HETEROSIS EXPRESSED BY CROSSES AMONG INBRED LINES WITHIN THE DUROC BREED OF SWINE

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INTRODUCTION

Genetic improvement of farm animals may be accomplished by use of one or more of the following methods: (1) selection, (2) inbreeding, and (3) outbreeding. A study of the effects of these methods reveals that each produces a somewhat different effect upon the population concerned. The choice of method to use will depend on the ultimate aim of the breeding operation. In most instances a combination of two of the methods used simultaneously, or all three methods used in proper sequence, should bring about the greatest improvement in a given period of time.

Selection has been a most effective tool in the hands of the breeder of plants and animals. Its general effect is to increase the frequency of the desired hereditary determiners by permitting the most desirable individuals to reproduce at a faster rate than the less desirable individuals. Its effectiveness is limited to the extent that the differences, for which selection is practiced, are hereditary differences. In general, the traits of most economic importance to the producer of livestock products are not highly heritable. For this reason phenotypic selection for these traits may not be very effective in the improvement of the genetic constitution of the group. The use of such aids to phenotypic selection as the pedigree, the lifetime performance of the individual, and the progeny test greatly increases the accuracy of selection. If the desired characteristic is the result of the extreme genotype, selection toward that extreme increases homozygosis. On the other hand, if the intermediate genotype produces the most desirable phenotype, selection is incapable of fixing that type.

The practice of mating plants or animals which are related by descent is referred to as inbreeding. Its continued use ultimately results in the formation of homozygous lines. The rapidity with which homozygosis is approached

is a function of the degree of relationship between the individuals mated. Self-fertilization is the most extreme form of inbreeding possible and is used extensively in plant breeding. Parent-offspring and full-sib matings are the most intense kind of inbreeding possible in non-hermaphroditic species.

Although much of the constructive work in the formation of the present breeds of livestock resulted from the mating of closely related animals, inbreeding has been frowned upon by the great majority of breeders. A general lowering of phenotypic merit among inbred animals has been the usual rule. In conjunction with selection, however, inbreeding offers an opportunity to fix many desired types including the intermediate if more than one pair of genes is involved, and if their effects are additive. It is a means for purging lines of undesirable recessive genes. Prepotency is a result commonly noted because of the degree of homozygosis attained.

Outbreeding refers to the mating of individuals less closely related than the average of the population concerned. As with inbreeding, there are various degrees of outbreeding. The mating of individuals from different families within the same breed, the mating of individuals belonging to different breeds, and the mating of individuals belonging to different species represent varying degrees of outbreeding. Some system of outbreeding is usually preferred by breeders because fewer undesirable individuals occur than under a system of close mating. In many instances the crossing of distinct lines or breeds results in an increased phenotypic merit in the first generation. Breeders commonly credit this increased desirability to the nicking of the lines crossed. Within limits it has been found that the wider the cross the greater the vigor exhibited due to this nicking effect.

Outbreeding is useful for introducing into a breed or strain certain hereditary factors not already present. Selection for these desired factors

may then be effectively practiced. For the production of market animals the crossing of distinct families, breeds, or species may be advantageous. Its general effect is to reduce homozygosity and, therefore, prepotency. This limits its use if prepotency and uniformity of progeny are important factors.

History of the present breeds of livestock shows that several forms of outbreeding have been used in their development. Breeders, who have fixed some undesirable traits in their herds while following a system of close mating, have often made an outcross to unrelated individuals within the same breed in an effort to correct these faults. Crosses between breeds and crosses between species have been used as foundation stock for new breeds. Many of the present breeds have been developed from such crossbred foundations. Familiar examples include the Poland China breed of swine, the Corriedale breed of sheep, the Santa Gertrudis breed of cattle and the American Saddle Horse.

The increased vigor and growth which accompany hybridization have been recognized for centuries. The popularity of the mule is an excellent example of the use to which early animal breeders put this vigor of hybridization. The occurrence of hybrid vigor was reported and described in detail by many of the early plant breeders and biologists including Kolreuter, Knight, and Darwin. It was noted that great differences existed in the manner in which this increased vigor was exhibited. In some crosses, there was increased vegetative growth; in others there was either a greater production of fruit, an increased resistance to disease, earlier maturity, increased fertility or an increased viability. The various attempts to define and explain this "increased stimulus from crossing" were not satisfactory.

The rediscovery and confirmation of the Mendelian principles of heredity brought about renewed interest in hybridization. It was in 1914 that G. H. Shull proposed the term "Heterosis" to describe "the developmental stimulation

resulting, by whatever mechanism, from the union of different gametes". Various theories were proposed to explain the reasons for the occurrence of increased growth and vigor. Some of these theories explain the results obtained very well, but as yet there is little direct proof to support any one of them to the exclusion of others.

During the past fifty years, considerable research has been conducted to study the effects of inbreeding on plant and animal material. It was found that the use of selected inbred lines of corn in crosses increased yield above that of the open-pollinated varieties from which they originated. Rather extensive trials at duplicating this work on laboratory animals indicated the possibility of using this method in the improvement of farm animals - especially swine and poultry.

Several state experiment stations began the inbreeding of swine, and in 1937 the Regional Swine Breeding Laboratory was established by the Bureau of Animal Industry of the United States Department of Agriculture in cooperation with a number of state experiment stations. In cooperation with the Regional Laboratory, the Oklahoma Station began the development of inbred lines within the Duroc breed of swine in 1938.

During sixteen of the twenty-two farrowing seasons since the spring of 1939 both inbred and line cross litters have been produced. In some seasons outbred Duroc and three-line cross litters were farrowed.

The purpose of this study was to determine if the crossing of moderately inbred lines within the Duroc breed of swine resulted in improved performance. If such an expression of heterosis did exist, it was thought that its manner of expression and the time at which it was first evident would be of considerable interest and value.

REVIEW OF LITERATURE

The Occurrence of Hybrid Vigor and Its Explanation.

Hybrid vigor, the manifest superiority of certain hybrids over their parents in size, yield, and general vigor, has been recognized for at least two and a half centuries. The first artifically produced plant hybrids studied, those originating from crosses made by Kolreuter during the middle of the 18th century, furnished some excellent examples. During the latter part of the same century Knight noted that hybrids were superior to pure types in plants and concluded that "nature intended that a sexual intercourse should take place between neighboring plants of the same species". Mendel's famous paper even contained an account of hybrid peas which exceeded either parent in height. Collins (1910) reported that the American Indians had regularly planted mixtures of corn to increase the yield.

The extensive studies made by Darwin during the 19th century emphasized that cross-fertilization resulted in greater vigor. However, he showed that this increased vigor resulted from the union of different germinal complexes rather than from the mere act of crossing.

G. H. Shull (1914) recognized that the decrease in size which accompanied inbreeding and the increase which was obtained by crossing were really different aspects of the same phenomenon. Along with East (1912), Shull felt that the increased vigor and yield obtained by crossing two inbred lines of corn were direct results of the heterozygosity of the hybrid plants. In 1910 Keeble and Pellew reported that the added height of the F_1 pea hybrids was simply the result of a combination of dominant factors for larger size. It was in 1914 that Shull proposed the term "heterosis" as a substitute for the awkward "stimulus of heterozygosity" and similar terms then in use.

In 1917 D. F. Jones revised the theory proposed by Keeble and Pellew to

take into account the facts then known about the linkage of factors. He showed that if there were many different sets of factors responsible for the expression of given trait, various linkage groups would exist. Desirable genes might be linked with some undesirable ones. This was offered to counteract objections to the earlier theory on the grounds that the distributions of succeeding generations from an F_1 were not skewed and that superior strains containing all the favorable dominant factors had not been obtained in one line through inbreeding and selection.

In 1936 East proposed an explanation of hybrid vigor which combined the early idea of heterozygosis and the theory proposed by Jones. His idea was that size traits were controlled by a large number of genes in different linkage groups, that dominance was not present, but that there were multiple allelic series. Each gene affects a slightly different physiological condition, thus giving maximum vigor when all gene pairs are heterozygous.

Sprague (1946) stated that heterosis is more likely the result of the action of dominant favorable genes than the result of physiological stimulation resulting from genetic diversity. Also in 1946 Hayes stated that heterosis results from several causes and he listed four of them: (1) partial dominance of linked growth factors, (2) complimentary action of genes all of which are necessary to condition the development of the character, (3) a reduction of the number of deleterious recessive factors which are likely to be in a homozygous condition, and (4) the increased stimulus from the heterozygous condition of multiple alleles that may have different physiologic effects.

Richey (1946a) concluded that the interaction of dominant favorable genes remains the most probable explanation for hybrid vigor and that highest yields tend to be obtained when the best products of selection are used in hybrid combination.

Crossbreeding Farm Animals

Considerable experimental work has been conducted during the first half of the 20th century to study the effects of crossing various breeds of all classes of farm animals. Lush (1945) has estimated that the increased performance obtained by crossing breeds of farm animals for such traits as size, fertility and growth rate is between two and eight percent.

Warren (1927) reported that birds resulting from crosses between Single Comb White Leghorn and Jersey Black Giant chickens were more productive than either parent. The crosses produced 213 eggs as compared to 162 and 174 eggs produced by the two parent breeds during the same period of time. Crossing increased the hatchability of the eggs and reduced the mortality of the chicks. Mature body weight and shank length of the crosses were intermediate to the two parent breeds. In 1928 he reported that crosses between the Single Comb White Leghorn and Rhode Island Red breeds were more viable and grew at a faster rate than purebred offspring from the same hens. The crossbred chicks produced by mating the Leghorn male to a Rhode Island Red female grew faster than those produced by the reciprocal cross. Age of the crossbreds at sexual maturity was intermediate to the two parent breeds in this experiment.

In 1941 Hess, Byerly and Jull showed that crossbred broilers gained at a faster rate and were more efficient in the use of feed than the purebred parental breeds.

Asmundson (1942) crossed several breeds of turkeys and found that some of the crosses exhibited considerably more hybrid vigor than others.

Crossbreeding of sheep has been practiced to a considerable extent in the western range area. The use of long wool and mutton type rams on the fine wool ewes has been found profitable for the sheep producers in this area.

Along the Gulf Coast, a common practice in beef cattle production has been

to cross the various British breeds of cattle with the Brahman cattle from India.

Black, Semple and Lush (1934) reported the results of an experiment conducted on the King Ranch in Texas in which Brahman bulls were bred to Hereford and Shorthorn cows. Rhoad and Black (1943) gave the results obtained by crossing Brahman cattle with the Hereford and Angus breeds of cattle in Louisiana. Hybrid vigor was quite noticeable in such items as weaning weight of the calf, weight at maturity, and rate of gain in feeding trials.

Hereford, Shorthorn and Angus breeds have been crossed at the U. S. D. A. Experiment Station at Miles City, Montana. Phillips and others (1942) reported that the crossbred calves were heavier at birth and at weaning time, made more rapid gains in the feed lot and were less susceptible to digestive disorders during the feeding period than purebred calves. No differences in the efficiency of feed utilization nor in the selling price of the two groups were found.

Crossbreeding experiments with swine have been quite numerous. Although results have varied somewhat, most of the evidence indicates that some system of crossing breeds of swine results in increased performance.

Hammond (1922) studied the weights and ages of the various breeds of swine and their crosses which were exhibited at the Fat Stock Show held by the Smithfield Club from 1901 to 1913. In several cases he found that the crosses were heavier than the larger of the parent breeds. In other cases, the crossbred animals were heavier than the average of the two parent breeds, but in one case he found that one crossbred group was smaller than the average of the two breeds.

Roberts and Laible (1925) double-mated a Duroc Jersey sow first to a Poland China and then to a Duroc Jersey boar. Six purebred Duroc pigs at birth weighed an average of 3.23 pounds while the four crossbred pigs averaged 3.75 pounds at the same time. At 180 days only two of the purebred pigs were alive and

they averaged 185.5 pounds. The four crossbred pigs which had been under similar conditions averaged 235.2 pounds at the same age. Shearer, et al (1926) made the reciprocal of the above cross and found that the purebred Poland China pigs were heavier at birth, but the crossbred pigs gained weight more rapidly after birth.

Winters and others (1935) made reciprocal crosses between Poland Chinas and Durocs and also between Durocs and Chester Whites. The crossbreds exceeded the purebreds in litter weight at birth by 13.4 percent and at weaning by 24.8 percent. They required 3.0 percent less feed and 8.7 percent fewer days to reach 220 pounds in weight. When the crossbred gilts were bred to a boar of a third breed, the advantage of the 3-breed cross pigs over the purebreds was 20.6 percent in weight of the litter at birth and 60.8 percent in litter weight at weaning. The saving in feed was 3.8 percent and the time required to reach 220 pounds was reduced by 8.6 percent. Some of the crossbred gilts were bred to a boar of one of the parental breeds. These back-cross pigs were also superior to the purebred pigs to about the same extent as were the first cross litters.

In a crossbreeding experiment including the Tamworth, Yorkshire, Poland China, Berkshire and Duroc Jersey breeds of swine, Shaw and MacEwan (1936) found no difference in the birth weights of the pigs. At weaning, however, the crossbred pigs weighed 39.4 pounds while the purebred pigs weighed 35.7 pounds. The crossbreds gained .09 of a pound more per day and required 11 pounds less feed per 100 pounds of gain than the purebreds.

A rather extensive study of the effects of crossing the Poland China and Duroc Jersey breeds of swine was reported in 1939 by Roberts and Carroll. Purebred litters of each breed were produced along with crossbred litters and litters which contained both purebred and crossbred pigs. The crossbred pigs on the average were heavier and more vigorous at birth as shown by scores given

each pig. More pigs were farrowed in those litters which contained both crossbred and purebred pigs. Purebred litters on the other hand contained more pigs per litter and fewer stillborn pigs than the crossbred litters. Mortality among the purebred pigs was a bit higher before vaccination than among the crossbreds. In the feed lot the crossbred pigs gained 1.65 pounds per day and required 402 pounds of feed per 100 pounds gain. The purebreds gained 1.59 pounds per day and required 409 pounds of feed per 100 pounds of gain.

