Master of Science | Animal Science

ABSTRACT

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Crossbred pigs were significantly heavier than purebred pigs at 154 days of age when comparisons were made using data from 28 litters on a within litter basis. Significant differences were observed for sire effects on the carcass value index.

It is evident from the variance component analysis that mating systems and sire comparisons can be made more efficiently on a within litter basis than on a between litter basis.

DOUBLE MATING FOR SIRE AND MATING SYSTEM EVALUATION IN SWINE

by

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I. INTRODUCTION

The value of an animal is a function of what it produces and its efficiency in production. With the advance of science in agriculture, efforts have been made to find out what items constitute quality of product and the efficiency of production, and to develop measures which reflect differences among them reliably. The problem of ascertaining criteria that constitute value and suitable measurements of them is important. It is for this reason that the animal breeder devotes considerable attention to testing and evaluation of both his techniques and livestock. Having once established the criteria of value, he can then design or modify his programs accordingly.

The progeny testing of boars has been practiced in Denmark since 1926. With minor variations, the same system of testing has been adopted in many other countries. The value of the progeny test in animal improvement has been well demonstrated, however, many sources of bias and extraneous variation limits their usefulness. Attempts have been made to control these sources of variation by testing animals under uniform conditions, and sometimes by using statistical corrections for certain environmental effects. Some of the bias and lack of precision inherent in progeny testing in swine could presumably be avoided by arranging for offspring from different males to be born in the same litter.

The productive traits of farm animals are largely of a quantitative nature. The proportion of the observed variation which is genetic depends largely on the trait considered, as well as the conditions of production and measurement. Measurements are relative to the conditions under which they are made and comparisons of merit may not be valid unless the animals have had an equal opportunity for the manifestation of merit.

Theoretically, double mating in swine provides an opportunity of testing animals under uniform conditions. In fact, it provides an improved progeny test which can eliminate to some extent differences attributable to the genetic constitution of dams. At the same time, differences in the test environment may be controlled when animals are reared under the same conditions of feeding and management. The double mating technique may also be useful for comparing different systems of mating where different breeds are used.

This study therefore, concerns itself with the evaluation of double mating in swine, firstly as a method for comparing mating systems and secondly, for sire evaluation.

II. REVIEW OF LITERATURE

The subject matter of interest in this study concerns both the theoretical and practical aspects of double mating. In genetic and reproductive studies with farm animals mating is usually homospermic, i.e., the female is inseminated in one heat period with semen from one male. In contrast, heterospermic insemination of a female in one heat period with semen from more than one male can be carried out by multiple natural mating, or by artificial insemination with mixed semen. For this reason, the attendant considerations of heterospermic inseminations will be briefly reviewed. In addition, some of the systems of mating previously studied and pertinent reports in the literature are considered.

1. PHYSIOLOGICAL ASPECTS

a. Double Mating in Swine

The earliest reports on the use of double mating technique in swine appear to be those of Lush *et al.* (1939) and Roberts and Caroll (1939). The former reported on experimental work at the Iowa Agricultural Experiment Station carried out over an eight year period from 1926 to 1933. The following table taken from their report, summarizes the number and types of matings that were made during each year of the experiment:

NUMBER AND TYPE OF MATINGS MADE EACH YEAR AND NUMBER AND BREEDING OF PIGS PRODUCED

Year of Experiment	No. of Sows Used	Breeding of Sows	Type of Mating Used	Breeding of Sire or Sires	Number and Breeding of Pigs Produced
1926	6	Poland China	Double	Poland and Duroc	23 purebred 38 crossbred
1927	6	Poland China	Double	Poland and Duroc	35 purebred 26 crossbred
	2	Poland x Duroc	Single	Duroc	19 3/4 Duroc--1/4 Poland
	3	Poland x Duroc	Single	Poland	31 3/4 Poland--1/4 Duroc
1928	5	Duroc Jersey	Double	Poland and Duroc	11 purebred 37 crossbred
	3	3/4 Duroc Jersey	Single	Duroc	25 7/8 Duroc--1/8 Poland
	3	3/4 Poland China	Single	Poland	16 7/8 Poland--1/8 Duroc
1929	5	Duroc Jersey	Double	Poland and Duroc	56 purebred 6 crossbred
	2	7/8 Duroc Jersey	Single	Duroc	21 15/16 Duroc--1/16 Poland
	3	7/8 Poland China	Single	Poland	22 15/16 Poland--1/16 Duroc
1930	3	15/16 Poland China	Double	Poland and Duroc	3 purebred 25 crossbred
	3	15/16 Duroc Jersey	Double	Poland and Duroc	26 purebred 6 crossbred
1931	1	Poland China	Single	York	10 crossbred
	3	Poland x Duroc	Double	York and Poland	13 backcross 15 3-way cross
	3	Duroc Jersey	Double	York and Duroc	11 purebred 15 crossbred
	1	Poland China	Double	York and Poland	3 purebred 8 crossbred
1932	5	Poland x Duroc	Double	York and Poland	14 backcross 36 3-way cross
	6	Poland China	Double	York and Poland	43 crossbred
1933	5	Poland x Duroc	Double	York and Poland	8 backcross 55 3-way cross
	3	Poland China	Double	York and Poland	6 purebred 27 crossbred

Source: Taken from Lush et al. (1939).

The work of Roberts and Caroll (1939) also involves the use of the Duroc Jersey and Poland China breeds in which double-matings were made such that cross-breds and purebreds were obtained in the same litter. In an attempt to eliminate the maternal effects, sows of each breed were selected in turn to be the dams of mixed litters.

Interest in these double mating studies was mainly in connection with the advantages of crossbreeding in swine. The hypothesis then, being that crossbreeding could be used in recombining the best characteristics of two or more breeds for the formation of a new breed. Following these early reports no work in multiple sire mating in swine seems to have been undertaken for another twenty years. Sumption et al. (1959) adopted the multiple sire technique with a view to inducing natural selection for aggressive mating behaviour and to augment simplicity of handling a larger population during the development of new lines.

In an attempt to assess some of the problems of multiple paternity and mating behaviour, Sumption (1961) made random matings by the exposure of a number of females of the Duroc breed simultaneously during one heat period and was able to demonstrate a social order in mating among sires. In the same experiment controlled multiple matings were attempted. Dams were mated in rapid succession to boars of five breeds. Others were double mated on day one of estrus to a Duroc sire and another boar of a second breed and on day two of estrus again to a Duroc sire and a boar of a third breed. This study revealed evidence of natural selection for certain aspects of mating efficiency in swine and also the occurrence of selective fertilization and/or combination. More important, was the demonstration that under certain conditions of the experiment (group exposure), variations in male and female mating behaviour were sufficiently large to indicate considerable non-randomness of mating frequency.

As suggested by Sumption and Adams (1961a) if multiple sire mating is to be useful as a breeding method from the standpoint of increasing recombination potential, three conditions must be satisfied within any population in which it was to be applied. These conditions are (i) multiple mating must occur frequently (ii) the fertile interval during estrus must be sufficiently long to afford the opportunity for multiple paternity and (iii) a high incidence of multiple paternity must ensue. The experiment reported in this paper was designed to investigate the factors influencing multiple paternity. They found that the fertile period during estrus was sufficiently long to permit the occurrence of multiple paternity; that the order of mating did not greatly influence the relative number of progeny per sire but that there was a lack of consistent effect of mating order. In so far as the use of the multiple mating technique for the rapid recombination of genes is concerned, there seems to have been a reasonable amount of success. Sumption *et al.* (1961b) utilized the multiple mating technique, using natural matings to develop the Minnesota #3 breed of swine.

As early as 1939, it was recognized that even though the order of mating within the time elapsing between services bore no significant relationship to parentage of pigs produced, a greater proportion of mixed litters resulted from matings with short intervals between services than from those in which the intervals were extended. This finding of Roberts and Caroll (1939) suggests that if the semen of both boars could be introduced into the sow simultaneously there would be an even greater probability of obtaining mixed litters. The development of artificial insemination first with dairy cows and then with other farm animals makes this a definite possibility.

Of the more recent reports on double mating in swine, the report of Hlebov (1965) from the U.S.S.R. is most interesting. He claims that conception rate, embryo weight at seventy and ninety days respectively, as well as litter size and birth weight were all increased when mixed inseminates were made. In an earlier publication Sokolovskaja *et al.* (1964) reported similar superiority with respect to conception rate and lower embryonic mortality in favour of inseminations made with mixed semen. Preliminary reports of work in the United Kingdom by Widdowson and Newton (1965) and Newton and Widdowson (1965) indicate that mixed inseminates can be used to obtain litters, in which pigs are satisfactorily subdivided between two boars. Serological markers were used to determine parentage. No detailed analysis of the results were contained in any of these reports. Cerne and Salehar (1964) report a lower fertility in a group of sixty-one sows that were experimentally inseminated with mixed semen from two boars. All other differences they reported were not significantly different from a control group, however, this appears to be the only report in the literature in which a detrimental effect of mixing is reported.

b. Double Mating in Other Species

It should be recognized that progeny testing by heterospermic insemination is limited to females of multiparous species. These will include some laboratory rodents, the pig and to some extent, sheep. Markers must be available to distinguish the paternity of offspring. Both phenotypic and serological markers have been used for this purpose.

Perhaps the first report on the production of mixed litters after a natural mating with two sires is that of Kopec (1923) with rabbits. Offspring from either sire were said to have an increased birth weight in mixed litters. However, there were only three mixed litters reported on in this experiment and the results would therefore have to be considered as inconclusive.

In many reports coming from the U.S.S.R. reviewed by Kushner (1954) inseminations with semen from two or more males have been claimed to have superior practical results. Among the claims made are increased conception rate, birth-rate, birth-weight, and growth and viability of the young. In a pilot experiment with heterospermic insemination in the rabbit Beatty (1957) could find no supporting evidence for these claims. The experiment did reveal however, that the birth weight and subsequent development of young in mixed litters can be influenced by interaction between embryos *in utero*.

Beatty (1960) in an investigation of the fertility of mixed semen from different rabbits observed in one experiment that the conception rate or percentage of inseminations yielding a litter tended to increase as the number of males contributing to the inseminate increased even though the net total number of spermatozoa was held constant. Hess *et al*. (1954) undertook laboratory examination of bull semen mixtures and included a field trial. They reported increased motility and percent alive in mixed ejaculates compared to regular samples. Conception rate was also claimed to be superior but these results could not be repeated by Campbell and Jaffre (1958) even though they followed the method outlined by Hess and his colleagues (1954). In 83 of 104 samples studied, they found a lower motility for mixed ejaculates than that in individual samples. Dott and Walton (1958) further investigated motility and survival in mixed bull ejaculates. Semen samples of five Dexter bulls were mixed and studied. No effect of mixing on the live/dead ratio nor the percentage abnormals was found. The mixtures of semen tended to have a motility which was nearer the value of the less active component of the mixture than that of the means of both components.

In the mouse, artificial insemination has been carried out using mixtures of sperm from a number of inbred lines each containing a suitable genetic marker. Such a trial was reported by Edwards (1955).

