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Title: ESTIMATES OF COMBINING ABILITIES, HETEROTIC EFFECTS AND PHENOTYPIC CORRELATIONS AMONG INBRED LINES OF BEEF CATTLE AND THEIR LINECROSSES

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The investigations were based on a complete diallel cross among three inbred lines of Hereford cattle. Records of Angus calves born during the same period were used to obtain more accurate estimates of environmental effects and to determine breed differences among the various traits included in the study. Estimates of general combining ability, specific combining ability and reciprocal effects were obtained. In addition, heterotic estimates of the linecross calves were determined as well as phenotypic correlations among all the performance traits, blood constituents, carcass traits, organoleptic measurements and endocrine gland weights.

General and specific combining ability effects were either small or nonexistent for all of the preweaning traits of the males except conformation score at 227 kg. Among the females, significant

general combining ability effects were detected for preweaning ADG, age at 227 kg. and condition score at 227 kg. Specific combining ability effects were nonsignificant among both sexes except for birth weights of the 2 $\times$ 3 and 3 $\times$ 2 cross females. Angus calves were smaller at birth, had higher preweaning gains, were younger at 227 kg. and had higher conformation and condition scores at weaning than the Hereford calves.

A significant heterotic effect was detected for percent stillbirths with the linecross calves showing more vigor and fewer dead at birth. The Angus exceeded the Herefords in percent calves born and weaned ($P < .01$). All other preweaning and weaning traits did not exhibit overall linecross superiority likely as a result of the low milk production of the inbred dams.

Angus calves were lower in postweaning rate and efficiency of gain, higher in conformation and condition scores and younger at the end of the feed test than the Herefords. General combining ability effects were significant or highly significant for conformation and condition scores at the end of the feed test for both sexes. A significant general combining ability effect was detected for feed efficiency of the males. Specific combining ability effects were significant for postweaning ADG of males and females. Heterotic effects were significant for postweaning rate of gain and feed per unit gain among the females and for age at 363 kg. among the males. Heterosis for conformation and condition scores were not found for either sex.

Angus calves had higher blood levels of amino acids and urea than Herefords. Amino acids and urea were higher in females than in males and increased with increasing age in both sexes. Creatinine levels in the blood were quite consistent between sexes and breeds. Differences in general combining ability, specific combining ability and heterosis were nonsignificant for all blood constituents at all weights.

The Angus excelled the Herefords in components of carcass grade, thyroid gland weight and testicle weight, but Herefords excelled in loin-eye area and percent lean in the 12th rib. General combining ability effects were significant or highly significant for components of carcass grade, percent drip, tenderness, juiciness and thyroid gland weight. No specific combining ability differences were detected. Heterotic effects were important only for testicle weight of the 1×2 and 2×1 cross males. For the entire study, line 1 excelled the other lines in general combining ability for most of the traits.

Correlation coefficients indicated that compensatory effects for poor suckling gains occurred during the early part of the post-weaning period. Birth weight was highly associated with preweaning growth rates in Hereford females but was not associated with pre-weaning growth rates in the Angus females. The relationship between suckling gain and conformation and condition scores at all weights were important, but no relationship between postweaning rate of gain and conformation and condition scores were found. Less efficient animals had higher blood levels of amino acids and larger amounts of fat in the carcasses. Conformation scores of the live animals were positively associated with carcass conformation, marbling, carcass grade and loin-eye area. This would indicate that muscling and carcass grade can be determined in the live animal.

Estimates of Combining Abilities, Heterotic Effects and Phenotypic Correlations Among Inbred Lines of Beef Cattle and Their Linecrosses

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INTRODUCTION

For years man has taken advantage of the variation that occurs in populations of animals to select superior animals for breeding purposes. Modern animal breeders still use selection as the chief tool for improvement, but inbreeding has also been used to varying degrees as a tool in the development of lines that will transmit superior performing ability with regularity.

With the establishment of inbred lines, it then becomes necessary to test these lines to evaluate how well they combine with other lines, because the merit of a line is determined from its value as a source of seedstock. If the lines are to be used in a top-cross breeding program, it is necessary to determine how well a line combines with an outbred population or with several other lines. On the other hand, if the lines are to be used in a rotational crossing program, it would be advantageous to determine which specific line crosses are superior and then use the best two or three as sire producing lines for commercial production.

When inbred lines are crossed in all possible combinations, the differences in the average performance of the lines in hybrid combination may be referred to as differences in general combining ability. Specific combining ability is used to designate those instances in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. Also, reciprocal crosses may not perform the same which gives rise to what is known as the reciprocal effect.

The first part of this study was directed towards evaluating three inbred lines of Hereford cattle for general and specific combining ability differences and reciprocal effects. Preweaning, postweaning, slaughter, and certain blood traits were analyzed for these effects.

It has generally been found that inbreeding, even at a slow rate, results in reduction of performance of lines at some level of inbreeding. Since the animals used in this study were all inbred to varying degrees, it might be expected that linecross individuals would exhibit a heterotic effect or recovery of performance from inbreeding depression for some traits. The second part of this study was directed towards the estimation of the amount of heterosis expressed in all the traits that were measured.

In addition to determining if there are combining ability differences and heterotic effects among linecross animals, it would also be important to know what the relationship is between various traits. If one trait is highly correlated with another performance trait then an increase in one automatically results in an increase in the other one. The genetic association between traits is important to know because this will have a marked effect on the program that the animal breeder will employ to maximize his selection progress. Also, if some early life trait is highly correlated with later life traits, then this early life trait can be used as a tool to predict the future performance of the animal. The third phase of this study was therefore directed towards obtaining simple phenotypic correlations among the various traits.

REVIEW OF LITERATURE

Combining Abilities

With the development of inbred lines of plants and animals it becomes necessary to test the superiority or inferiority of these inbred lines when used in hybrid combinations; hence the terms general and specific combining ability. Sprague and Tatum (1942) originally defined these terms as follows:

> The term general combining ability is used to designate the average performance of a line in hybrid combination. The term specific combining ability is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved.

One of the methods by which combining abilities can be determined is by the use of a diallel crossing system. Originally proposed as a method of progeny testing by Johs Schmidt (1919, 1920), the diallel crossing method has since been used extensively to estimate general and specific combining abilities and heterotic effects of lines or breeds. A diallel crossing system consists of a set of p inbred lines and their crosses. This procedure gives rise to a maximum of p^2 combinations. Data from such combinations can be most conveniently set out in a $p \times p$ table in which x_{ii} represents the mean value for the i^{th} inbred, x_{ij} the mean value of the F_1 resulting from crossing the i^{th} and j^{th} inbred and x_{ji} represents its reciprocal. Thus, the p^2 combinations can be divided into three groups: (1) the p parental lines themselves, (2) one set of 1/2 p (p-1) F_1's and (3) the set of 1/2 p (p-1) reciprocal F_1's (Griffing, 1956a). Statistical methods and the genetic theory underlying the analysis of data from diallel mating schemes have been presented by Dickinson and Jinks (1956), Gilbert and Jinks (1964), Griffing (1956a, 1956b), Henderson (1952), Hayman (1954a, 1954b, 1957, 1958, 1960), Kempthorne (1956) and Yates (1947).

Results of experiments have been somewhat conflicting depending upon the species used and the degree of similarity of the lines tested. In a study involving four lines of mice and all possible crosses of these lines, Carmon (1962) reported that general combining ability effects, maternal effects, and sex linked effects were highly significant for 21 and 45 day weight. Specific combining ability effects were nonsignificant.

Eaton, Neville and Dickerson (1950) conducted an experiment among 72 crosses involving nine inbred strains of mice on 579 litters over a five year period to determine the general and specific combining abilities of these crosses. Line differences were important only for individual mouse weight. Maternal influence was important for both litter size and individual mouse weight, but because of a correlation of -0.85 between litter size and individual mouse weight no differences in maternal influence were detected for total litter weight.

Specific linecross combinations were important though not significant for viability and total litter weight, but not for individual mouse weight. Ratios of variances from specific and general cross performance suggested heterozygote superiority for viability and total litter weight but little dominance for genes influencing individual mouse weight.

The effects of crossing lines of mice inbred without selection on litter size was investigated by Roberts (1960). Thirty lines of mice inbred up to an inbreeding coefficient of 0.50 with only natural selection being practiced were crossed in all combinations. The mean litter size of the linecross mice did not exceed that of the outbred population from which the inbred lines were derived. The estimation of variance components associated with general and special (specific) combining abilities were very small, especially those relating to special (specific) combining ability. Therefore, before selection between crosses becomes possible, high levels of inbreeding must be achieved.

A diallel study of avoidance conditioning in mice was conducted by Collins (1964). Significant genetic differences were demonstrated in the rate of avoidance conditioning among offspring from all 25 mating combinations of five highly inbred strains. Most hybrids learned better than either parent.

Kidwell *et al.* (1960) crossed four inbred lines of rats in all 16 possible combinations including inbreds and reciprocal crosses. Estimates of the effects of sex, heterosis, lines, general combining ability, specific combining ability, sex linkage and maternal effects on 28- and 70-day body weight were included in the model. The effects of sex, lines and maternal ability were highly significant at 28 and 70 days of age. General combining ability effects were highly significant at 70 but not at 28 days of age. No evidence of specific combining ability or sex linkage effects were detected.

Litter size and body weight in a diallel set of crosses among inbred strains of mice were analyzed by Jinks and Broadhurst (1963). They concluded that litter size was maternally determined at birth and there was no difference in survival to maturity among litters. Individual body weight at birth and maturity was found to be largely determined by the individuals own genotype whereas at weaning it was determined entirely by causes external to the individuals genotype. In addition, a strong maternal component was noted for a short period following weaning for individual body weight. The heritable component of individual body weight consisted of both additive and dominance effects. No heterosis was detected for litter size and almost none for body weight and total litter weight. For all characters, the best litter from the inbred strains was not exceeded by any outcross.

Hetzer *et al.* (1953) crossed females from seven inbred lines of swine, ranging from 24 to 44 percent inbreeding, in all possible combinations with non-inbred boars of the Berkshire, Chester White, Hampshire and Poland China breeds. The traits studied were litter size and litter weight at birth, 21 and 56 days of age. Differences among lines and among breeds were quite large although only the differences for litter weight at birth among lines were found to be statistically significant. Substantial but nonsignificant differences in specific combining ability effects were indicated for all traits studied.

In a later study to determine general combining ability and specific combining ability effects of six inbred lines of swine, Hetzer _et al._ (1959) found significant general combining ability effects for only one preweaning trait, total litter weight at 56 days. However, general combining ability effects were significant for all post-weaning growth traits and for all carcass traits except dressing percentage, accounting for five to seven and six to sixteen percent of the variation in these two sets of traits. Specific combining ability effects were significant only for yield of bacon indicating dominance and epistasis contributed little if anything to the variation in these data. Maternal effects were not significant for litter size but they differed significantly for litter and pig weight at 56 days, pig weight at 140 days, daily gain, dressing percentage, yield of bacon and yield of fat cuts, accounting for seven to 21 percent of the variation in these five latter traits.

Magee and Hazel (1959) estimated the differences in the general combining ability and general maternal effects from 2,137 three-line cross pigs of 12 Poland China inbred lines for 154 days weight.

The three-line cross pigs were produced by mating linecross sows to boars of a third inbred line. Differences in general combining ability were statistically significant accounting for four percent of the variation among pigs of the same season-farm group. Maternal effects of the lines and the interactions involving specific effects were not statistically significant.

Single crosses among 12 inbred lines of Poland China swine were made by Henderson (1949). A total of 214 litters representing 77 reciprocal crosses were farrowed and weights at 0, 21, 56, and 154 days of age were gathered. General combining ability differences accounted for not more than five percent of the variation, specific combining ability for five to 15 percent and maternal and sex linkage effect for none of the variation among crosses.

Bradford, Chapman and Grummer (1958) compared data on six lines of inbred swine and on the two- three- and four-line crosses between them for combining abilities. Subdivision of variance in the two-line crosses for 56-day pig weights indicated that maternal effects were more important than general combining ability and the opposite was true for five-month pig weights. Neither trait showed evidence of specific combining ability. The data also indicated that there was a negative genetic correlation between the additive effects in the pig and the maternal effects of the line.

Comparisons were made of the performance of Shropshire, Suffolk and Targhee breeds of sheep and their reciprocal first crosses by Bradley et al. (1965). No significant differences were found between breeds in numbers of lambs born of ewes exposed to rams. No significant breed interaction was detected for 120-day body weight and staple length. Breed-of-sire and breed-of-dam effects, however, were significant with respect to 120 day weight and staple length. Maternal effects were noticed for 120 day weight and staple length, but rankings by breeds were the same for breed-of-sire and breed-of-dam means.

A complete diallel cross among three inbred lines of Suffolk sheep for general and specific combining ability estimates was conducted by Schilling (1966). Birth weight, 120-day adjusted weaning weight, conformation at weaning, condition at weaning, yearling fleece weights, and yearling fleece grade were measured on the lambs born from the diallel cross. No significant general combining ability effects were observed for any of the six traits measured. Significant specific combining ability effects were observed only for yearling wool weight. Significant line-of-dam effects were observed for birth weight and yearling wool weight indicating a possible maternal effect for these two traits.

Damon et al. (1961) reported a genetic analysis of an experiment designed to evaluate breeds of beef cattle and breed crosses in the Gulf Coast Region. Angus, Brahman, Brangus, Charolais, Hereford and Shorthorn breeds were included in the study.

