A STUDY OF FACTORS AFFECTING PREWEANING TRAITS IN INBRED AND LINECROSS SWINE

by

Gerald Joseph More O'Ferrall

Thesis submitted to the Graduate Faculty of the

Virginia Polytechnic Institute

in candidacy for the degree of

MASTER OF SCIENCE

in

Animal Science

(Animal Breeding)

APPROVED: ______________________
Chairman

____

____

____

February, 1966

Blacksburg, Virginia

TABLE OF CONTENTS

INTRODUCTION

Inbreeding has been practiced by numerous livestock breeders for a great many years, more particularly since the phenomenal success of breeders with hybrid corn in the early 1930's. Many breeders in earlier times practiced inbreeding merely because it was convenient, while others did it deliberately, but whatever their objective the majority of breeders undoubtedly observed degeneration in certain traits, particularly in those related to reproductive fitness.

The use of inbreeding, however, was an essential element in the success of the noted breeders, who laid the foundations of the modern pure breeds of livestock. For example, Robert Bakewell in the mid 18th century in England practiced inbreeding in his cattle and sheep with great success. He followed the axiom 'like begets like' by breeding some of his better animals to their close relatives in order to fix their type.

It was only in the early part of the present century after the rediscovery of Mendel's work that researchers began to understand what was happening genetically and why degeneration occurred in reproductive fitness. It became clear that unobserved recessive characters are carried by many animals and plants and that these became important only when homozygous. The chances of being homozygous for the same hidden recessive genes are greater in related than in unrelated animals and these recessives are often lacking in vigor and consequently are deleterious.

The experiments of Shull and East with corn added considerably to our knowledge of heredity as well as of inbreeding. Shull (1911) found that on self fertilization, a seemingly homogeneous variety of corn broke into strains each highly uniform and differentiated from the others in numerous minute characteristics. He also noticed a decline in size and productivity in all strains in the earlier generations of selfing, but stability was soon reached. On crossing these strains there was, in general, a return to the original vigor. East (1909) working independently came to more or less the same conclusions.

The earlier experiments on inbreeding in animals generally showed the same results as found in corn; some of the lines or families soon died out while others suffered little if any decline in vigor. Although in general there is degeneration in reproductive traits, notably size and frequency of litters, compared with control stock, on crossing the inbred lines or families a marked improvement over the parental stocks was observed.

These experiments with rats and guinea pigs gave encouragement to pig breeders to practice inbreeding and to use the resulting inbred lines in different crosses in an attempt to develop outstanding new breeds and at the same time to study and develop new and more effective systems of breeding. While the inbred lines were being established by experiment stations, commercial pig producers were realizing more and more the value of crossbreeding.

The first experimental use of crosses among pure breeds was confined to a comparison of first crosses with their purebred parental breeds and the results generally showed an advantage in performance of the crossbred litters. It was soon realized, however, from later results that better returns would be obtained when the hybrid vigor of the sow herself was utilized to provide a more favorable intra-uterine environment from conception to farrowing, which would give larger numbers of live pigs farrowed, and also greater milk production from the sow.

Different systems of crossbreeding (rotational crossing and criss-crossing) were established and used by commercial pig producers to such an extent that it has recently been estimated that over 85 percent of the pigs marketed commercially in the U.S. are crossbred. In Great Britain, where no such definite pattern of crossbreeding has been established, over 60 percent of the litters produced annually are crossbred and some 70 percent of these crossbred litters are from crossbred sows. Thus there is little doubt that the commercial pig producer has not been slow in realizing the value of crossbreeding.

The present study is of data collected by the U.S. Department of Agriculture over four years (1950-53), in which seven inbred lines were maintained and at the same time crossed with sires of four pure breeds to give linecross litters. The aim of the study is to determine the differences between the inbred and linecross litters in litter size and litter weight at birth, 21 and 56 days of age and the effect of line of dam, year of birth and age of dam on each of these traits.

REVIEW OF LITERATURE

A. Effect of Inbreeding on Litter Traits

Inbreeding has been shown to have most deleterious effects on traits which show relatively little additive genetic variation, but in which the genotypic variation shows mostly dominance and epistatis. Traits concerned with reproductive fitness mainly fall under this category. Conversely it is mainly these traits, showing dominance and epistatic variation, that exhibit heterosis on the crossing of two unrelated or genetically different lines or breeds.

Although inbreeding mainly affects reproductive traits, litter size at birth, viability of individuals in the litter and consequently litter size weaned, King (1918 a, b) found no such effect on litter size in albino rats. These rats were derived from an original pair mating in 1909 and two strains A and B were derived from two male and two female progeny of this mating. The strains were brother x sister mated for 25 generations and by practicing careful selection of breeding stock she observed no decline in litter size; in fact her inbred strains had a slightly larger litter size than the laboratory control stock. In addition the growth and body weight of these rats was unaffected, as was the age at first mating, by the inbreeding.

Wright (1922) reporting on an inbreeding experiment with guinea pigs found that some inbred families, brother x sister mated for 20 generations, maintained litter size and general vigor, in spite of the inbreeding. On average, however, a decline in all elements of reproductive fitness was noted when compared to outbred lines.

Stewart (1945), in a study of factors affecting prolificacy in pigs, found that litter size decreased with an increase in the inbreeding of the dam but was apparently unaffected by the inbreeding of the litter. An increase of 10% in the inbreeding of dams of the same age resulted in a decrease of about 0.6 pigs per litter. These latter did not agree with the earlier findings of Hetzer, Lambert and Zeller (1940) who concluded that inbreeding had no apparent effect on the reproductive capacity of either boars or sows and that it was primarily the inbreeding of the litter that affected litter size. However, as Stewart pointed out, in Hetzer's work sows of all ages contributed to the mean litter size and as no correction was made for the effect of age differences in sows, the effects of inbreeding were confounded with the effects of these age differences. Stewart reported that age of dam at farrowing was a most important factor in determining sow performance, though the effect of age on litter size at first farrowing was much greater during the period prior to twelve months than afterwards. Gilts farrowing at 320 days averaged one pig less per litter and those farrowing at 410 days one-half pig more than those which farrowed at one year old.

Dickerson, Lush and Culbertson (1946), in order to measure the effect of inbreeding of the pigs on their performance, made an intra-sire comparison of 56 inbred and 60 single cross litters between inbred Poland China lines. The inbreeding of the litters averaged 42 percent and 6 percent and inbreeding of the dams 34 percent and 28 percent for inbreds and linecrosses, respectively. The comparison was made on litter size, litter weight and individual pig weight at four different ages

(0, 21, 56 and 154 days), the data having been adjusted for age and inbreeding of dam. In litter size the crosses surpassed the inbreds by 0.9, 1.3, 1.3 and 1.4 pigs at each of the four ages, giving a decline per 10 percent increase in inbreeding of the litter of 0.26, 0.35, 0.37 and 0.39 pig, respectively. The linecross litters were 3.1, 16.0, 55.0 and 290.0 pounds heavier at each of the four ages, giving a decline of 0.9, 4.0, 15.0 and 79.0 pounds per 10 percent increase in inbreeding of litter. The crosses likewise were superior by 0.08, 0.2, 3.4 and 25 pounds in individual pig weight. These workers concluded that in the development of inbred lines more careful selection is necessary for litter size and viability than for rate of gain. The performance of the single crosses, out of dams 28 percent inbred, averaged the same as published data for outbred Poland Chinas, which they interpreted as suggesting that the selection practiced in the development of the lines had effected considerable improvement.

Blunn and Baker (1949), from data on 3 groups of inbred lines, studied the effect of inbreeding of dam, inbreeding of litter and age of sow on factors affecting sow performance in 561 litters. The percentage inbreeding varied greatly between and within lines being from 0-49 percent for the dams and 1-54 percent for litters. All simple regressions of the production factors, (number farrowed, number born alive, litter size at 21, 56 and 168 days and litter weight at 56 and 168 days) on inbreeding of dam, inbreeding of litter and age of sow, were highly significant.

The inbreeding of dam and litter, while not too important in determining the size of the litter raised, exerted more influence on litter weight. Age of sow was the most important factor in determining the size of the litter farrowed and number of pigs born alive. It was still more important in determining the number of pigs alive at 168 days than was either of the other two factors.

Winters, Jordan, Hodgson, Kiser and Green (1944) presented a preliminary report on the performance of inbred line crosses both within and between breeds. There were seven lines within the Poland China breed as well as one line from each of three other breeds. They found support for the genetic theory that increased vigor followed the crossing of inbred lines. The increase in vigor was in close relation to the decrease in coefficient of inbreeding of the crossbreds. Line crosses between breeds gave a greater increase in vigor than line crosses within the Poland China breed. The genetic diversity of parental stocks was an important factor affecting the amount of increased vigor, while superior lines appeared to produce superior offspring.

