12.

Birth weight was affected significantly ($P < 0.05$) by sex and highly significantly ($P < 0.01$) by breed, treatment, and litter within treatment effects. There was no significant sire within breed effect.

Female pigs weighed less than male pigs, and the progeny of the Hampshire-Duroc boars were heavier than the offspring of any of the other breeds. Landrace progeny were the lightest, indicating that crossbred pigs have an advantage for birth weight. Piglets from treated sows weighed less than those from untreated sows.

Smith et al. (1973), utilizing Hampshire and Large White boars, found that breed of boar had no significant effect on mean piglet birth weight. Smith and Lishman (1974) in a study of Pietrain-Hampshire and Large White boars reported that breed of sire had no effect of total litter weight at birth. Lush et al. (1939) compared pure and crossbred progeny from 36 double-mated Duroc Jersey and Poland China sows. They reported that the crossbreds weighed 2.5% more at birth. O'Ferrall et al. (1968) observed that crossbred litters weighed 0.64 kg more than inbred litters when born.

Thus, some authors detect an effect of breed on litter and piglet weight at birth, while others do not. This may be a function of the actual breeds used in the cross, and the effects may be confounded by environmental differences.

Twenty-one day weight was affected significantly ($P < 0.05$) by breed, and highly significantly ($P < 0.01$) by litter within treatment effect.

Table 12: Least Squares Estimates of the Effects of Sex, Breed of Sire, Sire, and Treatment on Early Growth Performance

		Birth Weight	21-Day Weight	56-Day Weight
Sex of Pig				
Female		−0.042±0.009	−0.142±0.036	−0.180±0.103
Male		0	0	0
Breed of Sire				
Landrace		−0.090±0.018	−0.066±0.072	0.274±0.194
Hampshire		−0.008±0.035	0.239±0.138	0.882±0.386
Duroc		−0.030±0.034	0.315±0.134	1.132±0.375
Hampshire-Duroc		0	0	0
Sire				
267-C	(L)[a]	−0.057±0.063	−0.176±0.252	0.132±0.705
2749-C	(L)	−0.131±0.070	−0.336±0.282	−0.249±0.826
1043-D	(L)	−0.115±0.044	−0.207±0.187	−0.581±0.521
149-E	(L)	−0.175±0.044	−0.117±0.192	0.248±0.533
1500X-E	(L)	−0.051±0.044	0.094±0.202	0.266±0.570
1-F	(H)	−0.051±0.063	0.319±0.244	0.962±0.681
136-F	(H)	−0.116±0.083	−0.514±0.370	−0.788±1.064
547-F	(H)	0.007±0.077	0.421±0.294	0.920±0.814
71-E	(D)	−0.092±0.063	0.431±0.264	1.249±0.742
54-F	(D)	0.003±0.070	0.257±0.277	1.294±0.772
459-F	(D)	−0.140±0.083	0.110±0.337	−0.126±0.932
15-E	(HD)	−0.061±0.089	−0.561±0.337	−1.837±0.935
16-E	(HD)	−0.075±0.054	0.026±0.214	−0.117±0.598
2702-F	(HD)	0	0	0
Treatment				
Not Induced		0.104±0.010	0.014±0.041	0.324±0.114
Induced		0	0	0

[a]L = Landrace
H = Hampshire
D = Duroc
HD = Hampshire-Duroc

Sex of pig, sire within breed, and treatment effects were not significant.

Female pigs were lighter than male pigs. Crossbred pigs were heavier than the purebred Landrace offspring. This indicates a clear superiority of crossbred pigs over purebreds. There was no superiority of the Hampshire-Duroc progeny (three-breed cross) over those of the Hampshire or Duroc (two-breed cross) boars. Piglets of treated sows weighed only slightly less than those from control sows.

Smith _et al._ (1973) reported that total litter weight at weaning was greater in crossbred than in purebred litters, but no significant breed difference in mean piglet body weight was present. Smith and Lishman (1974) observed that breed of sire did not affect litter size or total litter weight at weaning.