Significant general combining ability effects were obtained for 180-day weight, slaughter calf grade, rate of gain on feed, weight per day of age and slaughter grade. Specific combining ability effects were significant or highly significant for all traits except slaughter calf grade. Specific combining ability effects were particularly important for rate or gain on feed and weight per day of age where they accounted for 21.0 and 27.4 percent, respectively of the variance among the crosses. Maternal effects were highly significant for all traits except slaughter grade. Sex linkage had little or no effect on all the traits included in the study.

Three inbred lines of Hereford cattle were crossed on a common tester line to produce linecross progeny by Flower et al. (1963). The inbred lines were then compared with their linecross progeny to determine if linecross progeny performance could be predicted based on the performance of the inbreds for the traits measured. Line differences were relatively small among the inbred lines for the productive traits measured. The lines ranked the same for birth weight as for the linecrosses when mated to a common tester line for measurement of performance. It appeared that linecross performance was not predicted from line performance for weaning weight and post-weaning daily gain due to inbred line difference in maternal ability and compensation for this effect. From estimates of hybrid advantage, it was concluded that the inbred lines showed general and specific combining ability differences as well as maternal effects since the effects could not be separated.

The weaning weights of 594 single cross Hereford calves were used to evaluate the performance of 13 inbred lines when crossed with each other and when crossed with an outbred control group by O'Bleness, Stonaker, and Henderson (1959). The differences between lines-of-sire and between lines-of-dam were significant at the 0.01 level of significance. The least squares estimates were used to rank the lines when the lines were used as sires and as dams. The order of the lines was not necessarily the same in the two rankings as indicated by a rank correlation of 0.11.

Bogart, MacArthur and Hornbeek (1967) reported on the results of the performance of topcross calves sired by four inbred lines of Hereford bulls mated to outbred Hereford tester cows. The results indicate that lines differ considerably in performance of topcross offspring but that certain lines are superior in one trait while others are superior in another trait. In general, the performance of topcross offspring reflects the performance level of the line for the various traits, particularly for traits of higher heritability such as postweaning rate of gain.

In a complete diallel mating plan involving three inbred lines of Hereford cattle, Hornbeek (1964) observed differences in general combining ability between lines for postweaning rate and economy of gain. These differences coincided with differences observed in the histories of the lines involved in the crosses. Specific combining ability differences were detected for postweaning rate and economy of gain favoring the faster gaining Lionheart and David lines.

Heterosis

Inbred females of four inbred strains of mice were mated singly with full-sib males of the same strain or with males of five other inbred strains by McCarthy (1965). Increases in litter size on crossing three female strains were attributable to the effect of crossing at one stage, i.e. early postimplantation mortality was reduced in crossing. Crossing had no influence on the litter size of the fourth strain of females at any prenatal stage of development or at birth. The results are evidence for heterosis in embryonic viability.

Carmon (1962) made all possible crosses among four lines of mice to estimate heterosis for 21- and 45-day weight. He found that heterosis, measured as a comparison between linebreds and crossbreds, was highly significant for both weights. The effects of heterosis were found to increase with increasing age. The poorest performing line performed the best in crosses while the better performing lines performed the poorest in crosses.

Brinks et al. (1967) studied the importance of heterosis within a breed on birth weight, preweaning daily gain, weaning weight and weaning score among a complete diallel of five inbred lines of Hereford cattle. Line-of-sire and line-of-dam effects were highly significant for birth weight of both males and females. Line-of-sire effects were significant for weaning weight of heifers whereas line-of-dam had a significant effect on preweaning gain and weaning weight of bull calves only. This is consistent with heritability estimates from half-sib correlations of heifer data and it has been observed that the influence of the dam has a greater effect on male calves than on heifer calves. Sire X dam interaction was highly significant for preweaning gain, weaning weight and weaning score in the heifer calves. The amount of crossline advantage for birth weight in males was inconsistent as evidenced by seven of the 20 crosses showing negative values. Heterosis was much greater in preweaning gain and weaning weight than in birth weight or conformation scores. Heifers exhibited 5.1 and 4.3 percent more heterosis for preweaning daily gain and weaning weight, respectively than bull calves. Weaning scores exhibited consistent heterosis in both sexes with males exhibiting 2.5 percent and females exhibiting 2.7 percent heterosis. In general, significance was not detected for differences in reciprocal crosses due to small subclass size.

In a later study on postweaning performance of the same Hereford bulls and heifers from the five X five diallel cross, Urick et al. (1968) reported on the amount of heterosis exhibited on feedlot weights and gains of the bulls and weights and gain of the heifers on the range for weaning to 18-months of age. The feeding period for the bulls was divided into seven, 28-day periods with weights and gains calculated for each period. The linecross bulls showed a marked advantage over the straightline bulls for all weights with the difference being highly significant. The difference between the line-cross and straightline means were highly significant in gain for the first 28-day period whereas differences in the gain over the entire 196-day trial was significant. All other gains from period two through seven showed no difference between linecross and straight-line bulls. The linecross heifers generally showed a greater advantage over straightline heifers than did the bulls. Highly significant differences were found for weaning weight, 12-month weight, 18-month weight and 18-month score among the heifers. Significant differences were detected in gain from weaning to 12-months of age and weaning to 18-months of age but differences in gain from 12- to 18-months of age were nonsignificant. The data provided evidence that linecross calves can probably withstand the stress of weaning and being placed on feed better than straightline calves.

A study was carried out by Turner, Farthing, and Robertson (1968), to determine the degree of heterosis exhibited in percent calf crop and to determine the calf mortality of various types of beef cows. Crossbred cows produced 9.6 percent more calves than straightbred cows which was highly significant. Death losses to weaning were similar. The differences between crossbred and straightbred cows in total loss, stillbirths, and loss of live calves was not statistically significant. Crossbred cows of Angus and

Brangus and Brahman breeds exceeded their parental average performance by 12.1 percent and 11.6 percent, respectively ($P < .05$). Brahman and Hereford crosses exhibited an 18.8 percent difference for calving percent or 28.1 percent advantage as a percent of the parental performance ($P < .01$).

Wiltbank et al. (1967) carried out a study to determine the effects on reproductive performance of straightbred Angus, Hereford and Shorthorn cows bred to produce either straightbred or crossbred calves. Cows bred to produce crossbred calves had a small, usually nonsignificant, advantage for most reproductive traits compared to cows bred for straightbred calves. When averaged over the four years, six percent more cows bred for straightbred calves conceived on first service ($P < .05$), two percent more cows became pregnant ($P > .05$), embryonic loss was one percent greater ($P > .05$), three percent more live crossbred calves were born ($P > .05$), four percent more crossbred calves were alive at two weeks ($P < .05$), four percent more calves were alive at weaning ($.05 < P < .10$) and postnatal mortality was three percent less ($P < .01$) in crossbred calves. Although the advantage in reproduction of cows bred for crossbred calves were small and generally nonsignificant, they tended to be quite consistent.

In a complete diallel of Hereford, Angus and Shorthorn breeds of cattle Gregory et al. (1965) found significant heterotic effects for birth weight, preweaning daily gain, 200-day adjusted weaning weight and weaning conformation score. Heterosis effects attributable to sires within a breed were not important so heterosis was a characteristic of the breeds. Differences between reciprocals were small for birth weight. Reciprocal differences were large for preweaning daily gain and weaning weight in crosses involving the Hereford breed with the other two breeds. Differences between reciprocals tended to be relatively large for weaning scores in crosses involving Angus cows.

Gregory et al. (1966b) studied postweaning traits of beef steers from a complete diallel mating system involving Angus, Hereford and Shorthorn breeds of cattle. Interactions between breed-of-sire and breed-of-dam were highly significant for age constant weights but were generally nonsignificant for average daily gain in three, 84-day postweaning periods or for different measures of feed efficiency. Differences among sires within breeds were great indicating the magnitude of additive genetic variation on these traits. The results show that heterosis effects on growth rate are related to age and decrease with increasing age after approximately one year. Heterosis effects on efficiency of feed were small and the crossbreds actually required more TDN per unit of gain in the third 84-day period than did the straightbreds. These results indicated that the heterosis effect on feed efficiency might be greater on a gain constant than an age constant basis.

In another study involving heifers from the same diallel crossing system of Angus, Hereford and Shorthorn breeds of cattle, Gregory et al. (1966) concluded that heifers generally exhibited more heterosis for postweaning traits than did steers of comparable breed crosses. Interactions between breed-of-sire and breed-of-dam were highly significant for 200-day weight, average daily gain from 200- to 396-days of age, average daily gains from 200- to 550- days of age, 396-day weight, 550-day weight and 550-day score. These significant interactions reflected the importance of heterosis on these traits. Sires X breed of dam interactions were nonsignificant indicating that the heterosis was due to breeds.

Gregory et al. (1966a) reported on the amount of heterosis exhibited by steers for slaughter and carcass traits resulting from the same complete diallel cross involving Angus, Hereford and Shorthorn breeds of cattle. Interactions between breed-of-sire X breed-of-dam were highly significant for many traits either associated with or affected by weight. However after adjusting these traits for the effects of weight, this interaction was not significant. Differences among sires within breeds were highly significant for most traits indicating the magnitude of additive genetic variation on these traits. Heterotic effects were highly significant for carcass weight and net merit at 452-days. Net merit was considered to be equal to the value of closely trimmed cuts minus feed costs from weaning to slaughter. Differences in carcass grade were considered in computing net merit.

In an experiment to determine the amount of heterosis among fertility and calf performance to weaning for two-breed crosses, three-breed crosses, backcrosses and straightbreds of Angus, Shorthorn and Hereford breeds of cattle, Gaines et al. (1966) found a highly significant difference in the number of calves weaned per 100 cows bred in favor of the crossbred calves. Calving percentage, expressed as calves weaned per cow bred, was 76 percent for purebreds and 89 percent, 84 percent, and 87 percent respectively for two-breed, three-breed and backcross matings. There was generally a small amount of heterosis exhibited for birth weight. Preweaning growth showed both maternal effects, as evidenced by highly significant differences for some reciprocals, and hybrid vigor which was demonstrated in all cases where Angus and Shorthorns were used. Heterotic effects were found in weaning weight for calves from Shorthorn and Angus cows, but maternal effects of Hereford dams prevented heterotic effects from being exhibited. Feeder grade at weaning was slightly lower among the crossbreds.

Later, Vogt et al. (1967) analyzed the postweaning performance to slaughter on the above mentioned calves. Heterotic effects were estimated by sex because of management differences and two-breed cross heifers were found to be significantly superior to their purebred contemporaries in feedlot average daily gain, slaughter weight and slaughter grade. No significant differences were found among the two-breed, three-breed and backcross heifer groups in the above mentioned traits. Among the steer groups, two-breed crosses were significantly superior to both purebred and backcross contemporaries in yearling average daily gain, yearling weight and slaughter weight and significantly superior to the purebreds, three-breed crosses and backcrosses in slaughter grade. Essentially no differences were found among the purebreds, two-breed cross, three-breed cross and backcross groups in feedlot average daily gain.

In the final phase of this crossbreeding experiment, Gaines et al. (1967) reported on the amount of heterosis of the two-breed, three-breed and backcross steers and heifers for carcass traits. It was concluded that there was some evidence of heterosis in those traits associated directly with growth, namely carcass weight, rib-eye area and carcass length. Slight indications of heterosis were seen in some other traits, but they were not large enough to be of practical importance.

Reynolds et al. (1959) investigated the birth weights of 940 calves of Brahman breeding and crosses involving Brahman, Shorthorn, Angus, Hereford, Native and Santa Gertrudis breeds of cattle. The general mean was 63.1 pounds with a 3.7 pound advantage of male calves over females. Purebred Brahman or F_1 Shorthorn X Brahman calves were comparable in weight and were 2.1 and 2.4 pounds respectively lighter than the mean of all calves. Calves from Hereford, Angus, Shorthorn and Santa Gertrudis bulls were 2.2 pounds heavier than the mean weight. From the data it would appear that maternal factors influenced birth weight to a greater extent than hybid vigor.

Another experiment was conducted by Damon et al. (1961) to evaluate breeds of beef cattle in the Gulf Coast Region. Angus, Brangus, Brahman, Charolais, Hereford and Shorthorn breeds were included in the studyand data were collected on 180-day weight, slaughter calf grade, rate of gain on feed, weight per day of age and slaughter grade. Significant or highly significant heterotic effects were found for all traits except slaughter calf grade.

An experiment with three lines of inbred Hereford range cattle mated to a tester line of Hereford cattle was made by Flower et al. (1963). They concluded that no hybrid effects were noted for birth weight but weaning weight, postweaning daily gain and final weight showed an average linecross advantage of 4.6, 4.3 and 4.7 percent respectively when compared to their inbred contemporaries. However the authors stated that it was difficult to ascertain whether the amount of heterosis was greater than would be expected simply from recovery of inbreeding depression since an outbred control herd was not maintained.

Blood Constituents

Levels of various blood serum constituents have been postulated to be a means by which growth rates of animals can be predicted. Nitrogenous constituents in particular show promise because of their importance in protein synthesis. Marshall and Halnan (1948) and Dukes (1955) in discussing the function of the liver in deaminating amino acids, states that excess amino acids which are not required for tissue repair or growth in the animal are deaminated and the nitrogenous portion is converted to urea. The non-nitrogenous portion can then be utilized for energy or other functions in metabolism. As such, an inverse relationship might be expected to occur between levels of blood urea and growth rate. Colby et al. (1950), found a negative but nonsignificant correlation between rate of gain and blood levels of urea which would support this hypothesis.

