GENETIC AND ENVIRONMENTAL ASPECTS OF REPRODUCTIVE PERFORMANCE AND PRE-WEANING GROWTH OF THREE PIG BREEDS IN LARGE-SCALE HERDS IN KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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To my Parents

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Data on reproductive performance and pre-weaning growth of pigs from three large scale herds in Kenya were studied to evaluate means and the effects of genetic and environmental factors on sow and piglet performance. The data comprised 1646 Landrace, Large White and Hampshire litter records from Zea, Ngata and Lanet herds and 2861 Landrace and Large White weaner records from Lanet. The records spanned a period of 15 years (1975-89). Sow traits studied were litter size at farrowing (LSF) and at weaning (LSW), litter weight at 3 weeks (LW3), litter weight at weaning (LWW), average piglet weight at birth (ABW) and at weaning (AWW) and farrowing interval (FI). Piglet traits studied were weaning weight (WW) and pre-weaning average daily gain (ADG).

Litter size at farrowing averaged 9.78±2.42 in Large White sows from Lanet, 8.79±2.41 in Landrace sows and 7.08±2.64 in Hampshire sows. Litter size at weaning averaged 8.09±1.61 and 7.47±1.40 in Large White sows from Lanet and Landrace sows respectively. Piglet weight at birth averaged 1.45±.19 kg in Large White sows from Lanet, 1.46±.22 kg in Landrace sows and 1.53±.29 kg in Hampshire sows. The farrowing interval, average litter weight at weaning and average piglet weight at weaning in Landrace sows were 194.46±33.08 days, 95.40±23.50 kg and 12.94±2.45 kg respectively. Landrace piglets grew faster and were heavier ($P<0.01$) at weaning than Large White piglets. Entire males

excelled both females and castrates in growth rate and average weaning weight.

Parity effects were significant for LSF, FI and litter weights. LSF peaked in the third and fourth parities in the Large White and Landrace sows respectively. Year and season of farrowing influenced growth traits and LSW. Growth performance and litter size at weaning declined in the latter half of the periods studied in the herds at Lanet and Zea. Inbreeding depression was considered a likely reason for the decline. At Lanet piglets born between September and March grew faster and were heavier ($P<0.01$) at weaning than those born during the rest of the year but the interaction between year and season of birth was significant.

Heritability estimates from paternal half-sibs were 0.21±.08, 0.19±.08, 0.13±.07, 0.15±.08, 0.17±.08, 0.23±.09 and 0.43±.12 for LSF, ABW, LW3, LSW, AWW, LWW and FI, respectively, in the Landrace breed. Heritability and repeatability estimates for reproductive traits were generally low. Genetic correlations between litter size and litter weights ranged from 0.94±.10 to 0.96±.04, while the corresponding phenotypic correlations ranged from 0.50 to 0.75. Correlations between litter size and average weights were all negative and low. Correlations between LW3 and LWW were positive and high. It was concluded that selection for high LW3 would be expected to improve LWW.

1 INTRODUCTION

Commercial pig production in Kenya started around 1905 when the first breeding stock was imported from Europe. Of the breeds imported, the Landrace soon gained popularity because of its good bacon qualities. Because of this desirable quality, more Landrace pigs were imported in the 1950's for crossing with the Large White breed. The Hampshire breed was introduced into the Kenyan pig industry about 20 years later to improve the meat quality of market pigs by crossing with the Large White and the Landrace breeds.

Although there has been a gradual increase in pig meat production in recent years, consumption has been increasing at a faster rate. In 1989 the total pig population in Kenya was estimated at 99,720 head and 4,979 tonnes of pig meat were produced against a demand of 5,129 tonnes. The resultant per capita consumption of pig meat was estimated at 0.22 kg (Ministry of Livestock Development (MLD), 1989). It is currently estimated that the commercial pig and poultry sector contributes about 65 % of all the white meat produced in Kenya, the rest mainly coming from fish. The sixth Development plan covering the period 1989 to 1993, (Kenya Government, 1989) indicates that although the demand for livestock products keeps rising in line with the population growth, the available land for grazing in the medium and high potential areas is decreasing rapidly. Possibilities for increasing livestock production in these areas lie mainly in rearing systems with a low input of land. Under this situation pigs, poultry and rabbits are particularly suitable for the small scale farms in such areas, but these species have not received sufficient attention in the past (MLD, 1980).

Lack of good quality breeding stock has been a constraint to pork production in Kenya (MLD, 1988). There is therefore a need to promote the availability of genetically superior stock. However, definition of selection criteria needed to achieve such a goal requires the knowledge of pertinent genetic and phenotypic parameters. Genetic improvement through within breed selection is largely dependent on the heritability of economically important traits and the relationships between them. Breed substitution also requires monitoring of economically important aspects of pig production. Reproductive performance and pre-weaning growth are among the most important economic traits in commercial pig production. Though much has been reported about these traits, information on parameters derived from the local populations is scanty. Literature on the role played by genetic and environmental factors on pig performance in this region is particularly lacking. Yet, to maintain efficient and economical management practices, along with an effective selection programme, the producer must understand the major sources of variation and their relative importance in affecting pig performance. Thus, the objectives of this study were:

i To evaluate mean reproductive and pre-weaning growth performance levels of Landrace, Large White and Hampshire pigs from three large scale herds in Kenya.

ii To evaluate the effects of genetic and environmental factors on sow and piglet performance in view of possible implications to the on-going and future breeding and management strategies.

2 LITERATURE REVIEW

2.1 Importance of Reproductive and Pre-weaning Growth

Most selection schemes in pigs, however simple, usually aim for high prolificacy, survival rate, weight gain and good carcass quality. Selection for large litter size and growth rate are two potential means of effecting genetic increase in biomass, the product of the litter size and mean individual body weight, in multiparous species. Applied to livestock, the expected result would be more meat produced per female bred. With high farrowing rates, more meat would be produced per unit of time. Reproductive traits include litter size and farrowing interval. These traits together with average weights influence the production cycle in one way or another.

2.1.1 Litter Size at Farrowing and at Weaning

Litter size plays a major role in pig production. To the producer, the number of live piglets born per sow per year is a realistic economic measure of reproductive efficiency (Wrathall, 1973). Besides the direct economic impact of litter size on profit, large litters allow greater selection intensities for other traits and, therefore, have an important impact on the rate of genetic improvement (Zimmerman and Cunningham, 1975). Even under natural selection, a heritable character expressed in large litters has higher chances of being passed over to the next generation, through random sampling, than one expressed in small litters.

Litter size at farrowing has a high positive genetic correlation with litter size at 3 and at 8 weeks (Strang and King, 1970). This means that the proportion of piglets reared increases with litter size. It would therefore be possible to improve litter size at weaning through direct selection for litter size at farrowing. However, piglets from large litters will have shared limited nutrients while *in utero* which can lead to a decrease in average piglet weight at birth. Intra-litter competition in large litters can also lower the rate of early weight gain. Large litters may therefore require more care and attention to ensure high survival rate and early growth rate than smaller ones.

Litter size at weaning has an economic importance in that piglet mortality decreases after weaning (Gupta *et al.*, 1982), so that most of the piglets weaned reach market weight. The number of piglets weaned also forms the potential replacement stock. Trauma is a common cause of early piglet mortality. Thus, litter size at weaning gives an indication of both prolificacy and mothering ability of a sow. For this reason, ranking sows based on their average litter size at weaning has an advantage over the use of litter size at farrowing. In simple selection schemes where calculations are not preferred, litter size can form a good selection criterion.

Factors affecting litter size include breed of dam

(Simpson *et al.*, 1986), prenatal and postnatal maternal influence (Azzam *et al.*, 1984; Nelson and Robison, 1976a; Eisen and Durrant, 1980, Joakimsen and Baker, 1977). Litter size is also influenced by age of the sow, location, year and occasionally season of farrowing.

2.1.2 Litter Weight at 3 Weeks and at Weaning

Litter weight at 3 weeks is a function of litter size (Yen *et al.*, 1987) and litter weight gain from birth to this age. Early pre-weaning litter weight gain depends, to a great extent, on the sow's milk production. Litter weight at three weeks can therefore be considered as a measure of the sow's total milk production.

Litter weight at weaning partly depends on the sow's prolificacy, the proportion of the piglets born alive that are reared to weaning and the pre-weaning litter weight gain. Omtvedt *et al.* (1966) considered litter weight at weaning to be the best single measure of a sows's reproductive performance because it combines both prolificacy and maternal ability. They found this trait to be influenced more by the number of pigs in the litter than by the average piglet weight at weaning. They reported phenotypic correlations of 0.79, 0.57, 0.56 and 0.50 for litter weight at weaning with litter size at weaning, survival rate, litter weight and litter size at farrowing respectively.

Litter weights are indications of prolificacy, survival rate and weight gain. They are easy to calculate compared to other measures of sow performance such as complex indices to evaluate sow performance. Litter weights are therefore useful for carrying out selection aimed at improving reproductive and growth performance at the farm level under limited computing equipment. An optimum nutrient supply for both the sow and the litter should be ensured so as to allow full expression of the herd's potential for litter weight.

2.1.3 Average Piglet Weight at Birth and at Weaning

The importance of average piglet weight at birth arises from its relationship with subsequent piglet performance. It is positively correlated with pre-weaning average daily gain (Hovorka and Pour, 1970) and with survival rate to weaning (Bereskin *et al.*, 1968, 1970). These could result from the fact that heavy piglets at birth compete well during suckling and are likely to evade the early causes of death such as trauma and starvation and may withstand some of the infectious diseases. The genes controlling pre-natal growth may also continue their influence even after birth. The effect of average piglet weight at birth on pig survival is essentially linear within a wide range of values suggesting that, for the pig, unlike the situation for beef cattle, above normal birth weights may not be detrimental to pig survival (Bereskin *et al.*, 1973). This may be a consequence of polytocous births in the pig, each individual piglet usually being only a small fraction of the total weight or volume expelled at parturition. Thus, chances of injury from difficult or delayed birth due to over sized foetus thereby might be lessened. Post-weaning average daily gain in gilts has also been found to increase with average piglet weight at birth (Rydhmer *et al.*, 1989). Thus selection for high piglet weight at birth would be expected to lead to fast growing weaners and subsequently early attainment of puberty or market weight.

Both genetic and phenotypic correlations between litter size and average piglet weight at birth are negative (Pop *et al.*, 1988). This means that heavy piglets at birth usually come from small litters and vice versa. The negative phenotypic correlation between litter size at farrowing and average piglet weight at birth can result from sharing limited space and nutrients during the gestation period. The corresponding negative genetic correlation can arise from antagonism between the effects of the genes controlling the two traits.

After weaning, maternal influence diminishes and the pig's genetic potential for growth can then be expressed fully. Heavy pigs at weaning will withstand the stress imposed by termination of suckling better and show higher post-weaning gain than light ones. This has been supported by Edwards and Omtvedt (1971) whose work on phenotypic correlations revealed average piglet weight at weaning to be positively correlated with post-weaning daily gain but negatively correlated with age at 90 kg and probe backfat. Such correlations suggest that pigs expected to provide lean cuts and fast growth during the growing phase can be selected based on their weight at weaning. Environmental factors affecting average piglet weight at birth and at weaning include year and season of birth, parity, breed and sex of the piglet. Litter size at farrowing is also an important source of variation for the average weight of a piglet during the pre-weaning stage.

2.1.4 Farrowing Interval

The reproductive cycle is composed of the gestation period, lactation length, and the weaning to conception interval (empty days). The management practices determine the lactation length and, to some extent, the interval between weaning and conception, partly through the sow's plane of nutrition during the service period. In normal husbandry practices, with weaning six to eight weeks after farrowing, lactation and the number of empty days together represent 25 to 35 % of the farrowing interval (Crighton, 1970). During the empty days, the sow consumes costly feed, occupying costly accommodation while producing nothing. Thus reducing the farrowing interval results in decreased feed consumption per breeding animal for a fixed number of parities, improved pregnancy rates (Brooks and Smith, 1980) and improved utilization of the breeding herd.