However, O'Ferrall _et al._ (1968) found an advantage of 6 kg for crossbred litters over purebred, and crossbred pigs were 0.3 kg heavier than purebreds at 21 days of age. Lush _et al._ (1939) reported a crossbred advantage of 10.7% in weight at weaning. King and Thorpe (1973) observed decreased individual weaning weights for progeny of crossbred sires.

Since heterotic effects decrease as an animal ages (Fredeen, 1957), it may be expected that individual piglet weight and total litter weight will vary greatly depending on the cross used to produce the piglets.

Fifty-six day weight was affected significantly ($P < 0.01$) only by litter within treatment effect. Sex, breed, sire within breed, and treatment effects were not significant.

Female pigs were lighter than male pigs, and the Hampshire-Duroc offspring were the lightest pigs at 56 days. Piglets from treated sows still weighed less than those of control sows.

O'Ferrall _et al._ (1968) reported an increased litter weight of crossbred litters at 56 days of 23.8 kg, and individual crossbred pig advantage of 1.5 kg over inbred pigs. Lush et al. (1939), utilizing double-mating, stated that crossbreds in the post-weaning period gained over their purebred littermates by 6.5%, and required 8.5% less feed per unit gain.

Breed of sire produced a significant effect on birth and 21-day weight. This was most likely due to the action of heterosis which resulted from crossbreeding. The heterotic effect produced by the Landrace ♀ x Hampshire-Duroc ♂ was greatest, since this cross produced the heaviest pigs at birth, although the Landrace ♀ x Duroc ♂ cross produced the heaviest pigs at 21 days.

As heterotic effects are generally only expressed early in life, and decrease as the animal develops (Fredeen, 1957), it appears that the superiority of the boars themselves begins to be expressed as their progeny age. Indeed, the Duroc boars' offspring were also the heaviest at 56 days (when heterosis is likely less important), and the Hampshire-Duroc progeny were the lightest.

Treatment (induction of parturition) had a significant effect on birth weight. It is evident that intrauterine growth continues until parturition, and that considerable weight gains are made by the piglets during the last few days of gestation. The treatment effect did not persist at weaning, indicating that induced piglets gain as rapidly as non-induced piglets from birth to weaning.

Litter within treatment effect was significant at birth, 21 days, and 56 days. This effect encompasses parity of the dam and non-measurable maternal factors such as milk-yield and "mothering-ability" of the sow.

Since this effect was present up to 56 days of age, it is apparent that maternal factors are important in the subsequent development of her offspring, even after they have left the sow.

The later growth and carcass traits which were studied were per cent carcass yield, carcass index, backfat depth, days to market, average daily gain (birth to market), average daily gain (21 days to market), and average daily gain (56 days to market).

Analysis of variance tables for the above characteristics are in Appendix Table F. Least squares estimates with their standard errors are in Table 13.

Per cent carcass yield was calculated by dividing carcass weight by final weight and multiplying by 100. A significant ($P < 0.05$) effect of sex of pig was found for carcass yield, while breed and sire within breed effects were not significant. Carcasses from female pigs procuced greater yields than those from male pigs. The Hampshire-Duroc progeny had the greatest carcass yields.

Smith et al. (1973) found that the progeny of Hampshire boars and Large White sows had higher carcass yields than purebred Large White progeny, even though the crossbred carcasses were shorter. In the present study, carcass length was not measured, since the overall carcass index did not include this characteristic.

Smith and Lishman (1974) reported higher carcass yields (3%) and shorter carcasses (3%) in the progeny of Pietrain-Hampshire boars on Large White females when compared with purebred Large White progeny.

Carcass index was very highly significantly ($P < 0.005$) affected only by sex of pig, with females being superior. The carcass index is based on backfat depth and carcass weight. Although breed differences were not

Table 13: Least Squares Estimates of the Effects of Sex, Breed of Sire, And Sire on Late Growth and Market Performance