Sperm mixtures were made with equal numbers of spermatozoa from each donor. Four types of sperm mixtures were made, viz. a triple mixture of three donors and three double mixtures containing three possible combinations of the three donors. These mixtures were used for inseminating estrous females of the same three lines as the donors. The results of this experiment indicated that the chance of fertilization by a particular type was not the same for all components of the mixture. There was an excess of eggs fertilized by a particular sperm type and the result was consistent throughout the series of nine sperm mixtures in which that particular type was a component. No explanation for this result was given but there was the speculation that there might be a tendency for a reaction of one sperm type with one particular egg type or with a particular uterine environment. Whether there was a differential rate of transport of one sperm type as opposed to the other was not indicated.

In experiments using mixed semen for inseminations in poultry, the reports are limited and somewhat conflicting. Parker et al. (1942) observed that about equal numbers of chicks were sired by Barred Plymouth Rock and New Hampshire males, but conspicuously fewer chicks were sired by the White Leghorn males. Allen and Champion (1955) found that spermatozoa possessing certain advantageous variations associated with or reflected in a high degree of motility and a low incidence of mortality were favoured in numbers of progeny sired when sperm from different males were pooled. This has been the only direct reference to preferential transport as opposed to selective fertilization in the literature.

c. Artificial Insemination in Swine

The technique of artificial insemination has not developed as rapidly in swine as in other farm species, primarily because of the problems encountered with the optimal time to service. The development of artificial insemination in farm animals has been reviewed by Walton (1933). Aamdal (1960) believes that insemination during the first half of estrus gives the best conception rate as in natural mating. The length of estrus in sows has been found to vary with the breed. According to Burger (1952) the optimum time for mating is in the first 12 to 24 hours of estrus. However, he also showed that in the Large Black breed fertile matings can be made at the onset of heat, i.e., up to 54 hours before ovulation and Hancock (1961) reovered eggs in the pronucleate stage from sows that had been mated or inseminated up to 72 hours previously. Hancock and Hovell (1962) concluded from their study of inseminations made at varying times before and after the onset of heat, that failure of fertilization was likely to be the greatest source of loss of fertility for inseminations made before heat and late in heat.

There is evidence that fertility following artificial insemination in the sow varies according to the site of semen deposition. Hancock (1959) showed that fertility in sows was higher when semen was deposited into the uterus compared to semen deposited into the cervical canal. In a later study Hancock and Hovell (1961) found that intra-uterine inseminations with 20 ml. of semen alone resulted in significantly superior fertility to conventional inseminations (into cervix) with 120 ml. semen. This comparison of fertility was made between numbers of sows with all ova cleaved (or "fertilized") and sows with none cleaved (or "fertilized").

In a study on the minimal volume of semen and the number of sperm for fertility in artificially inseminated swine, Wiggins _et al._ (1951) obtained 29 percent fertility in gilts inseminated with 0.1 cc. of semen diluted to 50 cc. and an average fertility of 91 percent with 20 cc. of semen diluted to 50 cc. In sows, they obtained 42 percent fertility with 1.0 cc. semen diluted to 50 cc. Stratman and Self (1960) showed that inseminations with 50 ml. volume of semen gave a higher survival rate and greater percent conception than either 10 ml. or 20 ml. Results were not significantly different for total number of sperm inseminated within the limits of the experiment (2.5, 5.0 and 10.0 billion spermatozoa).

2. GENETIC ASPECTS

a. Blood Groups in Swine

In early studies of animal blood groups, attempts were made to relate animal blood groups to those of man. Pigs for example have red blood cells which are agglutinated by anti-A antibody. These pigs are classified as group A and until a decade or so ago, A versus non-A was the only differentiating blood group in pigs for which the genetic basis was known.

The early studies of pig blood groups have had obscure applications. Pigs of superior productivity were being developed but little was being learned about individual genes causing differences among pigs. The effects of genes for coat colour were analysed, as were the effects of a number of undesirable traits. Rasmusen (1964) pointed out, however, that these genes were not very satisfactory to study in breeding experiments because they were not always readily identified and may sometimes be influenced by environment. In addition, genes for undesirable traits are expensive to maintain in an experimental herd.

Many different blood types have been reported in the pig. By a systematic studies of pig blood groups new blood factors on pig erythrocytes have been detected by means of immunization. These have been classified into fourteen genetic systems (Hojny and Hala, 1965; Andresen, 1966). Unlike the genes in earlier reports, these genes controlling the blood group systems are particularly useful as genetic markers. The red blood-cell antigens which they determine are influenced very little by environment, none of them have marked undesirable effects and their distribution can be accurately determined from generation to generation in breeding experiments (Andresen and Baker, 1963).

b. Serum Proteins

Smithies (1955) and Smithies and Walker (1955) demonstrated how starch gel electrophoresis could be used to show that serum proteins were genetically controlled. Kristjansson (1960) in his studies with swine concluded that the synthesis of serum-protein β was under the control of a single pair of alleles exhibiting partial dominance. Later, using starch gel electrophoresis, Kristjansson

(1961) observed ten haptoglobin fractions in sera collected from Yorkshire and Landrace pigs and from the reciprocal crosses between these breeds. He also presented data in support of the hypothesis that the synthesis of haptoglobin 1, 2 and 3 were under the control of alleles Hp^1, Hp^2 and Hp^3 respectively and that an individual possessing only one of the haptoglobins is homozygous for the allele controlling the synthesis of that haptoglobin and that an individual possessing two of the haptoglobins is heterozygous for the alleles controlling these haptoglobins.

Imlah (1965) reported on an investigation carried out in pigs to detect the possibility of association and genetic linkage between red cell factors and the genes controlling serum proteins at the transferrin, haptoglobin, haem-binding globulin, ceruloplasmin and amylase loci. He claimed that the transferrin locus in the pig showed three alleles Tf^a, Tf^b and Tf^c with six possible genotypes. The haptoglobin of pigs is believed to be represented by two possible genotypes only. In the same study Imlah (1965) found four alleles for the haem-binding globulins with ten possible genotypes, two alleles of the ceruloplasmins and three alleles for the amylase locus. However, Widdowson and Newton (1965) for their program of double mating, considered that there would be an insufficient number of phenotypes available to make indentification easy should starch gel electrophoresis of the β-globulins be used.

c. The Evaluation of Genetic Material

Genetic material is generally evaluated on the basis of pedigree or family information, phenotype and progeny testing. The particular form it takes would depend on the type of material, the information available or that can become available and the interest and objective of the researcher. Pedigree or family information has been used in dairy animals for many years. American Ayrshire bull calves were distinguished at registration as "Preferred Pedigree", "Approved" or "Selected Pedigree" according to their performance pedigrees. Investigations showed that three out of every four "Preferred" bulls, and two out of every three "Selected" have produced daughters of higher than average performance (Nichols, 1957). However, this method of evaluation is quite often based on ancestors derived from selected groups and also include gross inaccuracies.

Collateral relatives, such as brothers and sisters, aunts and uncles have been used as a progeny test of some ancestor. The conditions under which such tests are useful depends on (i) the observed sibs to the individual being tested are numerous (ii) the characteristic is expressed in only one sex (iii) measuring the characteristic destroys the individual before it can reproduce or (iv) the characteristic is all-or-none in its expression. These conditions all have attendant disadvantages and often cannot be met in experimental work.

Dairy researchers have been concerned for some time as to which method is best for determining which bulls are transmitting the highest milk production. Three main methods have been considered (1) the simple average yield of the sire's daughters (2) the comparison of daughters with their dams and (3) the comparison of daughters with their contemporaries in the same herds. Edwards (1932) considered progeny testing within a herd. By grouping the dams into two groups according to their yield, he found that the two most consistent assessment of the two groups of daughters was the simple average production. Because artificial insemination can spread a sire's progeny over many herds, the situation becomes quite different. MacArthur (1954) suggested that sires be judged by comparing their daughters with their contemporaries in the same herd. However, Robertson et al. (1956) believed that some method based on contemporary comparisons could be developed to give a satisfactory evaluation of sires used in different herds at different production levels. Based on the assumption that differences between herds at different levels of production are in the main due to differences in management rather than to differences in breeding value they presented a method for estimating the overall contemporary comparison. Gaunt and Legates (1955), in D.H.I.A. data in the United States, suggested that the daughter-contemporary differences had much usefulness as a basis to correct for certain environmental effects, particularly when large differences exist between herds.

d. The Reduction of Environmental Variation

In cattle, sheep and swine researchers have attempted to reduce environmental variation by the use of twins and litter mates. King and Donald (1955) in an analysis of intra-pair variances in live-weight in dairy cattle have partitioned the sources of variation into components, e^2, an environmental component occurring within twin pairs; g^2, the genetic variation; and m^2, the dam and other factors so that the following relationships obtain:

Monozygotic	- MZ -	e^2
Dizygotic	- BZ -	$e^2 + 1/2\ g^2$
Full Sibs	- FS -	$e^2 + 1/2\ g^2 + m^2$
Half Sibs	- HZ -	$e^2 + 3/4\ g^2 + m^2$
Unrelated	- U -	$e^2 + g^2 + m^2$

These relationships exemplify the changing importance of sources of variation as one moves from monozygotic twins to a pair of unrelated animals. In another study Donald (1958) reported on the variances in liveweight at three months and at eighteen months of age for paired animals of differing degrees of relationship ranging from 100 percent (one-egg twins) to 0 percent (unrelated) in cattle. At both ages, intra-pair variance increased as relationship diminished but more so at eighteen months. It also increased substantially from contemporaries to non-contemporaries. Watson (1961) studied variation in milk yield and butterfat percentage using paired lactation records of milk yield and fat percentage from experimental twins and commercial twins, full sisters and half-sisters. He observed that as the degree of contemporaneity of pair members declines the within-pair variances increases in size and the between-pair component decreases.

In experiments involving polytoccous species grouping by litters has been used for a long time, particularly in feeding experiments where the effect of a specific diet is being investigated. Quenouille (1954) cites an extreme example of an experiment conducted at the Rowett Research Institute in Aberdeen. In this experiment the weight gains of eight litters of five rats were measured. The animals of each litter were fed on five diets. After the variation in weight gains due to litters was removed, the treatment-comparisons when tested were found to be non-significant. However, a specific comparison previously planned in the experiment was shown to be highly significant indicating the increased accuracy in the treatment comparisons.

e. Systems of Mating in Swine

Mating systems have received major attention in swine breeding research in an attempt to discover effective methods for the genetic improvement of economic traits of low heritability. Stanislaw et al. (1967) undertook a study to obtain estimates of specific parameters in purebred and crossbred populations of swine for 56-day weight, postweaning average daily gain and probed back fat. Their studies showed that though variations in 56-day weight were largely due to non-genetic causes, the genetic variance accounted for a greater portion of the total variation in crossbreds than in purebreds.

The systems of mating that have been favoured in swine generally involve some form of crossbreeding. Following the success of hybrid corn in the United States, animal researchers devoted much time to crossing two or more breeds in an attempt to obtain recombination of some of the best characters. Roberts and Caroll (1939) and Lush et al. (1939) report some of this work from Illinois and Iowa respectively. The latter publication also reviews published material on cross breeding of swine. Comstock (1960) points out that any attempt to assess the improvement in market hogs that is likely or possible, poses two issues. The first is a consideration of the improvement likely to be achieved in the purebreds themselves and secondly, how much of this will be reflected in animals produced by crossing the breeds.