Hutton and Russell (1939) made reciprocal crosses between the Chester White and Yorkshire breeds. The sows producing crossbred litters weaned more pigs per litter than did the sows of the same breed producing purebred litters. The crossbred pigs were significantly heavier at 70 days of age, made faster gains in the feed lot, and the gains were made somewhat more economically than either of the purebreds.

Lush and co-workers (1939) published the results of crossbreeding studies conducted at the Iowa Station between 1926 and 1937. There were 108 litters and 1015 pigs in the study. About half of these litters were produced by the double-mating of sows to a male of the same breed and one of a different breed at the same heat period. A smaller percentage of stillborn pigs was found among the crossbred pigs than among the purebreds. Survival rate among the crossbreds until weaning was higher, and they averaged three or four pounds heavier at weaning time than the purebreds. Again the crossbred pigs gained from .09 to .12 of a pound more per day and reached 225 pounds final weight on 25 to 30 pounds less feed than was required by the purebreds. Some of the crossbred sows were bred, and they proved to be efficient producers when mated either to a boar of one of the parent breeds or to a boar of a third breed.

Starkey and Godbey (1940) bred Berkshire sows to both Berkshire and Duroc boars. Both purebred and crossbred pigs were raised in each litter. The crossbred pigs were heavier than the purebreds by .58 of a pound at birth and 12.6

pounds at weaning. They gained .38 of a pound more per day in the feed lot and went to market 28 days before the purebreds. They required 329 pounds of feed per 100 pounds of gain while the purebreds required 335 pounds.

Weaver (1940) at the Missouri Station double-mated six Duroc and six Poland sows to Duroc and Poland boars. The crossbreds were slightly heavier at birth. They were larger than the heavier of the purebred groups at weaning by about two pounds. Twenty representative pigs from each group were fed to an average weight of 225 pounds. The crossbreds reached market weight two weeks earlier than either purebred group, and their gains were slightly more economical.

Headley (1940) reported that crossbred Duroc X Poland pigs when fed on pasture gained more rapidly and used 22 pounds less concentrate per 100 pounds gain than purebred Duroc pigs.

In 1942 Carroll and Roberts made a study of a large amount of published data on the effects of crossbreeding in swine. They included only those experiments in which the performance of the crossbreds and the two parental breeds were reported separately. For crossing to be considered beneficial the performance of the crossbreds had to excell the performance of the better of the two parental breeds in all of the following items: (1) number of pigs farrowed, (2) birth weight, (3) survival ability, (4) weaning weight, (5) average daily gain, and (6) economy of gain. In their study they found that the crossbreds were intermediate in all traits to the parental breeds except that they were equal to the better breed in survival ability and slightly better than the high performing purebred parent in average daily gain. If the crosses had been compared to the average of the two parent breeds, they would have been superior in all respects except in number of pigs farrowed. However, they concluded that hybrid vigor cannot be expected in the majority of crosses between breeds of swine. Rather, they looked upon it as a grading-up process, from the poorer to the better purebred parent.

Lush, et al (1948) stated that the analysis used by the Illinois workers

> "was biased systematically by two things. First, which was the better of the two pure breeds to be compared to the crossbreds was not decided until after the results were known and was decided separately in each experiment. This method leads to the "better" breed being either A or B or a mixture of them in the averages which are compared to the crossbreds. This systematically biases the evidence against the crossbreds since there are two purebred lots to choose between in each comparison but only one crossbred lot. The average bias thus introduced is about half of the experimental error per lot. Also the practical farmer must decide which breed he will actually use before he could know which is the "better" one by this method. The second source of bias was that the characters were considered singly and separately. It often happens that one breed averages better in two or three characters and the other breed in two or three others. The practical producer must raise and sell the animal as a whole rather than for each character separately. The average effects of heterosis are such as to make the superiority of the crossbred somewhat higher when the whole animal is considered than when each character is considered separately."

Bray (1948) compared crossbred pigs produced at the Louisiana Station with a herd of Production Registry Durocs. The crossbreds were the results of rotating Duroc, Poland and Hampshire boars each generation on the crossbred gilts. The crossbred litters were 4.4 pounds heavier at birth, and fewer crossbred pigs were lost before weaning. The average number weaned was nine pigs per litter, weighing a total of 352 pounds at 56 days. No particular superiority over the purebreds in rate and economy of gain could be detected.

In 1948 Robison published the results of several crossbreeding experiments with swine in Ohio. In the experiment conducted at the Miami Station, first cross, three-breed cross, and four-breed cross litters were compared with an outbred Duroc herd. At 180 days of age single cross litters were larger by .3 of a pig and heavier by 180 pounds than the purebred Durocs. The three-breed crosses were larger by .9 of a pig and heavier by 105 pounds at six months of age. The four-breed cross litters contained 1.3 more pigs and weighed 335 pounds more than the purebred Durocs at 180 days.

In the Paulding County test purebred Hampshires were compared with crossbred litters. The crossbred litters were .7 of a pig larger at 180 days and

weighed 200 pounds more than the purebred Hampshires.

In the Madison County test crossbred litters contained 1.4 more pigs and weighed 292 pounds more than the purebred Poland China litters with which they were compared.

At the main station when purebred Durocs were used as controls, crossbred Berkshire X Durocs showed no increased vigor in rate and economy of gain up to 220 pounds. Poland X Durocs exceeded purebred Durocs by .07 of a pound per day and made 100 pounds of gain on 10 pounds less feed than did the purebred Durocs. Three-breed crosses exceeded the Durocs by .05 of a pound per day in gain from birth and required approximately 6 pounds less feed per 100 pounds gained.

Inbreeding and Crossing of Inbred Lines of Animals.

The general effects of inbreeding in corn and other plants were determined by plant breeders during the early part of the current century. The use of inbred lines for the commercial production of corn had already been suggested before much data could be accumulated on the effects of inbreeding on animals. Differences in the nature of the two classes of material make this readily understandable. Differences in rates of reproduction and the possible types of matings permit a much more rapid rate of inbreeding with plants than with animals.

In 1918 and 1919 a series of papers were published by King reporting the effects of inbreeding in the albino rat. She (1918a) reported that inbred lines were superior to control outbred stock for growth rate and mature size. The inbreds were not as heavy between the 16th and 25th generations (1919) as they had been up to that time, but they were still superior to stock rats carried concurrently as outbred controls.

She (1918b) also reported that the inbred lines averaged 7.5 young per litter as compared to 6.7 per litter for the outbreds. Length of life of the

rats increased with the inbreeding. Differences in disposition between the inbred lines were noted. She (1918c) also reported that, by selection and inbreeding, the ratio of males to females had been altered.

Sewall Wright (1922a, 1922b) analyzed the data on the effects of inbreeding and crossing of inbred lines of guinea pigs which had been accumulated by workers in the Bureau of Animal Industry of the United States Department of Agriculture. This study included 23 inbred families descended from 23 females and nine males by brother-sister matings for more than twelve generations. When these inbred lines were compared with a group of non-inbred controls which were maintained under identical conditions, it was found that the inbreds had suffered a genetic decline in vigor in all characteristics studied. The decline in fertility was greater than the loss of vigor in other respects. Although most of the families came from the same stock, a striking differentiation with respect to traits connected with vigor was found among them. There did not appear to be heredity of general vigor. The average vigor of a family in one respect was found to be in the main independent of its vigor in other respects. The study demonstrated in animal material that one of the most important results of inbreeding was the bringing to light and fixing of hereditary characters in a family. Crosses between inbred families resulted in a marked improvement over both parental inbred lines in all respects. A certain portion of the increase in vigor of the first cross between inbred families was maintained on resuming random mating. He suggested

> "That the results here point the way to an important application of inbreeding in the improvement of livestock because of the low heritability of traits which are of most economic importance. By starting a large number of inbred lines, important hereditary differences in these respects are brought clearly to light and fixed. Crosses among these lines ought to give full recovery of whatever vigor has been lost by inbreeding and particular crosses may safely be expected to show a combination of desired characters distinctly superior to the original stock. Thus a crossbred stock can be developed which can be maintained at a higher level than the original stock, a level which could not have been reached by selection alone. Further im-

provement is to be sought in a repetition of the process - the isolation of new inbred strains from the improved crossbred stocks followed ultimately by crossing and selection of the best crosses for the foundation of the new stock."

In 1941 (a) Eaton reported that some crosses between inbred lines of mice exceeded both parental lines, while some crosses showed no increased vigor. Three-line crosses exhibited more vigor than single crosses - especially as expressed by fertility and viability. He (1941b) also reported the effects of crossing inbred lines of guinea pigs. The greatest improvement in fertility was obtained when two strains, which were neither extremely high nor low in fertility, were crossed. When crosses were made between lines of high and low fertility, the hybrid was usually somewhat intermediate. The same situation was true for growth rate, but viability was increased in nearly all of the crosses. Greater fertility and viability resulted from combining three families than from a cross between only two of them.

Maw (1941) reported that crosses between related inbred lines of chickens showed but little improvement over the parental lines in productivity, growth and viability. Progeny resulting from the crossing of unrelated inbred lines were superior to the parental inbred lines and to random bred controls. In 1942 he showed that the use of inbred males on outbred females gave progeny which were more productive than crosses between related inbred lines. However, crosses between unrelated inbred lines were superior to the topcross progeny and random bred Leghorns both in egg production and viability.

McPhee (1930) reported that in general there had been a decline in vigor in the inbred lines of Chester White, Poland China, and Tamworth swine at Beltsville. The reduction in weight of the pigs at birth was slight and inconsistent. A rather definite decrease in weight of inbred pigs at weaning was observed, and mortality was especially high in the Poland China line. Segregation for color factors and swirls was observed. He reported (1931)that

the attempt to establish a line of Poland China swine by mating of full-sibs had failed, due to a decreased fertility and a high mortality rate.

Godbey and Starkey (1932) summarized the results of 63 litters of Berkshire swine which were intensively inbred. There was no correlation between the inbreeding of the litter and the birth weight of the pigs. However, the more highly inbred pigs were definitely smaller at weaning time.

Hodgson (1935) found that a decrease of about 2 pigs per litter at farrowing had resulted from inbreeding Poland China swine. In the fifth and sixth generations of full-sib matings, one inbred line raised 73 percent of the pigs farrowed while another raised only 38 percent. These figures were compared to 77 percent raised in an outbred herd. Twenty-two line cross pigs reached 200 pounds weight four weeks earlier than 16 outbred pigs and seven weeks earlier than the inbred pigs.

Willham and Craft (1939) found that inbred Duroc litters after about eight generations of half-sib matings had decreased from 8.9 pigs to 5.3 pigs farrowed. There had been no decrease in an outbred herd maintained as a control. The inbred pigs were .34 of a pound smaller than outbreds at birth, and 2.9 pounds lighter at weaning time. The outbred pigs gained more rapidly than those from the inbred line at all ages. Inbred pigs required approximately 21 pounds more feed than the outbred pigs to put on 100 pounds of gain. Death losses throughout the growing and fattening period were greater in the inbred than in the outbred group.

Baker and Reinmiller (1942) studied the effects of inbreeding on performance traits in swine at Nebraska. Based upon the regression of performance upon season, when corrected for age of dam, the data did not indicate any definite trend for the nine seasons in the number of pigs farrowed, the number of pigs farrowed alive, the number of pigs weaned, the weaning weight of litter, or the productivity index of the dam. They concluded that there had been no

marked deterioration in the four lines of inbred swine due to inbreeding. Actually the regression of 180-day weight on season was positive and highly significant.

Winters, et al (1944) found that the inbreeding of the dam was a more important factor in determining number of pigs farrowed than the inbreeding of the litter.

Comstock and Winters (1944) reported that the selection practiced at the Minnesota Station had been effective in raising the average daily gains in the inbred lines at that station. However, inbreeding had depressed litter size in spite of selection for this trait.

In 1943 Winters, Comstock and Daily reported that a cross between the Landrace and Tamworth breeds of swine had been used as a foundation for the Minnesota #1 breed which at that time had inbreeding coefficients of 24 percent. The wide segregation and general deterioration in performance generally believed to accompany the subsequent inbreeding of a crossbred population did not occur.

In 1948 Winters, et al reported that inbred lines had been developed without a serious decline in vigor. Hybrid vigor was obtained when the lines were crossed. The crosses of lines from different breeds exhibited more vigor than those between lines of the same breed.

Willham (1944) found that crosses between inbred lines within the Duroc breed gained faster than either outbred or crossbred pigs.

Winters, et al (1944) reported that line cross pigs were superior to the inbred parent lines in fertility, survival, rate of gain, economy of gain, and score for body conformation. They were also superior to selected non-inbred pigs used in feeding experiments in the mid-west. These workers pointed out that superior lines appeared to produce the superior crosses.

Dickerson, Lush and Culbertson (1946), using a procedure for obtaining weighted mean differences between inbred and line cross litters, found that hybrid vigor in the pigs was greater in viability than in rate of growth. The

crosses exceeded the inbreds in total litter weight at 154 days by 72 percent. They grew more rapidly from 84 days of age to 225 pounds, but they required as much feed per unit of gain as did the inbred pigs. The performance of these single cross Poland China litters, out of dams whose inbreeding coefficients were .28, averaged about the same as published data on outbred Poland Chinas in Experiment Station herds.

In 1947 Dickerson and co-workers from four of the cooperating stations of the Regional Swine Breeding Laboratory obtained intra-season differences between inbred and single cross litters within line of dam. There were 240 inbred and 158 line cross litters of the Poland China breed and 298 inbred and 176 line cross litters of the Duroc breed. For each 10 percent rise in litter inbreeding, independent of age and inbreeding of the dams, the decline averaged in litter size 0.2 of a pig at birth, 0.4 of a pig at 21 days, 0.5 of a pig at 56 and 154 days. In pig weight there was no decline to 56 days, but a decline of 3.6 pounds was found at 154 days. The rate of decline was similar for the same breed at different stations, but was faster for Durocs than Poland Chinas, especially in litter size.