The problem of a high average farrowing interval may result from poor service timing or it may be the result of poor performance by individual boars. Constant monitoring of boar fertility and precise timing of service are essential if high conception rates are to be attained. If the number of empty days has been reduced to an acceptable level, it may be worth to consider the effect of reducing the weaning age. With a high pre-weaning average daily gain, a slight reduction of weaning age can help to lower the lactation length without compromising piglet weight at weaning.

2.1.5 Pre-weaning Average Daily Gain

Several genetic analyses from pig populations have indicated high genetic correlations between pre-weaning average daily gain and gross feed efficiency, measured as feed consumed per litter per unit of gain, (Vangen, 1977; Vogt *et al.*, 1963). This means that fast growing piglets are efficient converters, and this is likely to continue even after weaning. Besides attaining market or breeding weight at an early age, fast growing pigs can also provide more meat per unit feed offered probably accompanied by a decrease in the unit cost of production.

Though high growth rate and prolificacy are desirable characters, they are difficult to combine in one breed. This is because even though piglets from large litters may have the genetic potential for fast growth, the lactational output of the dam can be a limiting factor. Other factors influencing early growth include breed and sex of the piglet, litter size at birth, location, year and season of birth.

2.2 Effects of Environmental Factors

The wide variation in sow performance as measured by the performance of her litter constitutes a major problem for the breeder who is attempting, through selection, to improve his breeding stock, and for the nutritionist conducting reproduction and lactation experiments. This wide variation consists of two major components, environmental and genetic variability. Environmental variation impedes the rate of genetic progress by causing errors in judgement of genetic merit. Knowledge of the variation attributable to non-genetic factors is of use in assessing the importance of environmental control and in identifying the specific type of programme that will most likely be efficient in achieving overall progress. These non-heritable factors include the parity or age of the sow, year and season of farrowing, intra-litter competition, nutrition, management practices and the sex of the piglet.

2.2.1 Parity

Gilts tend to have smaller litters and lower average piglet and litter weights than sows. Both the litter size and average weights increase progressively to about the third and the fourth parity, remain stable at 5^{th} and 6^{th} parities, then gradually decline thereafter (Yen *et al.*, 1987). However, Spath (1970) reported that average litter size at farrowing did not vary with parity. The females in his study may have come from herds subjected to direct selection for litter size so that maximum potential phenotype for this trait could have been reached at the first parity.

First farrowers may have small litters because at this stage the sow is not fully developed both physiologically and anatomically. The uterine environment is limited by this immaturity. Subsequent parities are associated with maturity of the sow which is accompanied by an increase in body weight. Thus the parity effect on litter size is associated with an increase in body weight at mating (Bowman *et al.*, 1961; Omtvedt *et al.*, 1965) possibly due to an increase in ovulation rate with body weight. However, an increase in ovulation rate in the pig tends to be associated with higher embryonic mortality (Fahmy and Dufour, 1976). On the other hand, low ovulation rate has been associated with low litter size in pigs (Penny *et al.*, 1971). It therefore appears that a slight increase in ovulation rate leads to an increase in litter size. Beyond a certain limit of ova production, prenatal deaths drastically reduce the size of the litter at farrowing. Bereskin and Frobish (1981) observed that the weight of a sow at breeding only affected total litter weight at farrowing but not litter size. Their findings however confirmed that sows farrow heavier piglets than gilts, a phenomenon possibly related to an increase in body weight as well.

Maturity of the sow is also associated with an increase in milk production. Ferreira *et al.* (1988) found that sows in their second lactation produced 10.7 % more milk than gilts, while sows in their third lactation produced 4.1 % more milk than sows in their second lactation. This advantage in milk production coupled with the superior maternal environment offered by older sows leads to faster growth of their piglets than those reared by gilts. As a result, sows usually wean heavier piglets than gilts (Chhabra, 1989a).

Knowledge of parity effects on litter performance is useful in culling decisions. Since gilt litters are usually smaller and lighter than those of sows, very high culling rates can lead to a lowering of the herd mean performance due to the high proportion of replacement gilts needed at high culling levels. On the other hand, keeping sows in the breeding herd for long especially after the sixth litter may be unprofitable. Determination of optimum culling rates is therefore necessary in any breeding herd.

2.2.2 Year, Season of Farrowing and their Interaction

Litter sizes at farrowing and at weaning have been reported to vary from one year to another in the subhumid tropics (Gupta *et al.*, 1982). Such variations can arise from variation in the genetic constitution of the animals maintained, variation in management practices and environmental conditions, nutrition and yearly differences in the incidence of diseases and parasites. A decline in litter size at farrowing can imply reduced reproductive performance over the years or increasing pre-natal mortality. Alternatively, reproductive performance can remain fairly constant while pre-weaning mortality and growth rate vary with years. The result would be variation in litter size and weight at weaning against a constant litter size at farrowing as reported by Sharma and Mishra (1989). There should be constant monitoring and evaluation of a herd's performance levels to allow taking corrective measures in good time.

The length of the photoperiod has been found to influence pig fertility. McGlone *et al.* (1988) observed that an extended photoperiod reduced days to return to oestrus and reduced sow lactation weight loss. Page *et al.* (1988) found that the effect of photoperiod on the reproductive failure in gilts and sows depended upon parity and the physiological stage at which it was imposed. But Greenberg and Mahone (1982) reported a non-significant effect of photoperiod on the length of service period, litter size and pre-weaning growth. Photoperiod is likely to have little or no effect on pigs reared in Kenya. The country being astride the equator, day and night hours do not vary much throughout the year.

High ambient temperatures can have adverse effects on pig fertility. This is because pigs have higher body temperatures and loose heat less efficiently than most other domestic animals (Steinbach, 1977). Alves *et al.* (1987) concluded that the pig has a distinct seasonal pattern of reproductive activity which is characterized by low fertility and oestrus activity during summer months. The main problems are failure to come on heat and silent heat in sows (Singh *et al.*, 1989a), possibly because of changes in sensitivity to the feedback of oestradiol (Armstrong *et al.*, 1986), and a refusal to mount by boars. Lower feed intake that may occur during hot seasons can predispose the endocrine system to these aberrations. Extreme temperature stress can also lead to a drop in litter size at farrowing and increased number of abortions (Mausolf and Horst (1986b). Irgang and Robison (1984) reported a higher farrowing interval in sows that first farrowed during the hot season than in those that first farrowed during the cold season. Flowers *et al.* (1989) observed that high ambient temperatures delayed attainment of puberty in gilts, but Minton *et al.* (1988) reported that heat stress at 33.3 °C did not affect piglet growth rate.

Much of the information from the literature indicates that season of farrowing usually has little or no effect on the number of piglets born but does influence the size of the litter at weaning. This may be related to survival rate to weaning. Piglets have little body reserves at birth (Msolla and Singh, 1986), and require a warm environment immediately after. Consequently, piglet mortality rates in temperate and subtropical areas are higher in winter than in summer (Singh *et al.*, 1989b). Likewise, Omeke (1989) reported higher piglet mortality rates in the wet season than in the dry season in Landrace and Large White sows in the tropics.

Heat stress can be reduced through provision of facilities for the pigs to cool themselves down during the hot season. Piglets should receive sufficient warmth and increased care and attention during cold seasons.

Interaction of year with season of farrowing has been found to influence litter traits. Yen *et al.* (1987) found this interaction to have a significant effect on litter size at farrowing. Such an interaction implies that the seasonal effect is not necessarily the same every year. This means that comparisons of performance levels should only be done between litters born in the same year and preferably the same season. If comparison across years or seasons are desired, statistical adjustments on the data should be done first.

2.2.3 **Age at First Farrowing**

Although gilts may come into first oestrus at 4 to 5 months of age, they are not usually bred until the third oestrus, so as to take advantage of any increase in ovulation rate. Therefore gilts are usually first bred at 7 to 8 months and farrow at 11 to 12 months of age. Prolonged age at first farrowing leads to fewer piglets produced during the productive life of a sow (Noguera and Guebler, 1984). This lowers the mean annual productivity per sow (Legault *et al.*, 1975; Hutchens *et al.*, 1982). However, Clark *et al.* (1988) observed a non-significant effect of age at first farrowing on the lifetime performance of a sow. Besides weaning few pigs during their reproductive life, sows that first farrow at an advanced age will have been fed for a long time before first service. The cost of feeding them the extra number of days may not be compensated for fully by any increase in litter size at farrowing from increased ovulation rate.

Delayed age at first farrowing can be due to management reasons such as failing to note when gilts first come into oestrus, or delayed physiological maturation due to nutritional and/or environmental stress. Fast growth to early puberty is, therefore, an essential attribute of replacement gilts. Constant monitoring of the replacement stock is necessary so as to note when puberty is attained. Overall, a reduction in the age at which gilts are bred can result in savings of both fixed and variable costs.

2.2.4. Maternal Influence

The dam influences her offspring through the environment she provides as well as through the genes she transmits. Post-natal maternal influences arise mainly from lactational output of the mother and her maternal instincts and can modify female reproductive performance, particularly in litter bearing species. Female mice born in large litters tend to have small body weights at sexual maturity (Rutledge *et al.*, 1972). Due to a positive correlation between body weight and ovulation rate, such females produce small litters and vice versa (Hanrahan and Eisen, 1974). Similar results have been reported in rats (Azzam *et al.*, 1984) and in laboratory species in general (Legates, 1972).

Gilts from large litters tend to take long to reach sexual maturity (Lamberson *et al.*, 1988) and produce smaller litters in their initial parities compared to the size of the litter from which they were selected (Kirkpatrick and Rutlegde, 1988). Revelle and Robison (1973) reported similar findings. Stewart and Diekman (1989) reported that pigs from large litters had lower survival rate from birth to weaning.

Maternal influence arises from the more social and/or nutritional competition in the large litters. Such exposure to greater stress of females in the large litters results in physiological immaturity of the reproductive system that persists at least until the first farrowing (Nelson and Robison, 1976b). Consequently, females from large litters are unable to fully express their genetic superiority. This constitutes a negative environmental correlation between the litter size of the dam and that of her daughter (Rutledge, 1980b). This leads to a low heritability in turn leading to ineffective selection for increased litter size (Malyshev and Saslina 1986). Reducing maternal influence would thus allow for more accurate estimation of the direct genetic effect on litter size. Management systems providing an optimal maternal environment conducive to normal physiological development need to be developed. Cross-fostering soon after birth to equalise litter suckled and supplementation can help to realise much of the potential for growth rate.

2.2.5 Sex of the Piglet

Males tend to grow faster and are usually heavier at weaning than females (Fahmy and Bernard, 1970). This can be a manifestation of the influence of sex hormones on growth. Male piglets may also compete well for suckling and creep feed due to their aggressive nature, but Kuhlers *et al.* (1980) reported a non-significant effect of sex on average piglet weight at weaning (42 days) in the Large White, the Landrace and the Duroc breeds. Likewise, Blair and English (1972) did not observe any significant sex differences in average daily weight gain. However, Bereskin *et al.* (1973) reported that males weighed significantly heavier than females at birth.

2.3 Effects of Genetic Factors

Knowledge of genetic factors is essential when carrying out selection. Performance in the various traits of economic importance usually varies from one breed to another. Heritabilities are necessary in choosing the right selection scheme to ensure high genetic gains. Measures of repeatability are useful as a guide to the improvement in performance that can be achieved through culling sows of poor performance. Genetic correlations are essential in predicting indirect response to selection and for determining the optimum weighting and expected response in selection to improve more than one trait.

2.3.1 Breed

In a study on reproductive traits in pigs, Yen *et al.* (1987) reported that the Hampshire produced significantly smaller litters (number born alive) and lower litter weight at 21 days than the Large White and the Landrace breeds. However, the Hampshire breed had the highest piglet survival rate up to 21 days of age. Studies in the tropics by Mausolf and Horst (1986b) indicated smaller litters in Landrace sows compared to the Large White.