Commonly, boars of three or four pure breeds or lines are used in rotation and crossbred replacement females are saved each generation for the production of market hogs. In an interesting study to determine whether progeny sired by crossbred sires were more variable than those sired by purebred sires, Rempel et al. (1964) found that differences in performance between progeny of purebred and crossbred sires existed only for backfat thickness and daily gain and concluded that the use of crossbred sires in systematic crossing systems need not result in increased variation among the progeny.

The evaluation of mating systems in swine is beset with many problems, the chief of which is environmental variation. However, Roberts and Caroll (1939) pointed out that purebred and crossbred pigs from different dams showed greater environmental differences than among purebred and crossbred pigs farrowed in the same litter. Such environmental differences might therefore mask the real effects of crossbreeding. The double mating technique for the production of purebreds and crossbreeds or backcrosses and three-breed crosses in the same litter seems to be ideally suited for adequate testing of these systems of mating.

III. THEORETICAL CONSIDERATIONS IN DOUBLE MATING

The object of a double mating program in swine is to provide a more sensitive method of assessing the relative merit of mating systems and evaluating boars. As early as 1939 Lush et al. (1939) in a well documented report indicated that the preponderance of evidence on the evaluation of crossbreeding work pointed to the same general conclusions as to the advantages of crossbreeding over purebreeding. He argued that especially in experiments in which small numbers of pigs were involved there was insufficient evidence to show statistically significant differences but that the combined weight of all the evidence was overwhelming. Double mating provides a more reliable measure of the effects of different types of breeding as well as a measure of the relative merit of boars since differences between dams are eliminated.

When sows are mated to two boars during the same heat period or inseminated with a sperm mixture from two males, the resulting litter may have progeny which are half-sibs in the same litter. Genetically this is a unique situation in that theoretically the composition of the mean squares would be:

Between litters	$k_3 \sigma^2_{pig} + k_4 \sigma^2_{sire} + k_5 \sigma^2_{lit}$
Between sires within litters	$k_1 \sigma^2_{pig} + k_2 \sigma^2_{sire}$
Between pigs within sires within litters	σ^2_{pig}

Baker et al. (1943) in an attempt to assess the relative importance of heredity and environment in the growth of pigs at different ages recognised the theoretical composition of mean squares and interpreted the three variances as follows: The variance expected between pigs in the same litter was designated R. Two pigs having the same sire but belonging to different litters may differ in whatever affected one litter but not the other and therefore this expected variance they designated as R + L. The variance expected for pigs differing in both litter and sires would contain R + L + S. The genetic implication in these two situations is readily seen in that in the double mating situation sires may be tested on a within litter basis while in the situation as outlined by Baker et al. (1943) evaluation would be on a between litter basis. In this same paper this is well demonstrated where in their test of variance between sires, the appropriate error was the mean square for between litters by the same sire. This error term is inflated by existing differences between dams as well as environmental differences peculiar to a litter.

The power of a double mating experiment can be illustrated roughly by analogy to the randomized complete block experiment in which means are tested against a more refined error in contrast to a completely randomized plot experiment in which the error term contains all extraneous sources of bias which cannot be associated with treatments. In the hypothetical example which follows, estimates of within litter variance and sire variance for 154-day weight in pigs are taken from the report of Craig et al. (1956) and are given as 164 and 25 respectively.

Assuming that a difference in merit between two boars is to be established and it is assumed that a difference of 6.0 lb. for 154-day weight is the minimal difference worth considering, the number of litters required to establish this difference can be roughly computed by use of the statistic "t" (Federer, 1955), in the formula:

$$r = \frac{2\ t\ \alpha^{2}\ S^{2}}{d^{2}}$$

where t = t-value at 0.05 percent level for the d.f. associated with S^2

S^2 = estimated experimental error variance

d = specified worthwhile differences.

By substitution in our hypothetical example, we find that for single matings:

$$r = \frac{2(1.64)^2 \times 164}{6.0} = 25 \text{ litters}$$

and for double matings:

$$r = \frac{2\ (1.64)^2 \times 25}{6.0} = 4 \text{ litters}$$

Even though this formula at best provides only a very rough estimate of requirements, it demonstrates the relative requirements for establishing differences under both types of experimentation. It should be pointed out that the assumptions for computing the number of litters required are that litters have equal representation from both boars, that there is a 100 percent survival. More important it assumes that the appropriate errors are not affected by any extraneous factors. These assumptions are highly idealistic and can never be attained in animal experimentation.

The double mating technique is comparable to the utilization of identical and fraternal twin comparisons or sire daughter averages and contemporary comparisons in dairy cattle. Edwards (1932) by grouping dams according to yield found that for judgement within a herd the most accurate simple criterion was the simple daughter average. Robertson et al. (1956) have pointed out that this was due to the fact that the heritability of milk yield is low and that when bulls were used in different herds at different levels of management, the situation becomes quite different. In the same paper, these workers presented a most striking example of considerable difference between the average yield of the bull's daughters in different groups, while the difference between the daughters and their contemporaries were more constant. The significant point here lies in the fact that for contemporary comparisons, each "herd year" contains two groups - the daughters of the bull being tested and other contemporary heifers. Differences are then weighted in accordance with the numbers in each group. By way of comparison, the double mating technique provides a similar opportunity of evaluating two boars within a single litter group. The essential element in these two situations is that bulls or boars may be judged from the performance of their progeny under the same conditions.

In experiments involving the utilization of twins the main advantage lies in the degree of environmental control. Maternal half-sibs differ from paternal half-sibs through the influence of the maternal environment during the prenatal and postnatal periods. Koch and Clark (1955) point out that its influence may be inferred from observation and by comparing relationships when it has been excluded with those in which it has been included such as paternal half-sibs compared with maternal half-sibs. This situation is paralleled in every double-mated litter in which the litter has representatives from both boars.

Donald (1958) in a study of variation in twin cattle has partitioned the variation in both monozygotic and dizygotic twin cattle. The pre-and post-natal environments (e^2) are the only known source of variation for within pairs of one-egg twins; this is inflated by a half of the genetic variation (g^2) characteristic from which the parents come in the case of two-egg pairs. Half-sibs on the other hand would contain three-fourths of the genetic variance as well as the maternal effects (m^2) due to their having different dams in addition to the error variance of the same order of size as that shown by twins.

In the double-mated litter, the maternal component is of course replaced by a component due to sire since progeny of different boars are paternal half-sibs. Robertson (1950) in citing four reasons for the resemblance of monozygotic twin pairs warns that though these reasons (genotype, prenatal and postnatal environment, contemporaneity, similar local environment) some of which may be trivial, in their net effect could effectively account for a reduction in environmental variation. Significant interactions could of course reduce the efficiency of twin experimentation as pointed out by King and Donald (1955) when one member of a pair is assigned to one treatment and the other to a second treatment. In such a case the error term is inflated by a treatment-set interaction unless this is computed. Likewise, in a double-mating experiment it is conceivable that interactions could reduce their effectiveness as a method for evaluating mating systems and boars.

IV. DATA SOURCE AND METHODS

a. General

The data used in this study constitutes a number of double matings made in the Macdonald College Swine Herd during the period 1964-1966. The total number of litters was 105 and involved 1,149 pigs. Of these there were 70 litters in which there were representatives from two boars. These litters represented purebred Yorkshire, purebred Landrace, purebred Lacombes, single crosses, backcrosses and their reciprocals together with a number of 3-way crosses. Sixteen of the 105 litters involved matings in which a Large Black boar was double mated with a purebred Lacombe, Landrace or Yorkshire female or crossbred of any two of these breeds. Data from these litters were considered only in the evaluation of the reproductive phase of this study.

The mating plan in the double mating program may be represented as follows:

(i) Purebreds vs. Crossbreds

Sires	Dams		
	Yorkshire	Landrace	Lacombe
Yorkshire Landrace	*	*	
Yorkshire Lacombe	*		*
Landrace Lacombe		*	*

(ii) Backcrosses vs. 3-way Crosses

Sires	Dams		
	York-Land	York-Lac	Land-Lac
Yorkshire Landrace		*	*
Yorkshire Lacombe	*		*
Landrace Lacombe	*	*	

The only restriction to the above plans for mating was that the matings between parents facilitated the use of the two blood group markers used in the program. This did limit considerably the number of sire combinations that were possible and as a result double matings not meeting the specifications of the original plans were carried out and are included in the analysis where they are of value.

b. Blood Group Factors as Markers

Unlike earlier work on double matings reported in the literature, identification of offspring was by blood groups. Blood samples of all stock were taken routinely and shipped to Miss R. Saison of the Department of Veterinary Bacteriology, Ontario Veterinary College, who kindly typed the samples.

c. General Procedures

All breeding stock were typed for 21 blood group factors. Two systems were chosen for use in the double mating program. The L-system and the N-system. Each system has two alleles which form closed systems. La and Lb and Na and Nb. The possible genotypes in each system are:

La La, La Lb and Lb Lb

Na Na, Na Nb and Nb Nb

Matings were arranged whereby combinations of one of the above systems in the blood group patterns of the sow and two boars involved will ensure identification of the sire of each of the progeny. Blood types expected in the progeny from single matings for the L-system are:

Type of Mating	Blood Types of Progeny		
La x La	La		
La x Lab	La	Lab	
Lab x Lab	La	Lab	Lb
Lab x Lb		Lab	Lb
Lb x Lb			Lb

(N may be substituted for L in the above table for the inheritance of the factors of the N-system).

Possible matings for blood factor identification of progeny from double matings for the L-system are:

Blood Type of Sows		Blood Type of Boars		Blood Type of Progeny
La	x	Boar 1	La	La
		Boar 2	Lb	Lab
Lb	x	Boar 1	Lb	Lb
		Boar 2	La	Lab

(N may be substituted for L in the above table for the inheritance of the N-system).

All progeny from double matings were bled and typed with a battery of reagents. Each animal was assigned to its sire on the basis of inheritance of the L- or N- factors. In addition, from the results of the comprehensive tests, it was possible to recognize the homozygous animals for factors other than the L and N systems. Other factors were used in a limited number of mating combinations for animals not suitable for the program on the basis of the L- and N- system.

d. Mating Techniques

Of the litters farrowed as a result of matings done during 1964, nine of them were from natural matings. However, the project was originally conceived with the idea of using the artificial insemination technique. For the most part, artificial insemination was the technique used but for a short period in the fall of 1965 low conception rates necessitated the use of natural matings as well. It should be pointed out that the low conception was not believed to be due to the artificial insemination technique but rather was the result of a number of other factors peculiar to the herd. A most outstanding observation was that this period of low conception followed a period when sows were idle for about two or three estrous cycles during remodelling of the barns.

A further contributing factor may have been the fact that estrus control was incorporated into the early studies on insemination technique and sows were inseminated without reference to the external signs of heat.

e. Collection and Evaluation of Semen

Boars were trained to mount a wooden dummy first in the presence of a sow in heat. Later the sow was not necessary and collection could proceed using the dummy.