Sierk (1948) reported that crosses of inbred lines within the Poland China breed resulted in increased vigor. Crosses between lines of different breeds showed a greater increase in performance than those between lines of the same breed.

Warwick and Wiley (1949) found that crosses between an inbred Chester White line and a Landroc line were heavier at 154 days of age than outbred and crossbred swine at the Indiana Station.

Squiers, et al (1949) reported that both inbred and line cross gilts produced about 11.0 ova at the first estrus which occurred about one month earlier for the line cross gilts than for the inbreds.

DESCRIPTION OF THE DATA

During the past eleven years the Oklahoma Agricultural Experiment Station in cooperation with the Regional Swine Breeding Laboratory has been developing inbred lines within the Duroc breed of swine. In sixteen of the twenty-two farrowing seasons from the spring of 1939 through the fall of 1949, both inbred and line cross litters were produced. In some seasons outbred Duroc and three-line cross litters were farrowed. The pigs were individually identified by ear notches at birth, and weights were recorded on each pig at birth, 21 days, 56 days, and 180 days of age.

In analyzing the data for the present investigation the following intra-season comparisons were made:

I. Inbreds versus single crosses within the same line of dam.

II. Average of the two parental inbred lines versus single crosses.

III. Single crosses versus three-line crosses.

IV. Three-line crosses versus outbred Durocs (conventionally bred Durocs produced by the mating of non-related non-inbred individuals).

V. Single crosses versus outbred Durocs.

The number of litters in each of the comparisons and their distribution by season are given in Tables 1 and 2.

Birth and 56 day records were included for 444 litters, but 21 and 180 day records were available for only 371 litters. In 1949, 21 and 180 day records were not available on 73 litters. The recording of 21 day weights was discontinued this year, and complete litters were not fed from weaning to 180 days.

Dams of both inbred and line cross litters were from seven different inbred lines. Line 3 was the only line regularly represented throughout the period covered by this study. This line was started in 1938. The foundation

Table 1.

DISTRIBUTION OF LITTERS BY SEASON AND COMPARISON

Season Farrowed	Line of Dam	Number of Litters: Comparison I Inbreds	Comparison I Crosses	Test Litters Inbreds	Test Litters Crosses
39S	3	9	4	3	2
39F	1	5	1		
	3	6	7	3	2
40S	2			2	1
40F	3	5	2	3	2
	1			2	1
41S	3	10	2	6	2
	2			1	1
41F	1	5	7	1	5
	3	10	4	4	3
	4			3	2
42F	1	3	5		
	3	9	5	1	4
43S	1	4	3		
	3	11	3	2	4
43F	3	7	7		
44S	3			5	2
44F	3	5	7		
45S	1	3	5		
	3	6	11		
45F	3	10	4	4	2
	6	4	5		
46S	3	9	7		
47F	3	5	4	2	1
	5	6	7	2	3
	7	4	3	2	2
48F	3	3	6	2	3
	5	3	6	2	4
	7	2	5	2	3
Total		145	120	52	49

Table 2.

DISTRIBUTION OF LITTERS BY SEASON AND COMPARISON

Season Farrowed	Number of Litters							
	Comparison II		Comparison III		Comparison IV		Comparison V	
	Inbred Litters	Single Cross	Single Cross	3-Line Cross	3-Line Cross	Outbred Duroc	Single Cross	Outbred Duroc
39S	16	4						
39F	11	7						
40F	10	2						
41S	15	2						
41F	15	4						
42F	12	5	10	6	6	7	10	7
43S	15	6					6	6
43F			20	3	3	5	20	5
44F			10	10				
45S	9	16					16	5
46S			17	3				
47S	15	14						
48F	9	16	17	2				
49S*							12	3
49F							25	3
49F*	---	---	---	---	14	2	6	2
Total	127	76	74	24	23	14	95	31

*Litters raised in dry lot on concrete floors.

stock consisted of ten females purchased from the Cameron herd located at Herman, Nebraska and one bred gilt selected from the Joe Pudenz herd at Carroll, Iowa. The three foundation boars were the sires of four litters purchased in dam from these two herds. Since 1939, this line has been bred as a closed line. During the period from 1940 to 1942, the line was split into two sub-lines, but they were later combined again into one line. The average inbreeding for the line has risen from almost zero in the first year of this study to approximately 25 percent in 1949. The average inbreeding of the boars and sows, weighted by the number of litters they produced in this study, was 16.4 percent. The growth rate of the pigs and the productivity of the sows have been above average. The type of this line would be considered intermediate.

Line 1 was used considerably during the first six years, but this line was discarded in 1946 because of its poor performance as an inbred line. In 1923, three sows and one boar from the Oklahoma A. and M. College herd were placed on an inbreeding experiment. Their descendants were bred by half-brother X half-sister matings until 1938. At this time, several sows of the line were bred to an unrelated outbred boar. Several individuals from this outcross were introduced into the line. It was then bred as a closed line until 1946. The average inbreeding of this line during the time it was used in this study was 37.2 percent. In contrast to other lines in this study, the average inbreeding of this line did not vary greatly from season to season. Mortality rate was quite high, and the growth rate of the inbred pigs was definitely low in this line. That the sows were good mothers was indicated by the performance of their non-inbred litters.

Line 2 contributed only a few litters to this study. The average inbreeding of the line at the time it was culled in 1941 for poor performance was about 17 percent.

Line 4 individuals which produced only a limited number of litters included in this investigation, were only 7.1 percent inbred on the average. The foundation animals were quite productive but the line was culled in 1943 because inverted nipples had become fixed in the line.

In 1942 the foundation stock for Line 5 was acquired from four different herds. In 1946, an outcross was made by adding breeding stock from a fifth herd. Except for litters produced during 1947, 1948 and 1949, this line was not uniformly inbred. The average inbreeding of the individuals producing either line cross or inbred litters was 10.0 percent. Individuals in this line were fairly long bodied, leggy, and a bit coarse. The sows were good producers but somewhat nervous.

In 1943 several sets of litter mates were purchased and some of them mated brother X sister to form Line 6. Some of the foundation animals, which were not inbred, as well as a few of the first generation inbreds were crossed with other lines. The individuals which produced litters that were included in the present investigation were only slightly inbred - 3.3 percent on the average.

Line 7 was formed by crossing three boars and one sow from one full-sib group of Line 6 with Line 1. The parents of this group of full-sibs had come from the herd of Willard Klein at Iowa Falls, Iowa. The average inbreeding of the individuals of this line which contributed offspring to the study was 13.4 percent. This line was discarded in 1949.

The lines used in crosses were in each case unrelated except insofar as they belonged to the same breed. Lines 1 and 7 are the only lines with a common origin, and these lines were never crossed. Actually line 7 is an outcross descendent of line 1 and replaced line 1 in the experiment. Foundation stock for the lines came from quite diverse stock within the Duroc breed. This may have some bearing on the results obtained by crossing lines.

The general practice in the experiment was to produce litters both in the spring and in the fall. The litters were farrowed in a central farrowing barn and the sows and litters were moved to small houses on pasture after three to four days. The pigs were creep-fed and the sows were fed standard rations. The pigs were weighed at 21 days, vaccinated for cholera and castrated before weaning. They were weaned for the most part at 56 days. The weights of the small number of litters which were not weaned on the 56th day were corrected to 56 day weight using correction factors reported by Whatley and Quaife (1937).

After weaning, the pigs were fed in groups sorted according to age and sex of the pigs. Weights were taken every two weeks after the pigs were five months old and the weights nearest 180 days were adjusted to that age. The rations and systems of management have changed slightly from season to season but the various lines and crosses received comparable treatment within the same season.

Rotation of pastures for control of internal parasites was practiced, but the rotation was inadequate resulting in considerable difficulty with roundworms, especially in the last five years. Within recent years routine treatment for roundworms in the growing pigs was practiced. This treatment was beneficial but did not give complete control. The herd has been clear of infectious abortion and no serious outbreaks of disease occurred during any of the seasons included in this study. Isolated cases of various skin disorders have occurred, the cause of which has not been determined.

MEASURES OF PERFORMANCE

A review of the literature reveals that the increased vigor obtained by crossing inbred lines of laboratory and farm animals might be expressed by one or more of the following: (1) larger size of the litter at birth, (2) increased viability, (3) increased growth rate, and (4) more efficient use of feed. The items of vigor were not shown to be highly correlated, although rate and efficiency of gain have sometimes shown a very close association. Inbred lines were formed which were characterized by various combinations of traits.

During the formation of the inbred lines of swine, a reduction in the number of live pigs farrowed per litter was generally noted. A higher percentage of these inbred pigs died before reaching a marketable weight. The pigs in many of the lines grew at a slower rate, and in some of the lines, they required more feed per unit of gain.

Crosses between the various breeds of swine were reported to be superior, on the whole, to the average of the parental breeds. In most instances, the crossbred pigs were more vigorous as shown by larger number of pigs per litter and by a more rapid rate of gain. They reached market weight from one to three weeks earlier than the purebreds. In some cases this resulted in a considerable saving in feed cost. In crosses between inbred lines within the same breed, Dickerson found that most of the vigor expressed was in the form of increased viability, although there was a general tendency for a greater proportion of the faster growing pigs to survive.

The number of pigs raised per sow and the growth rate of the pigs to a marketable weight are two important considerations in swine production. Since heterosis may be expressed in either or both of these factors, total litter weight was selected as the one best over-all measure of performance for this investigation. It is comparable to "yield per acre" which has been widely

used in variety tests by the plant breeder.

Earlier studies have emphasized the extremely important role of the sow in providing the proper environmental conditions for the litter during a relatively long period of time. The first 114 days of the pig's life is spent in the uterus of its dam where it is completely dependent upon the sow for its nourishment. From farrowing until about 21 days of age, the litter depends almost exclusively upon the milk of the sow for its growth. Milk remains an important constituent in the diet of the pig until it is weaned, but it begins to eat supplemental feeds at about three weeks of age. It, therefore, becomes less dependent upon the direct mothering ability of its dam as it grows older. Whether a litter is heavy or light at weaning time is certainly influenced to a great extent by the fertility, temperament, and milking capacity of its dam. The previous treatment of the litter by its dam undoubtedly influences its post-weaning performance. However, all litters depend upon the same source of feed between weaning and six months of age. Genetic differences among groups of pigs are more likely to be detected between weaning and six months of age because environmental conditions are more nearly alike for all groups at this time. However, litter weights at birth, 21, 56, and 180 days were studied in order to determine the time at which any expression of heterosis might first become evident.

Along with the litter weights at the four different ages, it was decided that the number of live pigs would give an indication of the relative importance of fertility and/or viability on litter weight.

Rate of gain of the individual pigs from about weaning time to market weight of about 225 pounds, along with the amount of feed consumed per one hundred pounds of gain, were the measures used for checking the differences in performance in one group of pigs. This group of test litters were samples drawn from the larger group of litters farrowed in these seasons. They permitted a more

direct measurement of the post-weaning rates of gain. They were the only measures available for checking efficiency of feed utilization in this study.

METHOD OF ANALYSIS

Other than the breeding of the litter some of the sources of variation which were considered important in determining total litter weight and number of pigs per litter were: (1) seasonal fluctuations in environment and changes in management from season to season, (2) age differences among the dams, (3) differences in maternal abilities which may be characteristic of different lines, and (4) differences in the coefficients of inbreeding among sows of the same line.

For this study all litters farrowed by sows were corrected to a gilt equivalent using correction factors obtained from the data and presented in Table 5. The analysis was restricted to comparisons within the same season so that changes in management and unavoidable differences due to season would be minimized. This restriction automatically reduced the mean differences in the coefficients of inbreeding among the sows of the same line.

In Comparison I, the mean differences were restricted to those between inbred and line cross litters produced by the same line of dam. Obviously this restriction could not be made in the other comparisons which include the following: II, in which the single crosses were compared to the average performance of the two parental inbred lines; III, in which the single crosses were compared to three-line crosses; IV, in which outbred Duroc and three-line cross litters were compared; and V, in which single crosses were compared to outbred Durocs.

There were unequal numbers of litters in the various lines and seasons. Yates (1934) suggested a procedure for weighting the mean difference in proportion to the reciprocal of its variance. The formula for this and a set of data to illustrate the procedure used are given in Table 3. This system for weighting the mean differences places most emphasis upon those comparisons which are most reliable from the standpoint of number and distribution of litters.

Dickerson (1946) used this method for weighting mean differences on similar data and suggested its use in the present investigation. A sample analysis of variance of the data used in Table 3 is given in Table 4. It illustrates the procedure used for testing the significance of the weighted mean differences obtained for the various items.