Henderson (1948) in studying results of single crosses of 12 inbred lines of Poland China swine found no differences in litter characteristics either for sex linked effects, or for maternal differences between lines. Differences among lines in their general combining abilities were small but positive and accounted for no more than 5 percent of the variability in any of the lines. Specific effects on the other hand accounted for from 5 to 15 percent of the variation, which was surprising as all the lines were related and came from the same breed.

The least squares estimates of inbreeding and age of dam effects, corrected for other effects, showed that litter size at birth generally decreased with an increase in inbreeding class of dam except for the 35-40 percent inbred group which had almost the same litter size as the lowest (15-25 percent) inbred group. However, in litter size at 21 and 56 days and in litter weight at 56 days there was a decrease with each increase in inbreeding group of dam. The estimates of age effects showed large differences due to gilts being less than or greater than 12 months at farrowing (4.9 vs. 6.3 pigs), while differences between gilts greater than 12 months and second or later litters were not so large (6.3 vs. 6.9). Likewise there was better survival in litters from second and later litter sows than from gilts, while the survival from an increase in inbreeding class of dam in general decreased with inbreeding, although that from the highest inbred group (·50 percent) was greater than the lowest (15-25 percent) group. This was probably due to the considerably smaller litter size at birth in the former group (4.5 vs. 6.9 pigs).

Hetzer, Hankins and Zeller (1951) in a study of single crosses, between the same inbred lines as were used in the present study, compared them with their parental lines to determine the effect of crossing. Comparing 35 inbred and 184 single cross litters they found that, when adjusted for age and inbreeding of dam, crosses exceeded inbreds by 1.2 (14%), 1.7 (27%) and 1.7 (29%) pigs per litter at birth, 21 and 56 days, respectively. Individual pig weights were also heavier in the crosses by 3 percent and 10 percent at 21 and 56 days. Thus the linecross litters showed a greater advantage in litter size and viability than in growth rate. They also observed that the lower the relationship between the inbreds, the higher was the performance of the crosses.

Chambers and Whatley (1951) studied heterosis in linecross litters of seven inbred lines of Duroc swine. Inbred and two-line-cross litters were produced regularly during the course of the study and in some years three-line-cross and outbred litters were farrowed to give more comparisons. The data, corrected to gilt equivalent age, showed that hybrid vigor was evident both in number of pigs per litter and litter weight at birth and increased as litters became less dependent on the direct mothering ability of dams. This vigor was expressed, to a greater extent, in the increased viability of the pigs and productivity of two line cross gilts, than in the increased growth rate of the individual pigs. The authors concluded that, because heterosis is expressed in both the number of pigs which survive and in growth rate, total weight of the litter seems to be one of the best overall measures of performance.

The effect of inbreeding, age and growth rate of sows on sexual maturity, rate of ovulation, fertilization and embryonic survival in 3 inbred (2 Poland China and 1 Hampshire) and 1 non-inbred (Duroc) line and in the six crosses between them was studied by Squiers, Dickerson and Mayer (1952) at Columbia, Missouri. A total of 278 gilts and 72 sows were studied in four seasons and their findings were as follows: 1) Crossbred females were bred on average 30.25 days earlier than their inbred dams. This represented an average 12.7 days delay in mating for each 10 percent increase in inbreeding. 2) Gilts ovulated an average 11.44 ova vs. 15.36 for sows and the crossbreds ovulated a highly significant 1.19 ova more than their inbred parents or a reduction of .55 ova for a 10 percent increase in inbreeding. 3) With respect to number of embryos present at 25 days gestation, gilts had a mean number of 7.27 and the sows 9.94 embryos. The crossbreds had a significantly greater number of embryos (1.85), which represented a decrease of 0.8 embryo per 10 percent increase in inbreeding. 4) Mortality to 25 days gestation, which was taken as the difference between the number of normal embryos recovered and the number of corpora lutea, amounted to about 35 percent, while on average a further 11 percent was lost between 25 days and birth. Crossbreds lost 0.81 fewer embryo than their inbred parents and this difference was highly significant. This represented an increase of .33 embryo lost for a 10 percent increase in inbreeding.

Rempel and Winters (1952) studied selection for factors of performance in inbred lines of Poland China pigs. The performance traits studied were number of live pigs farrowed, number of pigs weaned, conformation score, feed per 100 pounds gain, 154 day weight and average daily gain from 56 to 154 days. They found that theoretical and actual rates of change were in good agreement both as to direction and magnitude of change. Thus by means of selection, based on rigid performance testing, the performance of the pigs in these inbred lines had been fairly well maintained.

In a study of selection for fertility in the Minnesota No. 1 and No. 2 breeds, Fine and Winters (1952) compared the theoretical and the actual rates of change as determined by the regression of the trait on a time scale in years. In the Minnesota No. 1 breed the actual and predicted rates were in close agreement, but in the Minnesota No. 2 there was only agreement as to the direction of change.

Bradford, Chapman and Grummer (1958) studied the effects of inbreeding and the amount and effectiveness of selection practiced in the development of 5 inbred lines at Wisconsin. They found that the inbreeding of the litter was more important than inbreeding of dam. For an increase of 10 percent in inbreeding of the litter there was a decrease of approximately .20 pig farrowed and .45 pig weaned per litter; likewise there was a decrease of 6 pounds in individual pig weight and 75 pounds in total litter weight at 5 months. The corresponding decreases for 10 percent increase in inbreeding of dam were 0 and .10 pig and 1.5 pounds and 20 pounds, respectively. The selection practiced for performance traits within the lines during their development was apparently ineffective, even after adjustment for the estimated inbreeding effect. Dickerson and other project leaders of the Swine Breeding Research Laboratory (1954) in a similar study of the evaluation of selection in developing inbred lines likewise found that selection was ineffective for different production traits. The traits studied included sow performance as measured by the size of litters farrowed and weaned and the average weaning weight per pig in the litter; the growth rate of pigs was measured by their weights at 56 and 154 days of age.

Cobb (1958) used boars from the same inbred lines used in the present study, as topcross sires on purebred gilts of four pure breeds (Hampshire, Berkshire, Chester White and Poland China) for on farm tests in Pennsylvania. He found no differences between the topcross and purebred litters for number farrowed or weaned; the topcross litters, however, averaged 25.6 pounds heavier at weaning which was highly significant. He also found significant differences in favor of the topcrosses for individual pig weight at 140 days and for average daily gain from weaning to slaughter. Breed differences between the pure breeds were significant for number weaned and for weaning weight of litter independent of number farrowed.

Using some of the topcross gilts as dams in a later year Cobb compared purebred, backcross and three strain cross litters. There were highly significant differences between mating systems for number farrowed, number weaned, weaning weight of litter, 140 day weight and average daily gain. The purebred, backcross and three strain cross litters had 7.6, 10.0 and 9.5 pigs, respectively at birth and 5.3, 8.0 and 7.8 pigs at weaning. The weaning weights of the litters averaged 118, 239 and 226 pounds, respectively. The superior performance of the backcross and three strain cross litters was considered evidence of hybrid vigor in the top cross females.

Hetzer, Comstock, Zeller, Hiner and Harvey (1961) in 218 litters, which were crosses among the inbred lines represented in the present study, studied the general and specific combining abilities and maternal effects of the six lines. The characteristics studied included litter size, litter weight and individual pig weight at birth, 21 and 56 days of age. Age of dam effects were highly significant for all litter and pig traits. The effect of age of dam was most pronounced in sows farrowing their first litters at approximately one year of age. Gilts farrowing between 10-11.5 months had an average 1.03 pigs less at birth and 0.93 pig less at weaning than did gilts between 11.6-13.5 months. Litter size continued to increase with age of dam up to approximately 2 1/2 years. Sows in this age group produced litters that had 0.71, 1.03 and 1.15 more pigs at birth, 21 and 56 days than litters from 1 1/2 year old sows.

None of the regression coefficients of the litter and pig traits on inbreeding of dams or of litters was significant, although regression of litter weight at weaning on inbreeding of dam approached significance at the 5% level. Inbreeding of dam had more effect on litter and pig traits at birth, while inbreeding of the litter had equal or greater effect at 21 and 56 days on these traits. Line differences in maternal effects were significant or approached significance only for litter weight at birth and litter and pig weight at 56 days. The differences between the best and poorest lines averaged 2.05, 1.55 and 1.53 pigs for number at birth, 21 and 56 days, respectively, while the corresponding differences in litter weight were 5.1, 13.4 and 48.9 pounds.