Collection of semen was by the gloved-hand technique. Whole semen collected into insulated bottles was then strained through gauze and the total volume was recorded. A drop of strained semen was placed on a warm slide and examined microscopically. A rating based on a percentage scale was made for the proportion of motile sperm. In addition, type of motility (based on a scale of 1 - 5, consideration being given to direction and vigour with which sperm propel themselves) was recorded. Finally, a count of normal sperm cells was made, using a Spencer Hemocytometer; whole semen was diluted with sodium citrate solution with a few drops of formaldehyde added to kill the sperm.

f. Inseminations

A minimum of 10 billion sperm in 100 ml. of mixed semen was used per insemination. Where the concentrations of semen from any two boars varied widely, an egg yolk bicarbonate-glucose (Y.B.G.) extender was used to provide equal sperm concentrations from each boar in the mixture. These matings were compared with matings carried out with inseminations on an equal volume basis ignoring sperm concentration as well as matings in which one boar mated naturally while the other was done artificially. In the case of these mixed inseminations, artificial insemination always followed the natural mating immediately.

g. Traits Used in the Study

Following slaughter of animals (usually within a week of attaining the market weight of 190 lbs. body-weight) a record of the weights of carcass, R.O.P. (record of performance) and commercial cuts were obtained for each animal. Direct tracings were made to record the area of eye of lean (m. longissimus dorsi).

An index of carcass value calculated on the value of the four primal cuts (left-side only) as follows:

Index = (0.43 x trimmed ham) + (0.36 x trimmed shoulder) + (0.55 x trimmed loin) + (0.39 - R.O.P. grade) x trimmed belly

(R.O.P. belly grades run 1 - Excellent, 2 - Good, 3 - Fair, 4 - Poor)

Growth traits included in the study were weight-for-age for birth, 21 days, 56 days and 154 days of age.

V. METHOD OF ANALYSIS

The analysis of variance is a commonly used statistical method by which estimates of a number of variances are made and by which the significance of differences between these estimates is determined. With equal subclass frequencies the effects and sums of squares for totals are obtained directly from the class or subclass totals, and in fact is really a method of simultaneous consideration of all effects.

In this study unequal subclass frequncies cause the different classes of effects to be non-orthogonal. Thus it is necessary to consider all effects simultaneously in order to free them from entanglement. The method of analysis used is that of least squares estimates as outlined by Harvey (1960).

The standard mathematical model for the analyses and the assumptions underlying its use were as follows:

$$Y_{ijklm} = u + a_i + b_j + c_k + g_l + e_{ijklm}$$

where

Y_{ijklm} represents a measurement on the m^{th} pig of the l^{th} sex from the k^{th} sire in the j^{th} mating system and the i^{th} litter

u represents the population mean when equal frequencies exist in all subclasses

a_i represents an effect common to all pigs of the i^{th} litter

b_j represents an effect common to all pigs of the j^{th} mating system

c_k represents an effect common to all pigs of the k^{th} sire

g_l represents an effect common to all pigs of the l^{th} sex

e_{ijkl} represents the random errors which are assumed to be N.I.D. $(0, \sigma_e^2)$

All interactions are assumed to be equal to zero. In this model a_i - the litter effect, is assumed to be random, while b_j, c_k and g_l - the mating system, sire and sex effects respectively, are considered as fixed.

The least squares equation for the model may be represented in tabular form as follows:

	$\hat{u}$	$\hat{a}_i$	$\hat{b}_j$	$\hat{c}_k$	$\hat{g}_l$	R.H.M.
u :	$n_{....}$	$n_{i...}$	$n_{j..}$	$n_{..k}$	$n_{...l}$	$= Y_{....}$
a_i:		$n_{i..}$	$n_{ij.}$	$n_{i.k}$	$n_{ij.l}$	$= Y_{i...}$
b_j:			$n_{.j}$	$n_{.jkl}$	$n_{..kl}$	$= Y_{.j.}$
c_k:				$n_{..k}$	$n_{..l}$	$= Y_{..k}$
g_l:					$n_{..l}$	$= Y_{...l}$

The first equation pertains to the estimation of u. The left-hand members (L.H.M.) of the equation, i.e., the equations to the left of the equal sign, gives the number of observations in the various subclasses, the right-hand members (R.H.M.) gives the sum of the observed values.

The second set of equations give the equations pertaining to the number of litters while the third set refers to the mating systems, etc. The restrictions to permit calculation of the least squares were:

$$\hat{u} + \hat{a} = a_i$$

$$\Sigma_i \hat{b}_j = \Sigma_k \hat{i}_k = \Sigma_l \hat{g}_l = 0$$

Since the number of equations were too large to be handled for analysis $u + a_i$ sets of equations were absorbed and the reduced matrix was solved for fixed effects. The litter data were then corrected for fixed effects and the corrected sum of squares for a_i effects were computed. The computational work was carried out on an IBM 1620 computer.

VI. RESULTS

1. CHARACTERISTICS OF THE DATA

Fourteen boars sired the 1,149 pigs farrowed in the 105 litters which were obtained in this double mating study. Tables 1 and 2 show the breakdown by mating type, number and percentage of pigs sired by breed of boar as well as the number and percentage survival to 21 days.

The distribution of offspring sired by one boar ranged between 25.0 percent and 74.7 percent when matings were made to purebred females while matings with crossbred females showed a wider range (16.2 percent to 90.8 percent). Although the total number of matings to crossbred females were fewer in number the distribution of offspring by sires with crossbred females was more variable than was the case with purebred females. It must be pointed out however that most of the observed variation of sire representation in litters were in those litters which were in combination with a Large Black boar. All combinations with this boar were of the "mixed" type, i.e., a natural by the Large Black which was mature when acquired, followed by a natural mating or insemination with semen from a second boar.

In the original mating plans the intention was to place emphasis on comparisons between purebreds and crossbreds where purebred sows were used and to compare 3-way crosses and backcrosses

TABLE 1: TOTAL NUMBER OF PIGS BORN, FROM PUREBRED DAMS TOGETHER WITH DISTRIBUTION AND SURVIVAL TO 21 DAYS OF AGE

Breed of Sire	YORKSHIRE DAMS					LANDRACE DAMS					LACOMBE DAMS				
	Lits Far'd	Pigs Born	% Sired	No. Surv.	% Surv.	Lits Far'd	Pigs Born	% Sired	No. Surv.	% Surv.	Lits Far'd	Pigs Born	% Sired	No. Surv.	% Surv.
Yorkshire	6	28	46.7	23	83.7	8	63	74.7	54	86.1	4	23	47.7	19	83.2
Landrace		32	53.2	25	76.9		21	25.2	17	82.3		25	52.3	20	80.6
Yorkshire	6	31	48.7	25	81.6	10	40	43.6	30	74.9	7	16	53.9	11	72.1
Lacombe		32	51.2	24	73.8		51	56.3	41	81.3		13	46.0	10	78.8
Landrace	11	66	46.3	56	84.2	4	23	46.3	20	86.4	2	5	30.6	4	80.0
Lacombe		77	53.7	59	76.8		26	53.6	17	66.6		12	69.3	9	75.0
L'Black +															
York			44.4	19	81.6			75.0	6	75.0			51.2	13	81.0
Land	4	54	55.5	25	83.2	1	12	25.0	4	100.0	3	31	48.6	12	79.5
Lac															

TABLE 2: TOTAL NUMBER OF PIGS BORN, FROM CROSSBRED DAMS TOGETHER WITH DISTRIBUTION AND SURVIVAL TO 21 DAYS OF AGE

Breed of Sire	YORK-LAND DAMS					YORK-LAC DAMS					LAND-LAC DAMS				
	Lits Far'd	Pigs Born	% Sired	No. Surv.	% Surv.	Lits Far'd	Pigs Born	% Sired	No. Surv.	% Surv.	Lits Far'd	Pigs Born	% Sired	No. Surv.	% Surv.
Yorkshire	3	8	23.5	7	87.5	3	20	59.7	17	85.0	2	17	64.7	16	94.1
Landrace		26	76.5	21	82.8		13	40.2	11	87.8		9	35.3	7	77.8
Yorkshire	2	13	63.8	11	84.6	9	76	76.5	67	88.0	4	27	66.0	18	66.6
Lacombe		8	36.1	7	87.5		23	23.5	19	84.2		14	34.0	10	71.6
Landrace	4	28	84.7	25	89.1	4	33	55.0	25	75.7					
Lacombe		5	16.2	4	80.0		27	45.1	22	81.2					
L'Black + York			43.1	16	84.4			71.1	29	85.2			90.8	16	86.3
Land	3	44	56.8	25	80.0	3	46	28.8	10	76.8	2	21	9.0	1	50.0
Lac															

on a within litter basis where crossbred sows were involved. The problem of identification based on two blood group systems presented a considerable restriction. Thirty-one litters out of purebred sows and 19 litters out of crossbred sows met these restrictions for a total of 50 litters. The 31 purebred sows farrowed 42.4 percent purebred pigs and 57.6 percent crossbred pigs. In the 19 litters involving crossbred sows, there were 55.6 percent backcrosses and 44.4 percent 3-way cross offspring. The remaining double mated litters provide additional information on the effect of double mating on litter size and distribution of progeny.

Data on growth and carcass information after marketing each pig constitute a complete record. There were 474 pigs providing complete records.

2. TECHNIQUE AND EVALUATION STUDIES

a. Preliminary Technique Studies

Preliminary studies on the different methods of service were classified into three categories, viz, natural mating in which both boars were allowed to mate the female naturally during a single estrus; artificial insemination, in which the inseminate comprised a mixture of semen from two different boars and "mixed" in which an insemination was made with semen from a second boar following a natural mating by one boar. These "mixed" services are somewhat biased in that they involve natural matings by one or two boars which did not respond to training for semen collection. The number of litters produced, total number of pigs born, the average litter size and the percent sired by one boar are shown in Table 3. The "mixed" service failed to produce split litters, all offspring being sired by the boar providing the natural service. However, only two were attempted during this preliminary period. The percentage distribution of the progeny that were purebreds, crossbreds, back-crosses or 3-way crosses are shown in Table 4.

b. Representation in Double Mated Litters in Relation to Mating Technique

Table 5 summarizes the representation of sizes in double mated litters in relation to the mating technique that was used. Of the 105 double mated litters farrowed, 62 litters or 59 percent were litters in which there were two or more pigs per litter sired by each boar. On the other hand, the corresponding figure for natural double matings was three out of nine litters or 33.3 percent, and for "mixed" services in which double mating was accomplished by a natural mating followed by A.I. the figure was eight out of 18 litters or 44.4 percent.

When the two methods of artificial insemination (equal volume and equal concentration) are compared it can be seen that for inseminates providing equal sperm concentration from each boar there were four out of 12 litters or 33.3 percent of the litters farrowed, having two or more pigs sired by each boar. Correspondingly, for inseminates comprising equal semen volumes there were 47 out of a total of 66 litters or 71.2 percent of the litters in which there were two or more representatives from each boar.

TABLE 3: NUMBER OF LITTERS, PIGS BORN AND PER CENT SIRED BY ONE BOAR FOR THREE METHODS OF SERVICE DURING PERIOD OCT. 10, 1964 TO DEC. 17, 1964

Type of Service	No. Lits Born	No. Pigs Born	Avg. Lit. Size	% Pigs Sired By One Boar
Natural	9	117	13.0	88.0
Artificial	16	200	12.5	67.0
Mixed*	2	20	10.0	100.0[a]

*Natural mating followed by A.I.