Table 3

METHOD USED FOR OBTAINING WEIGHTED MEAN DIFFERENCES WITHIN SEASON AND LINE OF DAM

Season	Line of Dam	Line Cross: No. Litters (nc)	Line Cross: Mean Pigs per Litter (C)	Inbred: No. Litters (ni)	Inbred: Mean Pigs per Litter (I)	Mean Diff. (C-I)=D	Wt. for Mean Diff. W[1]	Wt'd. Mean Diff. (W)(D)
39S	1	4	9	4	6	+3	2.0	+6.0
	3	2	8	6	7	+1	1.5	+1.5
	5	8	7	8	8	-1	4.0	-4.0
40F	1	2	8	2	6	+2	1.0	+2.0
	3	1	8	1	6	+2	0.5	+1.0
	5	9	8	1	6	+2	0.9	+1.8
Total		26		22			9.9	+8.3

Total Wtd. Mean Heterosis = $\frac{S(WD)}{(SW)_t} = \frac{8.3}{9.9} = 0.84 = \bar{D}_t$

Weighted Mean for a season (39S) = $\frac{S(WD)y}{(SW)y} = \frac{6.0 + 1.5 + (-4.0)}{2.0 + 1.5 + 4.0} = + \frac{3.5}{7.5} = +0.47 = \bar{D}y$

Dy for (40F) = $\frac{2.0 + 1.0 + 1.8}{1.0 + 0.5 + 0.9} = \frac{4.8}{2.4} = 2.00$

[1] $W = \frac{1}{\frac{1}{nc} + \frac{1}{ni}} = \frac{(nc)(ni)}{nc + ni}$

Example: W for 39S line of dam 1 = $\frac{(4)(4)}{4+4} = 2.0$

S = Sum
Subscript y = Season
Subscript t = Total

Table 4

SAMPLE ANALYSIS OF VARIANCE OF DATA IN TABLE 3

a. Method and Components of Variance

Source of Variation	D. F.	Mean Square	Sums of Squares
Wt'd. Mean Heterosis	1	$L + yY + hH$	$\bar{D}_t^2 (SW)_t$
Heterosis X Season	1	$L + yY$	$S(\bar{D}y^2)(Wy) - \bar{D}_t^2(SW)_t$
Heterosis X Line of Dam within Season	4	L	$S(D^2)(W) - S(\bar{D}_y^2)(W_y)$

b. Example of Calculations

Source of Variation	D. F.	Mean Square	Sums of Squares
Wt'd. Mean Heterosis	1	6.99	$(0.84)^2 (9.9) = 6.99$
Heterosis X Season	1	4.27	$(0.47)^2 (7.5) + (2.0)^2 (2.4) - (0.84)^2 (9.9) = 11.26 - 6.99 = 4.27$
Heterosis X Line of Dam within Season	4	5.46	$(3)^2 (2.0) + (1)^2 (1.5) + (-1)^2 (4.0) + (2)^2 (1.0) + (2)^2 (0.5) + (2)^2 (0.9) - [(0.47)^2 (7.5) + (2.0)^2 (2.4)] = 33.1 - 11.26 = 21.84$

CORRECTION FACTORS FOR AGE OF DAM

A preliminary analysis of the data revealed that the dams of the inbred litters were approximately one-third year older than the dams of the line cross litters. Since very few sows in this study were more than two years old, this difference was a very important source of bias in favor of the performance of the inbred litters. It is known that the reproductive capacity of the sow increases rather sharply from twelve to eighteen months of age. In addition to this source of bias, the sows which farrowed more than one litter were selected on the basis of their previous litters. These two items in favor of the inbred litters were sufficient to mask or reduce the expressions of hybrid vigor when the line cross litters were compared to inbreds within the same line of dam. The greatest effect of these factors on litter performance occurred at birth and at 21 days of age, but the same effect was evident at weaning and to a lesser extent at 180 days of age.

If the comparisons were limited to those litters which were from sows of the same age, the number of litters which could be used for analysis was reduced to about one-third the total number available when age of dam was ignored. Although the number of litters was greatly reduced, it was found that when there was no difference in the ages of the dams the line cross litters were superior to the inbred litters in performance at all ages.

In order to make maximum use of all available information in this study, a set of correction factors was computed from the data so that the effects due to differences in the age of sows might be minimized.

The procedure was to obtain the weighted mean differences between the gilt litters and those from the sows of the various age groups. Comparisons were confined to those which occurred within the same season. A separate set for inbred and non-inbred litters was obtained. Although the differences were

somewhat larger between the age groups when they were producing inbred litters, the two groups were pooled to obtain the factors used in this study. If their use in this study was a source of error, the bias was relatively small and in favor of the inbred litters.

It should also be realized that there is some correction for the selection of the sows in this age correction. Therefore, the use of these factors may not be of value in another herd where selection of sows may have been of different intensity.

The factors given in Table 5 were used to correct all sow litters to a gilt equivalent age. Although published correction factors at all ages were not available for comparison with these, those obtained from this study are larger than those reported for numbers of pigs at birth and weaning. One possible explanation was that this population of older sows may have been more highly selected than those in the other studies. In addition the inbreeding of the sows within this study might have caused a greater spread between their performance as gilts and as older sows if the inbreeding has caused a delay in sexual maturity of the gilts. There is some experimental evidence that this delayed sexual development has occurred in some inbred lines.

Table 5

CORRECTION FACTORS USED FOR CORRECTING SOW LITTERS TO GILT BASIS

Age of Sows	No. Litters Sow	No. Litters Gilt	Total No. Farr.	Live Pigs Farr.	Live Wt. Farr.	No. 21 Days	Wt. 21 Days	No. 56 Days	Wt. 56 Days	No. 180 Days	Wt. 180 Days
1.0			1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1.5	105	183	.821	.803	.731	.879	.813	.881	.776	.855	.766
2.0	66	152	.760	.766	.693	.920	.798	.909	.759	.871	.796
2.5	37	93	.705	.753	.649	.862	.772	.875	.746	.847	.774
Mean Performance of 371 litters corrected to gilt basis for this study			7.85	7.38	17.85	6.09	57.4	5.90	145.6	5.17	769
Average weight per pig					2.42		9.43		24.7		148.7

RESULTS

The study has been divided into five different comparisons. Each one of them was studied to gain information of a different nature. Since many of the litters have been used in more than one comparison, it must be pointed out that some of the studies are not completely independent. However, this does not invalidate the conclusions drawn. The results of each comparison will be presented separately.

Comparison I

The weighted mean differences between inbred litters and line cross litters with the same line of dam were obtained according to the procedure outlined earlier. This comparison included 145 inbred litters and 120 line cross litters in 14 seasons. The distribution of these litters by season and line of dam is presented in Table 1. The results are presented in Table 6. There was no difference in the inbreeding coefficients of the dams of the two groups of pigs. The inbred pigs had coefficients of inbreeding which averaged .22 while the line cross litters were not inbred. The sires of the inbred litters were not quite so highly inbred as those of the line cross litters, but line and inbreeding of the sire were ignored in this comparison. The line cross litters were heavier than the inbreds at birth, 21, 56, and 180 days by 1.22, 7.42, 23.5, and 180.5 pounds respectively. At the same ages the line cross litters contained 0.43, 0.76, 0.85, and 1.08 more live pigs than the inbred litters. In total number farrowed the average difference in favor of the line cross litters was 0.58 of a pig.

The differences in number of pigs per litter at 21 and 56 days and the difference in litter weights at 56 days were significant at the 5 percent level of probability as shown in Table 7. The differences in both number of pigs per litter and litter weight at 180 days were significant at the 1 percent

Table 6.

WEIGHTED MEAN DIFFERENCES WITHIN SEASON, AGE OF SOW CORRECTED TO ONE YEAR.

	Comparisons				
	I	II	III	IV	V
Fx of litters	- 22%	- 26%	0	0	0
Fx of sire	+ 14%	+ 8%	-14%	+13%	+29%
Fx of dam	0	- 5%	-24%	0	+25%
At birth					
Total no.	+ 0.58	+ 0.74	+ 1.64**	+ 0.93	-0.97
No. live pigs	+ 0.43	+ 0.48	+ 1.36*	+ 1.17*	-0.92
Live wt. litter(lbs)	+ 1.22	+ 1.68	+ 2.94*	+ 2.75*	- 2.01
At 21 days					
No. pigs	+ 0.76*	+0.74	+1.15*	+ 1.60	-0.39
Litter wt. (lbs)	+ 7.42	+8.76	+9.55*	+13.01	- 5.31
At 56 days.					
No. pigs	+ 0.85*	+ 0.88	+ 1.20*	+ 1.49	- 0.28
Litter wt. (lbs)	+ 23.50*	+30.21	+29.68*	+24.73	-13.34
At 180 days					
No. pigs	+ 1.08**	+1.31	+1.66	+2.19	- 0.35
Litter wt. (lbs)	+180.9 **	+235.0	+ 297.8 *	+ 328.8	-13.5

*Denotes significance at the 5% level of probability.
**Denotes significance at the 1% level of probability.

level. In Comparison I the mean square for Heterosis X Line of Dam within Season was used as the error term for testing the significance of Weighted Mean Heterosis (Weighted Mean Difference) and Heterosis X Season. None of the interactions of Heterosis X Season were significant. If the sums of squares and the degrees of freedom for Heterosis X Season and Heterosis X Line of Dam within Season were pooled and used as the error term, the differences in number of pigs per litter and in litter weights at all ages, except at birth, would have been highly significant statistically.

This comparison gives an estimate of the effect of the heterozygosity of the pigs on litter performance when line and inbreeding of the dams are the

same. The weighted mean differences in litter weights for each of the comparisons at birth, 21, 56, and 180 days are presented graphically in Figures 1, 2, 3, and 4.

In Table 8 the mean performance of the 145 inbred litters is presented under Comparison I. The increased performance of the 120 line cross litters in this comparison (expressed in percentage advantage) is also given. These advantages are graphically presented in Figure 5. It is interesting that a 6.0 percent increase in number of live pigs per litter at birth was associated with a 7.1 percent increase in live weight of the litter at the same time. At 21 days the line cross advantage in number of pigs was 13.5 percent while the advantage in 21 day litter weight was 14.1 percent. Corresponding increases in number of pigs per litter and litter weight at 56 days were 15.8 percent and 17.9 percent and at 180 days were 23.6 percent and 27.0 percent.

These figures clearly reveal that the differences in the number of live pigs and in litter weight increased as the pigs grew older. At the same time they suggest that the differences in litter weights were due largely to the increased viability of the line cross pigs. The increased number of live pigs per litter was sufficient to account for about 85 percent of the difference in litter weight at birth, 96 percent of the advantage at 21 days, 88 percent of the increase at 56 days, and 87 percent of the difference at 180 days.

Efficiency of Gain

During twelve of the seasons line cross and inbred pigs with the same line of dam were placed on record of performance test shortly after weaning. Usually four pigs from each litter tested were fed a standard ration in dry lot from weaning to approximately 225 pounds weight. The distribution of the 49 line cross and 52 inbred litters by season and line of dam is given in Table 1. There was no difference in the average initial weights of the two groups of

Table 7

ANALYSIS OF VARIANCE FOR COMPARISON I
(SINGLE CROSSES MINUS INBREDS WITHIN LINE OF DAM)

a. Number of Pigs per Litter

Source of Variation	D. F.	Mean Squares				
		Tot. Farr.	Live Farr.	21 Days	56 Days	180 Days
Wt'd. Mean Heterosis	1	20.08	11.04	34.48*	43.13*	69.63**
Heterosis X Season	13	2.81	1.10	2.34	1.02	2.45
Heterosis X Line of Dam within Season	10	5.15	5.25	4.87	6.38	6.37

b. Litter Weight

Source of Variation	D. F.	Mean Squares			
		Birth	21 Days	56 Days	180 Days
Wt'd. Mean Heterosis	1	88.85	3,286	32,965*	1,953,874**
Heterosis X Season	13	9.16	164	1,290	98,341
Heterosis X Line of Dam within Season	10	37.06	703	3,305	152,727

c. Efficiency of Gain

Source of Variation	Degrees Freedom	Mean Squares
Wt'd. Mean Heterosis	1	820
Heterosis X Season	11	1,107
Heterosis X Line of Dam within Season	8	531

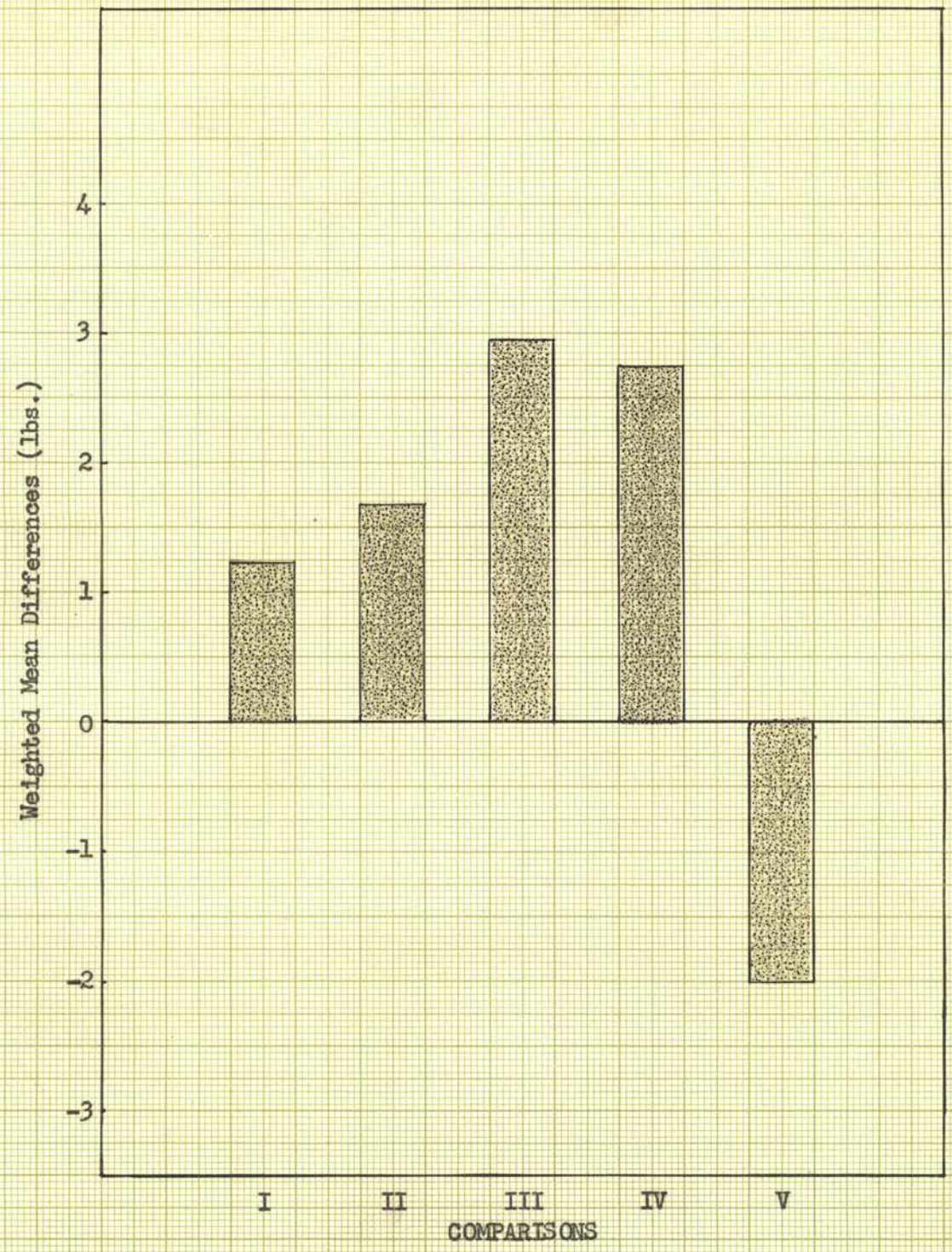

Figure 1. Weighted mean differences in litter weight at birth for each comparison.