In the ruminant, McDonald (1948, 1954) has shown that deaminization occurs in the rumen as well as in the liver due to the action of microorganisms in the rumen. The ammonia is then partly converted to microbial protein and partly absorbed by the ruminal veins. The ammonia is next carried to the liver via the portal vein where it is converted to urea. The efficiency of utilization of protein consumed by the ruminant must therefore, in part depend upon the quantity of ammonia produced in the rumen.

Lewis (1957) tested the hypothesis that blood urea levels can be used as a rate of ammonia loss from the rumen or as a supplementary test of the efficiency of protein utilization. Under a given feeding regime, the concentration of blood urea in sheep was found to be constant. Dietary changes led to different levels of blood urea concentration which were detected after a period of four to eight hours. Fluctuations in blood urea concentration in the sheep were not primarily due to changes in the overall nitrogen intake and as such, differences in blood urea concentrations were due to differences in efficiency of protein utilization.

Brody (1945) states that urea and creatinine levels represent extremes in the extent to which they are influenced by dietary protein, with creatinine the least affected. He also concludes that urinary creatinine levels reflects the mass of supporting muscle in the body. Marshall and Halnan (1948) suggested that urinary creatinine is a measure of tissue breakdown since it remains approximately the same on low or high protein diets. On the other hand, Williams (1954) found that creatinine was negatively associated with rate of gain in calves at 500 and 700 pounds and concluded that if creatinine excretion is considered a measure of muscle activity, the less the activity the greater the rate of gain. Age had an effect on creatinine as animals became more muscularly active with age.

Kugelmass (1959) states that blood amino acids are utilized by the liver for formation of most plasma proteins or are transported to tissue for temporary storage or synthesis of tissue proteins.

The rate of amino acid depletion is dependent upon the degree of depletion of plasma and tissue proteins, the pattern of amino acid mixtures for protein formation and the adequacy of hormonal control of protein metabolism. Protein anabolism is stimulated by growth hormone. Protein catabolism is stimulated by adrenocortical and excessive thyroid hormones.

Williams (1954) found that heifer calves had higher levels of uric acid, urea, amino acids and hemoglobin than did bull calves. He also concluded that blood constituents were inadequate in themselves as a means to rank the animals for rate and efficiency of gain. Sex differences in levels of blood constituents were also shown to occur at various weights in beef cattle by Bogart et al. (1963), MacDonald et al. (1953) and MacDonald, Krueger and Bogart (1956).

Bogart et al. (1963) reported that blood levels of free amino acids and urea increased as calves grew from 500 pounds to 800 pounds body weight. More rapidly gaining animals converted the feed they ate into body weight gains more efficiently than less rapidly gaining animals even though they ate no more per unit of body weight. They conclude that younger (smaller) animals are more efficient in withdrawing amino acids from the blood to develop muscular tissue resulting in lower blood levels of amino acids and their metabolites whereas the older (larger) animals are less efficient, deaminize the amino acids and excrete large quantities of urea. It appears that rapidly and slowly gaining calves either differ in their protein requirements with rapidly growing calves having the higher requirements, or they differ in their ability to withdraw the amino acids from the blood stream for the development of muscular tissue. Blood levels of creatinine, urea and amino acids have been reported by several authors and they have been summarized and presented in Table 1.

Correlations

Genetic correlations among all weights and gains from birth to 18 months of age in beef cattle were within a range of 0.40 to 0.99 except those involving gain during the first winter from weaning to 12-months of age according to Brinks *et al*. (1964). Growth from weaning to 12-months was only about 0.5 pounds per day so the authors concluded that this might be a test of ability to withstand winter conditions rather than gaining ability, thus perhaps explaining the low correlations. Eighteen-month weight was found to be a good single criterion for selection of growth throughout life.

Nelms and Bogart (1956) used 103 Hereford and Angus calves to determine the effects of birth weight, age of dam and time of birth on suckling gains of beef calves. Time of birth was broken down into 20-day periods beginning with March 1. Lines, time of birth and birth weight all affected rate of gain during the suckling period.

Table 1. Summary of studies by various investigators on blood levels of creatinine, amino acids and urea (mg/100 ml blood).

Author	Creatinine	Amino Acids	Urea
Folin and Denis (1914)	2.0	---	14.0
Scheunert and Von Pelchrizin (1923)[1]	1.2-2.5	---	10.0-23.7
Fearon (1926)	---	---	13.6-15.3
Colby et al. (1950)	1.32	---	12.0
Dinning et al. (1948)	---	---	14.0-24.0
Dukes (1955)	1.0-2.0	4.0-8.0	6.0-27.0
Hayden and Tubangui (1920)[1]	1.20	---	---
Hayden and Sholl (1924)[1]	1.37	---	---
Hayden and Fish (1928)[1]	1.84	---	---
Anderson, Gayley and Pratt (1930)	1.11-1.94	---	---
MacDonald et al. (1953)	---	7.03	---
MacDonald, Krueger and Bogart (1956)			
500 lb. Females	1.54	7.5	19.0
500 lb. Males	1.60	6.7	15.8
800 lb. Females	1.41	7.6	15.8
800 lb. Males	1.38	6.8	14.3
Bogart et al. (1963)			
500 lb. Females	---	7.38	14.57
500 lb. Males	---	6.72	11.80
800 lb. Females	---	7.64	19.18
800 lb. Males	---	6.80	15.46
Hornbeek (1964)			
450 lb. Females	1.41	6.90	16.91
450 lb. Males	1.43	6.72	15.76
750 lb. Females	1.40	6.88	17.16
750 lb. Males	1.41	6.39	15.88

[1] Cited from MacDonald, Krueger, and Bogart (1956).

The calves born in the first part of the season, with the exception of period one, gained 0.20 pounds more daily than the mean or 0.38 pounds more daily than those born in the last part of the season even though the breeding season was restricted to 90 days. This agrees well with the correlations reported by Bogart et al. (1956) between suckling gain and birth date (r=-0.23) and between suckling gain and birth weight (r=0.35).

Kidwell et al. (1959) conducted an experiment to study the relationship of selected production factors to conformation scores and body measurements, associations among the production factors, and the relation of carcass grade and fatness to consumer preference. They found little if any relationship between feeder grade and subsequent rate or economy of gain. Feeder grade was positively associated with carcass grade, dressing percent and percent fat in the 9-10-11 rib. Each grade was negatively associated with percent bone and muscle in the 9-10-11 rib section. It appeared that no relation occurred between slaughter score and rate and economy of gain, but there was a high relation between slaughter score and carcass grade; dressing percent; and percent bone, muscle, and fat in the 9-10-11 rib. Carcass grade was largely a function of percent fat in the carcass.

Genetic and phenotypic correlations among 182-day weight, feeder grade, average daily gain, feed efficiency and slaughter grade were obtained using 195 steers and 190 heifers by Carter and Kincaid (1959). No negative genetic correlations that would handicap selection were evident among the traits studied. The genetic correlations were all positive except those between grades and subsequent growth rates which appeared to be genetically independent. High positive correlations were found between gains in a particular period and grade at the end of the period. Perhaps the most important genetic correlation was between preweaning growth rate and subsequent rate of gain. The correlation coefficient was 0.69 for steers and 0.51 for heifers.

Koch and Clark (1955) reporting on the genetic and phenotypic correlations among economic characters in beef cattle, obtained a genetic correlation of only -0.05 between suckling gain and postweaning gains. Birth weight was fairly highly correlated with weaning weight (r=0.63), gain from birth to weaning (r=0.46) and yearling weight (r=0.40). Gain from birth to weaning was correlated with weaning score (r=0.50) and yearling weight (r=0.51). Weaning score was positively correlated with yearling score (r=0.45). Yearling weight and gain from weaning to yearling were correlated with yearling score with the following values respectively (r=0.49 and r=0.44).

Two studies were made on the relationships among scores and production traits in beef cattle by Bogart and Frischknecht (1967).

Weaning score was highly positively correlated with sucking gains but was lowly or negatively related to subsequent gaining ability. Weaning scores were highly correlated with subsequent scores. Preweaning weight was found to be slightly negatively associated with postweaning growth rate. Marlowe and Vogt (1965) obtained genetic correlations between preweaning daily gain and weaning grade on Angus and Hereford calves. The correlations were similar for both breeds with correlation coefficients of 0.23 and 0.21 for Angus and Hereford calves respectively.

Colby et al. (1950) correlated the blood levels of urea and creatinine in beef cattle with rate of gain. Urea was negatively correlated (r=-.55) with average daily gain as was creatinine (r=-.28), neither of which were significant. Price et al. (1956) found that urea levels in the blood at 500 pounds increased as feed consumed per 100 pounds gain increased (r=0.39). They also reported that amino acids in the blood at 800 pounds was significantly and inversely correlated with postweaning rate of gain (r=-.53). Amino acids at 500 and 800 lbs body weight were significantly and positively correlated with feed consumed per 100 pounds gain (r=0.47 and r=0.53 respectively).

Lofgreen and Garrett (1954) measured the urinary creatine excretion and the separable lean of the 9-10-11 rib cut of 18 Hereford steers. The creatinine excretion per unit of body weight was significantly correlated (r=0.67) with the percent separable lean in the soft tissue of the sample. Wuthier and Stratton (1957) determined that a significant relationship occurred between blood serum levels of creatinine and percent lean in the boned 9-10-11 rib cut of 35 animals (r=0.55). The levels of creatinine was also correlated (r=0.52) with rib eye area corrected for carcass weight in 27 beef cattle.

MATERIALS AND METHODS

A diallel mating system involving three inbred lines of Hereford cattle was initiated at the Oregon Agricultural Experiment Station, Corvallis, Oregon in 1962. Of the three lines, the Lionheart line was closed to outside breeding from 1950 to the initiation of the line-crossing program in 1962. A few cows were used to produce foundation animals in both the Prince and the David lines prior to 1950. No outside sires were used from 1948 to 1962 in all three lines. In addition, records from an Angus line were included to obtain more accurate estimates of environmental effects and correlations among the various traits measured. The Angus line has been maintained as a closed line from 1948 to the present time with the exception of one outside sire introduced in 1953, and used to sire some female replacements during the next two years. The Hereford lines were maintained as small, one sire and 12-15 cow lines while two sires and approximately 20 cows were routinely used in the Angus line. In each line, selection was practiced for increased preweaning gain, increased postweaning rate and efficiency of gain, and improved conformation and condition scores. In an attempt to maintain a high level of fertility, cows were culled if they missed two calves.

The data for this study were obtained over a four year period starting with the 1963 calf crop and extending through the 1966 calf crop. The breeding scheme for the diallel matings is hsown in the following breeding arrangement:

		LINE OF DAM		
		1	2	3
	1	IX1	1X2	IX3
Line of sire	2	2X1	2X2	2X3
	3	3X1	3X2	3X3

where 1, 2 and 3 are used as designations for the Lionheart, Prince, and David lines, respectively.

A total of six sires, two from each line were mated to 72 Hereford cows each year. The cows were assigned to the sires at random and a total of eight cows were allotted to each cross every breeding season. No cows were culled for the duration of the study except for those which had to be replaced because of disease or death.

The experiment was designed to use four sires from each line for the entire study with each sire being used two years in the following arrangement:

Breeding Season	Sires	
1962	Sire 1	Sire 2
1963	Sire 2	Sire 3
1964	Sire 3	Sire 4
1965	Sire 4	Sire 1

In this manner it was planned that effects of years could be separated from sire effects. However, it was possible to use the outlined rotation of sires only in line 2. One line 1 sire was inadvertently sold and one line 3 sire was infertile, thus making it necessary to modify the rotation scheme for these lines.

The experimental design and number of offspring by breed, sex and breeding group for the traits measured are presented in Tables 2 and 3. A total of 244 animals consisting of 182 Herefords and 62 Angus were available for the study. Slaughter and endocrine data were collected on 92 Hereford and 26 Angus males.

Management practices were similar from year to year with respect to pasture useage, feeding regime and care of the animals. All male calves were left intact for the entire testing period. Birth weights and birth dates were recorded for each calf and weights were obtained at two-week intervals throughout the preweaning period. The calves were weaned and suckling gains computed when weights of 170 and 193 kg. were reached by females and males, respectively. All calves were weaned by the middle of October regardless of their weights. No creep feed was available to the calves during the preweaning period.

Following weaning, the calves were allowed an adjustment period in the barn with the female calves starting on feed test at 182 kg. and the male calves starting at 204 kg. One-inch pellets

Table 2. Experimental design and number[1] of offspring by sex and breeding groups for preweaning and postweaning traits.

	Line of Dam							
	Line 1		Line 2		Line 3		Total	
Line of Sire	♂	♀	♂	♀	♂	♀	♂	♀
Line 1	11	10	15	9	9	12	35	31
Line 2	7	15	12	8	12	7	31	30
Line 3	17	6	8	9	11	4	36	19
Total	35	31	35	26	32	23	102	80

[1]There were also 33 males and 29 females of the Angus breed used, making a total of 135 males and 109 females involved in the study.

Table 3. Experimental design and number[1] of males by breeding group for slaughter traits.