		% Yield	Carcass Index	Backfat Depth (mm)	Days to Market	Birth to Market A.D.G. (kg/day)	Wean to Market A.D.G. (kg/day)	56 Days to Market A.D.G. (kg/day)
Sex								
Female		0.480±0.095	1.489±0.113	-3.749±0.094	9.524±0.657	-0.030±0.002	-0.037±0.002	-0.057±0.003
Male		0	0	0	0	0	0	0
Breed of Sire								
Landrace		-0.780±0.162	-0.516±0.192	0.538±0.160	3.686±1.102	-0.016±0.003	-0.019±0.004	-0.029±0.005
Hampshire		-0.930±0.327	0.281±0.389	-1.302±0.324	-3.427±2.216	0.008±0.007	0.009±0.008	0.011±0.011
Duroc		-1.018±0.299	0.008±0.356	-0.112±0.297	-0.100±2.073	0.004±0.006	0.003±0.007	0.002±0.010
Hampshire-Duroc		0	0	0	0	0	0	0
Sire								
267-C	(L)[a]	-0.088±0.562	-1.357±0.668	1.081±0.571	5.550±3.976	-0.029±0.012	-0.037±0.014	-0.054±0.019
2749-C	(L)	0.076±0.722	-0.593±0.857	-0.781±0.714	-2.500±5.082	-0.003±0.015	-0.006±0.018	-0.009±0.024
1043-D	(L)	-0.191±0.419	-0.522±0.498	-0.248±0.415	13.786±2.935	-0.052±0.009	-0.065±0.010	-0.092±0.014
149-E	(L)	0.129±0.438	-0.483±0.520	-0.802±0.434	10.989±2.949	-0.039±0.010	-0.050±0.011	-0.072±0.014
1500X-E	(L)	0.143±0.527	-2.117±0.626	3.872±0.521	5.596±3.367	-0.022±0.012	-0.032±0.012	-0.040±0.016
1-F	(H)	0.108±0.575	0.043±0.683	0.165±0.571	1.906±4.073	-0.016±0.012	-0.023±0.015	-0.035±0.019
136-F	(H)	-1.329±0.906	-0.254±1.077	-3.244±0.899	5.618±6.396	-0.034±0.019	0.041±0.023	-0.046±0.030
547-F	(H)	0.182±0.695	-0.389±0.826	-0.466±0.691	-0.885±4.380	0.006±0.013	0.002±0.016	0.004±0.021
71-E	(D)	-0.081±0.592	0.353±0.704	-2.599±0.586	6.734±4.169	-0.025±0.012	-0.036±0.015	-0.057±0.020
54-F	(D)	-0.686±0.615	-1.185±0.731	0.130±0.610	-3.237±4.191	0.004±0.013	0.003±0.015	0.007±0.020
459-F	(D)	0.172±0.735	-0.816±0.873	-0.996±0.727	5.541±5.200	-0.027±0.016	-0.037±0.019	-0.045±0.025
15-E	(HD)	1.261±0.759	-0.385±0.902	-0.750±0.750	8.549±5.361	-0.034±0.016	-0.043±0.019	-0.052±0.026
16-E	(HD)	0.924±0.494	-0.327±0.587	-0.712±0.490	6.854±3.234	-0.026±0.010	-0.036±0.012	-0.048±0.015
2702-F	(HD)	0	0	0	0	0	0	0
$\hat{c}$ (liveweight)				0.558±0.108	0.536±0.234			

[a] L = Landrace, H = Hampshire, D = Duroc, HD = Hampshire-Duroc

significant, the crossbred progeny were superior to the Landrace.

Backfat depth was measured at the shoulder and loin, and the two values added and adjusted for live weight. A very highly significant effect of sex again favoured the females. Breed and sire within breed effects were not significant. However, the Hampshire progeny were superior to the other crosses, and all crosses were superior to the purebred Landrace.

Louca and Robison (1967) found that gilts deposited less fat than barrows to 154 days. Smith et al. (1973) found that Hampshire-Large White carcasses were not significantly leaner than purebred Large White carcasses. Lishman et al. (1975) reported significant differences in the fat depth over the 'eye muscle' favouring the progeny of Hampshire-cross boars.

Days to market (adjusted for live-weight) was highly significantly altered by sex of pig and breed of sire. Gilts lagged seriously behind barrows in age to market by 9.524±0.657 days. Since gilts deposit less fat than barrows (Louca and Robison, 1967), they take longer to 'finish' and to reach market weight.

The Hampshire progeny were superior to the other crosses, reaching market weight 3.427±2.216 days sooner than the Hampshire-Duroc offspring, and over seven days sooner than the Landrace.