The only trait showing significance for general combining ability was litter weight at weaning, while litter weight at birth and 21 days bordered on significance. All the F-ratios except that for litter size at birth were greater than 1, which would seem to indicate that some of the variation in these traits is due to additive genetic effects. Specific combining effects were not significant for any traits and in fact only the F ratio for litter size at 21 and 56 days exceeded 1. The authors attribute the apparent inconsistency between this and the apparent heterotic effects obtained among crosses, as being due to insufficient numbers.

In a study of pre-weaning productivity traits in an inbred line of Poland Chinas, Noland, Gifford and Brown (1964) used data from 413 litters farrowed over a 22-year period. Inbreeding increased gradually from an average of 29 percent in 1944 to 66 percent in 1960 or averaged 2 percent per year. They found that inbreeding of dam had a significant effect on individual birth weight and total number of live pigs farrowed and was more important than inbreeding of litter in litter size at birth, number of live pigs at birth, litter size at weaning and litter weaning weight. Inbreeding of the litter had a significant effect on individual birth and weaning weights and had a greater effect on these two traits and on litter birth weight than did inbreeding of dam. It was interesting to note that the more highly inbred sows farrowed more pigs per litter than sows with low inbreeding, but as inbreeding increased there was a reduction in the number of pigs alive at birth and weaning; thus livability was the limiting factor in this line.

B. Effects of Crossing Pure Breeds

In one of the earliest reported studies of crossbreeding in pigs Winters, Kiser, Jordan and Peters (1935) showed the superiority of first cross and backcross pigs, which were similar in performance, over purebreds. Three breed cross pigs, on the other hand, were superior to the other crosses. They also showed that crossbred sows were superior to purebreds for producing market pigs and that the resulting pigs benefitted as much, if not more so, from being out of crossbred sows as being crossbred themselves.

Lush, Shearer and Culbertson (1939) using several different breeds also showed the superiority of crossbreeding. There were fewer stillbirths, pigs showed more vigor at birth and more survived to weaning than in purebreds, and crossbreds weighed heavier at weaning. They also found that breeds differ in their response to crossing. They pointed out that successful crossbreeding can be continued only by going to pure bred herds for boar replacements, as crossbreds have a lower value than purebreds as transmitters of inheritance.

In a review of the literature published up to that time, Carroll and Roberts (1942) questioned the advantages attributed to crossbreeding in pigs. However their definition of heterosis was that the crossbred performance should be greater than the performance of the better of the two parental strains of purebreds for the trait being studied, rather than the more commonly accepted mid-parent value. The main disadvantage here is that the same purebred is very often not superior in all traits being studied, e.g. litter size at birth and individual pig weights, so that the mid-parent value is better for comparison. Of the six traits for which data was reviewed, the crossbreds, under their definition, excelled only in their ability to make more rapid growth gains; they were intermediate (generally above mid-parent) for number of pigs farrowed, weight of pigs at birth, weight of pigs at weaning and ability to make more economical growth gains, while they were poorer than either pure breed with respect to vigor and survival of pigs.

Robison (1948) in a study on crossbreeding for the production of market pigs compared the number of pigs farrowed and weaned, feed efficiency and average daily gain in purebred Durocs and different types of crossbreds--first cross, backcross, three breed and rotational crosses. The purebreds farrowed more pigs but had fewer at weaning than the backcross or three breed cross, while rotationally crossed sows had only 16% mortality from birth to weaning. The crossbreds had heavier litters at weaning and reached 220 pounds from 3 to 13 days earlier than purebreds and in addition they required less food per pound of gain. As a result of this study he suggested rotating purebred sires of three or more breeds on successive generations of sows until some better plan was evolved. He goes on to point out that any merit crossbreeding might have is as a result of the pure breeding that preceeded it. For any improvements that are made and held in the inheritance of pigs, the producers of crossbreds must depend on the breeders of purebred and of inbred lines.

In a study of reciprocal crosses of Landrace x Poland China pigs, Gaines (1957) found that breed of sow had a significant effect in favor of the Landrace. In a three breed cross, breed of sire used had a significant effect when comparing Duroc and Chester White males on Poland x Landrace and Landrace x Poland sows. Chester Whites sired litters half a pig larger at birth which was significant, but by the time of weaning there was a quarter pig difference in favor of Duroc sired litters. Results of comparing Poland x Landrace and Landrace x Poland sows showed no significant difference thus indicating there was no maternal effect due to the way in which the two breeds were originally crossed. Furthermore, with increased crossbreeding of the sow a greater increase in litter size was obtained, from 9.9 pigs for a two breed cross to 10.7 for a four breed cross. Gaines, Thomas, Carter and Kincaid (1958) also found that crossbreds exceeded purebreds in number born alive by 0.2 pig and number weaned by 1.6 pigs, while crossbred pigs were on average 4 pounds heavier at weaning. These results also indicated the greater livability of the crossbred pigs.

Reddy, Lasley and Mayer (1958) noticed distinct variations in ovulation rate, prenatal mortality, litter size and uterine capacity between breeds and between families within breeds suggesting that the physiological components of fertility were greatly influenced by the genetic makeup of the animal. The boar had no influence on the performance of gilts mated to him. Landrace x Poland gilts ovulated 1.6 ova more than Durocs in the same year, while in the previous year a three-breed cross (Landrace x Poland x Duroc) ovulated 12.5 ova on average or 2.2 more ova than the Landrace x Poland gilts. Prenatal mortality was slightly higher in crossbred gilts but they farrowed 1.3 pigs more than the Durocs. They advise against breeding gilts too young as an increase of 10 days in age resulted in 0.67 more ova shed and 0.41 more embryos present at 55 days. (Squiers, et al. (1952) got an increase of 0.35 more ova shed and 0.5 more embryos at 25 days for each 10 day increase of age at first breeding.) Cox (1960) studied the relation between sex and survival in purebred and crossbred pigs from birth to slaughter. He concluded that heterosis as shown by reduced mortality was three times as great in males as in females, while the difference between male and female mortality was over twice as large in purebreds as in crossbreds.

While studying factors influencing the losses of pigs prior to weaning at 21 days in purebred Yorkshire and Landrace pigs and in the various crosses between them, MacDonald, Holness and Moxley (1963) found that maternal influence played a large part. Landrace (♂) x Yorkshire (♀) piglets had the lowest mortality at 13.6 percent, while Yorkshires were next with 15.9 percent. Landrace piglets, on the other hand, had the highest mortality with 20.0 percent, with the Yorkshire x Landrace piglets next with 19.3 percent, the backcrosses and crisscrosses fell in between. They found also that litter weight at birth had a significant effect on litter size at weaning, the least squares estimates showing .76 pig less at weaning in litters weighing less than 20 pounds, while 20-30 pound litters had .39 pig more, and litters weighing more than 30 pounds .37 pig more at weaning. The age of sow had no significant effect on number of piglets alive at weaning, the latter was mainly a reflection on the number of live pigs at birth.

Pani, Day, Tribble and Lasley (1963) studied the maternal influence in pigs as reflected by differences in reciprocal crosses between Landrace and Poland China and of the resulting crossbreds with Durocs. The traits studied included litter size, litter weight and average pig weight at birth, 56 and 154 days. The data were adjusted for inbreeding of dam where applicable and to a gilt litter basis. In crosses Landrace sows produced significantly larger litters than the Polands at all three ages. although the average weight of the pigs was lighter at each age. Total litter weight averaged 46.4 pounds heavier at 56 days and 170.4 pounds heavier at 154 days in favor of the Landrace.

A comparison of Landrace x Poland sows from Landrace dams with those from Poland dams, mated to Duroc boars showed that litter size, pig weight and total litter weight at all ages were slightly higher when Poland sows were mothers of the crossbreds. The differences, however, were not significant. In reciprocal crosses of Landrace x Poland pigs and Durocs, litter size, litter weight and average pig weight were all higher in litters of the crossbred sows. The crossbred sows weaned 2.2 more pigs per litter and their litters averaged 107 pounds more at 56 days and 407 pounds more at 154 days than those from Duroc sows.

In a study of the performance of some 34,000 litters of the Large White, Landrace and Wessex breeds on farms in Great Britain, Smith and King (1964) reported that in general there was lower mortality in crossbred litters. They had 2 percent more pigs at birth and 5 percent more at weaning than purebreds, while total litter weight was 10 percent greater in crossbreds at weaning. Crossbred sows showed more heterosis with 5 percent more pigs at birth, 8 percent more at weaning and an advantage of 11 percent in total litter weight at weaning.