[a]All pigs sired by boar providing natural service.

TABLE 4: PER CENT DISTRIBUTION OF PIGS BORN SHOWN ACCORDING TO MATING TYPE.

Mating Type	Natural	Artificial	A.I. & Natural
Purebred	31.1	3.1	0
Crossbred	68.9	96.9	100.0
Total	100.0	100.0	100.0
Backcross	40.9	49.1	100.0
3-way cross	59.1	50.9	0
Total	100.0	100.0	100.0

TABLE 5: SUMMARY OF SIRE REPRESENTATION IN DOUBLED MATED LITTERS IN RELATION TO MATING TECHNIQUE

Representation	Number of Litters in Each Mating Type				
	Natural Mating	Artificial Insemination		Mixed	Total
		Equal Conc.	Equal Vol.	Natural & A.I.	
Single sire represented	5	6	15	9	35
All but 1 pig from a single boar	1	2	4	1	8
All but 2 pigs from a single boar	0	0	9	1	10
3 or more pigs from each boar	3	4	38	7	52
Total	9	12	66	18	105

In an attempt to ascertain the main causes of poor conception in the herd the duration of the experiment was divided arbitrarily into four periods. The four periods comprised one four-month period extending between September 1964 to December 1964, two six-month periods in 1965 while 1966 was considered as a single period. The number of sows serviced, the number of sows producing litters and the farrowing percentages and the type of mating done are summarized in Table 6.

The percentage of services resulting in litters farrowed range between 20 percent and 80 percent. Generally poor conception rates were obtained from inseminations with mixtures in which there were equal sperm concentration (27.2 percent and 20.0 percent). During the period July 1965 to December 1965, poor conception rates were also obtained from inseminations with mixtures comprising equal volumes. The poor conception rates obtained in the earlier period, January 1965 to June 1965, correspond to that period in which extensive modifications were being carried out at the barns and sows were left open for two or three estrus periods. For the later period the effects of estrus synchronisation trials and temperature variations in the use of the egg-yolk-bicarbonate extender may have been primary contributors in accounting for the low conceptions.

Table 7 shows the means for motility rating and semen count together with mean volume for seven boars involved in the preliminary phases of this study. Mean volumes varied between 175 ml. and 465 ml. for boar #26 and 75 respectively. Sperm count showed some variation and was generally lower than average for boars #73, 75 and 76.

TABLE 6: COMPARISON OF DIFFERENT METHODS OF SERVICE SHOWING NUMBERS OF SOWS SERVICED, NUMBER OF SOWS FARROWED AND FARROWING PERCENTAGES - SUMMARIZED FOR FOUR PERIODS

	Sept. 64 - Dec. 64				Jan. 65 - June 65				July 65 - Dec. 65				Jan. 66 - Dec. 66			
	a	b	c	d	a	b	c	d	a	b	c	d	a	b	c	d
No. of sows serviced	16	36	-	5	-	8	22	-	-	25	30	19	-	64	-	10
No. of sows farrowed	9	16	-	2	-	5	6	-	-	6	6	8	-	39	-	8
Farrowing per cent	56.3	44.4	-	40.0	-	62.5	27.2	-	-	24.0	20.0	42.1	-	60.9	-	80.0

a - Natural service.

b - A.I. with equal volumes of semen per boar.

c - A.I. with equal sperm conc. per boar.

d - Mixed: natural service followed by A.I.

TABLE 7: SEMEN EVALUATION SHOWING MEANS FOR BOARS EVALUATED DURING PRELIMINARY STUDIES

Boar No.	No. of Samples	Motility %	Rating Index	Count[6] Per Ml.	Volume Ml.
26	23	80	2.5	287	175
27	14	85	2.0	156	220
38	18	75	2.0	228	180
73	19	75	2.0	148	420
74	15	80	2.0	196	300
75	13	80	2.0	110	465
76	11	75	2.0	128	200

c. Boar Performance

Table 8 illustrates the performance of boars involved in double matings and concurrent single matings. There was no significant difference with respect to either average litter size or survival at 21 days between progeny from double and single matings. Among the double matings however, there were highly significant differences ($P < .01$) in the proportion of progeny sired by three boars while three boars showed significant ($P < .05$) differences in the proportion of representation.

Of those boars showing significance in proportion of representation in the litters, boar #76 had a considerably lower percentage representation (29.2 percent) than expectation (50.0 percent), however, he was involved in only three litters. On the other hand, boar #26 sired a considerably greater proportion of pigs (72.1 percent) than was expected (50.0 percent) and was involved in a total of 27 litters.

It appears from the results that the Yorkshire boars tended to sire a greater proportion of offspring while Lacombe boars tended to sire a smaller proportion of pigs when double mated. The figures for the average litter sizes for the same boars used in single matings indicate no significant deviation from the average litter size of all matings.

Survival to 21 days was proportional to average litter size at birth in both groups.

TABLE 8: SURVIVAL AT 21 DAYS, PER CENT DISTRIBUTION OF PIGS BY SIRES IN DOUBLE AND SINGLE MATINGS

Breed of Boar	Boar No.	DOUBLE MATINGS No. Lits	Pigs Born	Avg. Lit. Size	Pigs Sired No.	Pigs Sired %	Survival No.	Survival %	SINGLE MATINGS No. Lits	Pigs Born	Avg. Lit. Size	Survival No.	Survival %
	23	1	12	12.0	5	41.6	4	80.0	-	-	-	-	-
	26	27	283	10.5	204**	72.1	150	73.5	8	103	12.8	86	83.5
A	27	6	62	10.3	38	61.3	34	89.5	9	108	12.0	98	90.7
	28	12	141	11.8	78	55.3	72	92.3	15	179	11.9	138	77.1
	29	23	230	10.0	93*	40.4	74	79.6	9	82	9.1	71	86.7
	41	8	79	9.8	41	51.9	40	97.6	3	30	10.0	29	96.7
	38	13	172	13.2	118**	68.6	97	82.2	11	118	10.8	100	84.7
B	51	18	225	12.5	97	43.1	79	81.4	-	-	-	-	-
	53	19	183	9.6	91	49.7	74	81.3	9	80	8.9	59	73.8
	73	32	269	8.4	82**	30.5	60	73.2	3	21	7.0	20	95.2
C	74	21	240	11.4	119	49.6	93	78.2	1	13	13.0	9	69.2
	75	9	109	12.1	73*	66.9	62	84.9	19	187	9.8	142	75.9
	76	3	48	16.0	14*	29.2	12	85.7	2	19	9.5	16	84.2
D	93	17	216	12.6	162	64.2	128	78.7	9	109	12.1	81	72.8
	Total			10.6	951		768			940	10.4	768	

**Significant at the 1 per cent level of probability (df=1).
*Significant at the 5 per cent level of probability (df=1).

A - Yorkshire, B - Landrace, C - Lacombe, D - Large Black.

d. Mating Systems

(i) Purebred and Crossbred Comparisons

Table 9. REPRESENTATION AND SURVIVAL TO 21 DAYS OF PUREBRED AND CROSSBRED PIGS IN THE SAME LITTER.

	TOTAL	REPRESENTATION No.	REPRESENTATION %	SURVIVAL No.	SURVIVAL %
Purebreds	302	128	42.4	104	81.2
Crossbreds	302	174*	57.6	135	77.5

* Significant at 0.05 percent level of probability (df = 1).

Comparison of group totals for purebred and crossbred occurring in the same litters show a significantly greater ($P < 0.05$) proportion of crossbred pigs compared with purebreds. There was no difference statistically in the number of crossbreds and purebreds surviving to 21 days (Table 9).

Further test of differences were made on the effect of breed of dam. These are shown in Tables 10 and 12. In Table 10 it can be seen that Landrace dams produced litters which had a significantly ($P < 0.01$) higher proportion of crossbreds than purebred pigs. In all other combinations there was no significance in the proportion of purebreds and crossbreds in the litters.

TABLE 10: CHI-SQUARE TEST FOR RANDOMNESS OF OCCURRENCE OF PUREBRED AND CROSSBRED PIGS IN DOUBLE-MATED LITTERS

Breed of Dam	Total	York Boars		Land Boars		Chi-Square	Total Pigs Born	York Boars		Lac Boars		Chi-Square
		Actual	Expt'd	Actual	Expt'd			Actual	Expt'd	Actual	Expt'd	
Yorkshire	60	28	30	32	30	0.13	63	31	31.5	32	31.5	0.008
		York Boars		Land Boars				Land Boars		Lac Boars		
		Actual	Expt'd	Actual	Expt'd			Actual	Expt'd	Actual	Expt'd	
Landrace	84	63	42	21	42	10.5**	49	23	24.5	26	24.5	0.92
		York Boars		Lac Boars				Land Boars		Lac Boars		
		Actual	Expt'd	Actual	Expt'd			Actual	Expt'd	Actual	Expt'd	
Lacombe	29	16	14.5	13	14.5	1.57	17	5	8.5	12	8.5	1.44

Expected values on the assumption that the ratio for each boar should be 50:50.

**Significant at the 1% level of probability (df=1).

(ii) Comparison of Backcrosses and 3-Way Crosses

Table 11. REPRESENTATION AND SURVIVAL TO 21 DAYS OF BACKCROSSES AND 3-WAY CROSSED PIGS IN THE SAME LITTER.

MATING TYPE	TOTAL BORN	REPRESENTATION		SURVIVAL	
		No.	%	No.	%
Backcrosses	214	119	55.6	101*	84.8
3-way cross	214	95	44.4	72	75.8

* Significant at the 0.05 percent level of probability (df = 1).

Table 11 illustrates the pattern of survival to 21 days for backcross progeny and 3-way cross pigs in the same litter as well as the representation of these two groups. In this instance backcrosses had a significantly greater ($P < 0.05$) percentage survival at 21 days of age than the 3-way crosses in the same litters. There was no significance with respect to the proportion of representation. In Table 12, it can be seen that Landrace boars crossed with Yorkshire-Landrace sows produced a significantly greater ($P < 0.01$) proportion of backcrosses than that expected. In all other groups the proportions of backcrosses and 3-way cross progeny were not statistically different.

e. Evaluation of Sires and Mating Systems

Least squares estimates of the influence of twelve sires on growth traits are presented in Tables 13 and 14. In computing these estimates purebred and crossbred progeny were considered as one group while backcrosses and 3-way crosses were considered as another. As can be seen the estimates are not very consistent and therefore

TABLE 12: CHI-SQUARE TEST FOR RANDOMNESS OF OCCURRENCE OF BACKCROSSES AND 3-WAY CROSSES IN DOUBLE-MATED LITTERS

Breed of Dam	Total Pigs Born	Land Boars		Lac Boars		Chi-Square	Total Pigs Born	York Boars		Lac Boars		Chi-Square
		Actual	Expt'd	Actual	Expt'd			Actual	Expt'd	Actual	Expt'd	
York-Land	33	28	16.5	5	16.5	8.00**	21	13	10.5	8	10.5	0.59
		York Boars		Land Boars				Land Boars		Lac Boars		
		Actual	Expt'd	Actual	Expt'd			Actual	Expt'd	Actual	Expt'd	
York-Lac	33	20	16.5	13	16.5	0.73	60	33	30	27	30	0.30
		York Boars		Land Boars				York Boars		Lac Boars		
		Actual	Expt'd	Actual	Expt'd			Actual	Expt'd	Actual	Expt'd	
Land-Lac	26	17	13	9	13.0	1.23	41	27	20.5	14	20.5	1.96

Expected values on the assumption that the ratio for each boar should be 50:50.