In a study on daily gain in the Landrace, the Large White and their half-breds, Deo *et al.* (1981a) found that the Landrace and the cross-breds were superior to the Large White from birth to 9 months of age. The Landrace was superior to the cross-bred from birth to 12 weeks, whereafter the cross-bred showed better growth than the Landrace in all subsequent growth periods. It therefore seems that, though the Large White may produce large litters, it is worth crossing their females with Landrace males to exploit the high growth rate of the cross-breds.

2.3.2 Heritability

In pigs, heritability estimates for reproductive traits are generally low (De Vries, 1990) while those for post-weaning growth are medium (Drewry, 1980). As a result, the ability to improve prolificacy in pigs through selection for litter size may be low. Theoretical work, however, has shown that it is possible to achieve fairly high rates of genetic improvement in litter size if the herd size is large and records on the dam and her relatives together with those of her sire are used (Avalos and Smith, 1987; Pathiraja, 1987). Moreover, the ability to change litter size by selection is not solely determined by the heritability. Another important factor is the total variation of the trait. The wide range of heritabilities for litter size reported in the literature, even where similar statistical methods are used, can be an indication of regional variation in the potential for this trait. Heritability estimate for a trait may be low due to low additive genetic variance, excessive environmental variability, negative correlation between direct genetic and maternal effects or negative correlation between components of the trait.

Table 1 summarizes some of the heritability estimates of the traits studied as reported in the literature. They were estimated from paternal half sibs. These estimates are generally low. The estimates for farrowing interval are slightly higher than the rest. The estimates for litter size are slightly varied and tend to agree with the indication from the literature that heritability for litter size is usually less than 0.18 and that the best estimate for the trait is probably less than 0.10 (Boylan *et al.*, 1961).

Table 1 **Heritability and Repeatability Estimates of Reproductive Traits in Pigs**

Trait	h^2	Repeatability	Breed	Source
Litter Size at Farrowing	0.16±.14		*	Pumfrey *et al.* (1980)
	0.12±.04		Large White	Gu *et al.* (1989)
	0.07±.03		Large White	Strang and Smith (1979)
	0.07±.02		Large White	Strang and King (1970)
	0.09±.04		*	Urban *et al.* (1966)
		0.15	Landrace	Strang and Smith (1979)
		0.15	Large White	Strang and Smith (1979)
Average Piglet Weight at Birth	0.47±.16		Landrace	Mishra *et al.* (1989)
Litter Weight at 3 Weeks	0.07±.04		Large White	Strang and Smith (1979)
	0.22±.08		Landrace	Vidovic *et al.*, (1975)
	0.08±.02		Large White	Strang and King (1970)
		0.15	Large White	Strang and King (1970)
Litter Size at Weaning	0.09±.03		Large White	Strang and King(1970)
	0.13±.05		*	Urban *et al.* (1966)
		0.14	Large White	Strang and King (1970)
Average Piglet weight at Weaning	0.12±.06		Large White	Strang and Smith(1979)
	0.11±.02		Large White	Strang and King (1970)
		0.04	Large White	Strang and King (1970)
Litter Weight at 8 weeks	0.12±.06		Large White	Strang and Smith (1979)
	0.03±.02		Large White	Strang and King (1970)
	0.19±.05		*	Urban *et al.* (1966)
		0.04	Large White	Strang and Smith (1979)
Farrowing interval	0.24±.50		Large White	Irgang and Robison (1984)
	0.24±.50		Large White	Irgang and Robison (1984)

* breed was not specified. Heritabilities were estimated from paternal half sibs.

2.3.3 Repeatability

Repeatability estimates for litter traits in pigs are generally low (Haley *et al.*, 1988). King and Gajic (1969) observed no great changes in sow reproductive performance from the first to the second litter. They reported that the number of piglets born alive tended to have a higher repeatability estimate (0.24±0.08) than the number of pigs surviving to weaning (0.05±0.09).

Table 1 shows some of the repeatability estimates of reproductive and pre-weaning growth traits as reported in the literature. These estimates are all low. Likewice, Gu *et al.* (1989) reported low repeatability estimates of litter traits varying between 0.12 and 0.18. With such low repeatability estimates the annual gain from culling of sows of poor reproductive performance is likely to be low. However, the cumulative effect of culling over a number of years may be substantial, thereby helping to maintain a high herd mean performance and profit margins.

2.3.4 Correlations

Little literature exists that provides correlations among reproductive or litter traits in pigs. The documented genetic and phenotypic correlations between weights at different ages confirm that gilts which grow fastest and are heaviest at various ages tend to reach puberty early and at heavier weights (Young *et al.*, 1978). Positive phenotypic correlations have been reported between litter size and litter weight. Table 2 presents genetic and phenotypic correlations between some pre-weaning traits of the Large White breed as reported by Strang and King (1970). Standard errors were not given. Bereskin and Frobish (1981) reported a phenotypic correlation between litter size at farrowing and litter weight at 3 weeks of 0.54 in the Large White breed. From Table 2, the genetic correlations indicate that it would be possible to improve both litter weight at 3 weeks and at weaning through direct selection for litter size at farrowing. However, selection for large litters at farrowing would lead to a low average piglet weight at weaning. The presented genetic correlations indicate that litter size at weaning can be improved by selection for litter weight at 3 weeks.

Table 2 **Genetic and Phenotypic Correlation Coefficients Among Pre-weaning Traits**

		(1)	(2)	(3)	(4)	(5)
Litter size at farrowing	(1)		0.8	0.9	0.5	-0.4
Litter weight at 3 weeks	(2)	0.5		0.9	0.3	-0.5
Litter size at weaning	(3)	0.7	0.8		0.3	-0.6
Litter weight at weaning	(4)	0.2	0.4	0.4		0.5
Average Piglet weight at weaning	(5)	-0.3	-0.2	-0.4	0.6	

Source: Strang and King (1970)
Genetic correlations above diagonal
Phenotypic correlations below diagonal

3 MATERIALS AND METHODS

3.1 Data Source and Location of the Herds

Data used in this study came from three pig herds maintained by the Agricultural Development Corporation (A.D.C.) at Lanet and Ngata in Nakuru District and at Zea in Trans Nzoia district. The records were made between 1975 and 1989 under fairly similar management practices. The herd at Ngata was a commercial one and obtained its foundation stock from Zea and later from Lanet. The herds at Zea and Lanet were maintained as breeding units selling purebred and occasionally crossbred stock to commercial producers. These two herds were located near the district meteorological stations while the herd at Ngata was near the National Plant Breeding Station (N.P.B.S.) at Njoro. The geographical locations of these stations are shown in Table 3. The Kitale station was just over 17 metres higher than that at Nakuru.

Table 3 Geographical Location of the Weather Stations near the Herd Sites

Area	Altitude (Metres)	Latitude	Longitude
Nakuru meteorological station	1872.26	0°16'S	36°04'E
National Plant Breeding Station	2164.63	0°21'S	35°36'E
Kitale meteorological station	1890.24	1°01'N	35°00'E

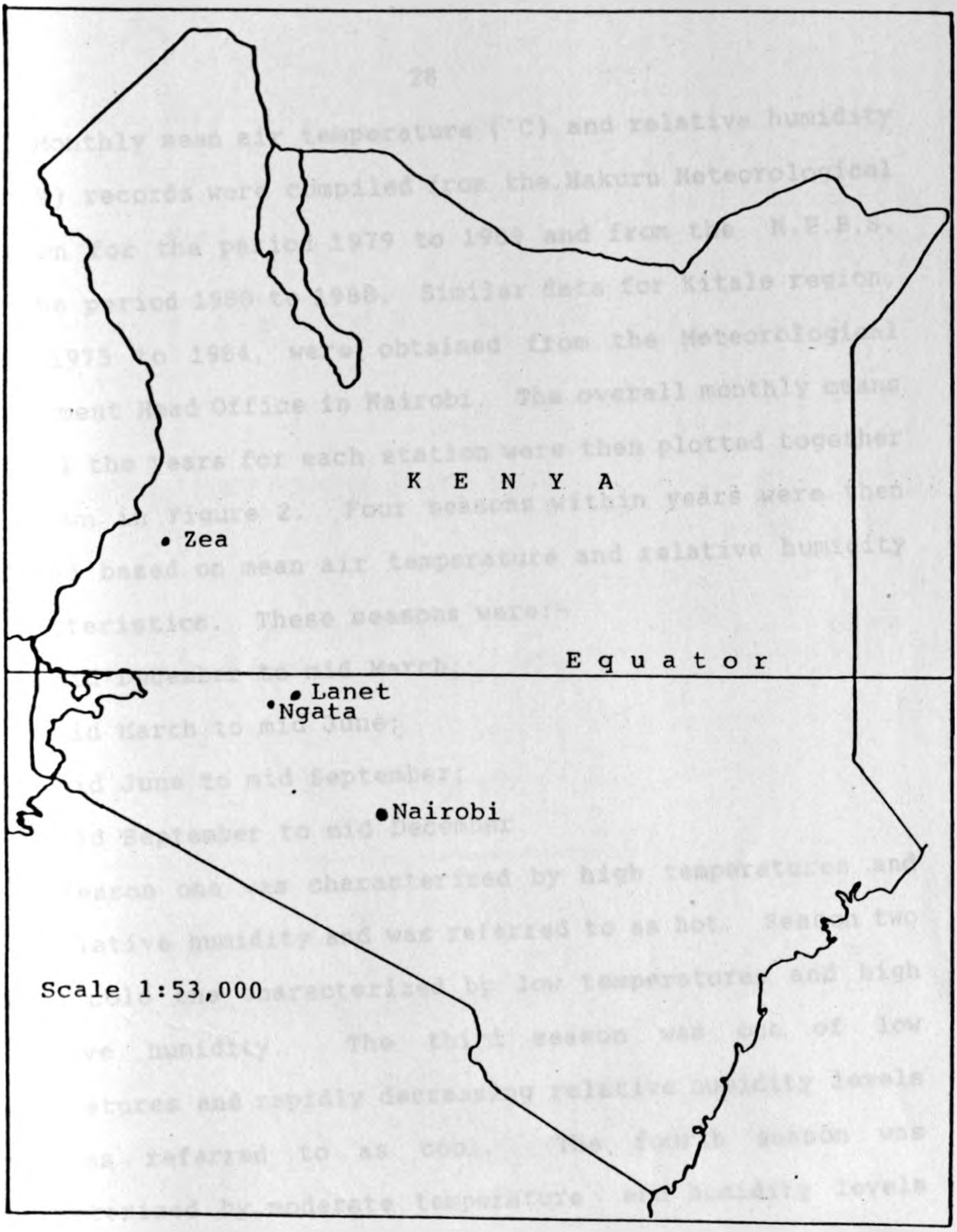

Figure 1: Location of the herds.

Monthly mean air temperature (°C) and relative humidity (R.H.%) records were compiled from the Nakuru Meteorological station for the period 1979 to 1989 and from the N.P.B.S. for the period 1980 to 1988. Similar data for Kitale region, from 1975 to 1984, were obtained from the Meteorological Department Head Office in Nairobi. The overall monthly means for all the years for each station were then plotted together as shown in Figure 2. Four seasons within years were then defined based on mean air temperature and relative humidity characteristics. These seasons were:-

1 : mid December to mid March;

2 : mid March to mid June;

3 : mid June to mid September;

4 : mid September to mid December.

Season one was characterized by high temperatures and low relative humidity and was referred to as hot. Season two was a cold one characterized by low temperatures and high relative humidity. The third season was one of low temperatures and rapidly decreasing relative humidity levels and was referred to as cool. The fourth season was characterized by moderate temperature and humidity levels and was referred to as warm. This seasonal classification was then used to evaluate the effect of season of farrowing on the reproductive performance and pre-weaning growth in pigs.