C. Other Factors Affecting Preweaning Traits

That there are real differences in the size and weight of litters produced by sows of different breed and age group has been well established. Lush and Molln (1942) found considerable differences between breed of sow with regard to size of litter farrowed in a study of some 7,000 litters. These differences ranged from Yorkshires with 10.7 pigs per litter born to Tamworths with 7.4 pigs per litter. Durocs (9.8), Landrace (9.7), Chester White (9.3), Hampshires (8.7), Poland Chinas (8.0) and Berkshires (7.7) fell in between. They also established that the productivity of the sow increased as her age at farrowing increased from one to two and a half or three years and thereafter tended to level off. The average difference between 1 and 1 1/2 year old sows was .57 pig and between 1 1/2 and 2 year old sows was 1.0 pig. Much of the later work, including a number of papers already cited, Stewart (1945), Blunn and Baker (1949), Henderson (1948), Squiers *et al*. (1952), Reddy *et al*. (1958) and Hetzer *et al*. (1961) reported age of dam as having highly significant effects on litter traits and although actual differences found were not the same, they showed the same general trend. It is now generally agreed that litter size does not vary significantly after 2 years of age or a sow's third litter, and generally third and subsequent litters may be grouped together. As already reported, Gaines (1957), Cobb (1958), MacDonald et al. (1963) and Pani et al. (1963) all found significant differences due to breed of sow.

Allen, Lasley and Tribble (1959) studied the milk production of inbred Landrace, Poland China, Duroc and Landrace x Poland sows. Milk production was recorded over a six-week period and Landrace sows produced the most. Their production reached a peak in the 4th and 5th week of lactation. Landrace x Poland sows were a close second in milk production; however, they reached peak production in the 2nd and 3rd weeks, a time when the piglet is almost solely dependent on the sow. The production of the Poland and Duroc breeds was considerably less than that of the other two. The authors did not find any significant correlation between age of sow at farrowing and her milk production.

Highly significant differences were found between breeds and crosses in total litter weight and average number of pigs per litter at birth and weaning. The largest litters at both ages were produced by crossbreds, with Landrace and Durocs next. The crossbreds were also superior in average litter weight at birth but the Landrace surpassed them in average litter weight at weaning in spite of weaning 1.3 less pigs per litter. This, however, may be accounted for by the fact that the crossbreds averaged 13 months and the Landrace 25 months of age at farrowing, although both groups produced almost the same quantity of milk.

MATERIALS AND METHODS

The data used in this study were provided by the Swine Research Branch of the U.S. Department of Agriculture and consisted of 229 inbred and 327 linecross (inbred females mated with purebred males) litters from their inbreeding and crossing program during the years 1950-53. The inbred lines used were the Landrace (L), Landrace-Chester White (L-CW), Landrace-Duroc (L-D), Landrace-Large Black (L-LB), Landrace-Poland China (L-PC), Landrace-Duroc-Hampshire (L-D-H) and Yorkshire-Duroc-Landrace-Hampshire (Y-D-L-H). The linecross litters consisted of progeny of females from these seven inbred lines mated to males of the four pure breeds, Berkshire, Chester White, Hampshire and Poland China.

A. History of the Inbred Lines:

The history of the development of these inbred lines has been reported by Cobb (1957) and Hetzer et al. (1961). The following section, with the exception of a few additions to table 1, giving the history of their development has been copied from Cobb's dissertation (1957):

> In 1934, the U.S.D.A. imported boars and sows of Danish Landrace, Danish Yorkshire and English Large Black breeding as the first step in forming inbred lines and determining their usefulness in crossing. Two inbred lines were formed from crosses made in 1934, between the Landrace and Duroc and between the Landrace and Poland China. Two more inbred lines were started in 1935 from crosses between the Landrace and Chester White and between the Yorkshire and Durocs. Another

line was started in 1936 from a cross between the Landrace and Large Black. In 1939, two new lines, one of which later replaced the Yorkshire-Duroc line, were started by crossing the Landrace-Hampshire (Montana No. 1) line with stock from the Yorkshire-Duroc and Landrace-Duroc lines. The Landrace-Hampshire line, referred to above, originated in Miles City, Montana, from a cross between Landrace and black Hampshire. Table 1 gives the average percentages of the inheritance of each line that was derived from the parental breeds, together with their year of foundation and number of foundation matings. The codes for the lines, given in Table 1, will be referred to in later tables.

Table 2 gives the average coefficients of inbreeding of the lines for 1947-48 and for the period covered by this study 1950-53. During this latter period the average inbreeding of the lines was from 27 to 46 percent. This table also includes the coefficients of relationship between the lines in 1947-48 and this ranged from zero to 25 percent.

B. Scope of the Data:

All the data were collected at the U.S.D.A. Research Center at Beltsville during the years 1950-53 and comprised a total of 229 inbred and 327 linecross litters, which were used in this study. Only litters in which one or more pigs were weaned at 56 days of age were used. This was done in order to avoid missing sub-class numbers and it had the effect of eliminating eight inbred and six linecross litters from the original data.

TABLE 1. Average Percentage of the Inheritance of the Parent Breeds Represented in the Lines in 1947[a]

Inbred Line	Year of Fdntn.	No. of Fndtn. Matings	Code	Percentage of Inheritance from Each Breed						
				Landrace	Chester White	Duroc	Hamps.	Large Black	Poland China	Yorkshire
Landrace	1934	16	L	100						
Landrace-Chester White	1935	7	L-CW	17	83					
Landrace-Duroc	1934	21	L-D	75		25				
Landrace-Large Black	1936	8	L-LB	74				26		
Landrace-Poland China	1934	17	L-PC	74					26	
Landrace-Duroc-Hampshire	1939	9	L-D-H	75		16	9			
Yorkshire-Duroc-Landrace-Hampshire	1939	2	Y-D-L-H	6		30	6			58

[a] These calculated percentages have remained essentially the same since 1947.

TABLE 2. Average Coefficients of Inbreeding and Relationship Among the Seven Inbred Beltsville Lines

Inbred Line	Inbreeding of Lines[a] 1947-48	Inbreeding of Lines[a] 1950-53	Relationship of Lines[b] L-CW	L-D	L-LB	L-PC	L-D-H	Y-D-L-H
L	.26	.33	.02	.22	.21	.18	.17	.00
L-CW	.42	.46		.01	.02	.01	.02	.00
L-D	.19	.27			.14	.14	.25	.02
L-LB	.17	.27				.12	.12	.00
L-PC	.24	.32					.11	.00
L-D-H	.25	.29						.03
Y-D-L-H	.27	.35						-

[a] Inbreeding coefficients refer to the average inbreeding of the sows used to produce litters in the years indicated.

[b] Relationship coefficients between pairs of lines are based on relationship among animals used for litters in 1947-48.

All the litters were spring born in the months from February to April and thus no seasonal effects had to be considered in the analyses. The sows ranged in age from 323 to 1492 days of age, but as Lush and Molln (1942) and Henderson (1948) found that age of dam did not affect litter size or litter weight in a linear manner, but rather had a curvilinear effect they were divided for the purposes of this study into three age classes: (1) Gilts $<$ 12 months of age at farrowing, (2) Gilts $>$ 12 months of age and (3) Sows having second or later (2+) litters. It was contemplated having a fourth age class and having a group of second litter and a group of third and later litter sows, but as there were very few sows with second litters it was decided to pool all those with second and later litters. The number of litters listed by age class of dam and year of birth within line of dam for the combined inbred and linecross data are contained in Table 3.

C. Statistical Methods:

The least squares method of estimating constants, as described by Harvey (1960), was used in the analysis of the data. The multiple classification model with interaction and unequal sub class numbers used in the analysis of the combined inbred and linecross data is listed below:

$$Y_{ijkmn} = \mu + T_i + L_j + S_k + A_m + (LS)_{jk} + E_{ijkmn}$$

where:

Y_{ijkmn} = the n-th litter from the m-th age class of dam, born in the k-th year from the j-th line of dam and of the i-th mating type.

μ = overall mean or effect common to all litters

T_i = effect common to all litters of the i-th mating type (i=1 or 2)

TABLE 3. Number of Litters Grouped Within Line of Dam by Year and Age Class of Dam for Combined Data

Line of Dam	No. of Litters	Age Class of Dam: (1) '50	'51	'52	'53	Total	(2) '50	'51	'52	'53	Total	(3) '50	'51	'52	'53	Total
L	79	6	3	-	3	12	10	8	11	5	34	12	10	3	8	33
L-CW	78	15	1	4	1	21	10	3	7	2	22	-	25	2	8	35
L-D	84	9	3	2	1	15	19	6	9	-	34	-	20	2	13	35
L-LB	74	10	-	-	7	17	17	2	6	5	30	-	18	4	5	27
L-PC	90	10	-	5	2	17	16	9	7	1	33	-	22	2	16	40
L-D-H	74	12	-	3	-	15	16	6	3	3	28	3	23	-	5	31
Y-D-L-H	77	11	-	4	7	22	13	10	4	6	33	1	11	7	3	22
		73	7	18	21	119	101	44	47	22	214	16	129	20	58	223

Year Totals:

1950	190
1951	180
1952	85
1953	101

L_j = effect common to all litters from the j-th line of dam ($j = 1, 2, \ldots\ldots 7$).