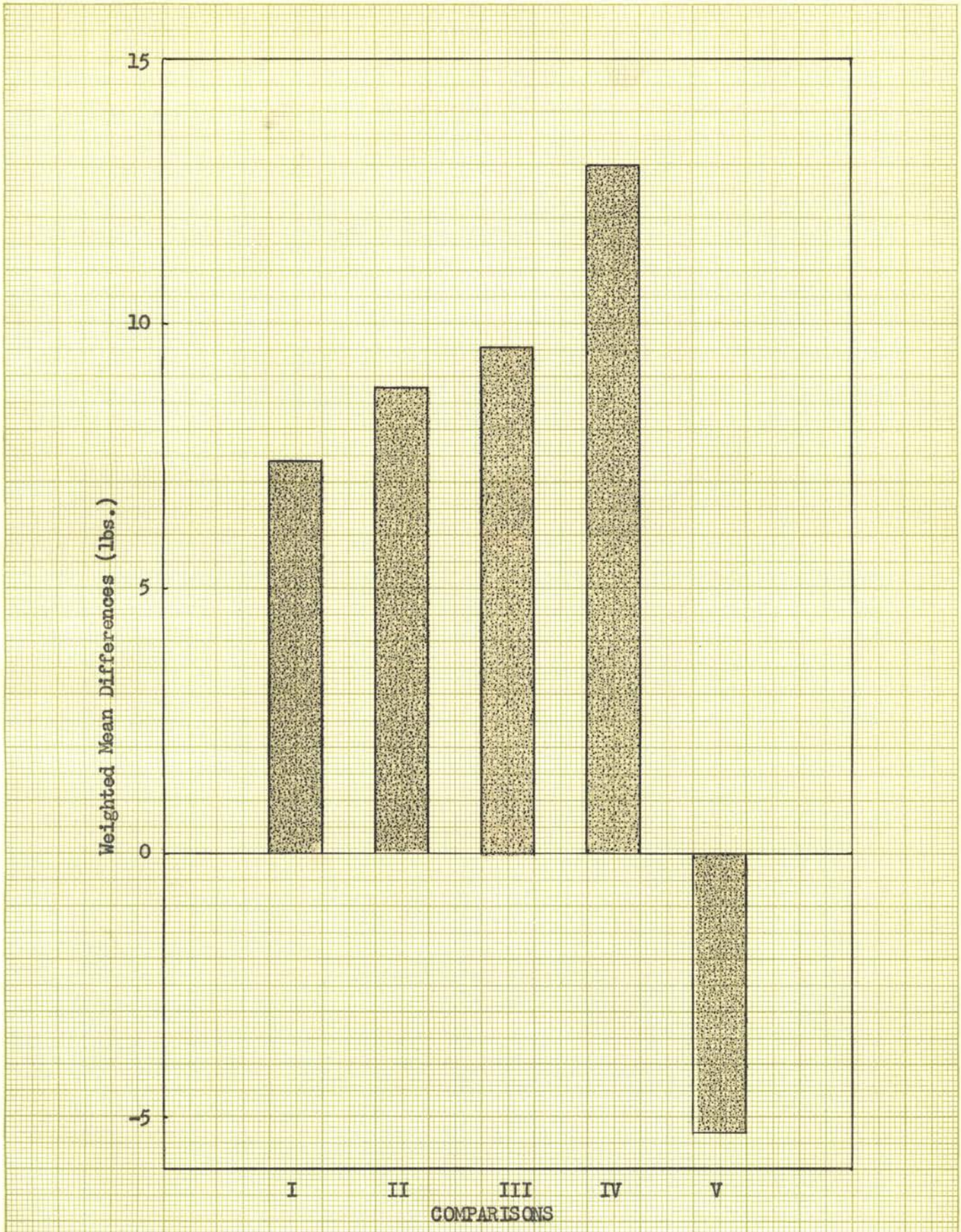

Figure 2. Weighted mean differences in litter weight at 21 days for each comparison.

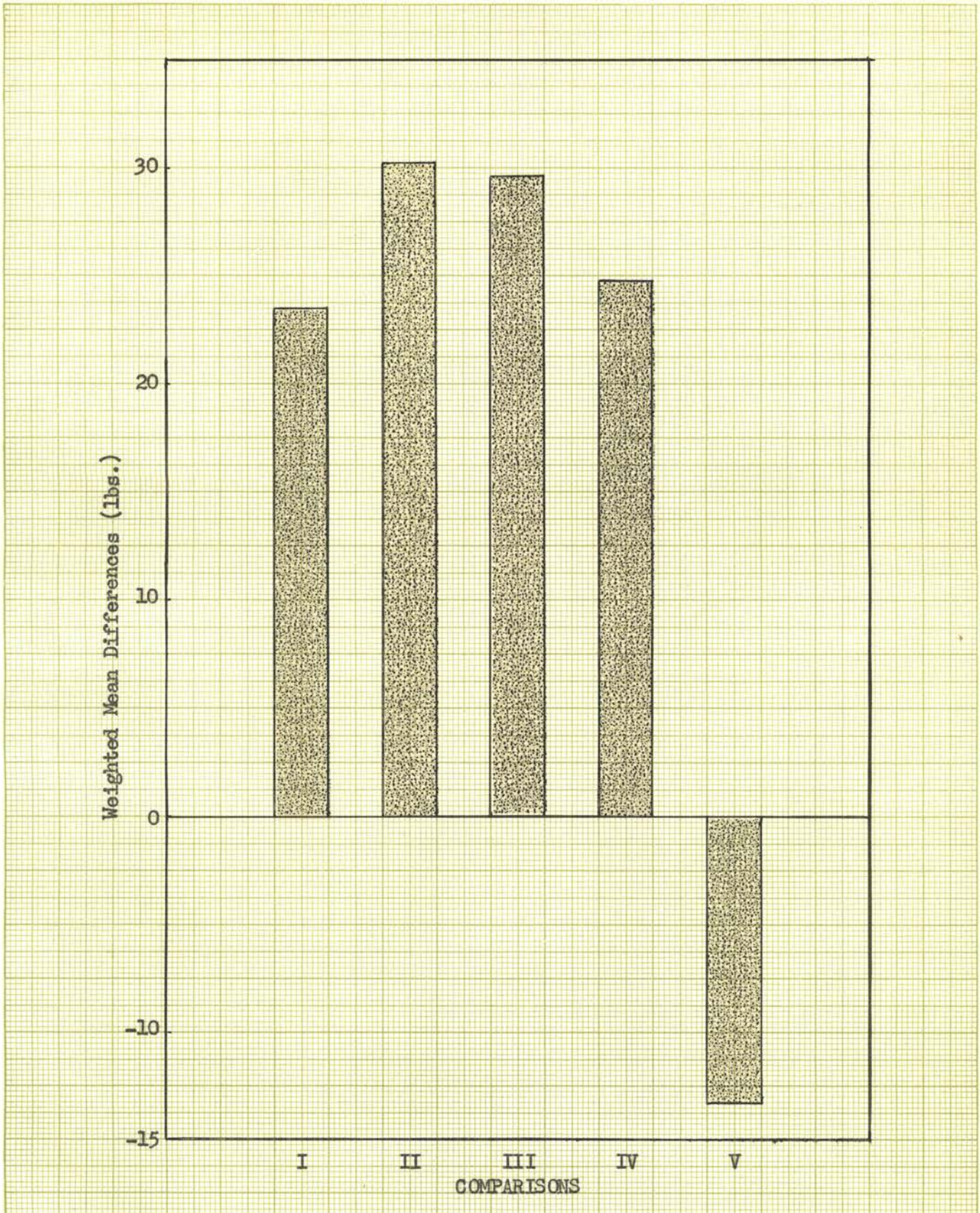

Figure 3. Weighted mean differences in litter weight at 56 days for each comparison.

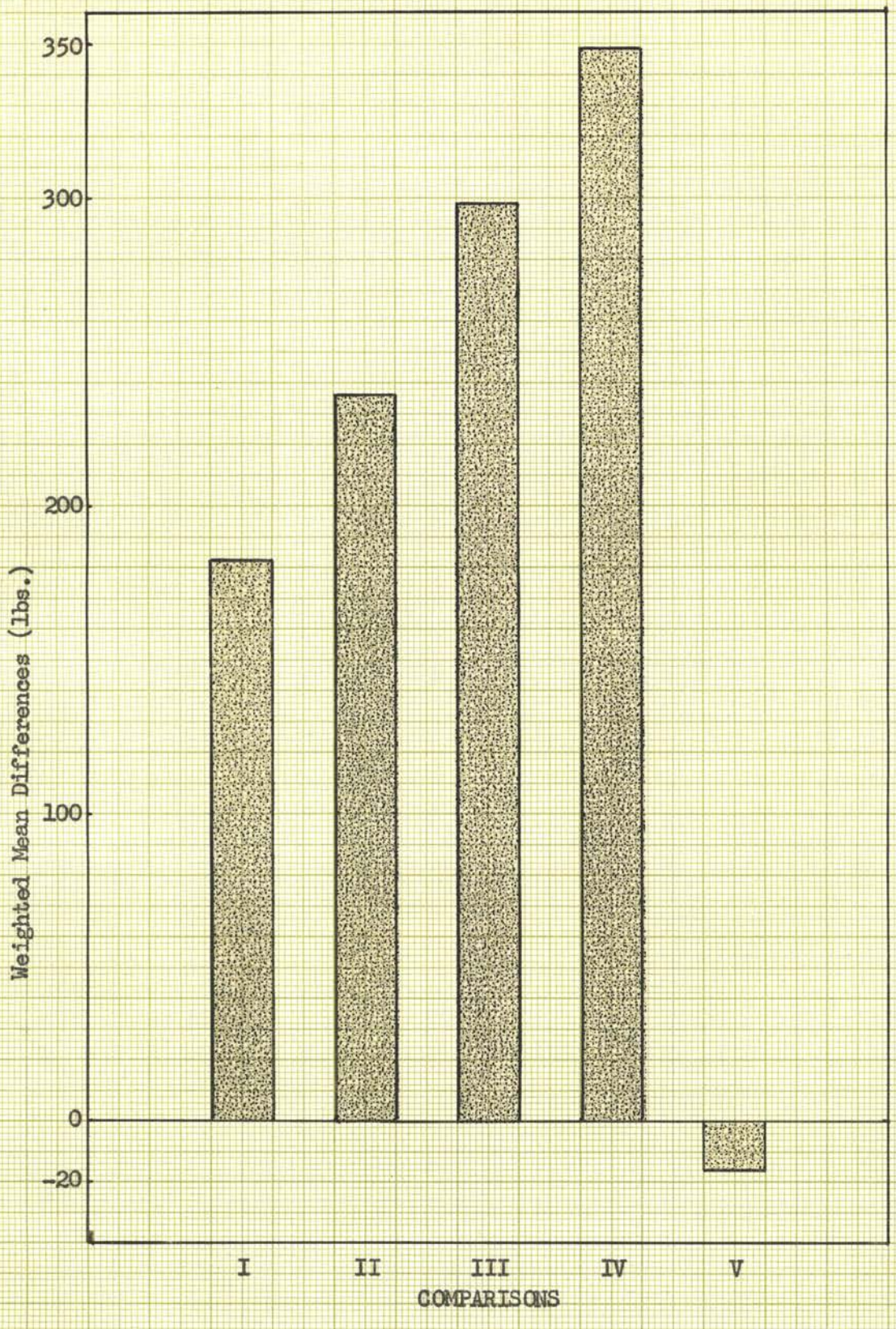

Figure 4. Weighted mean differences in litter weight at 180 days for each comparison.

Table 8.

MEAN PERFORMANCE AND PERCENTAGE ADVANTAGE IN LITTER WEIGHTS AND NUMBER OF PIGS PER LITTER AT FOUR DIFFERENT AGES.