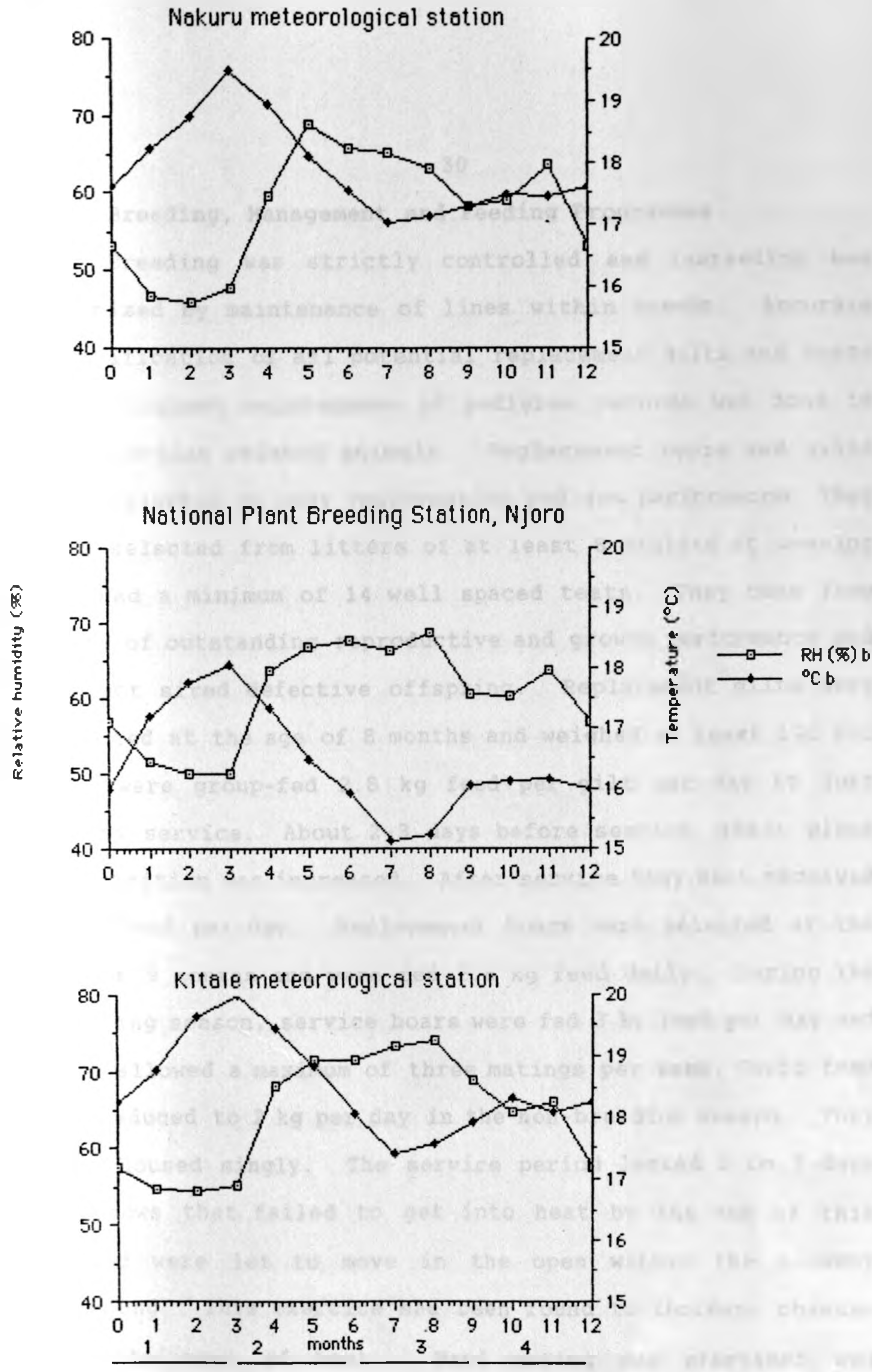

Figure 2: Classification of seasons

3.2 Breeding, Management and Feeding Programmes

Breeding was strictly controlled and inbreeding was minimised by maintenance of lines within breeds. Accurate identification of all potential replacement gilts and boars and efficient maintenance of pedigree records was done to avoid mating related animals. Replacement boars and gilts were selected on body conformation and sow performance. They were selected from litters of at least 8 piglets at weaning and had a minimum of 14 well spaced teats. They came from sires of outstanding reproductive and growth performance and had not sired defective offspring. Replacement gilts were selected at the age of 8 months and weighed at least 120 kg. They were group-fed 2.8 kg feed per gilt per day to just before service. About 2-3 days before service, their plane of nutrition was increased. After service they each received 2 kg feed per day. Replacement boars were selected at the age of 9 months and were fed 2.8 kg feed daily. During the breeding season, service boars were fed 3 kg feed per day and were allowed a maximum of three matings per week. Their feed was reduced to 2 kg per day in the non-breeding season. They were housed singly. The service period lasted 3 to 7 days and sows that failed to get into heat by the end of this period were let to move in the open within the piggery compound. This exercise had been found to increase chances of attainment of heat. Hand mating was practised and repeated at least twice.

During the service period each sow received 4 kg feed per day up to 5 days after service. Thereafter, they each got 2 kg of feed per day up to about 76 days of gestation when the plane of nutrition was increased for 1 month. One week before farrowing, each sow received 2 kg of feed per day. Three to four days before farrowing, sows were taken singly to previously washed and disinfected farrowing pens with a creep area. They were washed and given a mange treatment. Warmth was provided to the piglets in the creep area immediately after farrowing.

Each newborn litter was weighed soon after birth. This weight, together with the size of the litter and the date of farrowing were recorded on both the litter and the sow performance cards. Needle teeth were clipped soon after birth. Each piglet received an iron injection on the third day after birth. Creep feed was introduced after 7 days and was offered *ad libitum*. Piglets were usually weaned at 56 days of age. Males not needed as replacements were castrated at 21 days of age, and the size and weight of each litter at this age were recorded.

Tattooing and deworming of the piglets were done at weaning. They were then weighed singly in movable weighing crates and each weight was recorded alongside the pig's identification number on the litter performance card. Males and castrates were then separated from the females. Each of these two groups were then put in growing pens in groups of roughly similar weights. Thereafter, their progressive weights were recorded weekly on the post-weaning performance cards against their identification numbers. As they grew, they were constantly reallocated into the various pens on the basis of the attained live weight and fed a pig starter diet as shown in Table 4. A random sample of pig starter diet used at Lanet and analysed for nutrient content in the laboratories of the National Seed Quality Control Service of the Ministry of Agriculture revealed a low crude protein content of 11.44 % and a dry matter content of 91.02 %.

Table 4 Concentrate Fed to Breeding Pigs and Fatteners at Lanet

Live Weight (kg)	Feed Offered (kg per day and animal) Breeding Stock	Fatteners
25	1.0	1.0
30	1.2	1.2
35	1.4	1.4
40	1.6	1.6
45	1.8	1.8
50	2.0	2.0
55	2.1	2.1
60	2.1	2.1
65	2.3	2.3
70	2.3	2.3
75	2.4	2.4
80	2.5	2.4
85	2.6	2.7
90	2.7	2.7
95	2.8	2.9

3.3 Records

Two sets of data were collected. One set was composed of litter records showing sow performance. These litters were of Landrace and Hampshire sows from Zea herd and Large White sows from both Ngata and Lanet herds. The second set contained records of individual weaner piglets born at Lanet from Landrace and Large White sows.

Litter Records

The information compiled at the piggeries from the sow performance cards included:

- Sow's breed, identification and date of birth.
- Sow's sire and dam.
- Size of the litter at birth from which the sow was selected.
- For each parity:
  - Date of service and date of farrowing.
  - Litter size at farrowing (number alive) and at weaning.
  - Litter weight at 3 weeks and at weaning.

The litters used in the analyses were 1646 at farrowing and 1395 at weaning. From these, 7 traits were analysed, namely: litter size at farrowing and at weaning, average piglet weight at birth and at weaning, litter weight at 3 weeks and at weaning and farrowing interval in days. These were analysed as traits of the sow.

Piglet Records

In order to analyse weaning weight and pre-weaning average daily gain as traits of the piglet, the following entries concerning the piglets were compiled:

- Identification number.
- Sire and dam.
- Date of birth.
- Average piglet weight at birth and size of the litter into which the piglet was born.
- Date weaned and individual weaning weight. A total of 2861 weaner records from 362 litters were used in this analysis.

3.4 **Data Preparation**

Initial data preparation was done using Panacea data base programme (Pan Livestock Services, 1989). This included data edition and derivations concerning some of the traits. Litter records from the three herds covered different years with only some overlap. At Zea, Landrace and Hampshire records covered different years to a great extent. This necessitated separate runs for each breed within herds. Preliminary analyses revealed that year by season of farrowing interaction was significant for most traits studied. However, the distribution of records within the period of study made it necessary to group some years together as shown in Table 5.

Table 5 **Grouping of Some Years by Herd and Breed**

Herd	Breed[1]	Sample Size	Period Covered	Years
Sows:				
Zea	LR	1012	1975-1984	75, 76, 77, 78, 79, 80, 81, 82, 83, 84
	HS	130	1975-1984	75-76, 77, 78, 79, 80, 81, 82, 83-84
Ngata	LW	272	1980-1988	80, 81, 82, 83, 84, 85, 86, 87-88
Lanet	LW	232	1978-1989	78-81, 82, 83, 84, 85, 86, 87, 88, 89
Piglets:				
Lanet	LW	2224	1978-1989	78-80, 81, 82, 83, 84, 85, 86, 87, 88, 89
	LR	637	1978-1989	78-80, 81, 82, 83, 84, 85, 86, 87, 88, 89

[1]LR: Landrace, HS: Hampshire, LW: Large White.
For the Landrace breed, only records on farrowing interval for 1983 and 1984 were grouped together.

Among the weaner records there were few cases of piglets weaned earlier or later than 8 weeks and this necessitated adjusting weaning age to 56 days based on an equation of the form:

WW = [(WT-ABW)/actual weaning age in days]*56 + ABW

where WW : adjusted 56-day weaning weight (kg).

WT : unadjusted piglet weight (kg).

ABW : average piglet weight (kg) at birth of the litter into which the piglet was born. This adjustment of weaning weight was made in view of the fact that lactation length was mainly a management decision. Calculation of pre-weaning average daily gain (ADG) in kg/day was based on an equation of the form:

ADG = (WW-ABW)/56

where WW and ABW were the respective adjusted 56-day weaning weight and average piglet weight at birth of the litter into which the piglet was born.

3.5 Statistical Analyses

Heritabilities, repeatabilities, genetic and phenotypic correlations were estimated from variance and covariance components using the Mixed Model Least Squares and Maximum Likelihood Computer Programme of Harvey (1987) on a Multitech Plus 700 Personal Computer. For the traits of the sow, each model of analysis had one set of cross-classified non-interacting random effects. The random effects fitted in the estimation of heritabilities and repeatabilities were sires and sows (dams of the litters) respectively. Interactions of the random effects with all fixed effects were assumed to be negligible. The following statistical model was used in the analysis of the traits of the sow:

$$Y_{ijklm} = \mu + s_i + P_j + A_k + G_l + (AG)_{kl} + bC_{ijklm} + e_{ijklm}$$

where

Y_{ijklm} : the reproductive trait of the m^{th} sow farrowing during the l^{th} season in the k^{th} year, in her j^{th} parity, born (i.e. the sow) of the i^{th} sire;

μ : the overall mean of the trait;

s_i : the random effect of the i^{th} sire, assumed to be normally distributed with mean 0 and variance σ_s^2;

P_j : the fixed effect of the j^{th} parity (j = 1, 2, 3, 4, 5);

A_k : the fixed effect of the k^{th} year of farrowing (k= 1, 2,...., 10, for the Landrace breed);

G_l : the fixed effect of the l^{th} season of farrowing, (l=1,2,3,4);

$(AG)_{kl}$: the fixed effect due to the interaction between year and season of farrowing;

b : partial regression coefficient of the trait on a continuous covariate C (see below);

C_{ijklm} : age at first farrowing or size of the litter at farrowing into which the sow was born or the litter size at farrowing of the m^{th} sow;

e_{ijklm} : the random error, assumed to be normally and independently distributed with mean 0 and variance σ_e^2.