S_k = effect common to all litters born in the k-th year ($k = 1, 2, 3$ or 4).

A_m = effect common to all litters of the m-th age class of dam ($m = 1, 2$ or 3).

$(LS)_{jk}$ = effect common to all litters from the j-th line of dam born in the k-th year, after the effects of L and S were removed.

E_{ijkmn} = effect common to each individual litter or random errors, which are assumed to be normally and independently distributed with mean zero and variance σ_e^2.

1. Combined Analysis:

An analysis on the combined data was carried out using the model described above. A preliminary analysis was also run, in which the effects due to the breed of sire (in the linecross litters) and several additional two way interactions were included. Neither the breed of sire nor any of the interactions proved significant and they accounted for a very small fraction of the total variance. $(LS)_{jk}$ was the only interaction term that consistently had an F ratio greater than 1 for all the traits studied and so it was retained in the final analysis.

The normal equations, necessary to obtain the least squares constants, were solved by matrix inversion on the IBM 1620 digital computer. The standard errors of the estimated constants were also obtained in the usual fashion (Harvey, 1960), while Kramer's (1957) modification of Duncan's multiple range test was used to make pairwise comparisons among the groups of least squares means.

2. Inbred and Linecross Analyses:

A separate analysis was carried out on both the inbred and linecross data. However, as they behaved in roughly the same manner as the combined analysis, it was not considered necessary to include the models for these analyses.

The main purpose of these analyses, besides testing for main effects and interactions, was to test for the effects of inbreeding. The models contained terms to estimate both the linear and quadratic effects of the inbreeding of the dam and of the litter in the inbred data and of the inbreeding of the dam (linecross litters) on each of the traits measured. For none of the traits were the inbreeding effects significant in the case of the inbred litters and most of the F ratios were less than 1. However, when all the interactions, except the one for line of dam x year of birth, were eliminated, the linear effect of the inbreeding of the litter just reached the 5 percent level of significance for litter weight at birth.

In the analysis of the linecross data the inbreeding of the dam likewise showed no significant effect, either linear or quadratic, on the traits studied. Except for litter weight at birth (linear) and litter size at birth (quadratic), the F ratios were again less than 1. A further point worth noting from this analysis is that, when the terms for inbreeding effects and most of the interactions were removed, the $(LS)_{jk}$ interaction for litter size at 21 and 56 days showed significance at the 5 percent level.

RESULTS AND DISCUSSION

A. Litter Size:

Litter size was recorded at birth, 21 and 56 days of age. The figure for litter size at birth includes both live and stillborn pigs, while that for 21 and 56 days is the number of live pigs in the litter at these ages.

The analysis of variance for litter size for each of the three ages is given in Table 4. Included in this table are the degrees of freedom, mean squares, F test and whether the F value is significant at the 5 percent, 1 percent or 0.1 percent level of significance, for each of the main sources of variation. The least squares constants together with their standard errors, for litter size at each age, are given in Table 5. Table 6 contains the least squares means for litter size by line of dam for inbred and linecross litters.

1. Type of Mating:

There was no difference between inbred and linecross litters for number farrowed. This is rather surprising considering the results obtained by other authors; however, it is possible that the inbred litters contained a higher proportion of stillborn pigs, which would not be taken into account in the present analysis. That such may have been the case could be concluded from the number alive at 21 and 56 days, which showed highly significant differences of .82 and .94 pigs respectively in favor of the linecross litters. There was no difference between the average coefficients of inbreeding of the inbred (32.6 percent) and linecross (32.7 percent) dams; the difference in their average age at

TABLE 4. Analysis of Variance for Litter Size at Birth, 21 and 56 Days of Age

Source	d.f.	Birth M.S.	Birth F.	21 days M.S.	21 days F.	56 days M.S.	56 days F.
Type of Mating	1	.22	.03	81.98	14.57***	110.87	19.77***
Line of Dam	6	39.93	6.26***	18.36	3.26**	17.26	3.08**
Year of Birth	3	22.58	3.54*	19.07	3.39*	19.22	3.43*
Age Class of Dam	2	219.19	34.38***	179.07	31.83***	172.95	30.83***
Line x Year	18	7.94	1.25	7.43	1.32	7.30	1.30
Error	525	6.38		5.63		5.61	
Total	555						

* $P \leq 0.05$

** $P \leq 0.01$

*** $P \leq 0.001$

TABLE 5. Least Squares Constants ± Standard Errors for Litter Size at Birth, 21 and 56 Days of Age

	No. of Litters	Birth	21 days	56 days
Overall Mean (μ)	556	8.6±.1	6.6±.1	6.4±.1
Type:				
Inbreds	229	0.0±.1[a]	-.4±.1[a]	-.5±.1[a]
Linecrosses	327	0.0±.1[a]	.4±.1[b]	.5±.1[b]
Line of Dam:				
L	79	.1±.4[b]	0.0±.3[bc]	0.0±.3[bc]
L-CW	78	-1.6±.3[a]	-.9±.3[a]	-.9±.3[a]
L-D	84	- .1±.3[b]	-.3±.3[ab]	-.3±.3[ab]
L-LB	74	1.0±.3[c]	.8±.3[c]	.7±.3[c]
L-PC	90	0.0±.3[b]	-.1±.3[bc]	0.0±.3[abc]
L-D-H	74	.3±.3[bc]	.1±.3[abc]	.1±.3[abc]
Y-D-L-H	77	.3±.3[bc]	.4±.3[bc]	.4±.3[bc]
Year:				
1950	190	.3±.2[b]	.3±.2[bc]	.3±.2[b]
1951	180	- .5±.2[a]	-.1±.2[ab]	0.0±.2[ab]
1952	85	.6±.2[b]	.4±.2[c]	.4±.2[b]
1953	101	- .4±.2[a]	-.6±.2[a]	-.7±.2[a]
Age of Dam:				
Gilts $<$ 12 months	119	- .7±.2[a]	-.8±.2[a]	-.9±.2[a]
Gilts $>$ 12 months	214	- .9±.2[a]	-.7±.2[a]	-.6±.2[a]
2+ litters	223	1.6±.2[b]	1.5±.2[b]	1.5±.2[b]

[abc] Those constants having the same superscript are not significantly different from one another at the 5 percent level.

TABLE 6. Least Squares Means for Litter Size at Birth, 21 and 56 Days for Inbred and Linecross by Line of Dam[a]

		No.of Litters	Inbred	No.of Litters	Linecross
Birth:					
Overall Mean (μ)		229	8.6	327	8.6
Line of Dam:	L	34	8.7	45	8.6
	L-CW	26	6.5	52	7.4
	L-D	33	8.6	51	8.5
	L-LB	28	9.7	46	9.4
	L-PC	41	8.9	49	8.5
	L-D-H	36	8.8	38	9.1
	Y-D-L-H	31	9.2	46	8.9
21 Days:					
Overall Mean (μ)		229	6.2	327	7.0
Line of Dam:	L	34	6.2	45	7.0
	L-CW	26	4.8	52	6.4
	L-D	33	5.8	51	6.8
	L-LB	28	7.2	46	7.2
	L-PC	41	6.5	49	6.6
	L-D-H	36	6.3	38	7.2
	Y-D-L-H	31	6.7	46	7.4
56 Days:					
Overall Mean (μ)		229	5.9	327	6.9
Line of Dam:	L	34	5.8	45	6.8
	L-CW	26	4.7	52	6.2
	L-D	33	5.5	51	6.7
	L-LB	28	6.8	46	7.1
	L-PC	41	6.3	49	6.5
	L-D-H	36	5.9	38	7.0
	Y-D-L-H	31	6.5	46	7.3

[a] These line of dam means were taken from the inbred and linecross analysis respectively.

farrowing was negligible being 499 days for inbreds and 491 days for the linecross dams.

There are conflicting reports in the literature regarding the relative importance of inbreeding of the dam and inbreeding of the litter on litter size. In general it appears that the amount of inbreeding of the litter becomes increasingly important as individual pigs become older and that the mortality of pigs between birth and 21 days is primarily a measure of the mothering ability of the sow, while that between 21 and 56 days would be more related to the ability of the individual pigs in the litter to grow and survive. Stewart (1945), Hetzer et al. (1961) and Noland et al. (1964) all found that the inbreeding of the dam had more effect on litter size in the early weeks of life than had inbreeding of the litter. Dickerson et al. (1954) found that both had almost equal effect; they observed a reduction of .20 pig per litter born for each 10 percent increase in the inbreeding of the dam, and .17 pig decrease for a corresponding increase in the inbreeding of the litter. A somewhat similar observation was made by Falconer (1960) in a mouse experiment; although he found that the inbreeding of the litter had a slightly greater effect (.24 young per 10 percent increase of inbreeding) than did inbreeding of the litter (.17 young), on litter size at birth, the differences did not appear significant.