	Line of Dam			
Line of Sire	Line 1	Line 2	Line 3	Total
Line 1	11	13	7	31
Line 2	5	12	10	27
Line 3	16	7	11	34
Total	32	32	28	92

[1]Also 26 Angus males were used, making a total of 118 males involved in the carcass and endocrine study.

composed of two parts coarsely chopped alfalfa and grass hay, and one part concentrate as recommended by Nelms, Williams and Bogart (1953), comprised the entire ration for the feed test. The calves were individually fed and allowed three hours in the morning and three hours in the afternoon for eating with weights of feed consumed being recorded. During the feed test, the calves were weighed weekly until the females and males reached weights of 340 and 454 kg., respectively. The calves were scored for conformation and condition by a committee of three at 227 and 340 kg. for the females and at 227, 363 and 454 kg. for the males. Rate and efficiency of gains were computed at these weights and replacement sires were selected on the basis of their preweaning gains, postweaning rate and efficiency of gains, and conformation scores. Those not kept as replacements were slaughtered at a commercial abattoir. Testicle, pituitary, thyroid and adrenal gland weights were recorded when the males were slaughtered.

Carcass data consisting of dressing percentage; carcass conformation, maturity, marbling and grade; rib-eye area; fat thickness over the 12th rib; and percent fat, lean and bone in the 12th rib section were measured. Organoleptic data were taken on a rib section comprised of the 10th and 11th ribs of each carcass. A trained taste panel composed of eight members evaluated each 10-11 rib section for tenderness, juiciness, flavor of lean, flavor of fat and overall score. The scoring scale used for the taste panel evaluation ranged from one to nine with nine bing themost desirable or the most pronounced. Cooking data consisting of percent loss and percent drip in cooking were also obtained.

Blood samples from the jugular vein were obtained prior to the morning feeding from all calves at 204 and 340 kg. An additional sample was collected from the males at 454 kg. The blood was collected in tubes containing dried neutral potassium oxalate at the rate of one mg. per ml. of blood as an anticoagulant (Hawk, Oser and Summerson, 1954, p. 541). Whole blood filtrates were obtained subsequent to collection as outlined by Hawk *et al.* (p. 543-544).

Blood creatinine was determined by the Jaffe reaction following the method of Folin and Wu (Hawk *et al.*, p. 555-556) using the alkaline free filtrate with alkaline picrate to form a red color. The color was compared to a standard in a Bausch and Lomb Spectronic 20 colorimeter.

Amino acid nitrogen was determined by the method of Danielson (Hawk *et al.*, p. 565-566). Color was developed by the action between amino acids and β-napthoquinone-4-sulfonic acid in alkaline solution provided by sodium tetraborate.

Urea nitrogen was determined colorimetrically by the method of Karr (Hawk *et al.*, p. 554) using urease to convert the urea to ammonium carbonate and gum ghatti as a stabilizing agent to maintain a clear solution of the nesselerized ammonium carbonate. All blood constituents were calculated on the basis of mg. per 100 ml. blood.

Due to management differences between the sexes, the data were analyzed separately using least squares procedures. Year, age of dam, inbreeding of dam, breed, general combining ability, specific combining ability and reciprocal effects were determined for the performance, blood, slaughter and organoleptic traits that were included in the study. The mathematical model used for the analyses was derived from a model outlined by Griffing (1956a) and Henderson (1952, p. 365). The following mathematical model was used:

$$Y_{ijklmn} = \mu + y_i + a_j + B_k + bF_d + g_l + g_m + s_{lm} + r_{lm} + e_{ijklmn}$$

Where, Y_{ijklmn} is the performance of the n^{th} individual from parents of the l^{th} and m^{th} lines, the k^{th} breed and the j^{th} aged dam in the i^{th} year.

μ is the overall mean when F_d is equal to zero.

y_i is the effect of the i^{th} year (i=63-66)

a_j is the effect of the j^{th} aged dam (j=2-12)

B_k is the effect of the k^{th} breed (k= Angus and Hereford)

b is the regression coefficient which furnishes a measure of the linear relationship between the dependent variable, Y_{ijklmn} and the independent variable, F_d,

F_d is the inbreeding of the dam.

g_l & g_m is the general combining ability effects of the l^{th} and m^{th} line.

s_{lm} is the specific combining ability effects of the cross between the l^{th} and m^{th} line such that $s_{lm} = s_{ml}$

r_{lm} is the reciprocal genotypic effect involving crosses of the l^{th} and m^{th} line such that $r_{lm} = -r_{ml}$.

e_{ijklmn} is the error due to the failure of the model to completely specify the response.

The least squares means for the various linecrosses and inbreds were calculated by using the following equation:

$$\hat{\mu}_{lm} = \hat{\mu} + \hat{B}_k + \widehat{b\bar{F}}_d + \hat{C}_{lm}$$

where, $\hat{\mu}_{lm}$ is the least squares estimate of the mean for the cross between the l^{th} and m^{th} lines.

$\hat{\mu}$ is the least squares estimate of the overall mean when F_d is equal to zero.

$\hat{B}_k$ is the least squares estimate for the effect of the k^{th} breed.

$\hat{b}$ is the estimated coefficient for the regression of the dependent variable, y, on the average inbreeding of dam, $\bar{F}_d$.

$\bar{F}_d$ is the average inbreeding of the dams of the k^{th} breed.

$\hat{C}_{lm}$ is the least squares estimate of the effect of the l^{th} and m^{th} lines ($l \leq m$).

Mid-parent means were compared to the appropriate linecross means to determine the percent advantage (heterosis) for each cross. Standard errors of the differences between the cross and mid-parent means were computed and t-tests were made. All possible simple phenotypic correlations were calculated from the raw data for all the performance, blood, carcass, endocrine, and organoleptic traits that were included in the study.

RESULTS AND DISCUSSION

Combining Abilities of Preweaning Performance Traits

Differences in general and specific combining abilities were obtained on calves produced from a diallel mating plan involving three inbred lines of Hereford cattle. A total of 182 Hereford and 62 Angus calves were born over a four year period. The number of calves for each breeding group is presented in Table 2. Differences associated with years, age of dam, inbreeding of dam and breeds were removed from the data by least squares procedures so that more accurate general and specific combining ability effects could be measured.

Least squares means of six preweaning and weaning traits, consiting of birth date, birth weight, preweaning average daily gain (ADG), age at 227 kg,, conformation at 227 kg. and condition at 227 kg. are presented in Tables 4 and 5. Birth date, measured as days from January 1, showed no consistent difference between or within the sexes (Table 4). Among male calves, the 2 × 1 crosses were born the earliest with the 3 × 2 calves being born the latest. Among the female calves, the 1 × 2 crosses were born first with the 1 × 3 calves born last. Angus males were born an average of 9.48 days before Hereford males and Angus females showed a 3.24

Table 4. Least squares means of inbred and linecross calves by sex for birth date, birth weight and average daily gain from birth to weaning.

Line		Birth Date (Days)[1]		Birth Weight (kg)		ADG Birth to weaning (kg)	
Sire	Dam	♂	♀	♂	♀	♂	♀
1	1	85.97	89.33	36.69	32.56	0.767	0.848
1	2	93.15	81.33	35.84	30.69	0.776	0.762
1	3	88.30	92.66	35.58	31.03	0.753	0.776
2	1	83.52	84.75	36.09	33.84	0.894	0.744
2	2	87.44	82.07	34.61	33.68	0.744	0.767
2	3	84.42	90.41	35.60	29.68	0.776	0.721
3	1	91.58	82.82	35.13	31.92	0.794	0.826
3	2	96.89	86.90	35.30	28.39	0.776	0.703
3	3	88.04	86.50	35.37	31.87	0.780	0.776
Over-all Hereford		88.81	86.31	35.58	31.52	0.784	0.769
Angus		79.33	83.07	31.83	29.20	0.970	0.873

[1] Days from January 1.

Table 5. Least squares means of inbred and linecross calves by sex for age at 227 kg, conformation score at 227 kg and condition score at 227 kg.

Line		Age at 227 kg (days)		Conf. at 227 kg (units)[1]		Cond. at 227 kg (units)[1]	
Sire	Dam	♂	♀	♂	♀	♂	♀
1	1	235.71	232.57	11.64	11.86	10.66	11.04
1	2	232.32	244.00	11.39	11.52	10.60	11.07
1	3	242.11	249.86	11.22	11.28	10.54	10.73
2	1	218.87	249.64	11.51	11.44	10.48	10.64
2	2	251.67	255.65	11.52	11.12	10.61	10.69
2	3	241.66	261.06	11.47	11.07	10.82	10.33
3	1	234.84	242.61	11.34	11.57	10.39	11.12
3	2	234.01	276.68	10.54	11.02	10.19	10.52
3	3	238.50	252.27	11.30	11.36	10.52	10.76
Over-all Hereford		236.63	251.59	11.33	11.36	10.53	10.77
Angus		201.08	231.09	11.93	11.77	10.69	10.99

[1] Expressed over a range of 5 (inferior) to 15 (superior) with 10 being average.

advantage over Hereford females.

Birth weight showed a consistent sex advantage in favor of the males (Table 4). The mean weight of Hereford males was 35.58 kg. while Hereford females weighed only 31.52 kg. Hereford calves also had heavier mean birth weights than did Angus calves.

Preweaning ADG (Table 4) did not show a large sex advantage among the Hereford calves as was indicated by means of 0.784 and 0.769 kg. per day for males and females, respectively. In addition, no consistent difference between sexes was indicated by the data. Of the nine breeding groups, the females exceeded the males in five of them. In contrast to this was the rather large difference that occurred between the Angus males and females. The preweaning ADG of the Angus calves was higher than that of the Hereford calves and this might be used as evidence that the sex difference in the Hereford males was masked by the lower quantity of milk produced by the Hereford dams. Line 3 cows produced calves with the lowest preweaning ADG among the male calves and line 1 cows produced calves that had the highest preweaning ADG among the female calves.

The average age at 227 kg. body weight as presented in Table 5 shows a sex effect for both the Hereford and Angus breeds with the younger age of the males being due partly to the heavier birth weights and partly to an increased preweaning ADG among the males. The 1 × 2 and 2 × 1 males showed an advantage over all other inbreds and linecrosses whereas among the females the 1 × 1 heifers reached 227 kg. at the youngest age. Generally, calves of both sexes born from line 1 dams reached 227 kg. body weight at an earlier age than calves from females of the other two lines.

Conformation and condition scores at 227 kg. generally exhibited a slight advantage of females over males (Table 5). Female calves had higher mean conformation scores in six of nine breeding groups and higher mean condition scores in eight of nine groups. Angus calves had higher scores for both conformation and condition at 227 kg. than Hereford calves. Males and females of the 1 × 1 cross exceeded all others for conformation score whereas 2 × 3 males and 3 × 1 females excelled in condition at 227 kg.

Sources of variation, degrees of freedom and mean squares for birth date, birth weight, preweaning ADG, age at 227 kg., conformation at 227 kg. and condition at 227 kg. are presented in Table 6. Year effects were significant for conformation and condition at 227 kg. among the male calves. Year effects among female calves were significant for conformation at 227 kg. and highly significant for condition at 227 kg. Significant year effects for conformation and condition at 227 kg. may in part have been due to differences in pasture conditions but probably most of the year effects were caused by differences in the people who scored the calves as members of the scoring committee varied from year to year. Also if the differences in conformation and condition scores at 227 kg. were caused by differences in pasture conditions, it would be expected that year effects would be detected for preweaning ADG.

Age of dam had a highly significant effect on preweaning ADG, but no significant age of dam effects were detected in all other pre-weaning and weaning traits for both sexes (Table 6). These data agree with that reported by Brinks et al. (1967) in which age of dam had a highly significant effect on preweaning gain and weaning weight for both male and female calves but was not significant for birth weight and weaning score. Flower et al. (1963) found that age of dam had a highly significant effect on birth weight and weaning weight in heifers. Marlow and Gaines (1958) reported that age of dam was the most important source of variation affecting preweaning growth rate of beef calves.

Inbreeding of dam had a significant effect on age at 227 kg. and conformation at 227 kg. as well as a highly significant effect on birth date and preweaning ADG among male calves (Table 6). However among the females, inbreeding of dam significantly affected only preweaning ADG. The results of this study would indicate that in-breeding of dam had a larger effect on males than on females. This would agree with the results obtained by Brinks, Clark and Kieffer (1963). They found that inbreeding of the calf had a larger depressing effect on females than on males whereas inbreeding of the dam had a

Table 6. Analyses of variance by sex for preweaning and weaning traits.

Source of Variation	d. f.	Birth Date	Birth Weight	ADG Birth to Weaning	Age at 227 kg	Conformation at 227 kg	Condition at 227 kg
Males:		days	kg	kg	days	units	units
Years	3	1027.55*	19.464	0.0290	840.40	2.319**	2.826**
Age of Dam	10	421.22	26.887	0.0608**	2132.27	0.590	0.282
Inbreeding of Dam	1	2069.45**	0.176	0.1588**	3720.55*	3.201*	0.158
Breeds	1	242.48	213.675**	0.2952**	12309.42**	2.169*	0.248
General Combining Ability	2	38.44	21.962	0.0118	1582.50	1.687*	0.191
Specific Combining Ability	3	199.92	5.902	0.0212	1474.44	0.254	0.039
Reciprocal Effects	3	326.17	0.561	0.0211	428.53	1.178	0.593
Error	111	289.28	15.074	0.0207	900.52	0.493	0.352
Total	134						
Females:							
Years	3	895.09	15.777	0.0216	262.14	2.153*	2.514**
Age of Dam	10	592.31	26.191	0.0391**	1485.21	0.440	0.363
Inbreeding of Dam	1	0.11	32.805	0.0563*	2896.47	0.129	0.668
Breeds	1	157.62	235.125**	0.0896**	2470.62	3.150*	1.649*
General Combining Ability	2	115.67	2.329	0.0400*	3578.60*	1.849	1.111*
Specific Combining Ability	3	65.10	48.376*	0.0139	292.27	0.089	0.201
Reciprocal Effects	3	134.80	19.954	0.0035	402.44	0.116	0.511
Error	85	335.81	15.262	0.0126	849.15	0.619	0.316
Total	108						

*P < .05, **P < .01.

greater depressing effect on male calves than on female calves for birth weight, 180-day preweaning gain, weaning weight and weaning score.