A sow's age at first farrowing and the size of the litter at birth into which the sow was born were fitted as continuous covariates (symbolized as C in the equation above) in the analysis of the litter size at farrowing. The sow's litter size at farrowing was similarly fitted in the analyses of litter size at weaning, litter weights and average piglet weights. Parities one to four were studied as separate classes while the fifth and above were grouped together. Only Landrace records were used for the estimation of genetic and phenotypic parameters because of the small number of records available for the other breeds. For this reason, the random sire effect was removed in the analyses of the traits of the sow in the Large White and the Hampshire breeds. The Landrace records at farrowing represented a total of 64 sires and 196 daughter sows.

The variance component σ_s^2 was estimated as follows.

$$\sigma_s^2 = (MS_s - MS_w)/k$$

where

MS_s : mean square between sires;

MS_w : mean square of litters within sires;

k : $(s-1)^{-1}$ $[n.-(\Sigma n^2_i)/n.]$;

s : number of sires;

n. : total number of observations;

n_i : number of observations within the i^{th} sire.

$$\sigma_w^2 = MS_w$$

The variance component σ_s^2 estimates ¼ of the additive genetic variance. The variance component σ_w^2 estimates the remainder of the genetic variance plus all the environmental variance, so that:

$$4\,\sigma_s^2 = \sigma_A^2$$

and $\sigma_s^2 + \sigma_w^2 = \sigma_p^2$

Then heritability (h^2) becomes:

$$h_s^2 = 4\frac{\sigma_s^2}{\sigma_s^2 + \sigma_w^2}$$

In the programme, the standard error of the heritability was estimated from the approximate method of Swiger *et al.* (1964) which assumes normality of the intra-class correlation, t.

where

$$s.e.\ h_s^2 = 4\frac{\sqrt{2(n.-1)(1-t)^2[1+(k-1)t]^2}}{k^2(n.-s)(s-1)}$$

$$t = \frac{\sigma_s^2}{\sigma_s^2+\sigma_w^2}$$

Estimation of repeatability (R) was based on the statistical model:

$Y_{jk} = \mu + d_j + q_{jk}$

where Y_{jk} is the k^{th} measure on the j^{th} sow. Thus the variance component σ_d^2 represents the differences among measurements between sows. It estimates all the genetic variance and the proportion of the environmental variance peculiar to the sow. σ_q^2 represents the residuals among measurements within sows. The various fixed effects (as fitted in the estimation of heritabilities and correlations above) were included in the model for the adjustment of the records.

$\sigma_q^2 = MS_q$

$\sigma_d^2 = (MS_d - MS_q)/k_1$

Then, repeatability (R) becomes:

$$R = \frac{\sigma_d^2}{\sigma_d^2+\sigma_q^2}$$

$$k_1 = (d-1)^{-1}[m. - (\Sigma m_k^2)/m.]$$

where

m. : total number of observations;

m_k : number of observations taken on the k^{th} sow;

d : number of sows.

The estimate of the standard error of the repeatability by the programme was based on the formula by Swiger *et al.* (1964);

$$s.e.\ R = \frac{\sqrt{2(m.-1)(1-R)^2[1+(k_1-1)R]^2}}{k_1^2(m.-d)(d-1)}$$

Estimation of the genetic correlation coefficient (r_g) between any two traits (x and y) was based on the formula:

$$r_g = 4\frac{Cov_s}{\sqrt{(4\sigma^2_{s(x)} \times 4\sigma^2_{s(y)}}}$$

While the phenotypic correlation coefficients (r_p) were estimated from the formula:

$$r_p = \frac{Cov_w + Cov_s}{\sqrt{(\sigma^2_{w(x)} + \sigma^2_{s(x)}) \times (\sigma^2_{w(y)} + \sigma^2_{s(y)})}}$$

where Cov_w is the covariance among sib litters, Cov_s is the covariance among sires.

The analyses of piglet weight at weaning and average daily gain as traits of the piglet were based on a fixed model of the form:

$$y_{ijklmn} = \mu + B_i + F_j + P_k + A_l + G_m + (AG)_{lm} + zX_{ijklmn} + e_{ijklmn}$$

where

Y_{ijklmn} : measure on the n^{th} piglet farrowed during the m^{th} season, in the l^{th} year of farrowing, born in the k^{th} parity, of j^{th} sex and i^{th} breed;

μ : overall mean of the trait;

B_i : fixed effect of the i^{th} breed ($i = 1, 2$);

F_j : fixed effect of the j^{th} sex ($j = 1, 2, 3$);

P_k : fixed effect of the k^{th} parity of dam ($k = 1, 2, 3, 4, 5$);

A_l : fixed effect of the l^{th} year of farrowing ($l = 1, 2, 3, \ldots, 10$);

G_m : fixed effect of the m^{th} season of farrowing ($m = 1, 2, 3, 4$);

$(AG)_{lm}$: fixed effect due to the interaction between year and season of farrowing;

z : partial regression coefficient of the trait on a continuous covariate X (see below);

X_{ijklmn} : size of the litter at farrowing into which piglet ijklmn was born;

e_{ijklmn} : random error, assumed to be normally and independently distributed with mean 0 and variance σ_e^2.

4 RESULTS

4.1 Descriptive Statistics

Table 6 shows the descriptive statistics for the various traits studied in sows and piglets by breed and herd. The smallest litter size at farrowing was obtained in the Hampshire sows. All the three breeds had fairly high average piglet weight at farrowing. The Large White sows from the herd at Ngata showed slightly larger but more varied litter size at farrowing than those from the herd at Lanet.

Average piglet weight at weaning in Landrace sows was close to the weaning weight of the piglets from Lanet. The weaning weight and pre-weaning average daily gain given in Table 6 show the performance of both the Large White and the Landrace piglets. The separate breed performance among the piglets are presented as least squares means in Table 14.

The average farrowing interval in the Landrace sows was quite high. Since the lactation period was set at 56 days and the gestation period is usually about 114 days, then the obtained farrowing interval indicated an interval between weaning and conception of about three weeks.

Table 6 **Descriptive Statistics for Reproductive Performance and Pre-weaning Growth**

Trait	Herd	Breed	Sample size	Mean	Coefficient of variation (%)
Sows					
Litter Size at Farrowing	Lanet	L. White	222	9.78	24.73
	Ngata	L. White	272	9.99	32.44
	Zea	Landrace	1012	8.79	27.40
	Zea	Hampshire	131	7.08	37.24
Litter Size at Weaning	Lanet	L. White	216	8.09	19.91
	Ngata	L. White	243	8.58	18.87
	Zea	Landrace	936	7.47	18.73
Average Piglet Weight at birth (kg)	Lanet	L. White	232	1.45	12.94
	Zea	Landrace	1011	1.46	15.25
	Zea	Hampshire	130	1.53	18.44
Average Piglet Weight at Weaning (kg)	Zea	Landrace	929	12.97	18.86
Litter Weight at 3 weeks (kg)	Lanet	L. White	225	37.90	21.34
	Zea	Landrace	950	39.27	24.13
Litter Weight at Weaning (kg)	Zea	Landrace	929	95.40	24.63
Farrowing Interval (days)	Zea	Landrace	813	194.46	17.01
Piglets					
Weaning Weight (kg)	Lanet	L. White & Landrace	2861	13.37	19.20
Average Daily Gain (kg/day)	Lanet	L. White & Landrace	2861	0.21	21.50

Table 7 shows the level of significance for the fixed effects by breed and herd. Parity effects influenced litter size, farrowing interval and litter weights while year, season of farrowing and their interaction mainly influenced growth related traits and farrowing interval. Influence of litter size at farrowing was significant on all traits in which it was fitted. The full analyses of variance tables are presented in the appendices.

Tables 8 to 14 show the least squares means and standard errors for the various fixed effects (classes) for the different breeds in the respective herds. The least squares means for the interaction between year and season of farrowing were not listed as there were very many. The interaction was significant for most of the traits meaning that seasonal effects varied from one year to another.

4.2 Effects of Environmental Factors

4.2.1 Year of Farrowing

Year effects on litter size were significant only at weaning, except in Large White litters from the Ngata herd, (Table 7). The litter size at weaning in Large White sows from Lanet and the Landrace sows seemed to fluctuate around the mean (Tables 10 and 12).

Year of farrowing influenced (P<.01) average piglet weight at birth and at weaning in both the Landrace sows from Zea and Large White sows from Lanet (Table 7). Average piglet weight at weaning at Lanet was represented by weaning weight. In this herd, average piglet weight at weaning and average daily gain in the period 1978-85 excelled that in the period 1986-89 (Table 14). Litter weight at 3 weeks followed a similar trend, while the highest average piglet weight at birth was recorded prior to 1986 (Table 12). At Zea, there was a decrease in litter weight at 3 weeks and at weaning in Landrace sows (Tables 8 and 9) after 1981.

Average farrowing interval in Landrace sows was generally high. It was erratic in the former half of the period studied, but the yearly sample sizes for this trait were quite small in the earlier years compared to the latter years (Table 10).

4.2.2 Season of Farrowing and its Interaction with Year of Farrowing

Season of farrowing and its interaction with year of farrowing significantly influenced average weights and farrowing interval (Table 7). At Lanet, piglets born during the cold and the cool seasons (mid March to mid September) were heavier ($P<0.05$) at birth than those born during the rest of the year (Table 12). However, those born during the warm and the hot seasons (mid September to mid March) grew faster and were heavier ($P<0.01$) at weaning than those born during the rest of the year (Table 14). The interaction of year with season of farrowing was also significant ($P<0.01$).

At Zea, some of the heaviest average piglet weaning weights, litter weights at 3 weeks and at weaning were also recorded in Landrace sows farrowing during the hot season (Tables 8 and 9). Litter weight at 3 weeks in the Large White sows from Lanet did not vary with season of farrowing.

Farrowing interval was longest in sows farrowing during the cold season (Table 10), but this season had the fewest number of records. Farrowing records of the Landrace sows (Table 8) indicated that the cool season (mid June to mid September) had the highest number of litters (282) while the cold season (mid March to mid June) had the lowest (235).

4.2.3 **Parity**

Parity influenced ($P<0.01$) litter size at farrowing in both the Landrace and the Large White sows and litter size at weaning in Landrace sows (Table 7). Peak litter size at farrowing occurred in the fourth parity in Landrace sows (Table 8) and in the third parity in Large White sows (Tables 12 and 13).

Parity effects on average piglet weight at farrowing and at weaning in Landrace sows were non-significant ($P>0.05$) (Table 7). Likewise, weaning weight and average daily gain in the Large White and Landrace piglets from Lanet did not vary ($P>0.05$) with parity (Table 7). Parity effects on litter weights were significant ($P <0.05$) only in the Landrace sows. In these sows, litter weight at weaning was maximum in the second parity (Table 9).

Farrowing interval in Landrace sows decreased (P<0.01) between the first three parities (Table 10). The interval between the first and the second parities was particularly high.

4.2.4 Covariates

Litter size at farrowing had a negative correlation with average daily gain, average piglet weight at birth and at weaning. It had a positive correlation with litter size at weaning, litter weight at 3 weeks and at weaning. Age at first farrowing in the Landrace sows was 431.81 days with a standard deviation of 55.78 days. It had a negative correlation with a sow's litter size at farrowing.

4.2.5 Sex of the Piglet

Sex affected (P<0.01) both the weaning weight and pre-weaning average daily gain in the piglets from Lanet (Table 7). Entire males grew faster and were heavier than castrates or females at weaning. Castrates and females had similar growth rates and attained fairly similar weights at weaning (Table 14).

4.3 **Breed**

Breed influenced (P<0.01) both the weaning weight and pre-weaning average daily gain in the piglets from Lanet (Table 7). Landrace piglets excelled the Large White piglets in both the growth rate and average weight at weaning.

Though no statistical breed comparisons were carried out for the traits of the sow, the means in Table 6 indicated that the Hampshire sows may have produced the smallest litters at farrowing while the Large White sows may have produced the largest. There seemed to be no major differences in the average piglet weight at farrowing between the three breeds. Landrace sows seemed to have higher litter weights at 3 weeks than the Large White sows.