Wright (1922) on the other hand, in his work with guinea pigs, found that the mortality between birth and weaning is 75 percent dependent on the breeding of the young and 25 percent on the breeding of the dam, but that mortality at birth is almost wholly a maternal effect. He also noticed a marked improvement (11 percent) in the livability of first cross litters in spite of the dam being inbred. Bradford et al. (1958) working with pigs observed that there was a decrease of .20 pig farrowed and .45 pig raised for each 10 percent increase in inbreeding of the litter, the corresponding decrease per 10 percent increase in inbreeding of the dam was 0 and 0.1 pig, respectively.

2. Line of Dam:

There were highly significant differences between lines of dam for litter size at each of the three ages. The difference between the best and the poorest line was 2.6 pigs for number born, 1.7 and 1.6 pigs for number alive at 21 and 56 days, respectively. The L-LB line had the largest litters, having .6, .4 and .3 pigs more than the Y-D-L-H line which had the second largest litters, at birth, 21 and 56 days. The L-CW line, on the other hand, consistently gave the poorest performance, being significantly worse than any of the other lines for number farrowed (Table 5). The difference between this line and the L-D line, which was next poorest, was not so pronounced at 21 and 56 days but was still sizeable being .6 pig at each age.

The poor performance of the L-CW line is probably caused by two factors: (i) high coefficient of inbreeding in comparison to the other lines; over the four years of the study the average inbreeding was .46 percent which was considerably higher than any of the other lines and (ii) the line is 83 percent Chester White breeding and only 17 percent Landrace. Most of the other lines contain a high percentage of Landrace or Yorkshire breeding, both of which lines are generally considered better than the Chester White in mothering ability.

Hetzer et al. (1961) using these same lines of dam in a study of combining abilities likewise found the L-CW line to be considerably poorer than any other line for litter size. They found the Y-D-L-H line to be .65 pig superior at birth than any other line in spite of the fact that it had the second highest coefficient of inbreeding at that time, however at 21 and 56 days of age the L-LB line proved superior. From the least squares means in Table 6 it can be seen that the lines ranked similarly whether the litters were inbred or linecross, although the L-CW line and other lines did not differ as widely when the litters were linecross as when they were inbred.

3. Year at Birth:

Year of birth differences showed significance at the 5 percent level for litter size at all three ages. Litter size at birth was significantly smaller in 1951 and 1953 than in the other two years, which showed little or no difference. At 21 and 56 days, respectively the litter size in 1953 was .5 and .7 pig smaller than in 1951 and was significantly smaller than either of the other two years (Table 5). While undoubtedly environmental conditions would not be similar in all four years, much of these differences can probably be accounted for by differences in the average age of the dam at time of farrowing. The mean age in 1953 was 455 days, while those for the other three years were 478, 493 and 553 days for 1951, 1950 and 1952, respectively.

4. Age of Dam:

Effects due to differences in age of dam were highly significant at birth, 21 and 56 days. They accounted for almost 76 percent of the total variation in litter size at birth and while not so important proportionally they still accounted for over 50 percent of the variation at 56 days of age.

There was surprisingly little difference in litter size between gilts under or over one year of age at farrowing and although the older gilts did tend to rear slightly more pigs, the difference between them for litter size at birth, 21 and 56 days was not significant. This is contrary to the findings of numerous other workers. As recorded earlier, Stewart (1945), Henderson (1948) and Hetzer _et al_. (1961) all found differences of from 1.0 to 1.4 pigs between the two groups at birth, while Squiers _et al_. (1952) reported an increase of 0.5 embryo present 25 days after conception, for each increase of 10 days in age of the gilt, and Reddy _et al_. (1958) an increase of .41 embryo at 55 days post conception.

The difference between second and later (2+) litter sows and gilts under one year was considerable, being about 2.3 pigs per litter at all three ages. This difference falls within the range found by Henderson (1948) and Hetzer _et al_. (1961) between their oldest and youngest age group of sows. Lush and Molln (1942) did not find such large differences, there being only 1.57 pigs difference at birth between one and two year old sows and less than 1 pig difference at weaning. The mean ages of the three groups of sows in this study were 344, 385 and 755 days, respectively.

5. <u>Line x Year Interaction</u>:

As indicated earlier, this was the only interaction in the preliminary analysis that consistently gave an F ratio 1 and which was retained in the final analysis. The interaction continued to give an F value $>$ 1 but in no case was this found to be significant so that it can be assumed that all lines performed similarly in all years.

B. Litter Weight:

Total litter weight is an expression of both the number of pigs in a litter at any particular age and the growth rate of those pigs and thus it seems to be one of the best overall measures of sow performance. Litter weight was also recorded at each of the three ages, birth, 21 and 56 days.

The analysis of variance for litter weight is given in Table 7 and includes the degrees of freedom, mean squares, F test and level of significance of the F values. Table 8 contains the least squares constants and their standard errors for litter weight at each of the three ages, while Table 9 contains the least squares means by line of dam for inbred and linecross litters.

1. Type of Mating:

The difference in litter weight at birth between inbred and linecross litters was significant at the 5 percent level of probability. The difference was about 1.4 lb. per litter and thus, especially since there was no difference between the two groups in litter size, it seems to indicate that the linecross pigs showed better intra-uterine growth. It would seem, therefore, that when the mother and the fetus are both inbred, the growth of the fetus is adversely affected. This is interesting, because while Dickerson et al. (1946) and Hetzer et al. (1951) found differences in favor of single linecrosses over inbred lines in litter weight at birth, these differences were more than accounted for

TABLE 7. Analysis of Variance for Litter Weight at Birth, 21 and 56 Days

Source	d.f.	Birth M.S.	Birth F	21 Days M.S.	21 Days F	56 Days M.S.	56 Days F
Type of Mating	1	240.11	6.39*	21551.32	36.14***	340180.15	59.49***
Line of Dam	6	327.56	8.71***	2537.04	4.25***	25251.37	4.42***
Year of Birth	3	245.96	6.54***	3574.03	5.99***	78440.89	13.72***
Age Class of Dam	2	2392.94	63.64***	44247.25	74.19***	419929.9	73.43***
Line x Year	18	40.67	1.08	748.92	1.32	8731.48	1.53
Error	525	37.60		596.40		5718.44	
Total	555						

* $P \leq 0.05$

** $P \leq 0.01$

*** $P \leq 0.001$

TABLE 8. Least Squares Constants ± Standard Errors for Litter Weight at Birth, 21 and 56 Days of Age (lbs.)

	No. of Litters	Birth	21 days	56 days
Overall Mean (μ)	556	22.4±.3	71.6±1.2	211.3± 3.7
Type:				
Inbreds	229	- .7±.3^{a}	- 6.6±1.1^{a}	-26.2± 3.4^{a}
Linecross	327	.7±.3^{b}	6.6±1.1^{b}	26.2± 3.4^{b}
Line of Dam:				
L	79	1.3±.7^{c}	- 1.9±2.7^{ab}	-11.3± 8.3^{a}
L-CW	78	- 1.9±.7^{ab}	- 8.2±2.8^{a}	-25.0± 8.7^{a}
L-D	84	- 2.6±.7^{a}	- 5.8±2.7^{a}	-11.6± 8.3^{a}
L-LB	74	3.6±.7^{d}	8.5±2.8^{c}	31.5± 8.7^{c}
L-PC	90	- 1.5±.6^{ab}	- 1.2±2.5^{ab}	- 5.0± 7.9^{ab}
L-D-H	74	0.0±.8^{bc}	2.0±3.3^{abc}	2.9±10.3^{abc}
Y-D-L-H	77	1.1±.7^{c}	6.6±2.8^{bc}	18.5± 8.3^{bc}
Year:				
1950	190	1.1±.5^{bc}	- .7±1.9^{b}	-31.8± 6.0^{a}
1951	180	- .8±.5^{ab}	1.8±2.0^{bc}	5.5± 6.1^{b}
1952	84	1.8±.6^{c}	7.1±2.3^{c}	32.5± 7.2^{c}
1953	101	- 2.1±.6^{a}	- 8.2±2.2^{a}	- 6.2± 6.8^{b}
Age of Dam:				
Gilts < 12 months	119	- 3.2±.5^{a}	-14.3±1.9^{a}	-46.3± 6.0^{a}
Gilts 12 months	214	- 2.2±.4^{a}	- 9.1±1.6^{a}	-26.0± 4.8^{a}
2+ litters	223	5.4±.5^{b}	23.4±1.9^{b}	72.3± 6.0^{b}

^{abcd} Those constants with the same superscript are not significantly different from one another at the 5 percent level.