**Significant at the 1% level of probability (df=1).

TABLE 13: LEAST SQUARES ESTIMATES OF SIRE EFFECTS ON GROWTH TRAITS (TO 56 DAYS) BY MATING SYSTEM

Sire No.	BIRTH WEIGHT				21 DAY WEIGHT				56 DAY WEIGHT			
	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way
26	17	+0.72	27	+0.93	17	-1.31	27	+2.58	17	+7.50	27	-0.99
27	16	+0.47	10	+0.33	16	-1.61	10	-0.41	16	+0.49	10	-4.81
28	14	-0.64	14	-0.76	14	+1.44	14	-1.16	14	-4.26	14	-4.10
29	23	-0.28	16	-0.88	23	+2.05	16	-2.56	23	-2.19	16	+2.94
41	37	-0.62	-	-	37	+1.65	-	-	37	-2.06	-	-
38	15	+0.11	20	+0.72	15	-2.43	20	+2.10	15	-4.49	20	+4.41
51	48	+0.47	21	+0.35	48	+0.01	21	+2.43	48	+8.09	21	+4.55
53	42	-0.55	17	-0.48	42	+0.85	17	-1.09	42	-2.64	17	+1.03
73	14	+0.24	23	+0.65	14	-1.58	23	+0.88	14	-2.16	23	+3.42
74	62	+0.54	11	+0.42	62	-0.33	11	+1.99	62	+5.29	11	-1.06
75	16	-0.48	5	-1.02	16	+1.28	5	-4.71	16	-5.53	5	-5.03
76	-	-	9	-0.26	-	-	9	-0.08	-	-	9	-0.34

TABLE 14: LEAST SQUARES ESTIMATES OF SIRE EFFECTS ON 154 DAY WEIGHT BY MATING SYSTEM

Sire No.	154 DAY WEIGHT			
	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way
26	15	+ 6.71	16	+3.84
27	8	+ 3.44	-	-
28	8	- 6.17	9	-3.86
29	15	- 3.43	5	-3.03
41	17	- 6.24	-	-
38	7	-23.17	12	+4.37
51	36	+28.45	14	-4.93
53	22	- 5.66	6	-6.32
73	8	-13.07	18	+4.50
74	45	+24.16	8	-3.74
75	10	- 5.00	-	-
76	-	-	-	-

they do not indicate any definite trend. The estimates for sire #51 for birth-weight, 21-day weight and 56-day weight are consistent and may indicate some advantage in the use of this sire in all mating systems. Estimates of the sire effects on 154-day weight are erratic and sometimes conflict with those obtained at other stages of growth. Least squares estimates were also computed for carcass traits - area of eye of lean and the index of carcass value but again the results are inconsistent (Table 15).

Tables 16 and 17 show the least squares estimates of the influence of sex on growth and carcass traits. These estimates show that females were lighter than males at the four different periods but had a larger area of eye of lean and also had a better index of carcass value.

In addition to these least squares estimates tables of the mean squares with the corresponding degrees of freedom are shown for growth and carcass traits. These were prepared from the analyses of variance in which sires, sex and mating system were considered as random. The residual or error component reflects differences within sires within litters.

In Tables 18 and 19 which relate to the analyses of variance for purebreds and crossbreds litter mean squares were highly significant ($P < 0.01$) for both the growth and carcass traits. Similar results were obtained for the group of backcrosses and 3-way crosses (Tables 20 and 21). Among the group of purebreds and crossbreds, sex was significant ($P < 0.05$) at birth and highly significant ($P < 0.01$) for 154-day weight and all carcass traits considered.

TABLE 15: LEAST SQUARES ESTIMATES OF SIRE EFFECTS ON AREA OF EYE OF LEAN AND CARCASS VALUE INDEX BY MATING SYSTEM

Sire No.	AREA OF EYE OF LEAN				INDEX OF CARCASS VALUE			
	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way
26	15	+0.14	16	+0.33	15	+2.11	16	+3.15
27	8	+0.94	-	-	8	+1.58	-	-
28	8	-0.41	9	+0.13	8	+3.12	9	+4.21
29	15	-0.16	5	+0.14	15	-3.54	5	+1.20
41	17	-0.15	-	-	17	-3.48	-	-
38	7	+0.12	12	-0.32	7	+1.70	12	+2.02
51	36	+0.88	14	-0.19	36	+2.23	14	-3.54
53	22	-0.15	6	+0.16	22	-2.98	6	+3.92
73	8	+0.13	18	-0.28	8	+1.00	18	+2.49
74	45	+0.75	8	-0.19	45	+1.65	8	-2.47
75	10	-0.14	-	-0.10	10	-3.39	-	-
76	-	-	-	-	-	-	-	-

TABLE 16: LEAST SQUARES ESTIMATES OF SEX EFFECTS ON GROWTH TRAITS BY MATING SYSTEM

Sex	BIRTH WEIGHT				21 DAY WEIGHT				56 DAY WEIGHT			
	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way
Females	136	-0.06	95	-0.04	136	-0.17	95	-0.18	136	-0.01	95	-0.71
Males	168	+0.06	78	+0.04	168	+0.17	78	+0.18	168	+0.01	78	+0.71

TABLE 17: LEAST SQUARES ESTIMATES OF SEX EFFECTS ON 154 DAY WEIGHT, AREA OF EYE OF LEAN AND CARCASS VALUE INDEX BY MATING SYSTEM

Sex	154 DAY WEIGHT				AREA OF EYE OF LEAN				CARCASS VALUE INDEX			
	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way	No. of Observ.	PB-CB	No. of Observ.	BC 3-Way
Females	98	-6.33	48	-4.89	98	+0.16	48	+0.10	98	+0.33	48	+0.31
Males	93	+6.33	40	+4.89	93	-0.16	40	-0.10	93	-0.33	40	-0.31

TABLE 18: TABLE OF MEAN SQUARES FOR GROWTH TRAITS FOR PUREBREDS AND CROSSBREDS

Source	DF	MEAN SQUARES			
		Birth-Wt.	21 Day-Wt.	56 Day Wt.	154 Day Wt.
Litters	41	4.504**	25.919**	520.371**	2458.026**
Sires	10	0.182	3.227	60.188	378.690
Sex	1	0.801*	6.685	0.031	6058.872**
Mating System	1	0.397	0.005	70.691	1577.259**
Error	250	0.185	4.825	41.575	212.232

**Significant at the 1 per cent level of probability.

*Significant at the 5 per cent level of probability.

TABLE 19: TABLE OF MEAN SQUARES FOR CARCASS TRAITS FOR PUREBREDS AND CROSSBREDS

Source	DF	MEAN SQUARES		
		Area of Eye of Lean	% Lean Cut Yield	Index of Carcass Value
Litters	35	6.035**	5568.03**	30.497**
Sires	10	0.164	5.563	3.521**
Sex	1	3.771**	57.989**	16.809**
Mating System	1	0.012	0.797	1.970
Error	143	0.157	4.312	1.225

**Significant at the 1 per cent level of probability.

TABLE 20: TABLE OF MEAN SQUARES FOR GROWTH TRAITS FOR BACKCROSSES AND 3-WAY CROSSES

Source	DF	MEAN SQUARES			
		Birth-Wt.	21 Day-Wt.	56 Day-Wt.	154 Day-Wt.
Litters	19	3.508**	61.595**	582.373**	7219.638**
Sires	10	0.366	6.392	75.820	334.215
Sex	1	0.292	5.210	77.446	1789.169**
Mating System	1	0.028	0.745	6.932	104.750
Error	141	0.210	5.665	44.501	226.036

**Significant at the 1 per cent level of probability.

TABLE 21: TABLE OF MEAN SQUARES FOR CARCASS TRAITS FOR BACKCROSSES AND 3-WAY CROSSES

Source	DF	MEAN SQUARES		
		Area of Eye of Lean	% Lean Cut Yield	Index of Carcass Value
Litters	18	7.949**	32.853**	133.453**
Sires	7	0.409	8.104	1.134
Sex	1	0.781	115.937**	6.978*
Mating System	1	0.020	1.303	0.002
Error	60	0.209	6.070	1.205

**Significant at the 1 per cent level of probability.

*Significant at the 5 per cent level of probability.

Significance at the five percent level of probability was obtained for sex, for percent lean cut yield and carcass value index while it was highly significant ($P < 0.01$) for 154-day weight for the group of backcrosses and 3-way crosses. Mean squares for sires showed no significance for any of the growth traits but was highly significant ($P < 0.01$) for the carcass value index prepared for the group of purebreds and crossbreds. Mating system was similar to sires in that significance ($P < 0.01$) was obtained only in the one case of 154-day weight among the group of purebreds and crossbreds.

Least squares estimates of the effect of mating system on growth and carcass traits are presented in Tables 22 and 23. Crossbred pigs were heavier at birth, 21 days, 56 days and 154 days of age than were purebred pigs. Crossbreds also had a larger area of eye of lean, yielded greater percent lean cuts that resulted in a better index of carcass value than did their purebred litter mates. The estimates for backcrosses and 3-way crosses show no marked differences between them for either growth or carcass traits.

Adjusted means of the growth traits for the different mating types are shown in Table 24. These were prepared from the average for all the males and all females in each group corrected by the appropriate least square estimate. The growth curves shown in Figure 1, were prepared from these adjusted means. Crossbred pigs appear to do better than any other group while the distinction between backcrosses, 3-way crosses and purebreds is not as obvious. Purebreds were lightest at 154-days of age while backcrosses and 3-way crosses were intermediate between crossbreds and purebreds.