Table 7 **Level of Significance[1] for Fixed Effects on Reproductive and Pre-weaning Growth Traits by Breed and Herd**

Trait	Breed	Herd	PAR	YOF	SOF	YxS	LSF	AGE	LSBD	BREED	SEX
			Source of Variation[2]								
Sows											
Litter Size at Farrowing	L. White	Lanet	**	ns	ns	ns		**			
	L. White	Ngata	**	ns	ns	ns		ns			
	Landrace	Zea	**	ns	ns	ns		**	ns		
	Hampshire	Zea	ns	ns	ns	ns					
Litter size at Weaning	L. White	Lanet	ns	*	ns	ns	**				
	L. White	Ngata	ns	ns	ns	ns	**				
	Landrace	Zea	*	**	ns	*	**				
Average Piglet Weight at Birth	L. White	Lanet	ns	**	*	ns	**				
	Landrace	Zea	ns	**	ns	**	**				
	Hampshire	Zea	ns	ns	ns	*	**				
Average Piglet Weight at Weaning	Landrace	Zea	ns	**	**	**	**				
Litter Weight at 3 weeks	L. White	Lanet	ns	**	ns	*	**				
	Landrace	Zea	*	**	*	**	**				
Litter Weight at Weaning	Landrace	Zea	*	**	**	**	**				
Farrowing Interval	Landrace	Zea	**	**	*	**					
Piglets											
Weaning Weight	L. White & Landrace	Lanet	ns	**	**	**	**			**	**
Average Daily Gain	L. White & Landrace	Lanet	ns	**	**	**	**			**	**

[1] **: P<0.01, *: P<0.05, ns: not significant.
[2] PAR: Parity, YOF: Year of farrowing, SOF: Season of farrowing, YxS: Interaction of the year with season of farrowing, LSF: Litter size at farrowing, AGE: Age of sow at first farrowing (days), LSBD: Litter size at birth of the litter into which the sow was born.

Table 8 **Least Squares Means and Standard Errors for Litter Size at Farrowing, Average Piglet Weight at Birth, and Litter Weight at 3 Weeks in Landrace Sows**

Class		Litter Size at Farrowing		Average Piglet Weight at Birth		Litter Weight at 3 weeks	
		N	piglets	N	kg	N	kg
Mean		1012	8.92±.111	1011	1.49±.010	950	40.04± .442
Parity	1	188	8.25±.200	188	1.48±.019	176	41.04± .813
	2	171	8.73±.206	171	1.49±.019	160	41.38± .834
	3	157	9.14±.214	156	1.51±.020	150	39.34± .860
	4	131	9.42±.228	131	1.49±.021	127	39.80± .916
	5	365	9.04±.163	365	1.47±.015	337	38.65± .655
Season of Farrowing							
Mid Dec-mid Mar		247	8.83±.181	247	1.49±.017	231	41.94± .724
Mid Mar-mid Jun		235	8.82±.212	235	1.52±.020	223	40.11± .841
Mid Jun-mid Sep		282	9.00±.155	281	1.50±.014	266	39.36± .621
Mid Sep-mid Dec		248	9.02±.303	248	1.45±.028	230	38.75±1.205
Year of Farrowing	75	26	9.18±.539	26	1.62±.050	26	44.83±2.122
	76	58	8.71±.349	58	1.56±.032	57	36.35±1.401
	77	69	9.22±.300	69	1.52±.028	66	40.55±1.203
	78	76	9.12±.284	75	1.58±.026	73	45.35±1.138
	79	117	9.43±.230	117	1.42±.021	111	38.48± .931
	80	137	8.83±.215	137	1.48±.020	131	41.49± .855
	81	143	8.59±.219	143	1.44±.020	133	40.86± .887
	82	141	9.23±.214	141	1.45±.020	136	40.12± .856
	83	155	8.60±.206	155	1.42±.019	140	35.64± .849
	84	90	8.25±.637	90	1.41±.059	77	36.76±2.524

Table 9 **Least Squares Means and Standard Errors for Litter Weight at Weaning and Average Piglet Weight at Weaning in Landrace Sows**

Class		Litter Weight at Weaning		Average Piglet Weight at Weaning	
		N	kg	N	kg
Mean		929	100.61±1.109	929	13.41±.115
Parity	1	173	96.86±2.040	173	12.94±.212
	2	159	104.86±2.078	159	13.57±.216
	3	144	100.01±2.176	144	13.62±.227
	4	125	102.22±2.301	125	13.44±.240
	5	328	99.10±1.648	328	13.50±.172
Season of Farrowing					
Mid Dec-mid Mar		227	102.63±1.858	227	13.77±.193
Mid Mar-mid Jun		218	104.99±2.096	218	13.94±.218
Mid Jun-mid Sep		258	96.31±1.559	258	13.08±.162
Mid Sep-mid Dec		226	98.51±3.007	226	12.86±.313
Year of Farrowing	75	26	122.54±5.265	26	15.08±.548
	76	53	105.98±3.729	53	14.75±.388
	77	65	113.41±2.999	65	14.69±.312
	78	72	105.66±2.841	72	14.12±.296
	79	107	104.11±2.354	107	14.18±.245
	80	127	108.21±2.153	127	13.93±.224
	81	131	101.63±2.229	131	13.67±.232
	82	136	85.78±2.123	136	11.85±.221
	83	138	71.27±2.131	138	10.42±.222
	84	74	87.50±6.275	74	11.45±.653

Table 10 **Least Squares Means and Standard Errors for Litter Size at Weaning and Farrowing Interval in Landrace Sows**

Class		Litter Size at Weaning N	piglets	Farrowing Interval N	days
Mean		936	7.61±.065	813	195.37±1.469
Parity	1	174	7.58±.121	168	208.67±2.768
	2	160	7.81±.123	154	190.97±2.876
	3	145	7.47±.129	130	189.32±3.134
	4	126	7.75±.136	110	194.28±3.425
	5	331	7.42±.097	251	193.58±2.464
Season of Farrowing					
mid Dec-mid Mar		229	7.59±.109	200	190.33±2.863
mid Mar-mid Jun		220	7.60±.125	188	202.35±3.246
mid Jun-mid Sep		260	7.41±.092	216	194.97±2.423
mid Sep-mid Dec		227	7.83±.178	209	193.82±3.011
Year of Farrowing	75	26	8.07±.313	25	190.93±7.471
	76	55	7.26±.211	52	201.73±5.193
	77	66	7.69±.178	63	209.89±4.403
	78	72	7.59±.169	66	189.16±4.219
	79	108	7.51±.139	89	199.36±3.602
	80	127	7.89±.128	108	190.46±3.337
	81	132	7.64±.132	128	190.36±3.228
	82	136	7.54±.126	126	194.61±3.080
	83	139	7.05±.126	156	191.79±2.917
	84	75	7.84±.373		

Table 11 **Least Squares Means and Standard Errors for Litter Size at Farrowing and Average Piglet Weight at Birth in Hampshire Sows**

Class		Litter Size at Farrowing N	piglets	Average Piglet Weight at Birth N	kg
Mean		125	7.01± .831	130	1.54±.03
Parity	1	25	6.35±1.057	25	1.41±.079
	2	22	7.39±1.004	24	1.54±.076
	3	20	6.60± .993	20	1.57±.078
	4	19	7.27± .997	20	1.62±.079
	5	39	7.45±1.030	41	1.55±.063
Season of Farrowing					
mid Dec-mid Mar		27	6.07± .972	29	1.59±.065
mid Mar-mid Jun		36	6.93± .971	38	1.60±.065
mid Jun-mid Sep		20	7.77± .986	21	1.49±.078
mid Sep-mid Dec		42	7.29± .935	42	1.48±.064
Year of Farrowing	76	7	6.41±1.714	8	1.64±.115
	77	12	7.91±1.463	12	1.60±.122
	78	23	8.18±1.191	24	1.54±.091
	79	33	8.33± .957	33	1.36±.056
	80	22	7.16±1.015	23	1.54±.074
	81	12	5.74±1.181	12	1.57±.100
	82	9	5.86±1.269	9	1.61±.109
	83	7	6.52±1.783	9	1.43±.131

Table 12 **Least Squares Means and Standard Errors for Average Piglet Weight at Birth, Litter Size at Farrowing, Litter Weight at 3 Weeks and Litter Size at Weaning in Large White Sows from Lanet.**

Class		Average Piglet Weight at Birth N	kg	Litter Size at Farrowing piglets	Litter Weight at 3 Weeks N	kg	Litter Size at Weaning N	piglets
Mean		232	1.45±.018	9.35±.215	225	37.28± .729	216	7.93±.152
Parity	1	42	1.42±.038	8.07±.457	41	35.76±1.570	37	7.69±.329
	2	39	1.47±.039	8.75±.470	38	38.65±1.602	35	8.04±.342
	3	32	1.44±.043	10.03±.518	31	39.79±1.787	30	8.33±.363
	4	29	1.47±.043	10.02±.522	27	36.55±1.813	26	7.95±.367
	5	90	1.47±.024	9.87±.291	88	35.67± .995	88	7.65±.201
Season of Farrowing								
mid Dec-mid Mar		48	1.37±.035	9.82±.427	48	38.82±1.419	46	7.89±.286
mid Mar-mid Jun		71	1.50±.026	9.41±.314	71	38.03±1.058	69	8.08±.215
mid Jun-mid Sep		42	1.50±.044	8.53±.539	40	35.28±1.796	38	7.78±.362
mid Sep-mid Dec		71	1.44±.029	9.63±.347	66	37.00±1.255	63	7.97±.287
Year of Farrowing	81	36	1.37±.064	10.32±.774	36	41.89±2.593	36	7.61±.517
	82	24	1.70±.048	10.13±.578	23	46.64±1.950	23	8.53±.389
	83	27	1.51±.059	8.39±.717	27	33.74±2.419	27	7.10±.483
	84	17	1.50±.051	8.60±.625	17	40.96±2.109	17	9.05±.421
	85	21	1.50±.052	9.63±.628	21	39.86±2.106	20	8.50±.423
	86	17	1.43±.054	9.38±.656	15	35.84±2.284	16	7.53±.445
	87	26	1.40±.042	9.46±.509	26	35.40±1.707	22	8.22±.380
	88	31	1.35±.037	8.47±.448	30	31.48±1.549	27	7.79±.329
	89	33	1.32±.041	9.75±.498	30	29.73±1.873	28	7.05±.474

Table 13 **Least Squares Means and Standard Errors for Litter Size at Farrowing and at Weaning in Large White Sows from Ngata**

Class		Litter Size at Farrowing N	piglets	Litter Size at Weaning N	piglets
Mean		272	10.29± .275	243	8.71±.143
Parity	1	60	8.85± .500	53	8.68±.273
	2	47	10.46± .563	46	8.85±.288
	3	44	11.72± .572	39	8.81±.306
	4	35	10.66± .615	31	8.72±.331
	5	86	9.76± .437	74	8.47±.240
Season of Farrowing					
mid Dec-mid Mar		43	10.45± .621	40	9.14±.319
mid Mar-mid Jun		80	9.98± .450	71	8.64±.233
mid Jun-mid Sep		62	10.83± .613	51	8.71±.346
mid Sep-mid Dec		87	9.89± .422	81	8.33±.221
Year of Farrowing	80	23	11.84±1.143	22	9.42±.586
	81	35	10.73± .754	34	9.16±.377
	82	44	10.29± .499	37	8.96±.275
	83	53	9.58± .475	52	8.36±.242
	84	50	10.61± .546	43	9.02±.287
	85	40	9.94± .542	32	8.55±.298
	86	15	8.50± .913	11	8.24±.567
	87	12	10.81± .973	12	7.94±.484

Table 14 **Least Squares Means and Standard Errors for Weaning Weight and Pre-weaning Average Daily Gain in Landrace and Large White Piglets from Lanet**

Class		N	Weaning Weight (kg)	Pre-weaning Average Daily Gain (kg/day)
Mean		2861	13.29±.076	.21±.001
Breed	L. White	2224	12.72±.074	.20±.001
	Landrace	637	13.87±.122	.22±.002
Parity	1	508	13.34±.144	.21±.002
	2	565	13.53±.133	.21±.002
	3	445	13.19±.144	.21±.002
	4	334	13.03±.159	.21±.003
	5	1009	13.38±.100	.21±.002
Sex	Entire Males	736	13.68±.113	.22±.002
	Castrates	715	13.07±.114	.21±.002
	Females	1410	13.13±.088	.21±.002
Season of Farrowing				
mid Dec-mid Mar		631	13.50±.130	.21±.002
mid Mar-mid Jun		795	12.88±.114	.20±.002
mid Jun-mid Sep		553	13.03±.130	.21±.002
mid Sep-mid Dec		882	13.76±.146	.22±.003
Year of Farrowing	80	479	16.10±.166	.26±.003
	81	194	13.48±.271	.21±.005
	82	293	13.77±.190	.22±.003
	83	382	14.33±.165	.23±.003
	84	301	15.04±.164	.24±.003
	85	335	13.95±.149	.22±.003
	86	156	12.46±.217	.20±.004
	87	259	11.64±.184	.18±.003
	88	233	10.39±.185	.16±.003
	89	229	11.77±.288	.19±.005

4.4 Heritability and Repeatability Estimates

Heritability and repeatability estimates and their standard errors are presented in Table 15. These estimates were generally low. Heritability estimates for litter size and average piglet weight were higher at farrowing than at weaning, but the estimate for litter weight was higher at weaning than at 3 weeks.