Average daily gain (A.D.G.) from birth, weaning, and 56 days, to slaughter, was examined.

A.D.G. to market was very highly significantly affected ($P < 0.005$) by sex of pig and breed of sire, and significantly affected ($P < 0.05$) by sire within breed. Male pigs gained more per day than female pigs.

Landrace pigs were, again, the poorest performers during the periods of birth, 21 days, and 56 days to market. The Hampshire progeny were superior in all three phases. No heterosis appeared to be present for growth to market weight since the Hampshire-Duroc offspring consistently failed to attain growth rates superior to the average of the parental breeds, and were, in fact, inferior to both the Hampshire and Duroc progeny.

The effect of sire within breed becomes significant as the pigs age. Since heterosis decreases as an animal grows older (Fredeen, 1957), the superiority or inferiority of the individual boars becomes apparent.

Breed of sire was found to have a significant effect on growth at all stages (excepting 56 days), but no significant effect on carcass characteristics. It is likely that this is a clear indication of the presence of a heterotic effect for growth, which is not present for carcass characteristics.

On the whole, in the early stages of growth, the Hampshire-Duroc progeny were superior to the Hampshires' and Durocs' only for birth weight, and amongst carcass traits, only for carcass yield. The greater birth weight of the Hampshire-Duroc progeny over the Hampshire and Duroc progeny is very probably due to a heterotic effect, since, not only do the Hampshire-Duroc progeny exceed the average of the parental breeds but they are superior to that of the best parental breed, the Hampshires.

The superiority of the Hampshire-Durocs for carcass yield is most likely not due to heterosis but rather to this cross being a combination of breeds which combine well with the Landrace to produce high carcass yields.

In general, the crossbred boars performed well, although-they were not superior to their parental breeds for most traits.

VII. SUMMARY AND CONCLUSIONS

The purpose of this study was the evaluation of Hampshire-Duroc boars for reproductive and productive performance in comparison with Landrace, Hampshire, and Duroc boars. The effects of breed, sire within breed, and induction of parturition were studied in 92 double-mated litters representing 529 pigs. The data were analyzed by least-squares and non-parametric methods, as was semen data on the 14 sires used. Paternity identification of piglets was determined by bloodtyping.

Breed of sire effects were significant for birth weight, 21-day weight, days to market, and average daily gain (birth, 21 days, and 56 days to market), and number of progeny sired in each litter. Induction of parturition had a significant effect on birth weight only. Breed of sire and sire within breed differences were significant for semen volume.

Hampshire-Duroc progeny were superior to all other breeds for birth weight, but they decreased in superiority as the piglets aged, and were exceeded by all the other breeds at 56 days. The crossbreds' pigs had the greatest carcass yields, but ranked third behind the Hampshires and Durocs for carcass index, backfat depth, days to market, and average daily gain to market (from birth, 21 days, and 56 days). The Hampshire-Durocs were superior to the Landrace for these traits.

Hampshire-Duroc boars exceeded all other breeds for semen volume and were superior to the Landrace for live-dead rate of the sperm, to the Hampshires for sperm motility and overall score, and to the Durocs for sperm concentration and morphology. The crossbred boars appeared to be superior to the Landrace for all characteristics except live-dead rate of the sperm.

The Landrace boars were dominated by the other breeds in the double-matings, in that more crossbred than Landrace progeny were sired in the double-mated litters. No significant differences were found between the conception rates of the sows bred to each boar.

Sex ratio and per cent survival to weaning of the double-mated litters were not significantly affected by breed or sire within breed. Highly significant correlations were determined between the rankings for dominance and sex ratio, and dominance and sperm quality.

Hampshire-Duroc crossbred boars present advantages to the swine producer for several traits. They produced pigs which exhibited heterosis for birth weight. Also, they had superior carcass yields in comparison with the other breeds, which indicated a higher meat to waste ratio. However, for other important growth and carcass traits the Hampshire-Duroc progeny lagged behing the Duroc, and especially the Hampshire offspring. The Hampshire-Duroc boars appear to offer an advantage over purebred pigs, but cannot compete with the two-way crosses of Landrace x Duroc and Landrace x Hampshire. Naturally, the merits of entire breeds cannot be determined on the results of a single study, but these findings offer some indications as to the value of Hampshire-Duroc boars.