	Comparison I		Comparison II		Comparison III	
	Mean of Inbreds	Percentage Advantage of Crosses	Mean of Inbreds	Percentage Advantage of Crosses	Mean of Single Crosses	Percentage Advantage of 3-line crosses
At Birth						
Total number farrowed	7.54	7.7	7.47	9.9	7.66	21.4
Live pigs farrowed	7.11	6.0	7.06	6.8	7.29	18.7
Live litter weight	17.14	7.1	16.83	10.0	17.61	16.7
At 21 Days						
Number of pigs	5.62	13.5	5.55	13.3	6.39	18.0
Litter weight	52.78	14.1	51.06	17.2	61.31	15.6
At 56 Days						
Number of pigs	5.37	15.8	5.25	16.8	6.27	19.0
Litter weight	131.3	17.9	123.9	24.4	159.4	18.6
At 180 Days						
Number of pigs	4.58	23.6	4.35	30.1	5.66	29.3
Litter weight	669.4	27.0	606.9	38.7	889.3	33.5

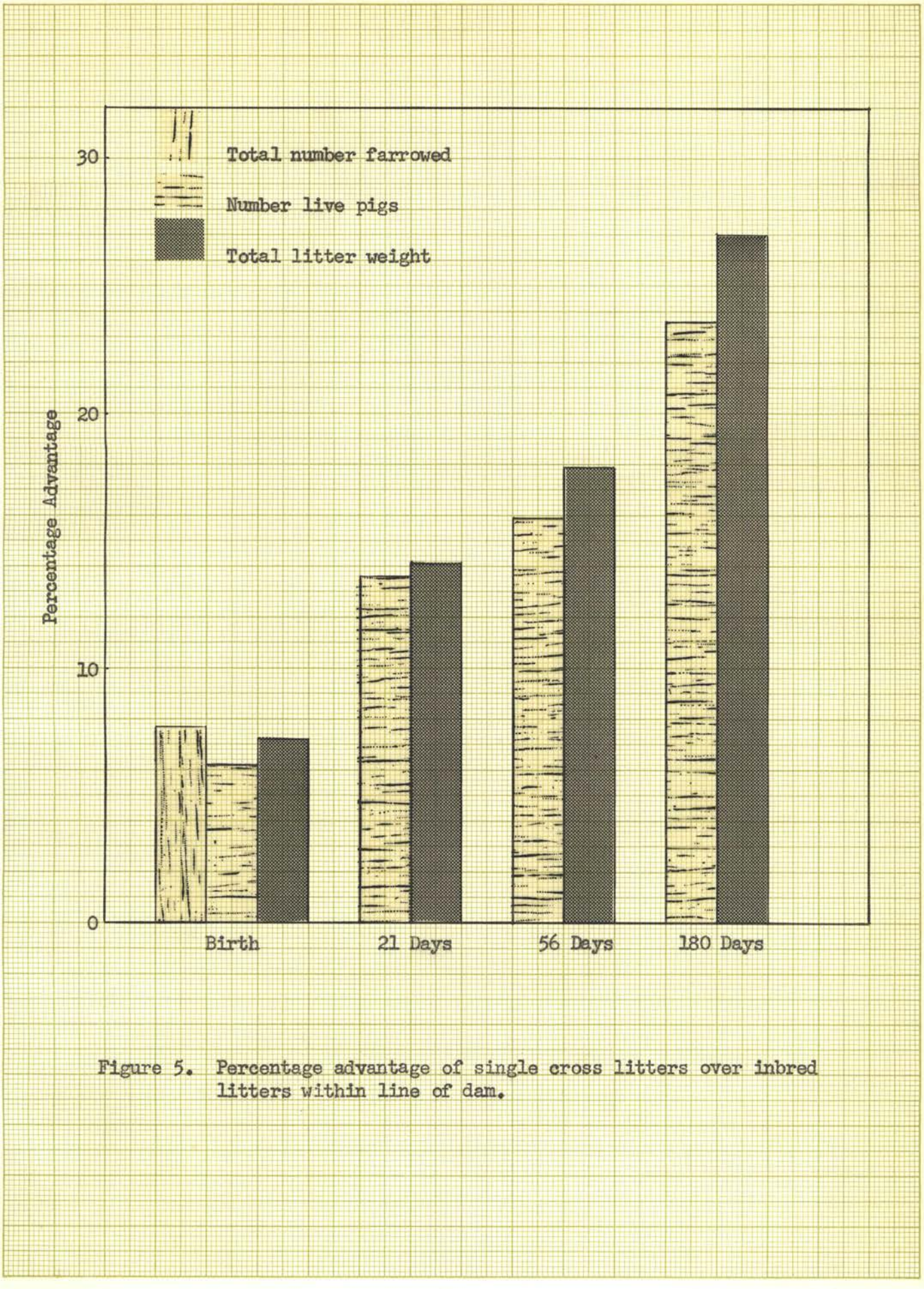

Figure 5. Percentage advantage of single cross litters over inbred litters within line of dam.

pigs nor the average inbreeding of their dams. The line cross pigs gained .03 of a pound per day more rapidly than did their inbred counterparts. They required six pounds less feed per 100 pounds of gain than did the inbreds. These differences were not significant at the commonly accepted level of probability. However, the increased rate of gain found here checked closely with the increased litter performance in Comparison I, after increased number of pigs per litter had been considered. The small difference in favor of the line cross pigs in efficiency of gain is not greatly different from other reports in this respect.

Comparison II

The performance of line or breed crosses has often been compared to the average performance of the two parental lines or breeds in other studies of the effects of crossing. There were ten seasons in this study in which line cross litters and inbred litters of both the parental lines were produced. Table 2 gives the distribution of 127 inbred and 76 line cross litters by seasons. The weighted mean differences within season for the number of pigs per litter and for total litter weights are given in Table 6. The differences in favor of the line cross litters are somewhat greater in this comparison than those in Comparison I. The differences in litter weights in favor of the crosses in Comparison II were 1.68 pounds at birth, 8.76 pounds at 21 days, 30.21 pounds at 56 days, and 235.0 pounds at 180 days. Corresponding increases in number of live pigs per litter were 0.48, 0.74, 0.88, and 1.31. The mean performance of the 127 inbred litters in this comparison (Table 8) was somewhat lower than the inbreds of Comparison I, thus accounting for some of the increased advantages of the line cross litters in this comparison. An examination of Figure 6 reveals that between 70 and 80 percent of the increased litter weight at the different ages may be attributed to an increased number of live pigs per litter.

All of the line cross litters and most of the inbred litters in this comparison had been used in Comparison I. For this reason no test for statistical significance of the differences was made.

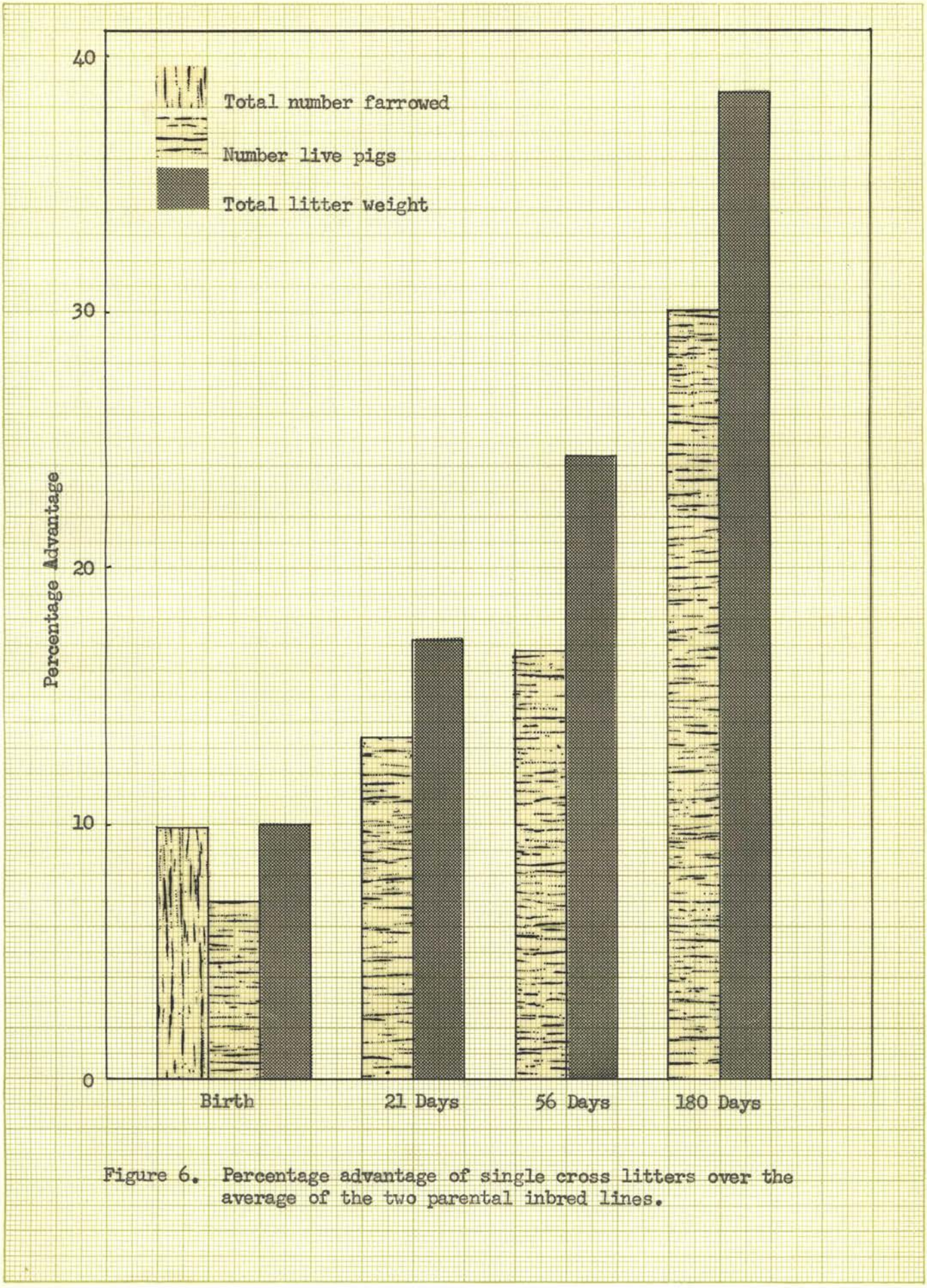

Figure 6. Percentage advantage of single cross litters over the average of the two parental inbred lines.

Comparison III

Some of the line cross gilts were bred to an inbred boar of another line and produced litters designated as "three-line cross" litters. During five seasons they occurred along with single cross litters. A direct comparison of the two groups gave a measure of the effect of the heterozygosity of the dam in combination with that of their litters. Table 2 shows the distribution of the 74 single cross and 24 three-line cross litters by seasons. Neither of the groups of pigs were inbred, but the single cross litters were farrowed and nursed by sows which had inbreeding coefficients of .24. The weighted mean differences in number of pigs per litter and in litter weight at all ages (Table 6) were quite large and very consistent from season to season in favor of the three-line cross litters. In litter weight the three-line crosses exceeded the single crosses by 2.94 pounds at birth, 9.55 pounds at 21 days, 29.68 pounds at 56 days, and 297.8 pounds at 180 days. Their advantage in number of live pigs per litter at the same ages were 1.36, 1.15, 1.20, and 1.66. When these weighted mean differences were converted to percentage increases over the mean performance of the single cross litters (Table 8), a striking difference between this comparison and the two preceding ones became apparent. This is shown in Figure 7. At birth, 21 days, and 56 days the three-line cross litters showed a greater advantage in number of live pigs than in litter weight. At 180 days the 29.3 percent increase in number of live pigs per litter was associated with 33.5 percent increase in litter weight. Apparently before weaning, the increase in number of live pigs in the three-line cross litters had been large enough to reduce the growth rate of the individual pig below that of pigs in the single cross litters which were smaller in number of pigs. The fact that they gained more rapidly between weaning time and 180 days of age indicates the three-line cross pigs had the ability to gain as rapidly as single crosses, but that their preweaning

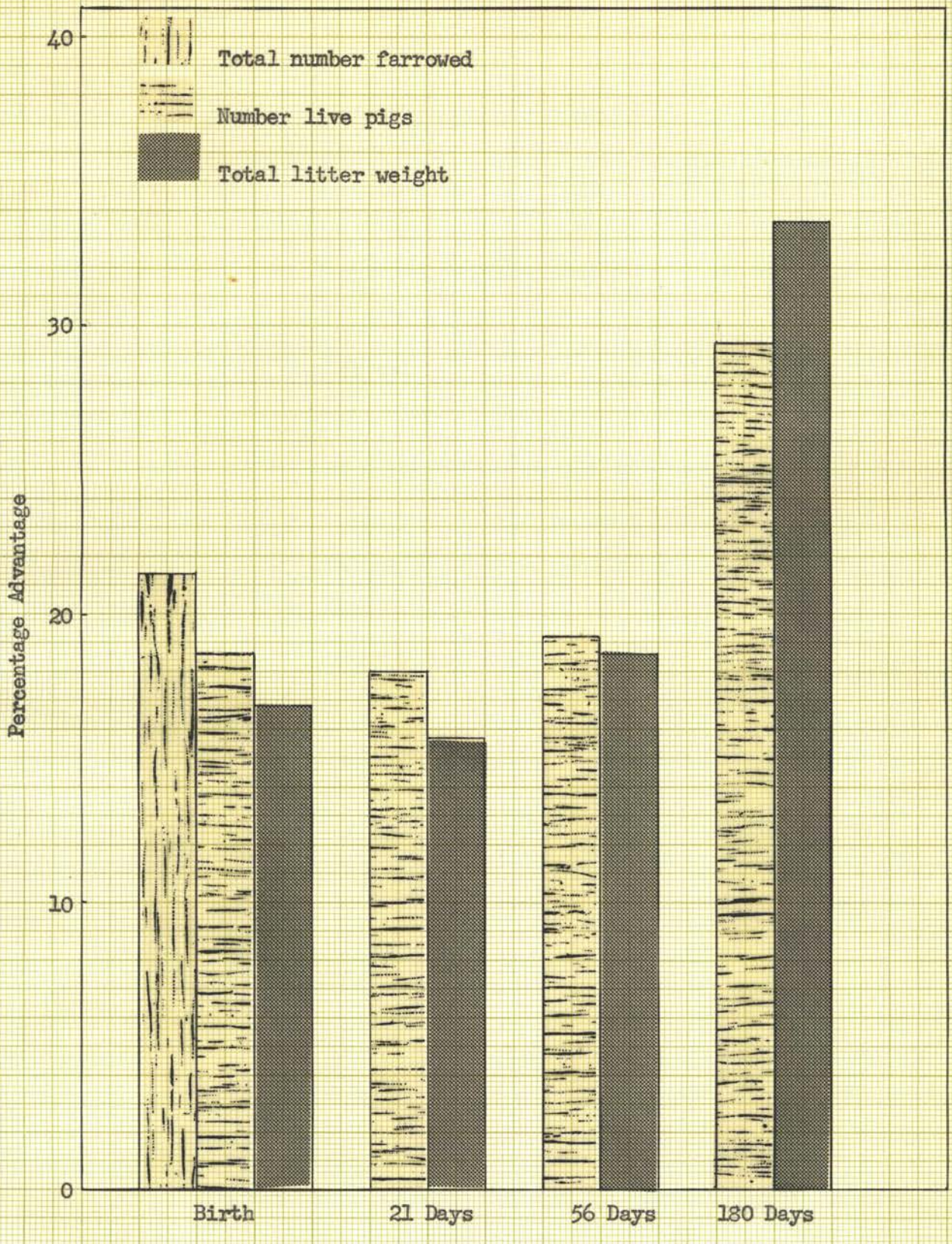

Figure 7. Percentage advantage of three-line cross litters over single cross litters.

environment was not optimum for maximum growth.