Repeatability estimates were lower than the corresponding heritability estimates. Repeatability estimate for litter size was higher at farrowing than at weaning. Estimates for average piglet weight did not change much between farrowing and weaning. The estimate for litter weight was higher at weaning than at 3 weeks.

4.5 Genetic and Phenotypic Correlations

Estimates of genetic and phenotypic correlations between the various traits are presented in Table 16. The results indicated moderate to high positive correlations between traits related to litter size and litter weights and between litter size at farrowing and at weaning. Positive genetic and phenotypic correlations between litter weight at 3 weeks and at weaning were obtained. The correlations between average piglet weight at birth and the other traits were negative, except for its correlation with average piglet weight at weaning.

Table 15 **Heritability and Repeatability Estimates**

Trait	Heritability	Repeatability
Litter size at farrowing	0.21+0.08	0.12±0.03
Litter size at weaning	0.15+0.08	0.06±0.03
Average piglet weight at birth	0.19+0.08	0.09±0.03
Average piglet weight at weaning	0.17+0.08	0.08±0.03
Litter weight at 3 weeks	0.13±0.07	0.05±0.03
Litter weight at weaning	0.23+0.09	0.08±0.03
Farrowing interval	0.43+0.12	0.13±0.03

Table 16 **Genetic[1] and Phenotypic Correlation Coefficients[2]**

Trait		(1)	(2)	(3)	(4)	(5)	(6)
Litter Size at Farrowing	(1)		-0.39	0.94	0.96	-0.15	0.96
			0.32	0.10	0.05	0.39	0.09
Average Piglet Weight at Birth	(2)	-0.39		-0.28	-0.54	1.00	-0.21
				0.29	0.26	0.33	0.26
Litter Weight at 3 Weeks	(3)	0.52	-0.07		0.96	0.43	1.00
					0.07	0.37	0.06
Litter Size at Weaning	(4)	0.74	-0.19	0.66		-0.22	0.96
						0.36	0.04
Average Piglet Weight at Weaning	(5)	-0.36	0.21	-0.03	-0.35		0.04
							0.33
Litter Weight at Weaning	(6)	0.50	-0.05	0.65	0.75	0.31	

[1] Standard errors are given below the correlation coefficients.

[2] Genetic correlations above diagonal
Phenotypic correlations below diagonal

5 DISCUSSION

5.1 Observed Means of the Traits Studied

Except for the average piglet weight at birth, the means of the other traits were generally lower than those reported in the literature. Rutledge (1980b) found that the mean piglet weight at birth ranged from 1.1±.05 to 1.3±.04 kg and age at first farrowing from 363±2 to 387±2 days. Morris (1975) also reported higher litter sizes at farrowing (10.70±2.62 and 10.09±2.55) and litter weights at 3 weeks (56.3±13.9 and 53.7±13.4 kg) in second parity sows of the Large White and the Landrace breeds respectively. However, litter sizes in the Large White sows obtained in this study were higher than the value of 8.8±.12 piglets at farrowing and 8.16±.11 piglets at weaning reported on the same breed by Sharma and Mishra (1989). Litter size at weaning in the Large White sows at Lanet was similar to the value of 8.6±2.5 piglets reported by Masembe (1985) from piggeries in and around Nairobi.

In a study on reproductive performance in large sow herds in Kenya, Spath (1970) reported a higher average piglet weight at weaning (17.1 kg) and a farrowing interval of 192.5 days but gave no standard errors. Litter weight at weaning in the Landrace sows was higher than the value of 88.77±1.20 kg reported by Sharma and Mishra (1989). Though the average daily gain obtained in this study was higher than the value of 0.19±0.003 kg/day reported by Miller *et al.* (1979), a higher growth rate would be desirable. An average piglet weight at weaning of 15 kg had been a target in these herds. With an average piglet weight at birth close to 1.5 kg, to attain this target weaning weight, growth rate should have been at about 0.241 kg per day.

The hypothesis has been proposed (Avalos and Smith, 1987; Rutledge, 1980a) that a maternal effect may exist such that females born or reared in larger litters than average would, as a consequence, produce smaller litters. However, the size of the litter at birth into which the sow was born had no significant effect on the size of her litter in the current study.

5.2 Effects of Environmental Factors

5.2.1 Year of Farrowing

There was a general decrease in average piglet weight at birth (Tables 8 and 12) and at weaning (Tables 9 and 14) in Landrace and Large White sows at Zea and Lanet. This occurred in the latter half of the period studied. The decrease in average piglet weight at weaning reflected low pre-weaning growth rates, which was confirmed by the decline in pre-weaning average daily gain in the herd at Lanet between 1984 and 1988 (Table 14).

The decrease in litter weight at 3 weeks in the herd at Lanet between 1984 and 1988 (Table 12) would partly be due to the decline in average piglet weight at birth and possibly a decrease in total milk production by the sow. The decrease in litter weight at weaning (Table 9) between 1980 and 1983 in Landrace sows from the Zea herd was partly due to the decline in average piglet weight at weaning. This could be due to poor lactational output of the dam, possibly resulting from inadequate feeding, either qualitatively or quantitatively. Inbreeding depression may also have contributed to the decline in average weights and growth rates. Though the breeding herds occasionally imported replacement stock, the units were quite small making it difficult to totally avoid mating related animals. This could have led to a depression in growth performance.

The average farrowing interval in the Landrace sows was generally longer than expected. The interval was longest in 1976 and 1977 (Table 10), but these were the years in which the records available were few. With weaning at 56 days and about a week's interval from weaning to re-mating, the target farrowing interval should be 177 days. Provision of adequate nutrition during the lactation and the service periods can help to approach the targeted farrowing interval. This would allow quick attainment of heat upon weaning the litter. With high pre-weaning growth rate, piglets could be weaned earlier and introduced to a starter diet.

Litter size at farrowing and average piglet weight at birth in Hampshire sows (Table 11) were rather erratic throughout the period of study. The least squares means for this breed had large standard errors because of the few number of records available for the analysis.

Prolificacy, as measured by litter size at farrowing was fairly constant over the years of study. Nutrition, herd monitoring and inbreeding depression (of both pre- and post-natal growth performance) were likely causes for the decrease in average weights and weight gain. Herd monitoring includes constant assessment of the herd fertility levels, care of the newborn litter and the overall management of the breeding stock. As Pathiraja (1986) noted, the plane of nutrition and management greatly influence the expression of the production potential of the pig genotype.

5.2.2 Season of Farrowing

Season of farrowing had no effect on litter size at farrowing and at weaning (Table 7). This could be possible if season of service did not affect ovulation rate. The non-significant influence of season on litter size at weaning suggested that this factor did not influence piglet survival from birth to weaning. These findings partly agreed with those of Alves *et al.* (1987) in which season of farrowing had a non-significant effect on litter size and average piglet weight at birth and at 21 days in Large White sows in Brazil.

Growth traits were, however, influenced by season of farrowing. At Lanet, piglets born during the cold season were disadvantaged in growth performance. At Zea, some of the heaviest litter weights and average piglet weight at weaning were observed in Landrace sows that farrowed during the hot season. This agreed with the work of Deo *et al.* (1981a) in which piglets born during the warm season had higher average weight at weaning than those born during the cold season. However, the results were different from the work of Rai and Desai (1985) in which average piglet weight at weaning did not vary with year or season of birth.

The effect of season can influence the performance of both the piglet and the dam. The season preceding farrowing can affect a sow's body condition by influencing feed utilization during the lactation period. Both the sow's body condition and feed utilization affect milk production and hence piglet growth rate. Effective protection and provision of warmth to the piglets and constant monitoring of the lactating sow are necessary for the attainment of high pre-weaning growth throughout the year.

Farrowing interval was longest in Landrace sows farrowing during the cold season (Table 10) but the number of records available in this season were few and so chance occurrence could not be completely ruled out. The shortest farrowing interval was observed in the sows farrowing during the cool season.

Further studies need to be carried out to evaluate the effect of season of service or of farrowing on other reproductive traits. Season of service may not affect litter size, but it may influence the proportion of sows and gilts showing oestrus, conception rates, or attainment of puberty. Paterson *et al.* (1989) reported that the level of boar stimulation required for rapid attainment of puberty was greatest in January (summer) and lowest in October (spring). In the current study, Landrace sows farrowing during the cool season were served between March and May, a period of rapidly decreasing temperatures. This season had the highest number of litters (282) (Table 8). Sows farrowing during the cold season were served between December and February, a hot period. This season had the lowest number of litters (235). Those farrowing during the warm and the hot seasons were served during cool to warm periods and the number of litters born in these two seasons were similar (247 and 248 respectively). Thus experiments to investigate the effects of season of service on the conception rates need to be conducted.

5.2.3 Parity

The increase in litter size at farrowing with parity up to about the third parity (Tables 12 and 13) agreed with the findings of French *et al.* (1979). Such an increase in litter size may arise from increased hormonal and uterine conditions for fertility and embryo survival with sow age. Another possible reason would be the effect of culling. The policy in these herds was to cull any sow that persistently produced small litters.

The results indicated that Large White sows apparently matured earlier and attained peak production earlier (third parity) than the Landrace sows. Whereas the maximum litter weight at three weeks in the Large White sows from Lanet occurred in the third parity (Table 12), the Landrace sows attained peak performance in this trait at the fourth parity (Tables 8 and 9). There was no evidence of differential selection pressures in the two breeds. Litter weights tended to decline after the fourth parity unlike the reports from temperate areas that sows maintain high performance up to the fifth or the sixth parity, and a slow decline thereafter (Mausolf and Horst, 1986a).

Average piglet weight at weaning did not vary with parity. This did not agree with the findings of Chhabra *et al.* (1989a) that older dams reared heavier piglets than gilts. Since sows used in this study first farrowed at late ages, they were likely to have attained full maturity at the time of first conception. There was therefore no significant increase in milk production with parity, and hence no significant differences in average weaning weight. Since average piglet weight at weaning in the Landrace sows was not affected by parity, the observed increase in litter weight at weaning (Table 9) between the first and the second parities was probably due to an increase in litter size between the two parities.

Farrowing interval was highest between the first and the second parities in the Landrace sows. This, coupled with the low litter size at first farrowing would mean that very high replacement rates might lower the herd average. Improvement of litter size and litter weight in the first parity could be effected partly by ensuring heavier body weights of gilts at first service.

5.2.4 Age at First Farrowing

Age at first farrowing in Landrace sows was high and quite varied indicating large differences in age at first conception. Studies in India by Chhabra *et al.* (1989b) showed a mean age at first conception in gilts of 255.81±4.60 days, while most studies have recommended an age at first farrowing of about 321-354 days. If the random sample of the starter diet (see Materials and Methods) is taken to be a representative of the starter feed used in these herds, then the low crude protein content may have contributed to the slow growth of the gilts and hence late attainment of puberty. Age at first farrowing can partly be reduced by provision of high crude protein feeds, among other ingredients, to facilitate fast pre- and post-weaning growth to age at first service.