It would appear that increased inbreeding of dam decreases preweaning gains of male calves more than female calves because the decreased milk production of the highly inbred dams prevents the males from exhibiting their greater growth potential as compared to female calves. Thus, for male calves the inbreeding of the dam sets the upper limits for preweaning gain, but for female calves the inbreeding of the calf determines the preweaning rate of gain.

For the males, significant breed differences were detected for conformation at 227 kg. and highly significant differences were detected for birth weight, preweaning ADG and age at 227 kg (Table 6). Females showed significant breed differences for both conformation and condition at 227 kg. as well as highly significant differences in birth weight and preweaning ADG. These results are consistent with the past performance of the two breeds in this herd as reported by Hornbeek and Bogart (1966). The Angus line has consistently had a higher percentage of cows conceiving on first service, smaller birth weights and higher preweaning ADG than the Hereford lines. However, only recently has the Angus line surpassed the Herefords with respect to conformation and condition scores.

General combining ability differences were generally nonsignificant for males (Table 6). Conformation at 227 kg. was the only preweaning or weaning trait of the six studied that showed a significant general combining ability difference among the males with line 1 being superior in this trait. Among the females, significant general combining ability effects were detected for preweaning ADG, age at 227 kg. and condition at 227 kg. (Table 6). Again line 1 was superior to lines 2 and 3 with respect to these three traits among female calves. For the male calves, no significant specific combining ability effects were detected for all six traits. For the female data, specific combining ability effects were nonsignificant for all traits except birth weight which was significant at the 0.05 probability level (Table 6). This specific combining ability effect was caused by the small birth weights of both the 2 × 3 and 3 × 2 females. The difference in specific combining ability for birth weight was not shown by males of these crosses as both had birth weights that exceeded the mean for all Hereford males. The low birth weights of the 2 × 3 and 3 × 2 females may be partly responsible for the relatively poor preweaning performance of these crosses. This hypothesis would be consistent with work reported by Nelms and Bogart (1956), Bogart _et al._ (1956) and Koch and Clark (1955) in which birth weight was found to have a rather large effect on preweaning gains and scores. No reciprocal effects were exhibited among the various linecrosses for any of the six traits studied in either the male or the female calves.

The results of the combining ability differences of this study generally agree with the literature. Hetzer *et al.* (1953) found significant general combining ability differences for only one preweaning trait, litter weight at birth, and no specific combining ability effects for any trait among four breeds of swine. Later Hetzer *et al.* (1959) reported that only one preweaning trait, total litter weight at 56 days, exhibited general combining ability effects among six inbred lines of swine. Among three inbred lines of Suffolk sheep no significant general or specific combining ability differences were detected for birth weight, 120-day adjusted weaning weight or weaning score by Schilling (1966). Likewise, Hornbeek (1964) found no significant general or specific combining ability effects for birth weight or suckling gain among three inbred lines of Hereford cattle.

In contrast to these reports in which combining ability effects were small for preweaning traits, O'Bleness, Stonaker and Henderson (1959) found highly significant line-of-sire and line-of-dam effects for weaning weight among linecrosses of 13 inbred lines of Hereford cattle. Damon *et al.* (1961) conducted a crossbreeding experiment in the Gulf Coast area and found significant general combining ability effects for 180-day calf weight and slaughter calf grade. Specific combining ability effects were important for 180-day weight but not for slaughter calf grade.

The results of the present study and others reported in the literature would indicate that general and specific combining ability differences are very small among linecrosses within a breed for preweaning and weaning traits. However among breed crosses where more genetic diversity is found, general and specific combining ability differences are frequently detected for preweaning and weaning traits.

Combining Abilities of Postweaning Performance Traits

The least squares means of postweaning ADG, feed per unit gain, age at the end of the feed test, conformation score at the end of the feed test and condition score at the end of the feed test are presented in Tables 7, 8 and 9. All groups of males had higher rates of gain and were more efficient in feed utilization than females (Table 7). In addition, all inbred and linecross groups of males reached 363 kg. at an earlier age than any group of females reached 340 kg. (Table 7). Hereford males and females exceeded corresponding Angus males and females in rate and efficiency of gain. However, the Angus males reached 363 kg. body weight 23.4 days before the Hereford males because of their excellent preweaning gains. Among the females, the advantage for age at 340 kg. was only 1.7 days in favor of the Angus breed.

Table 7. Least squares means of inbred and linecross calves by sex for postweaning average daily gain, feed efficiency and age at the end of the feed test.

Line		ADG (kg)		Feed Efficiency (kg)[1]		Age (days)	
		204-363 kg	182-340 kg	204-363 kg	182-340 kg	363 kg	340 kg
Sire	Dam	♂	♀	♂	♀	♂	♀
1	1	1.270	0.957	6.38	8.13	344.32	359.12
1	2	1.374	1.021	5.88	7.44	333.42	358.82
1	3	1.393	1.030	5.85	7.37	342.58	354.91
2	1	1.383	1.048	5.54	7.34	311.47	356.30
2	2	1.347	0.925	5.69	8.33	350.93	357.76
2	3	1.288	1.012	5.91	7.45	345.49	371.03
3	1	1.347	0.921	6.14	8.15	333.47	361.43
3	2	1.352	0.989	5.85	7.47	331.52	391.84
3	3	1.329	0.989	5.95	7.71	339.82	364.73
Over-all Hereford		1.343	0.988	5.91	7.71	337.00	363.99
Angus		1.234	0.879	6.70	---	313.58	362.29

[1] Expressed as feed per unit gain.

Among specific linecrosses, the 1 × 2 and 1 × 3 crosses and their reciprocals were particularly rapid in rate of gain in both sexes. However, in feed efficiency those crosses with line 2 involved were generally superior to other linecrosses.

The conformation and condition scores for males at 363 kg. and for females at 340 kg. are presented in Table 8. The crosses of line 1 with lines 2 and 3 were generally superior to the crosses of lines 2 and 3 in both sexes. Sex differences were small and inconsistent. Angus males and females had higher conformation and condition scores than Herefords.

The males were continued on feed test until they reached 454 kg. body weight at which time those not kept for replacement sires were slaughtered. Least squares means for ADG from 204-454 kg., feed efficiency from 204-454 kg., age at 454 kg., conformation at 454 kg. and condition at 454 kg. are presented in Table 9. Generally only small changes occurred in the ranking of the means of the various groups when compared to the means in Tables 7 and 8. However, it is interesting to note how much smaller the difference was between the inbreds and linecrosses for the various traits at 454 kg. than at 363 kg. Rate and efficiency of gain decreased with increasing age but conformation and condition scores increased with increasing age.

The analyses of variance for the postweaning traits are presented in Tables 10, 11 and 12. Year effects were highly significant

Table 8. Least squares means of inbred and linecross calves by sex for conformation and condition scores at 363 kg (males) and 340 kg (females).

Line		Conformation (units) at[1]		Condition (units) at[1]	
		363 kg	340 kg	363 kg	340 kg
Sire	Dam	♂	♀	♂	♀
1	1	12.67	12.72	12.03	12.50
1	2	12.38	12.78	12.07	12.44
1	3	11.66	12.30	11.36	12.45
2	1	12.95	12.42	12.16	12.45
2	2	12.22	11.58	11.83	11.63
2	3	12.12	11.71	11.74	11.71
3	1	11.94	12.06	11.66	12.05
3	2	11.60	12.17	11.58	12.12
3	3	12.10	12.23	11.74	12.17
Over-all Hereford		12.18	12.22	11.80	12.17
Angus		12.78	12.28	12.17	12.02

[1]Expressed over a range of 5 (inferior) to 15 (superior) with 10 being average.

Table 9. Least squares means of inbred and linecross males for postweaning average daily gain, feed efficiency, age at 454 kg, conformation score at 454 kg and condition score at 454 kg.

Line Sire	Line Dam	ADG (kg) 204-454 kg	Feed Efficiency[1] (kg) 204-454 kg	Age (days) at 454 kg	Conformation[2] (units) at 454 kg	Condition[2] (units) at 454 kg
1	1	1.311	6.96	411.58	12.82	12.41
1	2	1.347	6.54	404.63	12.49	12.28
1	3	1.365	6.66	408.94	12.10	12.00
2	1	1.343	6.41	382.42	13.51	12.85
2	2	1.334	6.31	424.61	12.42	12.24
2	3	1.288	6.64	416.08	12.27	12.16
3	1	1.343	6.82	401.72	12.54	12.22
3	2	1.338	6.51	402.05	12.50	12.23
3	3	1.325	6.62	409.37	12.49	12.23
Over-all Hereford		1.333	6.61	406.82	12.57	12.29
Angus		1.228	7.41	387.30	13.03	12.48

[1] Expressed as feed per unit gains.

[2] Expressed over a range of 5 (inferior) to 15 (superior) with 10 being average.

for ADG from 204-363 kg. and from 182-340 kg. for males and females, respectively (Tables 10 and 11). Year effects were not significant for ADG from 204-454 kg. in the males as can be seen in Table 12. It seems likely that over the smaller weight increment of 204-363 kg., compensatory growth early in the test period caused the highly significant year effect for both sexes. Thus it might be advisable to feed the males over a feed period of approximately 250 kg. weight change to remove an effect caused by differences in pre-weaning performance. Another alternative would be to have a longer adjustment period in the barn prior to initiation of the feed test if the most accurate measure of genetic differences in rate of gain is desired from year to year.

Year effects were significant for condition of males at 363 kg. and condition of females at 340 kg. (Tables 10 and 11). Highly significant year effects were detected for condition of the males at 454 kg. (Table 12). Members of the scoring committee varied from year to year and the year effect may be more attributable to differences in people than to enviornmental differences. Age of dam effects as presented in Tables 10-12 were not important for any of the post-weaning traits among both sexes except for ADG among the females.

Inbreeding of dam had little effect on postweaning traits among the females, but was significant for ADG from 204-363 kg. among the males (Tables 10 and 11). Differences due to inbreeding of dam were highly significant for condition of males at 363 kg. (Table 11), and were significant for condition of males at 454 kg. (Table 12). The effects of inbreeding of dam on ADG of males was likely a compensatory effect since inbreeding of dam had a depressing effect on preweaning ADG among the males. The regression of ADG on inbreeding of dam was positive and tends to furnish support for this contention. A permanent or longer lasting environmental effect on condition of the males seems to have been induced by the inbreeding of the dams as the regression of condition on inbreeding of dam was negative at both weights although it was smaller at 454 kg. than at 363 kg. This differential effect of inbreeding of dam by sexes agrees with the results reported by Brinks, Clark and Kieffer (1963) in which inbreeding of dam was found to have larger effects on male calves than on female calves.

Breed differences as presented in Table 10 were significant for ADG from 204-363 kg. among the males. Differences between breeds for feed efficiency were highly significant at both weight intervals in the males (Tables 10 and 12). Among the females, highly significant breed differences were detected for ADG from 182-340 kg. but differences in feed efficiency could not be measured because individual feed efficiency records were not obtained on the Angus females (Table 11). These breed differences would agree with the history of the two breeds in this herd as reported by Hornbeek and Bogart (1966).

General combining ability differences were generally not important for postweaning growth traits, but significant or highly significant general combining ability effects were detected for conformation and condition scores for both sexes (Tables 10-12). Significant general combining ability differences were found in males for feed efficiency from 204-363 kg. and highly significant differences were detected for conformation and condition scores at both weights. General combining ability effects were significant for conformation at 340 kg. and highly significant for condition at 340 kg. among the females. The significant general combining ability effect on feed efficiency among the males was the result of the efficient line 2 males. The general combining ability effects on conformation and condition scores were the result of the lower scoring line 3 calves.

Specific combining ability effects were not important for the postweaning traits except ADG from 204-363 kg. in the males, ADG from 182-340 kg. in the females and age at 363 kg. in the males (Tables 10 and 11). Reciprocal effects were nonsignificant for all traits in both sexes except for conformation at 454 kg. in the males as shown by Table 12. This was caused by the large differences between the conformation scores of 1 × 2 and 2 × 1 males. The very high average score of 2 × 1 males could have been a result of chance since only seven males of this particular cross were produced over the four years.

Table 10. Analyses of variance for postweaning traits of males from weaning to 363 kg body weight.