TABLE 9. Least Squares Means for Litter Weight at Birth, 21 and 56 Days for Inbred and Linecross by Line of Dam (lbs.)[a]

	No.of Litters	Inbreds	No.of Litters	Linecross
Birth:				
Overall Mean (μ)	229	21.8	327	23.2
Line of Dam: L	34	23.6	45	23.9
L-CW	26	19.4	52	21.8
L-D	33	18.9	51	20.6
L-LB	28	25.3	46	26.5
L-PC	41	20.7	49	21.0
L-D-H	36	22.0	38	24.1
Y-D-L-H	31	23.0	46	24.6
21 Days:				
Overall Mean (μ)	229	65.0	327	78.2
Line of Dam: L	34	63.2	45	75.7
L-CW	26	51.9	52	73.4
L-D	33	58.5	51	73.4
L-LB	28	74.4	46	83.2
L-PC	41	66.2	49	73.4
L-D-H	36	69.4	38	79.5
Y-D-L-H	31	70.9	46	86.5
56 Days:				
Overall Mean (μ)	229	185.0	327	237.4
Line of Dam: L	34	170.2	45	226.6
L-CW	26	152.3	52	218.3
L-D	33	173.3	51	226.7
L-LB	28	223.4	46	252.6
L-PC	41	182.9	49	228.4
L-D-H	36	192.8	38	243.5
Y-D-L-H	31	200.1	46	260.2

[a] These line of dam means were taken from the inbred and linecross analysis, respectively.

by increased litter size. It appears then, that for litters of equal size, inbreeding of the litter has a deleterious effect on the total litter weight.

Differences in litter weight at 21 and 56 days were highly significant and were probably accounted for, as much by the differences in average pig weight between the two groups as by differences in litter size. The linecross pigs were on average .7 lb. (11.2 vs. 10.5 lb.) heavier at 21 days and 3.3 lb. (34.7 vs. 31.4 lb.) heavier at 56 days of age. These differences for mean pig weights are in close agreement with those found by Dickerson _et al_. (1946) and Hetzer _et al_. (1951); the greater differences in total litter weight observed by these workers can be attributed to the larger differences in the size of their litters.

2. _Line of Dam_:

As in the case of litter size, line of dam differences in litter weight were highly significant at all three ages. The L-LB litters were significantly heavier than those of the other six lines at birth and significantly heavier than four of the six lines at 21 and 56 days. The L-CW, as well as having the smallest litters, also had the lightest litters at each age except at birth, when the L-D litters were lightest. The lines which differ significantly from one another are indicated by the superscripts in Table 8. Hetzer _et al_. (1961) also found these lines to rank in approximately the same order with respect to litter weight. The range of the differences between lines in the present study is greater than they observed, but their overall mean was considerably larger at each age, due to the fact that they were only dealing with reciprocal crosses between the lines and their litter sizes were larger.

Table 9 shows that in general the lines ranked similarly for both inbred and linecross litters and again the L-CW line did not differ from the other lines nearly as much when the litters were linecross as when inbred.

3. Year of Birth:

Year differences were highly significant at all three ages. The best results were obtained in 1952 not only in terms of larger, but also considerably heavier litters. As indicated previously this is probably due principally to the sows being older at farrowing in that year. The litter weight at weaning in 1950 is rather poor in comparison to 1952 when one considers that the litter size in both years was similar. This would seem to indicate that the spring of 1950 was unfavorable for pre-weaning growth, as the litters weaned in that year were significantly lighter than those weaned in the other three years. This could be due, either to inclement weather conditions or to a high incidence of disease or parasites.

4. Age of Dam:

Effects due to differences in age of dam were again highly significant for all litter weights. Again they account for a very high proportion of the variation in total litter weight ranging from about 73 percent at birth to about 48 percent at 56 days. There were differences of 1.0 lb., 5.2 lb. and 20.3 lb. (Table 8) between gilts farrowing their first litter under one year of age and those farrowing over one year of age at birth, 21 and 56 days, respectively. The differences found here agree very closely with those observed by Hetzer *et al*. (1961) and with the 19 lb.

increase in litter weight at weaning reported by Henderson (1948). In addition the average increase of 33.1 lb. at 21 days observed by the former workers between the litter weight of gilts over 11.6 months and sows in their third or later litter is in close agreement with the 32.5 lb. difference observed here between gilts over one year and sows, when it is remembered that only a small proportion (32/223) of the sows in this group produced second litters. The 98.3 lb. difference, however, between these two age groups in 56-day litter weight is considerably greater than the 80 lb. difference observed by these workers.

5. Line x Year Interaction:

Although the F value for this interaction was again > 1, it did not prove significant at any of the three ages; however, it did approach the 5 percent significance level for litter weight at 56 days of age.

CONCLUSIONS

There is little doubt from the results of these analyses that age of dam differences, especially those between gilts and older sows, are the most important source of variation in both litter size and litter weight and consequently in overall sow performance. The age of the gilts did not affect the number of young farrowed, but the older gilts did rear more pigs and had heavier litters at weaning so that in general it seems advisable not to breed gilts at too young an age.

In developing inbred lines one generally hopes to obtain one or two lines, that when crossed together or with another strain, will raise progeny which will be superior to the original breeds or strains one started with. However, in pigs, the length of time that it takes to develop a highly inbred line and the large number of lines that would have to be raised, in order to have a reasonable probability of obtaining a good combining line, in general makes it impractical. Thus the commonly accepted forms of crossbreeding are likely to prove much more profitable in time.

There did not appear to be any differences among the seven inbred lines of dam in the way in which they combined with the four pure breeds used as sires in this study. All ranked approximately the same for litter size and weight irrespective of whether inbred or crossed and the line x breed of sire interaction within the linecross data did not show any significance. However, as the average inbreeding of the dams was only 33 percent and none of the lines were highly inbred, one could probably not expect to observe much difference in combining ability as a result of inbreeding. These results agree in general with those of Hetzer _et al_. (1961), who, when they tested reciprocal crosses among six of these lines for specific and general combining abilities in preweaning traits, found no specific effects, while general combining effects only showed significance for litter weight at weaning.

Cobb (1958), using males from these same inbred lines, found that when crossed with females of four pure breeds there was no difference between the size of the resulting litters and of purebred litters, although the crossbred pigs were heavier at weaning. However, when the crossbred females were backcrossed or crossed with a third strain they proved much superior to the purebred females in the numbers born and weaned and in the growth of their progeny. Similar results were observed in a further phase of the U.S.D.A. inbreeding program (not included in the present study), when the linecross females were backcrossed to purebred males. Thus, as in most crossbreeding work with animals, the major advantage is achieved, not in the first cross, but rather when the mothers themselves are crossbred and they produce larger litters and faster growing progeny.

SUMMARY

Data comprising a total of 556 litters, 229 inbred and 327 linecross, were analyzed by least squares analysis to determine the effect of several factors on litter size and litter weight at each of three ages, birth, 21 days and 56 days. The following is a summary of the results obtained:

1. Type of mating, i.e. whether the litters were inbred or linecross, had no effect on litter size at birth, although the linecross litters had a significantly higher weight. Both litter size and litter weight at 21 and 56 days showed highly significant differences in favor of the linecross pigs ($P<0.001$).

2. There were very large differences between the seven lines of dam for both litter size and litter weight; these differences were highly significant at all three ages. The L-LB line was superior both in litter size and litter weight at each age, while the L-CW line, which was the most highly inbred, was the poorest performer in both traits at each age with the exception of litter weight at birth. The differences between these two lines amounted to 2.6, 1.7 and 1.6 pigs and 5.5 lb., 16.7 lb. and 56.5 lb. at birth, 21 and 56 days, respectively. The lines of dam ranked in approximately the same order irrespective of whether the litters were inbred or linecross although the differences between them were greater in the inbred litters.

3. Differences in year of birth showed significance for litter size at each age ($P<0.05$), while the differences in litter weight were highly significant ($P<0.001$). These differences especially in the

case of litter size, are attributed mainly to differences in average age of the dams farrowing in each year; however in 1950 other adverse environmental conditions appear to be influencing litter weight.

4. Age of dam at farrowing was the most important single factor affecting both litter size and litter weight. It accounted for over 70 percent of the variation in both traits at birth and for about 50 percent of the variation at 56 days. There was little difference between gilts under or over one year of age for litter size although the older gilts raised about 0.5 pig more per litter. There was approximately 2.4 pigs difference between sows in their second and later litters and the younger gilts at birth and at 56 days; there was 119 lb. difference in litter weight between these two groups at the latter age.