5.2.5 Sex of the Piglet

The results obtained in the present study were in agreement with the findings of Kuhlers *et al.* (1980) who reported higher pre-weaning weights in entire males than in females. Sidor and Jedlika (1972) also reported significant differences in daily gain between sexes. However, Gipp *et al.* (1969) observed non-significant sex differences in average daily weight gain while Deo *et al.* (1981b) reported higher average piglet weight at weaning in the females than in the entire males.

5.3 Effects of Genetic Factors

5.3.1 Breed

Results of this study generally agreed with those of Deo *et al.* (1981a) in which Landrace piglets grew faster than the Large White piglets. The fast growth rate in the Landrace piglets may imply that Landrace sows produced smaller litters than the Large White sows leading to less intra-litter competition in the former. However, this was not statistically tested. Alternatively Landrace piglets might have been genetically superior to the Large White piglets in growth rate or there might have been breed differences in milk production by the dams.

Results of the litter size at farrowing were in agreement with the work of Yen *et al.* (1987) who reported larger litters in Large White sows than in Landrace and

Hampshire sows. It appears that Large White sows would be suitable for the maximization of the number of pigs weaned per sow per year. One way of improving the growth rate of their piglets would be to cross them with Landrace boars. The early decline in litter weights in the Large White sows may indicate differences in the productive adaptability of the two breeds to the prevailing conditions.

5.3.2 **Heritability Estimates**

The heritability estimates obtained in this study were generally low, but within the range of values reported in the literature. Heritability estimates for litter size at farrowing given in literature are quite varied. The estimate obtained in this study was not high enough to permit effective selection for litter size. The lower heritability estimate for litter weight at 3 weeks compared that for litter weight at weaning was an indication of high maternal influence early in the life of the piglets. Litter weight at 8 weeks can be considered as a crude index combining prolificacy, mothering ability, piglet viability and pre-weaning growth. The heritability estimate for this trait was slightly higher than the estimates for its two major components (litter size at weaning and average piglet weight at weaning). The decline in heritability estimates for litter size and average weight from birth to weaning was in line with the findings of Vangen (1980). Heritability estimate for farrowing interval was slightly higher than those for the other traits, but this may not justify selection for this trait. This is because the lactation length, which is a major determinant of the farrowing interval, mainly depends on management policies.

In view of the low heritability estimates for litter traits obtained in this study, it seems that only limited selection effort for litter size and average piglet weight can be justified. Secondly, since litter size and average piglet weight tend to be negatively correlated, there is the danger that selection for large litters is likely to lower average weights. High litter weight at weaning would be a good selection criterion as it combines both prolificacy and pre-weaning growth. To increase the accuracy of selection, information on the sow and that of her relatives as well as those of her sire need to be used. As the herd size increases, substantial genetic gains are likely to be realized. Thereafter, moderate selection pressure on reproductive traits may be necessary to maintain the established levels of performance.

To maximise the overall economic gains, it is necessary to include reproductive traits in selection schemes together with the more heritable post-weaning growth and carcass traits. Contribution from the reproductive traits may be small but the unit cost of the overall improvement may be lowered.

5.3.3 Repeatability Estimates

The repeatability estimates for litter traits obtained were generally low, especially those for average piglet weight at birth and at weaning, litter weight at three weeks and at weaning. King and Gajic (1969) reported repeatability estimates of 0.24±0.08, 0.45±0.07, 0.05±0.09, 0.15±0.08 and 0.18±0.08 for litter size at farrowing, average piglet weight at birth, litter size at weaning, litter weight at weaning and average piglet weight at weaning respectively.

The low repeatability for litter performance traits raises the question of whether culling of sows on the basis of litter size is worthwhile. However, if the culling is based on the mean of several records, the accuracy of culling could be increased, but the improvement in the herd mean performance may be small. This is because the repeatability of litter size is low and, since gilt litters are smaller than sow litters, the increased proportion of gilts replacement required at higher culling levels is likely to depress the herd's mean litter size. Despite the small expected annual change, the accumulated change over a few generations might be substantial. Culling will also help to maintain acceptable average litter size in the herd over generations. Sows could also be culled based on their average litter weight at weaning.

Repeatability estimates were lower than the corresponding heritability estimates. One possible reason for this was the fact that sires came from different sources. They were therefore of different genetic backgrounds. Those imported came from different countries and/or herds while majority of those locally raised came from herds other than the one their performance was studied in. Most of the sows were used in the herds where they were raised and thus had a common environment. This would have the effect of raising the sire variance much higher than the sow variance and since heritabilities were estimated from the paternal half-sib method, heritability estimates exceeded the repeatability estimates.

5.3.4 Genetic and Phenotypic Correlations

Correlation coefficients obtained in this study (Table 16) were similar to those reported by Strang and King (1970). Genetic correlation coefficient between average piglet weight at birth and at weaning was high and positive and was consistent with the estimate reported by Bereskin (1984). But the corresponding phenotypic correlation coefficient was low meaning that the observed weight of a piglet at birth may not be a good indicator of its pre-weaning growth performance and hence its expected weight at weaning. This implies that although a piglet may be genetically superior in growth rate, the milk output of the dam may be a limiting factor, particularly in large litters.

The phenotypic correlation coefficient between litter size at farrowing and at weaning was high and positive suggesting that the size of a litter at farrowing would be a good predictor of the expected size of the litter at weaning. The corresponding genetic correlation coefficient was also high and positive. The negative phenotypic correlation coefficient between litter size at farrowing and average piglet weight at birth could mainly be due to sharing limited uterine space and nutrients. The negative genetic correlation coefficient between the two traits was in agreement with the findings of Pop *et al.* (1988) and suggested that prolificacy and early growth in pigs may be under the influence of genes with antagonistic effects to some extent. After birth, intra-litter competition in large litters leads to nutritional stress of the piglets which leads to the negative phenotypic correlation between litter size and pre-weaning average daily gain. This eventually results in the negative phenotypic correlation between litter size and average piglet weight at weaning. These relationships make it difficult to improve both litter size and average piglet weight simultaneously. Using litter weight at weaning as a selection criterion provides a way of striking a balance between litter size and average piglet weight. The high positive genetic correlation coefficient between litter weight at 3 weeks and at weaning indicated that, under similar conditions of environment, litter weight at weaning may be improved through direct selection for litter weight at 3 weeks.

Knowledge of the relationships between the various reproductive and growth traits is necessary for the construction of selection indices for use in multiple trait selection programmes. Further information on how reproductive traits and pre-weaning growth are related to the more heritable traits such as carcass traits is necessary in assessing the expected market quality of the pig meat.

6 CONCLUSIONS

Data sets from three large scale pig herds in Kenya were used to evaluate mean performance levels and the effects of genetic and environmental factors on sow and piglet performance. This was done in view of possible implications to the on-going and future breeding and management strategies. Reproductive and pre-weaning growth performance records on Landrace, Large White and Hampshire pigs covering a period of 15 years (1975-89) were analysed. The following conclusions were made from the study:

1 Heritability and repeatability estimates for reproductive traits in pigs are generally low. However, these traits are worth including in selection objectives alongside growth and carcass traits. Moderate selection and culling levels are necessary to prevent decline in performance over time.

2 Except for average piglet weight at birth, mean reproductive and pre-weaning growth performance levels were lower than most of the values reported in the literature on the same breeds under similar environments.

3 Growth performance declined in the latter years of study. Nutrition, herd monitoring and inbreeding depression were considered the most likely reasons.

4 Piglets born during the cold season were disadvantaged in pre-weaning growth performance and subsequently were lighter at weaning than those born during the rest of the year.

5 Litter weight at weaning can be a good selection criterion as it combines both prolificacy and mothering ability.

6 Selection for heavy litter weight at 3 weeks would be expected to lead to heavy litters at weaning.

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8 APPENDICES

A1 Analysis of Variance for Litter Size and Average Piglet Weight at Birth in Landrace and Hampshire Sows

Source	Landrace df	Landrace Litter Size at Birth (piglets)	Landrace Average Piglet Weight at Birth (kg)	Hampshire df	Hampshire Litter Size at Birth (piglets)	Hampshire Average Piglet Weight at Birth (kg)
Parity	4	28.16**	.05	4	1.72	.09
Year	9	10.20	.30**	7	5.19	.10
Season	3	1.71	.08	3	13.64	.02
Year*Season	27	6.92	.13**	21	3.58	.15*
REGRESSIONS						
Litter Size	1		7.18**	1		.82**
Age	1	116.00**			8.95	
LitSizDam[1]	1	3.63				
Error		5.79 (966)	.05 (966)		6.94 (94)	.08 (93)

** P<0.01, * P<0.05, df for error in brackets.
[1] LitSizDam refers to the size of the litter (at birth) into which the sow was born.

A2 Analysis of Variance for Average Piglet Weight at Weaning, Litter Size at Weaning and Litter Weight at 3 Weeks in Landrace Sows

Source	df	Mean Squares: Average Piglet Weight at Weaning (kg)	Litter Size at Weaning (piglets)	Litter Weight at 3 Weeks (kg)
Parity	4	10.75	4.90*	234.69*
Year	9	191.76**	6.49**	708.08**
Season	3	32.71**	3.33	273.11*
Year*Season	27	34.44**	3.08*	257.87**
REGRESSION				
Litter Size	1	786.45**	2099.44**	29257.37**
Error		5.98 (884)	1.96 (891)	87.80 (905)

** P<0.01, * P<0.05, df for error in brackets.

A3 Analysis of Variance for Litter Weight at Weaning and Farrowing Interval in Landrace Sows

Source	df	Litter Weight at Weaning (kg)	df	Farrowing Interval (days)
	Mean Squares			
Parity	4	1398.65*	4	8311.33**
Year	9	17225.97**	8	2988.27**
Season	3	2499.82**	3	2902.06*
Year*Season	27	2553.29**	24	2544.75**
REGRESSION				
Litter Size	1	160559.42**		
Error	884	552.15	773	1094.11

** P<0.01, * P<0.05,

A4 Analysis of Variance for Litter Size at Farrowing and at Weaning in Large White Sows from Ngata

Source	df	Litter Size at Farrowing (piglets)	Litter Size at Weaning (piglets)
	Mean Squares		
Parity	4	45.22**	0.99
Year	7	13.22	3.78
Season	3	6.99	3.95
Year*Season	21	5.07	3.59
REGRESSIONS			
Litter Size	1		1046.68**
Age	1	.56	
Error		10.49 (235)	539.60 (206)

** P<0.01, * P<0.05, df for error in brackets.

A5 **Analysis of Variance for Litter Size at Farrowing and at Weaning, Average Piglet Weight at Birth and Litter Weight at 3 Weeks in Large White Sows from Lanet**

Source	df	Mean Squares: Litter Size at Farrowing (piglets)	Average Piglet Weight at Birth (kg)	Litter Weight at 3 Weeks (kg)	Litter Size at Weaning (piglets)
Parity	4	26.40**	0.05	115.68	2.60
Year	8	8.49	0.28**	535.67**	6.39*
Season	3	7.89	0.10*	63.70	.54
Year*Season	24	7.28	0.04	120.05*	4.07
REGRESSIONS					
Age	1	58.41**			
Litter Size	1		0.84**	5794.46**	401.99**
Error	(191)	5.84	0.04	65.44 (184)	2.60

** $P<0.01$, * $P<0.05$, df for error in brackets.

A6 **Analysis of Variance for Weaning Weight (kg) and Average Daily Gain for Large White and Landrace Piglets from Lanet**

Source	df	Mean Squares: Average Weaning Weight (kg)	Pre-Weaning Average Daily Gain (kg/day)
Breed	1	476.45**	.13**
Parity	4	13.29	.00
Sex	2	81.50**	.02**
Year	9	587.66**	.17**
Season	3	74.38**	.03**
Year*Season	26	41.28**	.01**
REGRESSION			
Litter Size	1	1192.61**	.33**
Error	2814	6.59	.00

** $P<0.01$, * $P<0.05$