Source of Variation	d. f.	ADG 204-363 kg	Feed Efficiency 204-363 kg	Age at 363 kg	Conformation at 363 kg	Condition at 363 kg
MALES:		kg.	kg	days	units	units
Years	3	0.0735**	1.073	653.52	1.203	1.167*
Age of Dam	10	0.0272	0.472	1471.10	0.771	0.310
Inbreeding of Dam	1	0.0864*	0.737	1293.39	4.010	3.047**
Breeds	1	0.0806 *	7.141**	5644.41*	1.914	0.379
General Combining Ability	2	0.0400	1.703*	2457.20	8.317**	3.257**
Specific Combining Ability	3	0.0614*	0.607	2861.50*	0.450	0.268
Reciprocal Effects	3	0.0097	0.323	1099.22	0.894	0.197
Error	111	0.0162	0.391	830.72	0.623	0.329
Total	134					

*P < .05, **P < .01.

Table 11. Analyses of variance for postweaning traits of females from weaning to 340 kg body weight.

Source of Variation	d. f.	ADG 182-340 kg	Feed Efficiency 182-340 kg	Age at 340 kg	Conformation at 340 kg	Condition at 340 kg
FEMALES:		kg	kg	days	units	units
Years	3	0.0668**	1.810	545.90	1.192	0.983*
Age of Dam	10	0.0254*	1.866	1398.81	0.315	0.258
Inbreeding of Dam	1	0.0182	0.107	1563.10	2.074	0.006
Breeds	1	0.1246**	----	211.44	1.769	0.368
General Combining Ability	2	0.0004	0.090	1400.56	2.753*	2.021**
Specific Combining Ability	3	0.0278*	2.296	992.69	1.018	0.500
Reciprocal Effects	3	0.0151	0.646	485.29	0.508	0.397
Error	85(57)[1]	0.0101	1.011	818.05	0.642	0.333
Total	108(79)[1]					

*P < .05, **P < .01.

[1] The error and total degrees of freedom in parentheses were used for feed efficiency from 182-340 kg as records were not obtained on the Angus females.

Table 12. Analyses of variance for postweaning traits of males from weaning to 454 kg body weight.

Source of Variation	d. f.	ADG 204-454 kg	Feed Efficiency 204-454 kg	Age at 454 kg	Conformation at 454 kg	Condition at 454 kg
		kg	kg	kg	units	units
Years	3	0.0104	0.513	882.41	0.509	3.753**
Age of Dam	10	0.0140	0.362	1504.92	0.263	0.101
Inbreeding of Dam	1	0.0284	0.939	1074.96	1.685	1.505*
Breeds	1	0.1092*	7.205**	3749.74	1.479	0.028
General Combining Ability	2	0.0133	1.334	2057.32	5.005**	2.516**
Specific Combining Ability	3	0.0176	0.136	2763.13	0.658	0.319
Reciprocal Effects	3	0.0442	0.096	1065.44	1.839*	0.541
Error	111	0.0161	0.444	1185.47	0.597	0.320
Total	134					

*P <.05, **P< .01

Most combining ability studies on postweaning traits have indicated that general combining ability effects are quite large while specific combining ability effects contribute little to the variation in the data. Kidwell et al. (1960) mated four inbred lines of mice in a complete diallel cross. They found highly significant general combining ability differences for 70-day weight but no specific combining ability effects were detected for that trait. In six inbred lines of swine Hetzer et al. (1959) found significant general combining ability effects for all postweaning growth traits, but specific combining ability effects were nonsignificant for all the traits studied. Magee and Hazel (1959) found significant differences in general combining ability among three-line cross pigs of 12 Poland China inbred lines for 154 day weight. Henderson (1949) found nonsignificant general combining ability effects on 154 day weights among single crosses of 12 inbred lines of Poland China swine which disagrees with the results reported by Magee and Hazel (1959).

Damon et al. (1961) found significant general combining ability and significant or highly significant specific combining ability effects on rate of gain, weight per day of age and slaughter grade among cattle of Angus, Brahman, Brangus, Charolais, Hereford and Shorthorn breeds and their crosses. Hornbeek (1964) observed significant general and specific combining ability differences of three inbred lines of Hereford cattle for postweaning rate and economy of gain.

In the present study, the results would indicate that the three inbred lines of Hereford cattle were genetically very similar with respect to postweaning growth traits. The line 3 males and females were somewhat low in conformation and condition scores which may have provided an opportunity for significant general combining ability differences to be detected.

Combining Abilities of Blood Constituents, Carcass Traits and Endocrine Gland Weights

Blood samples were taken from all male calves at 204 kg., 340 kg. and 454 kg. body weight. Females were bled at 204 kg. and 340 kg. body weight. Blood levels of creatinine, amino acid nitrogen and urea nitrogen, expressed as mg. per 100 ml. whole blood (mg. %), were determined as previously described.

The least squares means for creatinine, amino acids and urea in the blood are presented in Tables 13, 14 and 15. Blood levels of creatining were very consistent over all weights in both sexes (Tables 13-15). Males had slightly higher blood levels of creatinine than females which agrees with the data reported by MacDonald, Krueger and Bogart (1956) and Hornbeek (1964). In the present study, the higher blood content of creatinine at both weights may indicate a higher percentage of lean body mass in males than in females.

Amino acid nitrogen and urea nitrogen were higher in females than in males and increased with increasing ages in both sexes (Tables 13 and 14). These results agree with those reported by MacDonald, Krueger and Bogart (1956), Bogart et al. (1963) and Hornbeek (1964). The mean levels of amino acid nitrogen were somewhat higher at each weight than reported by the above authors.

Males were gaining more rapidly than females at all weights that blood samples were collected. The growth rate of both sexes tended to decrease with increasing age. The increasing levels of amino acids in the blood with increasing age would agree with the results of Williams (1954). He concluded that physiologically, females have a decreased protein anabolism compared to males therefore, not drawing on the amino acids for growth to the same extent. The excess amino acids are then deaminated resulting in more urea being formed.

Blood urea nitrogen and feed consumption increased with increasing age but growth rate decreased as age increased. It would appear that as the animal increases in age, protein anabolism decreases and fat deposition increases resulting in higher levels of urea in the blood from deaminization of the excess amino acids not utilized for growth.

The analyses of variance for the blood constituents are presented in Tables 16 and 17. Year effects were highly significant for creatinine, amino acids and urea nitrogen at all weights in both sexes.

Table 13. Least squares means of inbred and linecross calves by sex for blood constituents at 204 kg body weight.

Line		Creatinine (mg) at 204 kg		Amino Acids (mg) at 204 kg		Urea Nitrogen (mg) at 204 kg	
Sire	Dam	♂	♀	♂	♀	♂	♀
1	1	1.47	1.45	7.74	7.66	14.22	15.77
1	2	1.46	1.47	7.24	7.29	14.46	15.53
1	3	1.59	1.44	7.55	8.01	14.29	15.59
2	1	1.46	1.42	7.23	7.88	14.36	15.13
2	2	1.48	1.45	7.11	7.57	14.19	15.37
2	3	1.48	1.45	7.75	8.14	14.41	15.24
3	1	1.43	1.43	7.49	7.71	14.55	14.80
3	2	1.47	1.45	7.09	8.10	13.83	15.22
3	3	1.48	1.45	7.32	7.83	14.25	15.51
Over-all Hereford		1.48	1.45	7.39	7.80	14.28	15.35
Angus		1.48	1.45	8.42	8.32	15.27	16.03

Table 14. Least squares means of inbred and linecross calves by sex for blood constituents at 340 kg body weight.

Line Sire	Line Dam	Creatine (mg) at 340 kg ♂	Creatine (mg) at 340 kg ♀	Amino Acids (mg) at 340 kg ♂	Amino Acids (mg) at 340 kg ♀	Urea Nitrogen (mg) at 340 kg ♂	Urea Nitrogen (mg) at 340 kg ♀
1	1	1.49	1.47	7.55	8.26	15.20	16.67
1	2	1.47	1.47	7.99	7.85	15.25	16.06
1	3	1.53	1.46	7.72	7.88	15.35	16.80
2	1	1.46	1.47	7.83	7.86	14.77	16.70
2	2	1.48	1.47	7.35	7.44	15.69	17.02
2	3	1.46	1.46	7.38	7.78	14.40	15.52
3	1	1.46	1.45	7.96	8.94	15.11	16.39
3	2	1.48	1.44	7.69	9.59	14.75	16.86
3	3	1.48	1.45	7.65	8.16	15.11	16.48
Over-all Hereford		1.48	1.46	7.68	8.20	15.07	16.50
Angus		1.46	1.47	9.28	8.52	15.35	17.09

Table 15. Least squares means of inbred and linecross males for blood constituents at 454 kg body weight.

Line Sire	Line Dam	Creatinine (mg) at 454 kg	Amino Acids (mg) at 454 kg	Urea Nitrogen (mg) at 454 kg
1	1	1.50	7.61	15.60
1	2	1.48	8.27	15.97
1	3	1.53	7.89	16.32
2	1	1.46	7.18	14.90
2	2	1.52	7.78	14.81
2	3	1.45	7.94	15.12
3	1	1.50	8.31	15.05
3	2	1.51	7.73	14.57
3	3	1.49	7.96	15.39
Over-all Hereford		1.49	7.85	15.30
Angus		1.47	8.62	16.20

Whether these year effects could be accounted for by differences in the preparation of new chemical solutions from year to year or were associated with yearly effects on metabolism was not known.

Age of dam effects were nonsignificant except for creatinine at 454 kg. among the males (Table 17). Inbreeding of dam differences were not important for the blood constituents except that a significant inbreeding of dam effect was detected for urea nitrogen at 340 kg. among the females (Table 16).

Breed differences were significant for levels of amino acids and urea nitrogen at most weights but breed differences for both sexes were not significant for creatinine as shown by Tables 16 and 17. Highly significant breed differences were detected in amino acids at 204 kg., urea at 204 kg. and amino acids at 340 kg. whereas significant breed differences were found for amino acids and urea at 454 kg. among the males. For the females, a significant breed difference was detected for urea nitrogen at 204 kg. and a highly significant difference occurred for urea at 340 kg. (Table 16). These breed differences were expected since the growth rates of the two breeds were different.

General combining ability, specific combining ability and reciprocal effects were generally nonsignificant at all weights in both sexes for the three blood constituents measured (Tables 16 and 17). A highly significant general combining ability effect for creatinine at

Table 16. Analyses of variance by sex for blood constituents at 204 and 340 kg body weight.

		Weight of calves					
		204 kg			340 kg		
Source of Variation	d.f.	Creatinine	Amino Acids	Urea Nitrogen	Creatinine	Amino Acids	Urea Nitrogen
Males:		mg	mg	mg	mg	mg	mg
Years	3	0.0647**	11.039**	45.719**	0.0584**	28.164**	10.578**
Age of Dam	10	0.0118	0.912	2.906	0.0062	0.558	2.805
Inbreeding of Dam	1	0.0074	2.612	0.330	0.0000	0.213	0.858
Breeds	1	0.0011	23.152**	17.690**	0.0028	40.240**	2.473
General Combining Ability	2	0.0020	1.319	0.544	0.0016	0.540	0.045
Specific Combining Ability	3	0.0097	1.234	0.492	0.0060	0.900	3.426
Reciprocal Effects	3	0.0484**	0.579	0.591	0.0101	0.249	0.616
Error	111	0.0088	1.493	2.499	0.0053	1.543	2.288
Total	134						
Females:							
Years	3	0.0171**	14.958**	31.752**	0.0286**	13.622**	43.361**
Age of Dam	10	0.0036	0.826	2.423	0.0027	0.917	2.668
Inbreeding of Dam	1	0.0043	0.404	3.749	0.0004	0.785	8.452*
Breeds	1	0.0002	2.696	13.070*	0.0017	2.847	14.348**
General Combining Ability	2	0.0005	0.928	1.833	0.0083**	0.878	0.320
Specific Combining Ability	3	0.0007	0.200	2.738	0.0009	1.987	1.154
Reciprocal Effects	3	0.0047	0.714	0.984	0.0012	4.362	3.004
Error	94	0.0027	1.314	2.675	0.0025	2.027	1.804
Total	117						

$*P < .05$, $**P < .01$.

Table 17. Analyses of variance for blood constituents of males at 454 kg.

Source of Variation	d. f.	Creatinine	Amino Acids	Urea Nitrogen
Males:		mg.	mg.	mg.
Years	3	0.0525**	15.524**	20.761**
Age of Dam	10	0.0123*	1.444	1.375
Inbreeding of Dam	1	0.0001	1.345	0.007
Breeds	1	0.0037	13.156*	12.999*
General Combining Ability	2	0.0019	4.815	5.763
Specific Combining Ability	3	0.0140*	0.828	1.551
Reciprocal Effects	3	0.0061	2.056	4.837
Error	111	0.0049	2.142	3.011
Total	134			

* $P < .05$.

** $P < .01$.

340 kg. in the females was detected and a specific combining ability difference occurred for creatinine at 454 kg. among the males. A highly significant reciprocal effect involving males of 1 × 3 and 3 × 1 crosses occurred for creatinine at 204 kg. (Table 16). The general lack of significance for combining ability differences in blood constituents agrees with the results as reported by Hornbeek (1964).

Least squares means of the various carcass traits, organoleptic measurements and endocrine gland weights are presented in Tables 18 through 21. From the data in Table 18 it can be seen that Line 1 males and their crosses excelled the others in carcass conformation, carcass maturity, marbling and carcass grade. No consistent line differences existed for dressing percentage. The carcasses from the Angus males had higher conformation scores, higher degrees of marbling in the loin-eye, graded higher and had higher dressing percentages than the Hereford males.