Although there were only five seasons in this comparison and a large value of "F" was required for statistical significance, it will be noted in Table 9 that all of the weighted mean differences for both number of pigs and litter weights were significant except number of pigs at 180 days. In Comparison III, IV, and V, the mean square for Heterosis X Season had to be used as the error term for testing the significance of the Weighted Mean Heterosis.

Table 9.

ANALYSIS OF VARIANCE FOR COMPARISON III
(THREE-LINE CROSSES MINUS SINGLE CROSSES)

a. Number of Pigs per Litter

Source of Variation	D. F.	Mean Squares				
		Tot. Farr.	Live Farr.	21 Days	56 Days	180 Days
Wt'd. Mean Heterosis	1	42.2**	29.0*	20.8*	22.6*	43.3
Heterosis X Season	4	0.26	1.41	1.84	1.86	5.81

b. Litter Weight

Source of Variation	D. F.	Mean Squares			
		Birth	21 Days	56 Days	180 Days
Wt'd. Mean Heterosis	1	135.7*	1432*	13,828*	1,391,706*
Heterosis X Season	4	10.89	88	1,239	74,273

COMPARISON IV

During three seasons, three-line cross litters occurred along with outbred Duroc litters. Since only 23 three-line cross litters and 14 outbred Duroc litters were involved, conclusions drawn from this comparison must be tentative. However, the differences are given in Table 6, and along with the other comparisons, this one adds information which is needed in arriving at methods for the use of inbred lines of swine.

In Comparison IV neither the litters nor their dams were inbred. The sires of the three-line crosses had inbreeding coefficients which averaged .13, and the outbred litters were sired by non-inbred boars. The differences were again in favor of the three-line cross litters. The magnitude of the differences were roughly the same as their advantage over single cross litters in Comparison III. Their advantages in litter weights were 2.75 pounds at birth, 13.01 pounds at 21 days, 24.73 pounds at weaning time, and 348.8 pounds at 180 days. In number of live pigs per litter the corresponding increases were 1.17, 1.60, 1.49, and 2.19 pigs. Figure 8 reveals that the increased number of live pigs overcompensated for the increased litter weight at birth, 21, and 56 days of age. At 180 days not only were there more live pigs per litter but the individuals were gaining at a faster rate, therefore, giving a total litter weight advantage of nearly 350 pounds at six months of age.

Analysis of variance (Table 10) shows that the differences in number of live pigs per litter at birth as well as the difference in birth weight were significant at the 5 percent level of probability. Data were available for only two seasons at 21 and 180 days so no analysis at these dates was made.

Although the number of litters and seasons is not as large as one would like for this particular comparison, the results may be indicative of what can be expected from the use of inbred lines. The line cross gilts are evidently

quite efficient as producers of pigs. Their increased productivity over the mean performance of the outbred Durocs is given in Table 11.

Table 10.

ANALYSIS OF VARIANCE FOR COMPARISON IV
(THREE-LINE CROSSES MINUS OUTBREDS)

a. Number of Pigs per Litter

Source of Variation	D. F.	Mean Squares		
		Tot. Farr.	Live Farr.	56 Days
Wt'd. Mean Heterosis	1	5.93	9.39*	15.2
Heterosis X Season	2	0.86	0.24	2.06

b. Litter Weight

Source of Variation	D. F.	Mean Squares	
		Birth	56 Days
Wt'd. Mean Heterosis	1	51.86*	4194
Heterosis X Season	2	0.71	406

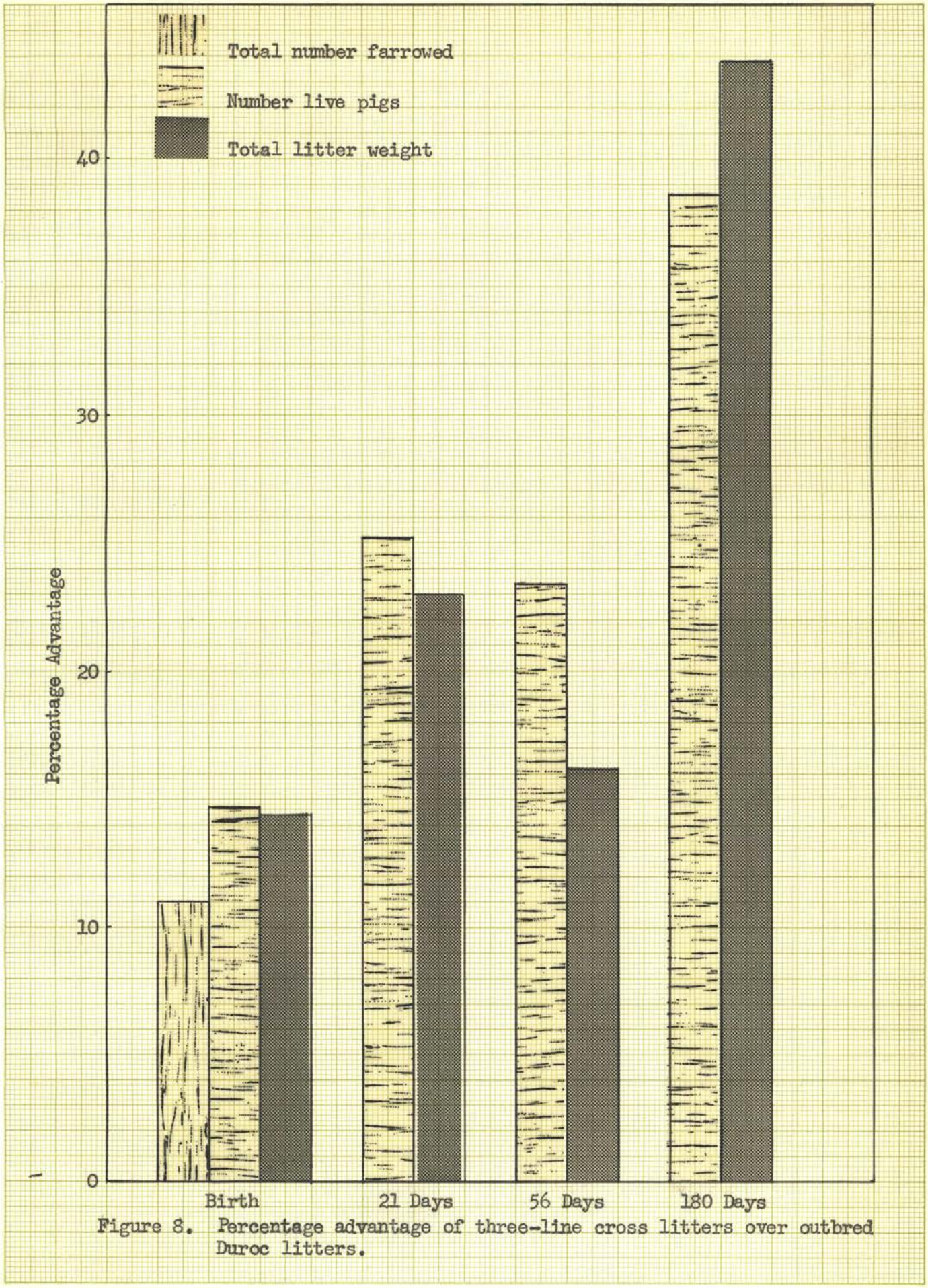

Figure 8. Percentage advantage of three-line cross litters over outbred Duroc litters.

Table 11.

MEAN PERFORMANCE AND PERCENTAGE ADVANTAGE IN LITTER WEIGHTS AND NUMBER OF PIGS PER LITTER AT FOUR DIFFERENT AGES

	Comparison IV		Comparison V	
	Mean of Outbreds	Percentage Advantage of 3-line Crosses	Mean of Outbreds	Percentage Advantage of Single Crosses
At Birth				
Total number farrowed	8.57	10.8	8.79	-11.0
Live pigs farrowed	7.97	14.7	8.38	-11.0
Live litter weight	19.04	14.4	20.37	- 9.9
At 21 Days				
Number of pigs	6.36	25.2	6.64	- 5.9
Litter weight	56.56	23.0	63.92	- 8.3
At 56 Days				
Number of pigs	6.39	23.3	6.74	- 4.2
Litter weight	153.0	16.2	169.3	- 7.9
At 180 Days				
Number of pigs	5.67	38.6	5.63	- 6.2
Litter weight	794.9	43.9	754.0	- 1.8

COMPARISON V

Ninety-five line cross and 31 outbred Duroc litters were produced during seven of the seasons included in this study. Most of the outbred Duroc litters were produced by sows which had been purchased as foundation stock for new lines. The line cross litters included all those which were produced in the same seasons in which the outbreds occurred. Many were included in one or more of the other comparisons but some had not been used before. Fourteen of the outbred litters had been included in Comparison IV.

The dams and sires of the line cross litters were inbred 25 and 29 percent respectively. The weighted mean differences, although very inconsistent from season to season, were slightly in favor of the outbred Duroc litters (Table 6). Outbred litters weighed 2.01 pounds more at birth, 5.31 pounds more at 21 days, 13.34 pounds more at weaning and only 13.5 pounds more at 180 days. The outbred litters contained 0.92 more live pigs at birth, 0.39 more at 21 days, 0.28 more at 56 days, and 0.35 more pigs at 180 days. In making this comparison the mean performance of the outbred litters was subtracted from that of the single cross litters. That resulted in weighted mean differences which were negative. When these figures were converted to percentages (Table 11) and plotted in Figure 9, two interesting observations were made. The increased number of pigs per litter at 21 and 56 days of age was not large enough to account for the increased weight of the outbred litters. This indicates that the non-inbred mothers were providing a better environment for their pigs than the inbred dams of the single cross litters.

At 180 days, the mean difference in the number of pigs per litter in favor of the outbreds was large enough to account for three and one-half times as much difference in total litter weight as actually existed at that time. This indicated a faster rate of gain for the line cross pigs after weaning.

Statistical analysis of the data resulted in "F" values indicating no more than sampling variations between the two groups at all ages, both for number of pigs per litter and for total litter weight (Table 12). Except at birth, the weighted mean differences were small, and a check of the data by seasons revealed that the differences were not consistently in favor of the outbreds.

The results from Comparisons III and IV also indicated that no differences were to be expected between line cross and outbred Duroc litters in this study. When the data were checked, it was noticed that one particular cross between two of the lines had been largely responsible for the negative mean differences in this phase of the study. These particular litters had even poorer performance records than the average of their parental lines within the same season.

Table 12.

ANALYSIS OF VARIANCE FOR COMPARISON V
(SINGLE CROSSES MINUS OUTBREDS)

a. Number of Pigs and Litter Weight at Birth and at 56 Days

Source of Variation	D. F.	Mean Squares				
		At Birth			At 56 Days	
		Tot. No.	Live No.	Weight	Number	Weight
Wt'd. Mean Heterosis	1	20.24	18.20	86.89	1.69	3,827
Heterosis X Season	6	4.86	4.58	22.67	1.82	2,536

b. Number of Pigs and Litter Weight at 21 and 180 Days

Source of Variation	D. F.	Mean Squares			
		At 21 Days		At 180 Days	
		Number	Weight	Number	Weight
Wt'd. Mean Heterosis	1	2.27	421	1.81	2,725
Heterosis X Season	3	2.30	241	3.61	84,786