TABLE 22: LEAST SQUARES ESTIMATES OF EFFECT OF MATING SYSTEM ON GROWTH TRAITS

Mating System	No. of Observ.	Birth-Wt.	21 Day-Wt.	56 Day-Wt.	154 Day-Wt.
Purebreds	67	-0.078	-0.009	-1.052	-6.822
Crossbreds	237	+0.078	+0.009	+1.052	+6.822
Backcrosses	108	+0.019	+0.099	+0.303	+1.507
3-way crosses	65	-0.019	-0.099	-0.303	-1.507

TABLE 23: LEAST SQUARES ESTIMATES OF EFFECT OF MATING SYSTEM ON CARCASS TRAITS

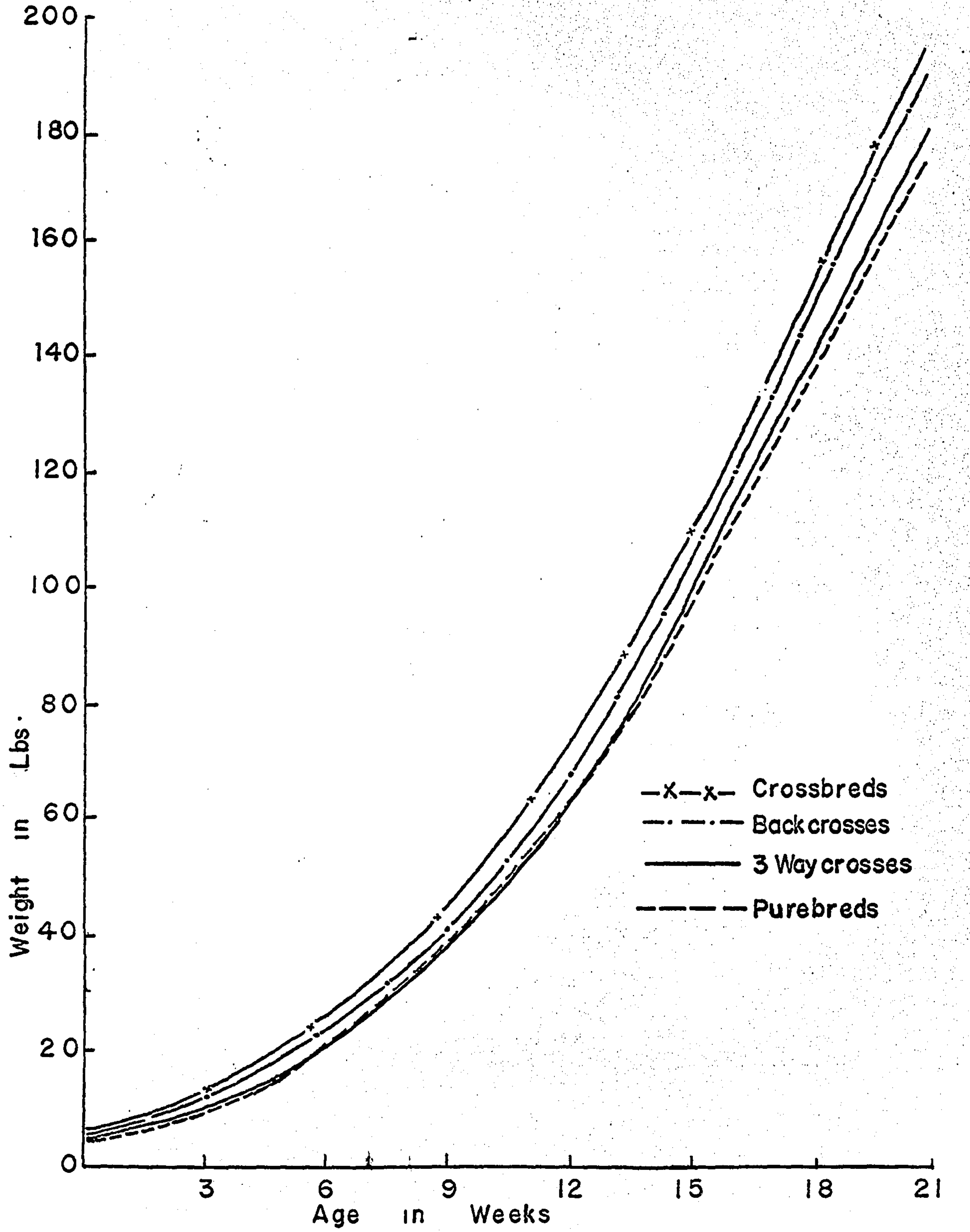
Mating System	No. of Observ.	Area of Eye of Lean	% Lean Cut Yield	Index of Carcass Value
Purebreds	67	-0.018	-0.153	-0.241
Crossbreds	237	+0.018	+0.153	+0.241
Backcrosses	108	+0.021	+0.168	+0.007
3 way crosses	65	-0.021	-0.168	-0.007

TABLE 24: ADJUSTED MEANS* FOR GROWTH TRAITS

Mating Type	No. of Observ.	Birth-Wt.	21 Day-Wt.	56 Day-Wt.	154 Day-Wt.
Purebreds	67	2.82	11.88	33.79	173.14
Crossbreds	237	2.96	11.90	35.89	186.78
Backcrosses	108	2.93	11.32	31.10	182.78
3-way crosses	65	2.89	11.12	30.50	180.76

*Obtained from the averages of all males and all females in each group corrected by the appropriate least squares estimate.

Fig. I Showing Growth Curves for Different Mating Systems



Because of the way in which the analyses were handled litter variance includes the effects of season, litter sequence, pre- and post-natal effects of the dams, etc. Some indication of variation between litters for both groups (purebreds - crossbreds and back-crosses - 3-way crosses) is obtained from the least squares estimates shown in Tables 25 and 26. Variation ranged between 1.25 lbs. at birth to 27.38 lbs. at 56 days of age.

The components of variance for litter, sire and individual pigs within a litter were estimated for birth weight, 21-day weight, 56-day weight and 154-day weight.

These were also expressed as a percent of the total variation and are shown in Tables 27 and 28.

TABLE 25: LEAST SQUARES ESTIMATES OF DIFFERENCES BETWEEN LITTERS IN PUREBRED AND CROSSBRED GROUP

Litters	No. of Observ.	Birth-Wt.	21 Day-Wt.	56 Day-Wt.
1	10	-0.499	+0.244	+ 1.948
2	7	+0.691	+3.097	- 0.848
3	5	+0.084	+3.227	- 1.157
4	9	-0.032	+2.769	+ 5.486
5	12	-0.429	-1.198	- 4.729
6	9	-0.587	+0.317	+ 1.139
7	7	+1.037	+2.353	+ 4.772
8	11	-0.476	-1.633	- 8.947
9	12	+0.077	+0.643	- 2.983
10	6	+0.956	+2.576	- 1.057
11	7	-0.507	-0.387	- 3.337
12	6	-0.029	+1.416	+ 1.222
13	11	-0.233	-1.268	- 0.097
14	10	-0.313	-1.769	+ 0.255
15	12	-0.046	-0.847	- 0.658
16	10	+0.204	-2.596	- 7.661
17	4	+0.921	-0.815	-10.557
18	6	-0.565	+1.315	+ 0.139
19	7	-0.527	+0.017	+ 4.923
20	9	-0.045	-0.879	+ 1.629
21	4	+0.928	+2.565	- 0.974
22	8	+0.277	-2.392	+ 0.910
23	9	-0.369	-0.981	+18.273
24	7	+0.331	+0.045	+15.043
25	12	-0.334	-1.629	- 4.906
26	10	-0.199	-1.107	+ 0.033
27	10	+0.136	-1.056	- 1.971
28	11	-0.451	-2.028	- 4.980
Females	102	-0.058	-0.179	- 0.161
Males	139	+0.058	+0.179	+ 0.161

TABLE 26: LEAST SQUARES ESTIMATES OF DIFFERENCES BETWEEN LITTERS IN BACKCROSSED AND 3-WAY CROSSED GROUP

Litters	No. of Observ.	Birth-Wt.	21 Day-Wt.	56 Day-Wt.
1	10	-0.688	-1.141	+10.786
2	9	-0.254	+0.378	+ 1.790
3	10	-0.523	-0.951	- 5.615
4	14	-0.408	-2.715	- 5.359
5	9	+0.043	+0.445	+ 4.416
6	8	-0.384	-3.531	- 8.403
7	6	-0.174	-0.561	- 0.373
8	11	-0.294	-0.281	- 2.103
9	10	-0.617	-4.954	-10.264
10	6	+1.144	+0.477	+ 9.995
11	8	-0.613	-2.354	- 7.739
12	3	-0.445	+0.100	- 9.166
13	9	+0.500	+3.636	- 5.272
14	12	+0.291	+1.353	- 8.286
15	9	+1.033	+3.793	+ 8.094
16	8	+0.532	+5.851	+18.178
17	11	+0.859	+0.451	+ 9.320
Females	85	-0.054	-0.165	- 0.606
Males	68	+0.054	+0.165	+ 0.606

TABLE 27: COMPONENTS OF VARIANCE AND PER CENT OF TOTAL VARIANCE FOR BIRTH WEIGHT AND 21 DAY-WEIGHT IN DIFFERENT MATING SYSTEMS

Source	BIRTH WEIGHT				21-DAY WEIGHT			
	Purebred - Crossbred		Backcross-3Way Cross		Purebred - Crossbred		Backcross-3 Way Cross	
	Component	Per Cent	Component	Per Cent	Component	Per Cent	Component	Per Cent
Litter	0.51	68.9	0.34	57.6	2.62	30.8	5.82	38.9
Sire	0.04	5.4	0.04	6.8	1.06	12.5	3.44	23.1
Pig--within sire, within litter	0.19	25.7	0.21	35.6	4.83	56.7	5.67	37.9

TABLE 28: COMPONENTS OF VARIANCE AND PER CENT OF TOTAL VARIANCE FOR 56 DAY-WEIGHT AND 154 DAY-WEIGHT IN DIFFERENT MATING SYSTEMS

Source	56-DAY WEIGHT				154-DAY WEIGHT			
	Purebred - Crossbred		Backcross-3 Way Cross		Purebred - Crossbred		Backcross-3 Way Cross	
	Component	Per Cent	Component	Per Cent	Component	Per Cent	Component	Per Cent
Litter	58.45	51.5	56.02	49.2	356.6	52.5	1124.2	75.4
Sire	13.44	11.8	13.26	11.7	110.7	16.3	140.6	9.4
Pig--within sire, within litter	41.57	36.6	44.50	39.1	212.23	31.2	226.04	15.2

VII. DISCUSSION

a. Mating Technique

The preliminary studies involved 27 litters and therefore could provide only a trend. The double matings were fairly successful as evidenced by the farrowing percentages obtained. The proportion of sire representation in each of the three categories: natural, artificial insemination and mixed service, resulted in a high proportion (67 to 100 percent) of offspring being sired by one boar (Table 3) but this was not borne out when the information was summarized for the entire period.

The sire representation in double mated litters in relation to mating technique (shown in Table 5) provide some interesting information. If it is assumed that in a double mating a minimum of two pigs from each boar must be obtained before the method can be regarded as useful for comparisons then only 59 percent of all the matings meet these requirements. On the other hand, for those matings done by artificial insemination 70 percent of the litters produced after insemination with mixtures of equal volumes satisfied these requirements while the corresponding figure for insemination with mixtures of equal concentration was only 33.3 percent. It should be noted however, that the number of litters involved in the case of mixtures of equal concentration were very small relative to the number of litters with equal volumes.

The figures presented in Table 6 showing the farrowing percentages throughout the duration of the investigation threw some light on the causes of poor farrowing. Generally poor farrowing percentages were obtained during the six-month period January 1965 to June 1965. These resulted from services made with inseminates of equal sperm concentration from two boars. Apart from the problems associated with the use of diluents or extenders, estrus synchronisation was also attempted and some females were inseminated without the external symptoms of heat. Another contributing factor was a period of non-breeding (in early 1965) when females were left open for two or three estruses on account of construction and repairs at the College Farm.