The overall Hereford mean for carcass conformation was low to average choice whereas the mean carcass conformation for the Angus males was average to high choice. The Angus and Hereford carcasses both averaged A in maturity as was determined by the degree of ossification and color of the lean tissue in the carcasses. The marbling in the loin-eye was a slight minus amount for the Herefords whereas the Angus carcasses averaged a slight plus to small minus amount. The mean carcass grade, expressed in terms of U.S.D.A. bull grades, was high good to low choice for the Herefords and average choice for the Angus. The higher dressing percentage of the Angus carcasses was an indication of an increased amount of fat deposition as compared to that of the Herefords.

Data on the physical separation of the 12th rib cut, loin-eye area in square centimeters and fat depth in centimeters over the 12th rib are presented in Table 19. No consistent line differences occurred among the means for the physical separation of the 12th rib cut but the Angus carcasses had a higher percentage of fat and a lower percentage of lean and bone than the Herefords. Carcasses from line 2 bulls and their crosses excelled in loin-eye size when compared to the other groups. Carcasses from Hereford males had larger loin-eyes and less fat over the 12th rib than the Angus carcasses. The mean percentages of the physical separation are somewhat higher for percent lean and percent bone and lower for percent fat than the figures reported by Brackelsburg et al. (1968). They found that among steer carcasses ranging from low good to average choice, the percentages of fat, muscle and bone in the 12th rib section were 39.91, 46.57 and 13.52, respectively. The increased percentages of lean and bone and decreased percentages of fat in the present study are indicative that bull carcasses do not deposit as much fat as steer carcasses at the same weights. Also the males in the present study were not fed a high concentrate ration which

Table 18. Least squares means of inbred and linecross males for components of carcass grade and dressing percentage.

Sire	Dam	Conformation[1] (units)	Maturity[2] (units)	Marbling[3] (units)	Grade[4] (units)	Dressing Percentage (%)
1	1	11.14	5.32	7.97	10.34	56.73
1	2	10.82	5.33	7.25	9.90	56.25
1	3	10.52	5.46	6.86	9.73	56.48
2	1	10.98	5.65	7.75	10.35	56.87
2	2	10.69	5.07	6.30	9.45	56.68
2	3	10.81	5.23	6.14	9.21	56.65
3	1	10.97	5.53	7.40	9.86	56.13
3	2	10.53	5.43	5.87	8.68	55.86
3	3	10.73	5.34	6.90	9.66	56.44
Over-all Hereford		10.80	5.37	6.94	9.69	56.45
Angus		11.49	5.36	9.61	11.25	57.68

[1]Expressed over a range from 7 (low good) to 15 (high prime) with 11 being average choice.
[2]Expressed over a range of 1 (B+) to 6 (A-).
[3]Expressed as a range from 1 (practically devoid -) to 15 (modest +) with 7 being slight - .
[4]Expressed as a range from 7 (low good) to 12 (high choice) with 10 being low choice bull grade.

Table 19. Least squares means of inbred and linecross males for physical separation of the 12th rib cut, loin-eye area and fat depth over the 12th rib.

Line		12th Rib Separation			Loin-eye	Fat Depth
Sire	Dam	Fat (%)	Lean (%)	Bone (%)	Area (cm^2)	(cm)
1	1	30.16	51.54	18.30	74.90	0.71
1	2	27.51	53.79	18.70	78.58	0.65
1	3	25.68	54.89	19.44	79.16	0.69
2	1	29.50	52.60	17.90	80.65	0.67
2	2	27.14	54.61	18.26	80.32	0.76
2	3	28.32	54.21	17.47	77.55	0.84
3	1	29.71	51.76	18.53	77.10	0.80
3	2	27.06	53.18	19.76	75.74	0.63
3	3	28.19	53.21	18.60	77.61	0.74
Over-all Hereford		28.14	53.31	18.55	77.96	0.72
Angus		30.65	51.19	18.15	74.22	0.95

should have prevented them from having a high fat deposition in the carcasses.

Cooking and organoleptic data from a two-rib roast consisting of the 10-11 rib section are presented in Table 20. No line or breed difference was found for percent weight loss in cooking, lean flavor or fat flavor, but roasts from line 3 males and their crosses were higher in percent drip, tenderness score and juiciness score than roasts from the other crosses. The higher tenderness and juiciness scores of these roasts were likely the result of a higher percentage of fat as was indicated by the higher percent drip for roasts from line 3 males and their crosses.

The least squares means for overall organoleptic score and endocrine gland weights are presented in Table 21. Line 3 males and their crosses excelled in overall organoleptic score. Breed differences were not detected for overall organoleptic score, pituitary weight and adrenal weight. Mean thyroid and testicle weights were larger for the Angus than for the Hereford males. It was noted that the Angus males were usually more nervous than the Hereford males and the larger thyroid glands of the Angus males might be an indication of a slight hyperthyroid condition as compared to that of the Herefords. This is only an hypothesis since the reports in the literature on the association between thyroid gland weight and thyroxine output are somewhat conflicting.

Table 20. Least squares means of inbred and linecross males for cooking and organoleptic measurements.

Line		Cooking	Cooking	Organoleptic Measurements			
Sire	Dam	Loss (%)	Drip (%)	Tenderness[1] (units)	Juiciness[1] (units)	Lean Flavor[1] (units)	Fat Flavor[1] (units)
1	1	22.43	5.84	6.05	5.91	6.26	5.88
1	2	22.81	5.57	6.08	5.95	6.30	5.87
1	3	22.83	5.26	6.55	6.47	6.24	5.93
2	1	21.72	4.50	5.55	5.82	6.16	5.95
2	2	22.85	5.37	5.83	5.89	6.34	5.79
2	3	22.97	6.18	6.31	6.24	6.39	6.03
3	1	21.04	5.60	6.27	6.17	6.48	6.00
3	2	21.13	5.54	6.17	6.45	6.22	6.20
3	3	22.16	5.60	6.12	6.14	6.26	5.92
Over-all Hereford		22.22	5.50	6.10	6.12	6.29	5.95
Angus		22.28	6.49	6.11	6.01	6.08	5.90

[1] Expressed as a range of 1 to 9 with 9 being the most pronounced.

Table 21. Least squares means of inbred and linecross males for organoleptic measurements and endocrine gland weights.

Line Sire	Line Dam	Over-all Organoleptic Score (units)	Pituitary (gms)	Thyroid (gms)	Adrenal (gms)	Testicles (gms)
1	1	5.93	1.91	22.17	15.65	479.30
1	2	5.98	1.83	21.01	17.53	432.09
1	3	6.27	1.94	19.66	16.97	452.89
2	1	5.50	1.65	18.96	15.71	426.68
2	2	5.88	1.77	16.92	15.44	451.19
2	3	6.20	1.90	16.41	14.82	470.47
3	1	6.18	1.81	21.30	14.69	505.00
3	2	6.36	1.88	16.99	15.10	454.50
3	3	6.03	1.83	18.76	15.60	460.69
Over-all Hereford		6.04	1.84	19.13	15.72	459.20
Angus		5.89	1.94	22.75	15.95	527.86

[1] Expressed as a range of 1 to 9 with 9 being the most pronounced.

Analyses of variance for the various carcass traits, organoleptic data and endocrine gland weights are shown in Tables 22-25. Year effects were highly significant for carcass maturity, marbling in the loin-eye, carcass grade, percent fat in the 12th rib section, percent bone in the 12th rib section, loin-eye area, fat depth, percent cooking loss, percent drip, flavor of lean, flavor of fat and overall organoleptic score (Tables 22-25). Significant year differences were detected for percent lean in the 12th rib section, tenderness, juiciness, and thyroid gland weight (Tables 23-25). The year effects may have been caused by differences in people making the measurements, by differences in individual sires that were used from year to year, or by the effect of yearly differences on animals of similar genotypes.

Age and inbreeding of the dams had little or no effect on most of the carcass, organoleptic, or endocrine measurements (Tables 22-25). A highly significant age of dam effect was detected for carcass maturity (Table 22) whereas inbreeding of dam effects were significant only for percent lean in the 12th rib section (Table 23).

Breed differences were highly significant for carcass conformation, loin-eye marbling, carcass grade and fat depth over the 12th rib (Tables 22 and 23). The Angus had the larger values in all instances. Significant breed differences were detected for loin-eye area, percent drip, thyroid gland weight, and testicle weight with the

Table 22. Analyses of variance for components of carcass grade and dressing percentage of males.

Source of Variation	d.f.	Conformation	Maturity	Marbling	Grade	Dressing Percentage
		units	units	units	units	%
Years	3	0.8209	2.4564**	63.509**	15.460**	3.980
Age of Dam	10	0.6118	1.0530**	3.226	1.530	1.741
Inbreeding of Dam	1	0.0023	0.0062	1.189	0.304	6.177
Breeds	1	5.6638**	0.0007	99.831**	27.893**	10.225
General Combining Ability	2	2.2823*	0.3394	15.806*	7.329**	0.938
Specific Combining Ability	3	0.2008	0.4927	1.023	0.883	0.238
Reciprocal Effects	3	0.4178	0.1697	0.777	0.520	1.202
Error	94	0.5806	0.2581	3.205	1.294	2.566
Total	117					

*P < .05, **P < .01.

Table 23. Analyses of variance for physical separation of the 12th rib cut, loin-eye area and fat depth over the 12th rib of males.

Source of Variation	d.f.	12th Rib Separation: Fat	12th Rib Separation: Lean	12th Rib Separation: Bone	Loin-Eye Area	Fat Depth
		%	%	%	cm^2	cm
Years	3	139.88**	44.73*	54.57**	675.999**	0.379**
Age of Dam	10	16.95	22.44	6.70	67.845	0.088
Inbreeding of Dam	1	27.09	53.44*	4.47	7.825	0.012
Breeds	1	40.78	15.76	5.84	200.082*	0.638**
General Combining Ability	2	14.86	18.59	3.56	85.535	0.127
Specific Combining Ability	3	9.28	6.14	0.35	52.653	0.039
Reciprocal Effects	3	29.91	16.96	7.90	13.860	0.071
Error	94	15.54	12.61	5.14	47.325	0.065
Total	117					

*P < .05, **P < .01.

Table 24. Analyses of variance for cooking and organoleptic measurements of males.

Source of Variation	d. f.	Cooking Loss	Cooking Drip	Organoleptic measurements			
				Tenderness	Juiciness	Lean Flavor	Fat Flavor
		%	%	units	units	units	units
Years	3	55.566**	10.349**	2.001*	0.950*	4.310**	9.454**
Age of Dam	10	4.084	1.618	0.643	0.353	0.208	0.106
Inbreeding of Dam	1	0.194	3.293	0.624	0.106	0.104	0.171
Breeds	1	0.061	6.943*	0.114	0.035	0.356	0.001
General Combining Ability	2	3.760	4.838*	1.720*	1.614**	0.117	0.015
Specific Combining Ability	3	0.412	2.362	0.318	0.199	0.255	0.450
Reciprocal Effects	3	9.840	1.936	0.424	0.195	0.147	0.043
Error	94	4.524	1.535	0.541	0.276	0.201	0.186
Total	117						

*P < .05, **P < .01.

Table 25. Analyses of variance for over-all organoleptic score and endocrine gland weights of males.

Source of Variation	d. f.	Over-all Organoleptic Score	Pituitary Weight	Thyroid Weight	Adrenal Weight	Testicle Weight
		units	gms	gms	gms	gms
Years	3	2.961**	0.0987	168.977*	8.494	14097.75
Age of Dam	10	0.243	0.0349	34.634	2.878	9727.00
Inbreeding of Dam	1	0.001	0.0273	111.054	11.006	13493.92
Breeds	1	0.342	0.1648	322.304*	5.894	32472.01*
General Combining Ability	2	0.685	0.0356	177.426*	11.840	8412.27
Specific Combining Ability	3	0.621	0.0772	8.726	4.481	3660.56
Reciprocal Effects	3	0.264	0.0577	8.600	11.056	4478.96
Error	94	0.318	0.0665	54.040	4.430	6787.69
Total	117					

*P < .05, **P < .01.

Angus having the larger values except for loin-eye area. Differences among the lines in general combining ability were highly significant for carcass grade (Table 22) and juiciness (Table 24) as determined by the taste panel. Significant general combining ability effects were found for carcass conformation, marbling in the loin-eye, percent drip, tenderness (from taste panel evaluations) and thyroid gland weight (Tables 22, 24 and 25). Line 1 excelled in carcass conformation, marbling, carcass grade and thyroid weight while line 3 was highest in percent drip, tenderness and juiciness. No specific combining ability or reciprocal effects were significant for any of the carcass, organoleptic or endocrine gland traits that were included in the study.

In a related study, Hetzer et al. (1959) measured general combining ability differences among six inbred lines of swine. They found that general combining ability effects were significant for all carcass traits except dressing percentage. The traits measured were dressing percentage, percent yield of lean cuts, percent yield of bacon, percent yield of preferred cuts (sum of lean cuts and bacon), percent yield of fat cuts, and backfat thickness. Specific combining ability effects were significant only for yield of bacon. Maternal differences were significant for dressing percentage, yield of bacon and yield of fat cuts.

Schilling (1966) reported that among three inbred lines of

Suffolk sheep, general combining ability effects were significant for carcass grade, fat trim in the carcass, percent kidney knob fat, and weight of trimmed legs. A highly significant general combining ability difference was found for fat thickness over the 12th rib. No significant general combining ability differences were found for adrenal, pituitary and thyroid gland weights.