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Appendix Table A: Analysis of Variance for Semen Volume, Concentration (10^6/ml), And Concentration, Motility, Morphology, Live-Dead Rate, and Total Scores

		Mean Squares						
Source	d.f.	Volume	Conc. (10^6/ml)	Conc. Score	Motility Score	Morphology Score	Live-Dead Rate Score	Total Score
Breed of Sire	3	30.803**	12.649	0.493	0.721	0.171	0.038	0.131
Sire/Breed	10	12.934**	21.790	1.512	0.170	0.140	0.041	0.221
Age	1	0.327	17.536	0.605	0.229	0.252	0.014	0.043
Age^2	1	0.001	27.094	1.428	0.183	0.171	0.009	0.090
Residual	24	3.837	10.559	0.791	0.226	0.091	0.317	0.122

**P < 0.01

Appendix Table B: Raw Means of Reproductive Data

		No. of Pigs at Birth	No. of Pigs at Weaning	No. of Pigs at 56 Days	No. of Pigs at Market	No. Pigs/Litter at Birth	Survival Birth to Wean (%)	Sex Ratio (%)
Sex								
Female		409	390	384	325	-	-	-
Male		421	375	357	204	-	-	-
Breed of Sire								
Landrace		291	280	274	192	3.16	96.83	42.38
Hampshire		165	144	134	89	6.11	91.93	58.98
Duroc		185	169	167	124	5.97	94.85	47.61
Hampshire-Duroc		189	172	166	124	5.56	93.59	53.42
Sire								
267-C	(L)[a]	47	46	45	31	2.76	97.22	52.74
2749-C	(L)	27	23	22	14	1.59	90.74	24.07
1043-D	(L)	77	76	76	55	3.67	99.38	42.34
149-E	(L)	82	77	76	57	3.28	95.42	47.84
1500X-E	(L)	58	58	55	35	4.83	100.00	35.17
1-F	(H)	43	43	43	31	4.30	100.00	47.03
136-F	(H)	88	67	57	32	8.80	76.70	67.33
547-F	(H)	34	34	34	26	4.86	100.00	65.31
71-E	(D)	48	37	37	26	4.80	90.83	46.17
54-F	(D)	70	70	68	56	6.36	100.00	47.23
459-F	(D)	67	62	62	42	6.70	93.60	49.62

[a] L = Landrace, H = Hampshire, D = Duroc

Appendix Table B (Cont'd): Raw Means of Reproductive Data

	No. of Pigs at Birth	No. of Pigs at Weaning	No. of Pigs at 56 Days	No. of Pigs at Market	No. Pigs/Litter at Birth	Survival Birth to Wean (%)	Sex Ratio (%)
Sire							
15-E (HD)[a]	62	60	60	49	7.75	96.65	54.97
16-E (HD)	62	59	58	48	4.43	95.13	51.75
2702-F (HD)	65	53	48	27	5.42	89.76	54.33
Treatment							
Not Induced	612	557	534	-	4.78	94.52	48.37
Induced	218	208	207	-	3.89	96.13	48.23

[a] HD = Hampshire-Duroc

Appendix Table C: Analysis of Variance for Sex Ratio And Per Cent Survival (Birth to Weaning)

		Mean Squares	
Source	d.f.	Sex Ratio	% Survival
Breed of Sire	3	0.1113	0.068
Sire/Breed	10	0.0943	0.081
Treatment	1	0.0002	0.050
Residual	56	0.0920	0.045