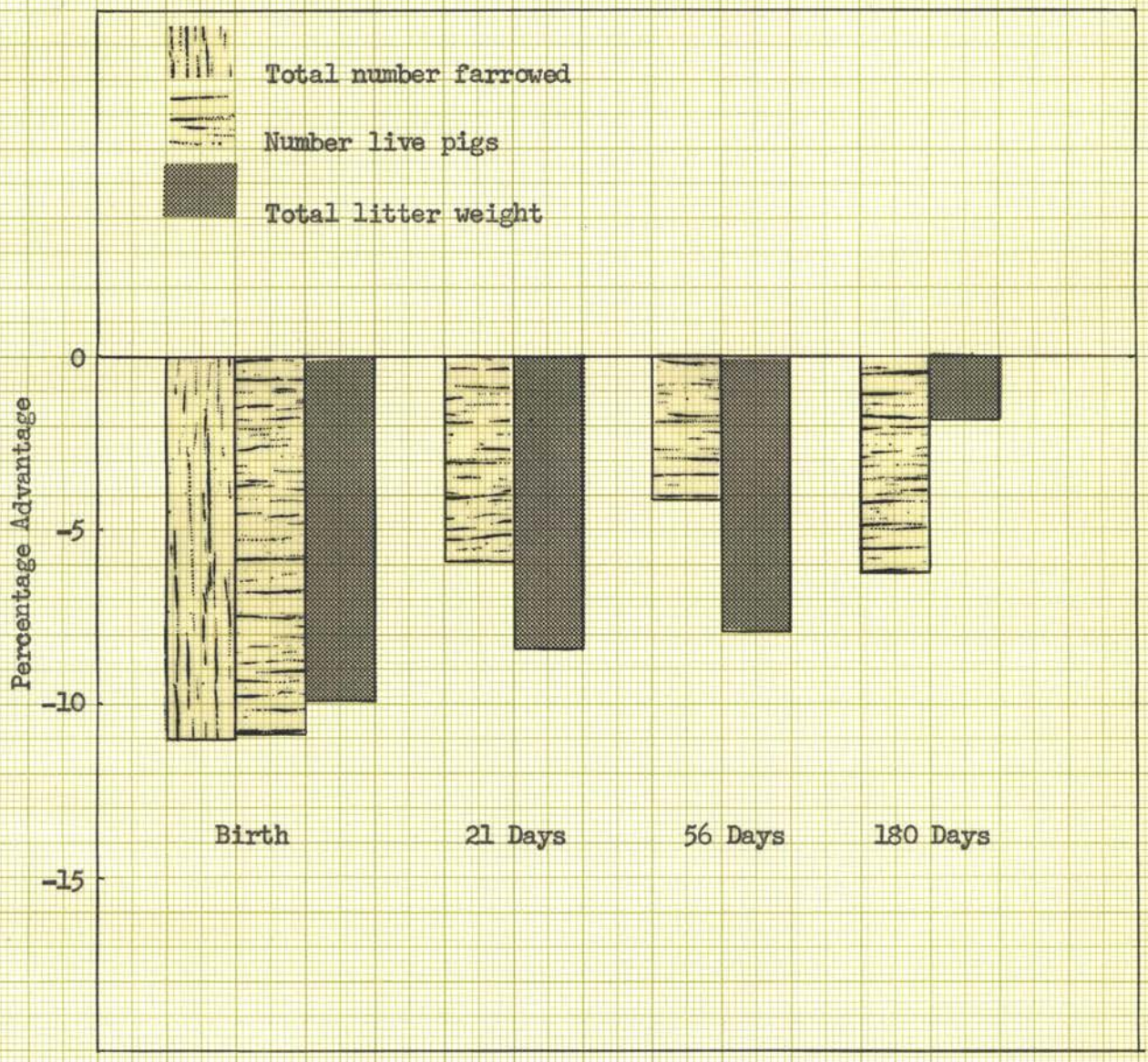

Figure 9. Percentage advantage of single cross litters over outbred Duroc litters.

DISCUSSION

In general the results of this investigation were in line with the results obtained by other investigators on the effect of inbreeding, or its converse, the effect of crossing.

Dickerson, Lush, and Culbertson (1946) crossed inbred Poland China lines in 1942 and 1943 at the Iowa Station. They calculated the intra-season weighted mean differences between the line cross and inbred progeny of the same boar. The differences were adjusted to zero mean difference for age and inbreeding of the dams by multiple regression. They found that the line cross litters exceeded the inbred litters in number of pigs at birth, 21, 56, and 154 days by 0.9, 1.3, 1.3, and 1.4 pigs respectively. In litter weights corresponding differences in favor of the line crosses at the same ages were 3.1, 16.0, 55.0, and 290.0 pounds per litter.

These differences are somewhat larger than weighted mean differences found in Comparison I, in which the inbreds were compared to line crosses with the same line of dam. However, the mean performance of the inbred litters in the Iowa experiment was much inferior to the performance of the inbreds in Comparison I, both for number of pigs per litter and for litter weights. The inbred Poland China litters were more highly inbred than the Duroc litters in this investigation. The mean differences between the inbreeding of the inbred litters (42.4 percent) and the line cross litters (5.8 percent) was 36.4 percent in the Iowa experiment. The differences obtained for each of the items of performance were then expressed by the Iowa workers as "decline per 10 percent inbreeding of the litter". In their experiment this decline amounted to.26, .35, .37, and .39 of a pig per litter at birth, 21, 56, and 154 days. When comparable figures were obtained for Comparison I of the present investigation, in which the inbred litters had inbreeding coefficients

of .22, the decline amounted to .27, .35, .39, and .49 of a pig per litter at birth, 21, 56, and 180 days for each 10 percent inbreeding of the litter.

The differences in litter weight at the Iowa Station were also larger than those obtained for litter weight in Comparison I. However, when both are expressed as decline per 10 percent inbreeding of the litter, the results at the two stations are in close agreement.

In the same study the Iowa workers fed a sample of the line cross and inbred pigs from 84 days of age to a final weight of about 225 pounds. The line cross pigs were 6.3 pounds heavier than the inbreds when placed on test at 84 days of age. They gained .14 of a pound more per day and required 9 pounds less feed per 100 pounds of gain than the inbreds. When these mean differences were adjusted to zero difference in initial weight and total gain of the pigs, the advantage of the line cross pigs was only .03 of a pound per day in rate of gain, and no difference was found in efficiency of gain. This is exactly the same difference in rate of gain from weaning to 225 pounds obtained in the present investigation in which there was no difference in the average initial weights of the line cross and inbred pigs. However, in the present experiment six pounds less feed were required per 100 pounds gain by the line cross pigs. This difference was not statistically significant.

Winters, et al (1944) reported that line cross litters, which were 28 percent less inbred than the parent inbred litters with which they were compared, contained .52 of a pig more per litter at birth and 1.28 more pigs per litter at weaning than the inbred litters. These figures are also in line with those found in Comparison I of this investigation.

From the records at four of the stations cooperating with the Regional Swine Breeding Laboratory, Dickerson, et al (1947) studied the effect of inbreeding of the litter using differences between inbreds and line crosses, within season and line of dam, as the primary observation. For each 10 percent

rise in litter inbreeding, independent of age and inbreeding of the dam, the decline averaged in litter size .2 of a pig at birth, .4 of a pig at 21 days, and .5 of a pig at 56 and 154 days. In pig weight no decline was observed up to 56 days, but it amounted to 3.6 pounds per pig at 154 days. These figures were averages for lines from both the Poland China and Duroc breeds and are again not greatly different from the results obtained in Comparison I. The fact that no differences in individual pig weights were found up to weaning time supports the finding in this study that about 90 percent of the differences found in litter weight could be accounted for by an increased number of pigs per litter.

In Comparison I heterosis was more pronounced in number of pigs per litter than in the increased growth rate of the individual pig. The increased number of pigs at birth was probably due to a lower prenatal mortality rate among the line cross pigs. The inbred dams were from the same line, were inbred to the same degree, and were all age corrected to one year. Therefore, it seems unlikely that the dams of the line cross litters shed more ova at the time of breeding than those which were bred to a boar of the same line. The difference in favor of the line cross litters became larger with age because death losses were greater among the inbreds. About 64 percent of the live inbred pigs farrowed were alive at 180 days while about 75 percent of the line cross pigs survived.

The literature on the effects of inbreeding on swine indicates that inbreeding, at a rapid rate at least, has resulted in a sharper decline in size of litter than in the growth rate of those individuals which survived. Relatively more lines have been culled for low fertility and/or low viability of the pigs than for a slow rate of gain. Comstock and Winters (1944) showed that more emphasis on selection for litter size than for growth rate would be re-

quired if both were to be maintained at a high level in the formation of inbred lines. It is not surprising, therefore, that crossing of inbred lines resulted in a more marked increase in litter size at all ages than in individual pig weights at those same ages.

In Comparison II, line cross litters were compared with the average of the two parental lines. Like Comparison I, this one gives a measure of the effect of the heterozygosity of the pig on litter performance. Unlike the first comparison, it gives equal consideration to the performance of the lines of the sire and dam. Insofar as the heredity of the pig is responsible for the performance of the litter, this is justifiable. However, it is known that the maternal abilities of lines differ, and that litter performance is controlled to a large extent by its dam's capacity as a mother - especially at birth, 21, and 56 days. Reciprocal crosses between two lines may give different results because of the differences in maternal abilities.

The differences obtained in Comparison II were larger than those obtained in Comparison I. Since all of the line cross litters in Comparison II were included in Comparison I, the differences are a bit misleading until it is noted that a large part of the line cross litters were sired by boars from line 1, which was more highly inbred than other lines in this comparison and which, as an inbred line, was very poor in performance. The majority of the line cross litters were produced by dams from line 3, which was not highly inbred and which was quite satisfactory in performance. The average performance of the parental lines was, therefore, lower in every item than the average performance of the inbred litters in Comparison I. This lower average of the inbred litters, therefore, accounts for at least part of the apparent increased vigor in this comparison.

Crossbred gilts, when mated to a boar of a third breed or to a boar of one of the parent breeds, were found in experiments by several workers to produce

excellent litters. In most cases the performance of three-breed cross litters were superior to single cross litters. This has been credited to an expression of heterosis in the productivity of the sow.

In the present investigation it was found that three-line cross litters were much superior to single cross litters when they were produced in the same season. Part of this increased performance is undoubtedly due to the heterosis being expressed by the increased fertility and productivity of the hybrid dam. Part of the increased litter performance may be the result of additional desirable genes which may have been transmitted by the boar from the third unrelated inbred line. The interaction between the heterosis expressed in productivity items of the line cross sows and that expressed by increased viability and growth rate of their litters must not be ignored. The increased performance of the three-line cross litter is more likely the product of the two effects than simply the addition of the heterosis of the litter plus the effect of heterosis on the productivity of the dam.

The differences in Comparison III may be larger than would have been obtained if all the possible three-line crosses had been made. The line cross gilts, which produced three-line cross litters, may have been more highly selected than the inbreds which produced the single cross litters. However, all three-line cross and single cross litters which were farrowed in the same season were included in the study.

The comparisons in which the three-line cross and single cross litters are compared with outbred Duroc litters indicate that inbred lines may be used in a system of crossing which may raise the level of performance in certain economically important traits above that obtained by conventional methods of breeding.

The fact that the three-line cross litters excelled the outbreds to about the same extent that they exceeded the single crosses was interesting and

served as a check of the comparison in which single crosses and outbreds were compared directly. In Comparison IV, neither the dams nor the litters were inbred. The fact that the litters, which were the result of crossing three inbred lines, were superior to the outbred litters may be an indication that the process of inbreeding has resulted in the removal of certain undesirable or deleterious recessive genes which normally exist in a non-inbred population. The crossing of such purged lines would be expected to result in a higher average level of performance than that of the random mating population from which they were formed. The fact that inbreeding usually results in a lowered level of phenotypic merit is also an indication that such genes do exist in heterozygous condition in random breeding populations as recessive or incompletely dominant genes with lethal or less drastic effects. The inbreeding process brings these genes into a homozygous condition. This permits selection against such genes within the group.

In Comparison V of this investigation there was a slight advantage of the outbred Duroc litters over the single cross litters. The difference was not consistent from season to season. In the fall of 1942 one particular group of line cross litters were inferior in performance to either of the parental lines. The large number of litters included in this particular season weighted this season difference rather heavily in computing the weighted mean differences, and thus accounts for the small advantage of the outbreds over the line crosses in this comparison.

Since the single crosses are the result of crossing all lines which were developed in the project and since the litters were handicapped by having an inbred dam, it is not surprising that the single cross litters were not superior to outbred controls. Rather it is encouraging that the performance of the single cross litters was not greatly different from that of outbred litters. There was a definite indication that the line cross pigs made more rapid gains than

the outbreds from weaning to 180 days of age.

Willham (1944) reported that line cross pigs gained faster than either outbred or crossbred pigs at the Oklahoma Station. Winters, et al (1944) found that line cross litters at the Minnesota Station were superior to a selected group of outbred and crossbred pigs which were raised at midwestern experiment stations. Dickerson (1946) pointed out that the line cross litters in the Iowa study were about equal in performance to outbred Poland Chinas in Experiment Station herds. The lack of an adequate control group of outbreds in the experiment along with the line crosses, however, precludes any definite conclusions in the Minnesota and Iowa experiments.

SUMMARY AND CONCLUSIONS

The litter weights and number of pigs per litter for 371 litters of Duroc swine at birth, 21, 56, and 180 days of age were studied. The same items were studied on 73 additional litters at birth and 56 days. All litters were farrowed at the Oklahoma Agricultural Experiment Station during the period from 1939 to 1949 inclusive. Inbred litters from seven different lines as well as single cross, three-line cross and outbred Duroc litters were included in the study. Intra-season weighted mean differences were obtained for number of pigs per litter and litter weights at birth, 21, 56, and 180 days for five different comparisons.

The comparisons made were: I. Single cross litters with inbred litters within line of dam; II. Single cross litters with the average of the two parental inbred lines; III. Three-line cross litters with single cross litters; IV. Three-line cross litters with outbred Duroc litters; V. Single crosses with outbreds. The data on litters produced by sows over one year of age were corrected to a gilt equivalent age.

Hybrid vigor was evident in both number of pigs per litter and litter weights at birth and increased in degree of expression as the litters became less dependent upon the direct mothering ability of the dams.

This vigor was expressed to a greater extent in the increased viability of the pigs and productivity of hybrid gilts than in the increased growth rate of the individual pigs.

There was no difference in the performance of line cross litters raised by inbred sows and the performance of outbred Duroc litters which were produced in the same season.

Three-line cross litters raised by line cross dams and sired by inbred boars of a third line were superior to both single cross and outbred Duroc

litters with which they were compared.

Increased number of pigs per litter in most cases was sufficient to account for a large percentage of the increase in total litter weight.

When number of pigs and initial weights were controlled, advantages of line cross pigs over inbreds with the same line of dam in post-weaning rate of gain and efficiency of gain were relatively small and inconsistent.

Because heterosis has been expressed in both number of pigs which survived and the growth rate of the individual, total weight of the litter is the one best over all measure of performance for comparison of lines or crosses in which heterosis is to be studied. The use of either number of pigs per litter or average weight of the pigs at a given time may be misleading.

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