Farrowing percentages for both methods of artificial matings range between 20.0 percent and 62.5 percent. This compares with those reported by Borton and co-workers (1965) who reported farrowing percentages between 38.5 percent to 56.1 percent and 42.9 percent to 54.8 percent for gilts and sows respectively in A.I. studies. Farrowing percentages from these natural matings are also in agreement with those reported by the same workers.

b. Boar Performance

Borton *et al.* (1965) reported significant boar differences for litter size in the A.I. swine at Michigan State University. Similar differences were reported by Paredis (1962) but the figures for average litter size sired by different boars (Table 8) were not significantly different either in the double mated group or those involved in concurrent single matings. A chi-square test of significance for average litter size (double-mated group vs. single mated group) revealed no signficant difference. While this is in agreement with the findings of Cerne and Salehar (1964), the report of Roberts and Caroll (1939) is most definite in their claim. However, the observation in rabbits by Beatty (1957), that mixed litters containing both types of young have high numbers of young per litter, with low birth weight, may have provided the explanation for their findings.

Survival at 21 days of age was not significantly different for either the double-mated or single mated groups. It should be noted that where average litter size was small, percentage survival at 21 days seemed to be greater than those of larger average litter size. This observation was also reported by Holness (1963).

The proportion of representation in the litters sired by the individual boars range between 29.2 percent for boar #76 and 72.1 percent for boar #26. These figures suggest that boars sired considerably less in the case of boar #76 and more in the case of #26, than their fair share of progeny. In Table 7, the average figures are presented for the evaluation of the semen collected from a number of these boars. While the average percent motile sperm was about the same for all animals (approximately 80 percent), the spermatozoa count per milliliter showed wide variations (100×10^6 - 300×10^6 sperm per milliliter). Boar #26 had the highest average sperm concentration while boar #76 had an average count of 128 x 10^6 spermatozoa per milliliter and on the basis of equal volumes may be expected to sire a greater number of progeny. However, equal concentration mixtures of sperm from these two boars resulted in a greater number of progeny sired by boar #26. The sperm concentration seemed to have no effect on progeny sired, but further investigation is required. The normal spermatozoa concentration of boar semen is stated to be in the neighbourhood of 150 to 250 x 10^6 per milliliter (Borton et al., 1965).

c. Mating Systems

(i) Purebred and Crossbred Comparisons

Representation and survival figures for purebred and crossbred progeny in the same group of litters shown in Table 9 indicate that crossbreds were significantly ($P < 0.05$) more frequent in occurrence. This suggests that there was some preferential selectivity in favour of crossbreds, however, supporting evidence was not obtained when the sub-totals for individual mating combinations were examined. This is in agreement with the findings of Lush and co-workers (1939) who could find no general tendency for more purebreds or crossbreds to be produced in their double mated litters.

When mating combinations were examined on the basis of the breed of dams (Tables 10 and 12) it was found that Landrace boars produced significantly ($P < 0.01$) fewer pigs when mated in combination to Landrace and Lacombe dams. This appears to be an individual boar peculiarity rather than an effect of the mating system. There were only ten litters involved and the boars involved consistently sired a greater proportion of offspring when used in combination with the other sires.

The survival figures for these two groups of pigs show no significance and while high, have a similar pattern to that obtained by Roberts and Caroll (1939) who reported 43.3 and 41.1 percent mortalities for all purebred and crossbred groups respectively.

(ii) Comparison of Backcrosses and 3-way Crosses

As shown in Table 11, backcrosses showed a significantly greater ($P < 0.05$) survival to 21 days of age than did the 3-way cross littermates. This is in conflict with the theories on heterosis and also raises the question as to why similar results were not observed in the purebred-crossbred group. Lush et al. (1939) stated that for characteristics determined by the animal's genetic make-up or inheritance, the effect of heterosis is greatest in a first generation cross (of purebred parents) while those characteristics which are largely determined by the producing and nursing ability of the animal's dam, the effect of heterosis would be greatest in the offspring of first-cross dams mated to purebred males from a third breed. Louca and Robison (1967) ascribe differences in litter size at birth to be largely a result of environmental fluctuations while genetic differences in the dam's ability to care for the litter through lactation and/or behaviour were manifest at 56 days. Therefore, it seems that at 21 days both the individual's genotype for survival and the dam's mothering ability exert their influence.

The proportion of representation of backcross and 3-way cross littermates were not significantly different and there appears to be no tendency for either the one or the other to be produced with greater frequency.

d. Sire and Mating System Evaluation

In this experiment emphasis is placed on comparisons of mating systems. Sire comparisons are valid if sire by mating system interactions are not significant. Roache (1964) noted that sires tended to retain their relative level of merit regardless of mating system.

The least squares estimates of sire effects on growth and carcass traits (Tables 13-15) were computed to provide some indication of the relative merit of sires when used in different mating systems. Roache (1964) found that breed of dam effects were important for all growth traits, however, boars were mated to the same females thereby reducing the dam component of the litter differences so that a more sensitive estimate of sire effect should result. These estimates do not show any definite trend for sire effects on either the growth or carcass traits. In the analyses of variance in which sires, sex and mating systems were considered as fixed effects, significance was not obtained for sire effects except in the case of carcass value index (Tables 18-21). It may be that sire effects relative to other effects such as mating system and sex are small and therefore do not readily show up. In addition, the portion of the variance between pigs attributed to litter in this analysis includes pre- and post-natal effects of the dams, season, litter sequence, pathological conditions, etc., and all other effects common to pigs in a litter. Some indication of the litter variation can be obtained from the least squares estimates of differences due to litters for some of the growth traits shown in Tables 25 and 26. Furthermore, as can be seen from the numbers of observations available for computing the least squares estimates of sire effects, it might be that the numbers are inadequate for the detection of small sire differences.

Baker and co-workers (1943) obtained significance for sire effect on weight at 56, 84, 112, 140 and 168 days of age using a much larger group of data. They also claimed that a sire effect may have existed at birth and at 21 days but their data was perhaps too small to show significance. In the same paper absolute values of variances for the sire effect were shown to comprise 0.08 in a total variance of 4.49; 2.6 in a total of 42.6; 37 in a total of 491 and 77 in a total variance of 774 for 21-day-, 56-day-, 140-day-, and 168-day weights respectively. These correspond to 1.8 percent, 6.1 percent, 7.5 percent and 9.9 percent respectively. The contribution of sire effect on birth-weight was zero. Components of variance and their corresponding percent of total variation for birth-, 21-day-, 56-day- and 154-day weights were computed and are shown in Tables 27 and 28. These figures indicate that sires accounted for 6 percent of the total variance at birth, 12 percent for 21-day and 56-day weights. The figure for 154-day weight is inconsistent (16 percent in the group of purebreds and crossbreds and 9 percent in the backcrosses and 3-way crosses). This is probably accounted for by the small numbers involved particularly in the group of backcrosses and 3-way crosses. There may have also been some degree of selection in the animals being retained in the herd to 154 days of age.

The least squares estimates of sex effects on the traits considered (Tables 16 and 17) show differences in all growth traits in favour of males. Estimates were similar for both the purebred-crossbred group and the backcross-3-way cross group. The analysis of variance for the growth traits (Tables 18 and 20) show that at birth the difference of 0.12 lbs. was significant ($P < 0.05$) for purebreds and crossbreds but a difference of 0.08 lbs. was not significant for backcrosses and 3-way crosses. Differences for 154-day weight were highly significant ($P < 0.01$) for both groups. Carcass traits for purebreds and crossbreds (Table 19) also showed significant sex differences, the estimates showed differences of 0.32 inches for area of eye of lean and 0.66 cents for carcass value index. These findings agree with those of Craig _et al._ (1956), Hetzer _et al._ (1956), Self _et al._ (1957) and Bruner _et al._ (1958).

In the same sets of analyses least squares estimates of mating system effects on growth and carcass traits were computed. In general, small differences (not statistically significant) were shown in favour of crossbred pigs for growth traits up to 56 days of age (Table 22). These results are supported by the findings of workers in the United Kingdom, North America and Australia as documented by Lush et al. (1939) and who themselves reported similar results. The tables of the analyses of variance are most interesting in that a highly significant ($P < 0.01$) mating system effect was obtained for 154-day weight in the group of purebreds and crossbreds but not for backcrosses and 3-way crosses. The least squares estimates also reflect this, in that there is a difference of 13.6 lbs. for 154-day weight between purebreds and crossbreds but only 3.0 lbs. difference between backcrosses and 3-way crosses for the same age. Roberts et al. (1939) reported a small but significant difference in favour of crossbreds over purebreds in a double-mating experiment. Lush et al. (1939) have pointed out that with characteristics such as growth rate there was much variability with herds, breeds and even within litters so that by double mating the highly significant difference for 154-day weight obtained in this experiment might be expected. Gaines and Hazel (1957) were able to demonstrate significant differences for 154-day wieght for Poland boars topcrossed on Landrace sows in a large experiment involving 83 litters where comparisons were on a between litter basis.

The adjusted means for growth traits (Table 24) were plotted against the age of pigs in weeks and the resulting growth curves are shown in Figure 1. Beginning with an initial advantage in birth weight (while not significant) crossbred pigs maintained this advantage throughout up to 154 days of age. Backcrosses and 3-way crosses are intermediate between purebreds and crossbreds. The least squares estimates (Tables 22 and 23) suggests that 3-way crosses were not superior to backcrosses in this study. This conflicts with Lush et al. (1939) who claim that for characteristics which are largely determined by the producing and mothering ability of the animal's dam, heterosis is greatest in the offspring of first cross dams mated to purebred males of a third breed in which case heterosis should at least have shown up in the early growth traits.

VIII. SUMMARY

Double mating studies were undertaken to investigate the technique as a method for evaluating mating systems and sires for growth and carcass traits. Of 105 double mated litters obtained, 62 litters were farrowed in which each boar was represented by two or more baby pigs. A total of 66 litters were conceived following insemination with a mixture of equal volumes of semen from two boars. Forty-seven litters (71 percent) farrowed two or more pigs from each sire. Other double mating techniques studied were less successful. These provided eight litters of 18 farrowed, four litters of 12 farrowed and three litters of nine farrowed in which there were two or more baby pigs sired by each boar for combined natural and artificial insemination, A.I. with mixtures of equal sperm concentration and natural double mating respectively.

Among the 14 boars involved in this study, one boar consistently sired a greater proportion of the baby pigs (72.1 percent) in double mated litters while another sired a consistently small proportion (29.2 percent) when involved in double matings. This differential sire representation did not appear to be related in any way to litter size in single matings involving these same boars.

In purebred-crossbred comparisons growth traits (birth-, 21-day-, 56-day- and 154-day weights) were consistently superior for crossbreds but significant only for 154-day weight. The carcass traits studied (area of eye of lean, percent lean cut yield and carcass value index) were not significantly different for the two groups.

In the 3-way cross and backcross comparisons there were no significant differences between the two mating systems for growth and carcass traits considered. In both analyses sex differences were similar to those reported in other studies.

The analyses of variance revealed that sire effects were not significant for growth traits and for carcass traits with the exception of carcass value index among the purebred and crossbred data.

While the limited amount of data resulted in a wide range of estimates of the relative size of the litter, sire and within sire, within litter variance components between pigs (the averages were 53 percent, 12.3 percent, 34.7 percent respectively) it is evident that mating system and sire comparisons on a within litter basis would be considerably superior to between litter comparisons.

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