Appendix Table D: Raw Means of Productive Data

	Birth Weight (kg)	21-Day Weight (kg)	56-Day Weight (kg)	Days To Market	Carcass Yield (%)	Backfat Depth (mm)	Carcass Index	A.D.G. (kg) Birth-Market	A.D.G. (kg) Wean-Market	A.D.G. (kg) 56 Days-Market
Sex of Pig										
Female	1.43	4.76	15.40	168.79	77.39	70.54	102.28	0.50	0.55	0.62
Male	1.45	4.89	15.38	160.80	76.86	73.81	100.86	0.52	0.58	0.67
Breed of Sire										
Landrace	1.42	4.70	15.19	170.05	77.04	72.47	101.41	0.49	0.54	0.61
Hampshire	1.47	5.09	16.77	159.47	76.90	70.18	102.33	0.53	0.59	0.67
Duroc	1.42	4.72	15.84	160.98	77.49	72.71	101.69	0.53	0.58	0.68
Hampshire-Duroc	1.46	4.91	14.17	167.74	77.30	71.02	101.85	0.50	0.54	0.63
Sire										
267-C	1.50	4.52	15.26	169.63	77.00	74.32	100.87	0.49	0.54	0.62
2749-C	1.35	4.38	14.26	165.79	77.22	73.82	101.14	0.50	0.56	0.64
1043-D	1.46	4.85	14.92	167.82	76.55	71.17	101.58	0.49	0.54	0.62
149-E	1.42	4.90	16.08	169.73	77.30	71.79	101.60	0.49	0.54	0.61
1500X-E	1.32	4.51	14.67	175.02	77.35	73.45	101.40	0.48	0.53	0.60
1-F	1.65	5.50	17.57	159.39	76.61	69.08	102.35	0.52	0.57	0.65
136-F	1.40	4.89	16.22	163.63	77.09	69.69	102.78	0.52	0.58	0.66
547-F	1.43	4.97	16.68	154.82	77.01	72.10	101.73	0.55	0.61	0.71
71-E	1.35	4.91	16.20	165.41	77.00	68.87	102.62	0.51	0.56	0.63
54-F	1.42	4.77	16.38	155.73	77.40	73.87	101.32	0.54	0.61	0.71
459-F	1.46	4.56	15.02	165.30	77.92	73.54	101.60	0.52	0.57	0.66

Appendix Table D (Cont'd): Raw Means of Productive Data

	Birth Weight (kg)	21-Day Weight (kg)	56-Day Weight (kg)	Days To Market	Carcass Yield (%)	Backfat Depth (mm)	Carcass Index	A.D.G. (kg) Birth-Market	A.D.G. (kg) Wean-Market	A.D.G. (kg) 56 Days-Market
Sire										
15-E	1.48	4.55	14.64	166.06	76.79	70.60	101.51	0.50	0.55	0.64
16-E	1.60	5.59	14.65	171.49	78.20	72.93	101.75	0.49	0.53	0.61
2702-F	1.31	4.56	12.99	163.70	76.61	68.40	102.63	0.51	0.56	0.66
Treatment										
Not Induced	1.46	4.79	15.33	-	-	-	-	-	-	-
Induced	1.39	4.93	15.55	-	-	-	-	-	-	-

Appendix Table E: Analysis of Variance for Birth Weight, Weaning Weight, and 56-Day Weight

Source	d.f.	Mean Squares		
		Birth Weight	Weaning Weight	56-Day Weight
Sex	1	0.313*	3.312	5.123
Breed	3	0.230**	2.589*	12.510
Sire/Breed	10	0.055	0.793	5.631
Treatment	1	1.529**	0.027	13.599
Litter/Treatment	90	0.355**	4.528**	33.828**
Residual	(724)	0.058	(659) 0.870	(635) 6.634

*P < 0.05; **P < 0.01

Appendix Table F: Analysis of Variance for Per Cent Carcass Yield, Carcass Index, Backfat Depth, Days to Market, and Average Daily Gain to Market (From Birth, Weaning, and 56 Days)

		Mean Squares						
						A.D.G.		
Source	d.f.	% Carcass Yield	Carcass Index	Backfat Depth	Days to Market	Birth To Market	Weaning to Market	56 Days to Market
Sex	1	22.081*	212.023***	1346.440***	9235.974***	0.089***	0.135***	0.324***
Breed	3	6.610	9.471	62.938	855.727***	0.010***	0.015***	0.031***
Sire/Breed	10	1.967	3.789	29.066	311.222	0.004*	0.005**	0.010**
Residual	454	3.495	4.934	34.168	175.602	0.002	0.002	0.004

*P < 0.05; **P < 0.01; ***P < 0.005