5. Year x line of dam interaction did not have any significant effect on litter size or litter weight.

ACKNOWLEDGEMENTS

The author wishes to thank all those who assisted in making this study possible. In particular he would like to thank Dr. J. A. Gaines for his willing assistance at all times and wise counsel on many occasions. Special thanks are also due to Dr. R. C. Carter, Dr. C. Y. Kramer and Mr. G. W. Litton for their advice and help in reviewing this thesis. The author also wishes to express his thanks to Dr. C. M. Kincaid and Dr. H. O. Hetzer of the U.S.D.A. Swine Research Division for providing the data for this study and to Dr. R. P. Lehmann and Gary V. Richardson of the U.S.D.A. Biometrical Services for their assistance in analyzing the data.

The writer wishes to make special acknowledgement to his wife, Anne, for her forbearance and encouragement all through this work. Thanks is also due to Mrs. Carrie Lindsay for typing the manuscript.

This work was carried out while the author was on leave of absence from the Animal Breeding and Genetics Department of An Foras Taluntais, Dunsinea, Castleknock, Co. Dublin, Ireland.

LITERATURE CITED

Allen, A. D., J. F. Lasley and L. F. Tribble. 1959. Milk production and related performance factors in sows. Mo. Agr. Exp. Sta. Res. Bul. 712.

Blunn, C. T. and M. L. Baker. 1949. Heritability estimates of sow productivity and litter performance. J. Animal Sci. 8:89-97.

Bradford, G. E., A. B. Chapman and R. H. Grummer. 1958. Effects of inbreeding, selection, linecrossing and topcrossing in swine. I. Inbreeding and selection. J. Animal Sci. 17:426-440.

Carroll, W. E. and E. Roberts. 1942. Crossbreeding in swine. Does it offer an effective method for the improvement of market hogs? Ill. Agr. Exp. Sta. Bul. 489.

Chambers, D. and J. A. Whatley, Jr. 1951. Heterosis in crosses of inbred lines of swine. J. Animal Sci. 10:505-515.

Cobb, E. H. 1958. Comparative performance of purebred and crossbred swine on Pennsylvania farms. Ph.D. Thesis. Iowa State Univ., Ames, Iowa.

Cox, D. F. 1960. The relation between sex and survival in swine. J. Heredity 51:284-288.

Dickerson, G. E., J. L. Lush and C. C. Culbertson. 1946. Hybrid vigor in single crosses between inbred lines of Poland China swine. J. Animal Sci. 5:16-24.

Dickerson, G. E., C. T. Blunn, A. B. Chapman,,R. M. Kottman, J. L. Krider, E. J. Warwick, J. A. Whatley, Jr. in collaboration with M. L. Baker, J. L. Lush and L. M. Winters. 1954. Evaluation of selection in developing inbred lines of swine. Mo. Agr. Exp. Sta. Res. Bul. 551.

East, E. M. 1909. The distinction between development and heredity in inbreeding. Amer. Nat. 43:173-181.

Falconer, D. S. 1964. Introduction to quantitative genetics. Oliver and Boyd Ltd., Edinburgh and London. 2nd Reprinting, p. 253.

Fine, N. C. and L. M. Winters. 1952. Selection for fertility in two inbred lines of swine. J. Animal Sci. 11:301-312.

Gaines, J. A. 1957. Differences in litter size and growth rate among purebred and crossbred swine. Ph.D. Thesis, Iowa State Univ., Ames, Iowa.

Gaines, J. A., H. R. Thomas, R. C. Carter and C. M. Kincaid. 1958. Swine Breeding: Tidewater Research Station 1949-56. Va. Agr. Exp. Sta. Bul. 499.

Harvey, W. R. 1960. Least squares analysis of data with unequal subclass numbers. U.S.D.A. Agricultural Research Service Pub. ARS-20-8.

Henderson, C. R. 1948. Estimation of general, specific and maternal combining abilities in crosses among inbred lines of swine. Ph.D. Thesis, Iowa State Univ., Ames, Iowa.

Hetzer, H. O., R. E. Comstock, J. H. Zeller, R. L. Hiner, and W. R. Harvey. 1961. Combining abilities in crosses among six inbred lines of swine. U.S.D.A. Tech. Bul. 1237.

Hetzer, H. O., O. G. Hankins and J. H. Zeller. 1951. Performance of crosses between six inbred lines of swine. U.S. Dept. Agr. Circ. 893.

Hetzer, H. O., W. V. Lambert and J. H. Zeller. 1940. Influence of inbreeding and other factors on litter size in Chester White swine. U.S. Dept. Agr. Circ. 510.

King, Helen D. 1918a. Studies on inbreeding: I. The effects of inbreeding on the growth and variability in the body weight of the Albino rat. J. Exp. Zool. 26:1-54.

King, Helen D. 1918b. Studies on inbreeding: II. The effects of inbreeding on the fertility and on the constitutional vigor of the Albino rat. J. Exp. Zool. 26:335-378.

Kramer, C. Y. 1957. Extension of multiple range tests to group correlated adjusted means. Biometrics 13:13-18.

Lush, J. L. and A. E. Molln. 1942. Litter size and weight as permanent characteristics of sows. U.S. Dept. Agr. Tech. Bul. 836.

Lush, J. L., P. D. Shearer and C. C. Culbertson. 1939. Crossbreeding hogs for pork production. Iowa Agr. Exp. Sta. Bul. 380.

MacDonald, M. A., D. E. Holness and J. E. Moxley. 1963. Some factors influencing the losses of pigs prior to weaning. Canad. J. Comp. Med. 27:237-240.

Noland, P. R., W. Gifford and C. J. Brown. 1964. Effects of inbreeding in a Poland China line of swine on certain productivity traits. Ark. Agr. Exp. Sta. Bul. 681.

Pani, S. N., B. N. Day, L. F. Tribble and J. F. Lasley. 1963. Maternal influence in swine as reflected by differences in reciprocal crosses. Mo. Agr. Exp. Sta. Res. Bul. 830.

Reddy, V. B., J. F. Lasley and D. T. Mayer. 1958. Genetic aspects of reproduction in swine. Mo. Agr. Exp. Sta. Res. Bul. 666.

Rempel, W. E. and L. M. Winters. 1952. A study of selection for factors of performance in inbred lines of Poland China swine. J. Animal Sci. 11:742 (abstract).

Robison, H. L. 1948. Crossbreeding for the production of market hogs. Ohio Agr. Exp. Sta. Bul. 675.

Shull, G. H. 1911. The genotypes of maize. Amer. Nat. 45:234-252.

Smith, C. and J. W. B. King. 1964. Crossbreeding and litter production in pigs. Anim. Prod. 6:265-271.

Squiers, C. D., G. E. Dickerson and D. T. Mayer. 1952. Influence of inbreeding, age and growth rate of sows on sexual maturity, rate of ovulation, fertilization and embryonic survival. Mo. Agr. Exp. Sta. Res. Bul. 494.

Stewart, H. A. 1945. An appraisal of factors affecting prolificacy in swine. J. Animal Sci. 4:250-260.

Winters, L. M., P. S. Jordan, R. E. Hodgson, O. M. Kiser and W. W. Green. 1944. Preliminary report on crossing of inbred lines of swine. J. Animal Sci. 3:371-379.

Winters, L. M., O. Kiser, P. S. Jordan and W. H. Peters. 1935. Six years' study of crossbreeding in swine 1928-34. Minn. Agr. Exp. Sta. Bul. 320.

Wright, S. 1922. The effects of inbreeding and crossbreeding on guinea pigs. III. Crosses between highly inbred families. U.S. Dept. Agr. Bul. 1121.

The vita has been removed from the scanned document

A STUDY OF FACTORS AFFECTING PREWEANING
TRAITS IN INBRED AND LINECROSS SWINE

by

Gerald J. More O'Ferrall

(ABSTRACT)

The aim of the study was to determine the differences between inbred and linecross litters in litter size and litter weight at birth, 21 and 56 days of age. The effect of line of dam, age of dam and year of birth on each of the production traits was also studied. Data comprising 556 litters (229 inbred and 327 linecross) from seven inbred lines developed by the U.S.D.A. at Beltsville were analyzed by the method of least squares. There were no differences between the inbred and linecross litters for number farrowed, but highly significant differences ($P<0.01$) were observed for all other traits. The lines of dam differed considerably in performance; the L-LB line gave the largest and heaviest litters and the L-CW line the smallest and lightest litters at each of the three ages. Age of dam at farrowing was the most important single factor affecting both litter size and weight. It accounted for 70 percent of the variation in both traits at birth and about 50 percent at weaning. Sows weaned litters, which were 2.4 pigs larger and 119 pounds heavier than those weaned by gilts farrowing under one year of age.