The results of the present study would imply that general combining ability differences increase among later life traits while specific combining ability effects decrease. These results would be consistent with the knowledge of most production traits in beef cattle. Additive genetic variation accounts for only a small portion of the total phenotypic variation for early life traits but the amount of the total phenotypic variation that is due to additive effects increases for later life traits. On the other hand, dominance and epistasis contribute less and less to the total phenotypic variation among later life traits.

The data would indicate that little genetic diversity occurred between the lines for most of the performance traits included in the present study. This is evidenced by an almost total lack of general combining ability differences among the growth traits although conformation and condition scores showed several general combining ability differences. For some traits which have not received direct selection such as carcass traits, sufficient genetic diversity between the lines was developed to detect significant general combining ability effects.

These results are not too surprising when a close inspection of the lines is made. All three lines were developed from the same breed which would limit the amount of genetic diversity that might be desired. Also some of the line 2 and line 3 females used in the initiation of the lines were related. Selection was practiced for the same characters and under the same environmental influences which would cause gene frequencies to change in the same direction and reduce differences between the lines. Finally, the inbreeding of the lines may not have been sufficiently high to diverge the lines to the extent that general and specific combining ability differences could be measured.

In view of these findings, it might be advantageous to select for different traits in each line. With this practice, selection for the particular character of interest would be very efficient. Not only would the level of performance be high for the selected character, but genetic divergence between the lines would be increased. The feasibility of this method of selection may be debatable, but to have general and specific combining ability differences between lines, genetic diversity must be present.

The only advantage of inbred lines is in their increased regularity of transmission of characters; therefore, before lines are closed it would be advisable to first test the lines to be used for potential combining ability. This would enable one to locate the better combining stocks from which closed lines could be developed that would produce superior linecrosses.

Heterosis of Reproductive, Preweaning and Weaning Traits

Heterosis for reproductive performance was studied using calving records of 282 Hereford cows bred to produce inbred and linecross calves (Table 26). In addition, breed comparisons were made between 86 matings in the Angus line and the 282 Hereford matings (Table 27). Statistical differences were determined by the Chi-square test. The reproductive traits studied were percent calves born, percent calves stillborn, percent loss from birth to weaning and percent calves weaned.

Table 26. Reproductive performance of Hereford cows bred to produce inbred and linecross calves.

Mating	No.	% calves born[1]	% calves stillborn[2]	% loss[2]	% calves weaned[1]
Inbred	90	72.2	13.8	13.8	62.2
Linecross	192	70.3	5.2	5.2	66.7
Total	282	70.9	8.0	8.0	65.2

[1] Percent of cows exposed.

[2] Percent of calves born.

The reproductive performance of cows bred to produce inbred and linecross calves is presented in Table 26. Percent calves born, expressed as percent of calves born from cows exposed, was 72.2 percent for cows giving birth to inbred calves and 70.3 percent for cows producing linecross calves. This difference was not significant. However, stillbirths and weak calves resulted in 13.8 percent of the inbred calves born being dead within the first 24 hours as compared to 5.2 percent of the linecross calves. This difference was significant as shown by the Chi-square test. No inbred or linecross calves died after the first 24 hours; consequently, the percent loss for the entire preweaning period was the same as for percent stillbirths. Due to the increased stillbirths of the inbred calves, 4.5 more calves per 100 cows exposed were weaned in favor of the linecross calves. The difference in percent calves weaned was not significant,

Differences in percent calves born between cows bred to produce inbred or linecross calves would be expected to be small because inbred cows were used to produce both inbred and linecross calves. Thus the maternal environment would be very similar and no differences in ovulation rate, uterine environment, or other factors affecting calving percentage would be expected between the two groups. The only factor that might cause a difference in calving percentage would be an increased embryo mortality due to a higher incidence of homozygous recessive lethals among the inbred embryos.

Percent stillbirths and death in the first 24 hours was greater among the inbred calves apparently because of the effect of inbreeding of the calf. Also the high percentage of stillbirths among the inbred calves in this study compared with the percent stillbirths in outbred or crossbred populations reported in the literature would indicate the difference is mostly attributable to the inbreeding of the calves. Gaines et al. (1966) reported death losses of seven percent among purebred calves and Turner, Farthing and Robertson (1968) found only 2.8 percent stillbirths among straightbred calves. The value of 5.2 percent stillbirths for linecross calves in the present study is similar to that reported by the above authors and is likely a more accurate estimate of the percent stillbirths of an outbred population.

The comparison of reproductive performance between the Hereford and Angus breeds is presented in Table 27. The percent calves born was 87.2 for the Angus breed and 70.9 for the Hereford breed. The difference between breeds in percent calves born and percent calves weaned was highly significant. A large part of the breed differences may be due to the differences in average inbreeding of the dams. The average inbreeding of the Hereford dams was 14.2 percent whereas the average inbreeding of the Angus dams was only 4.9 percent. Whether the difference in calving percentage was due to genetic differences in favor of this herd of Angus or due to the differences in average inbreeding of dams between the breeds in this herd cannot be determined because of the experimental design.

Heterosis of the preweaning, postweaning, blood, carcass and endocrine traits was determined by comparing the least squares means of a particular linecross plus its reciprocal with the appropriate mid-parent mean. The difference was obtained and the cross advantage, expressed in percent (heterosis), was calculated by dividing the difference between the two means by the mid-parent mean. The significance of the amount of heterosis exhibited was determined by using the t-test on the difference between the linecross and inbred means.

Table 27. Reproductive performance of Hereford and Angus cows.

Breed	No.	% Calves born[1]	% Calves Stillborn[2]	% loss[2]	% Calves weaned[1]
Hereford	282	70.9	8.0	8.0	65.2
Angus	86	87.2	0.0	2.7	84.9
Total	386	74.7	5.8	6.5	69.8

[1] Percent of cows exposed.

[2] Percent of calves born.

The amount of heterosis exhibited for the various preweaning and weaning traits is presented in Tables 28-30. Generally the heterotic effects were small and nonsignificant with males showing more heterosis than females.

Estimates of heterosis for birth date, measured as days from January 1, and birth weight are presented in Table 28. No significant differences were detected among either the males or females for birth date. All three linecross male groups were actually born on the average, later than the inbred males whereas the 1 × 2 and 1 × 3 female crosses exhibited a slight advantage over the inbreds. The trend for inbred calves to be born first would agree with that found by Wiltbank _et al_. (1967). Among a study of straightbred and crossbred calves, they reported that six percent more cows bred for straightbred calves conceived on the first service ($P < .05$).

Birth weight among the males showed no significant heterotic effects but the linecrosses exhibited a slight advantage (Table 28). However, among the females, all linecross groups were smaller at birth than the corresponding inbreds with the difference between the comparison of the 2 × 3 and 3 × 2 linecrosses with their inbred contemporaries being highly significant. The overall difference between the linecross and inbred groups was also significant.

The amount of heterosis for preweaning ADG and age at 227 kg. body weight among the males and females is presented in Table 29. No significant differences were found for preweaning ADG or age at 227 kg. of either male or female groups. The linecross males exhibited 5.26 and 3.30 percent heterosis for preweaning ADG and age at 227 kg. respectively, whereas negative heterotic effects of -5.00 and -2.90 percent for preweaning ADG and age at 227 kg., respectively were found among the females. From Table 30 it can be seen that small, nonsignificant negative heterotic effects were generally exhibited for conformation and condition scores at 227 kg.

by both sexes. Only conformation score at 227 kg. of the 1 $\times$ 3 and 3 $\times$ 1 cross males showed a significant negative heterotic effect.

The results of the present study with respect to heterosis among preweaning and weaning traits do not generally agree with the literature. Gregory et al. (1965) found significant heterotic effects on birth weights, preweaning daily gain, 200-day adjusted weaning weight and weaning conformation score among crosses of Angus, Hereford and Shorthorn breeds of cattle. Gaines et al. (1966) reported that a small amount of heterosis was exhibited for birth weight among crosses of Angus, Hereford and Shorthorn cattle. Preweaning growth showed both maternal and heterotic effects. Heterotic effects were detected among crosses involving Shorthorn and Angus cows but maternal effects of Hereford dams prevented heterotic effects from being exhibited for preweaning growth.

Brinks, et al. (1967) reported that among linecrosses of inbred lines of Hereford cattle, significant heterotic effects were observed for birth weight and highly significant heterotic effects were found for preweaning ADG, 205 day weaning weight and weaning score for both male and female calves. They also found that females generally exhibited more heterosis for preweaning traits than males.

In the present study the inbred females were actually superior to the linecross females for the various preweaning and weaning traits studied. It would appear that no homogametic heterosis occurs

Table 28. Heterosis of linecross calves by sex for birth date and birth weight.

Line		Birth Date (Males)				Birth Date (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	days	days	days	%	days	days	days	%
1	1	85.97	....	....	....	89.33	....	....	....
2	2	87.44	....	....	....	82.07	....	....	....
3	3	88.04	....	....	....	86.50	....	....	....
1 / 2	2 / 1	88.34	86.71	1.63	1.88	83.04	85.70	-2.66	- 3.10
1 / 3	3 / 1	89.94	87.00	2.94	3.38	87.74	87.92	-0.18	- 0.22
2 / 3	3 / 2	90.67	87.74	2.93	3.34	88.66	84.29	4.37	5.18
LC-SL[1]		89.65	87.15	2.50	2.87	86.48	85.97	-0.51	- 0.59

Line		Birth Weight (Males)				Birth Weight (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	kg	kg	kg	%	kg	kg	kg	%
1	1	36.72	....	....	....	32.59	....	....	....
2	2	34.64	....	....	....	33.71	....	....	....
3	3	35.37	....	....	....	31.87	....	....	....
1 / 2	2 / 1	36.00	35.68	0.32	0.90	32.29	33.15	-0.86	- 2.59
1 / 3	3 / 1	35.39	36.05	-0.66	-1.83	31.93	32.23	-0.30	- 0.93
2 / 3	3 / 2	35.48	35.00	0.48	1.37	29.06	32.79	-3.73**	-11.38
LC-SL[1]		35.67	35.58	0.04	0.11	31.09	32.72	-1.63*	- 4.98

*P < .05, **P < .01.

[1]Over-all linecross minus straightline (inbred) averages.

Table 29. Heterosis of linecross calves by sex for preweaning average daily gain and age at 227 kg.

Line		ADG Birth to Weaning (Males)				ADG Birth to Weaning (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	kg	kg	kg	%	kg	kg	kg	%
1	1	0.77	....	....	....	0.85	....	....	....
2	2	0.74	....	....	....	0.77	....	....	....
3	3	0.78	....	....	....	0.78	....	....	....
1 2	2 1	0.84	0.76	0.08	10.53	0.75	0.81	-0.06	-7.41
1 3	3 1	0.77	0.77	0.00	0.00	0.80	0.81	-0.01	-1.23
2 3	3 2	0.78	0.76	0.02	2.63	0.71	0.78	-0.07	-8.97
LC-SL		0.80	0.76	0.04	5.26	0.76	0.80	-0.04	-5.00

Line		Age at 227 kg (Males)				Age at 227 kg (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	days	days	days	%	days	days	days	%
1	1	235.71	....	....	....	232.57	....	....	....
2	2	251.67	....	....	....	255.65	....	....	....
3	3	238.50	....	....	....	252.27	....	....	....
1 2	2 1	225.60	243.69	18.09	7.42	246.82	244.11	- 2.71	-1.11
1 3	3 1	238.47	237.10	- 1.37	-0.58	246.24	242.42	- 3.82	-1.58
2 3	3 2	237.84	245.08	7.24	2.95	268.87	253.96	-14.91	-5.87
LC-SL		233.97	241.96	7.99	3.30	253.98	246.83	- 7.15	-2.90

Table 30. Heterosis of linecross calves by sex for conformation and condition scores at 227 kg.

Line		Conformation at 227 kg (Males)				Conformation at 227 kg (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	units	units	units	%	units	units	units	%
1	1	11.64	....	....	....	11.86	....	....	....
2	2	11.52	....	....	....	11.12	....	....	....
3	3	11.30	....	....	....	11.36	....	....	....
1 2	2 1	11.45	11.58	-0.13	-1.12	10.86	11.49	-0.63	-5.48
1 3	3 1	11.28	11.47	-0.19	-1.66	10.93	11.61	-0.68	-5.86
2 3	3 2	11.01	11.41	-0.40*	-3.51	10.43	11.24	-0.81	-7.21
LC-SL		11.25	11.49	-0.24	-2.09	10.74	11.45	-0.71	-6.20

Line		Condition at 227 kg (Males)				Condition at 227 kg (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	units	units	units	%	units	units	units	%
1	1	10.66	....	....	....	11.04	....	....	....
2	2	10.61	....	....	....	10.69	....	....	....
3	3	10.52	....	....	....	10.76	....	....	....
1 2	2 1	10.54	10.64	-0.10	-0.94	10.86	10.87	-0.01	-0.09
1 3	3 1	10.47	10.59	-0.12	-1.13	10.93	10.90	0.03	0.27
2 3	3 2	10.51	10.56	-0.05	-0.47	10.43	10.73	-0.30	-2.80
LC-SL		10.50	10.60	-0.10	-0.94	10.74	10.83	-0.09	-0.83

*P < .05.

in these lines for preweaning traits. This lack of heterosis among both males and females is probably due to the strong masking effect of the lowered milk production of the inbred dams and perhaps due to a lack of genetic diversity among the lines.

Heterosis of Postweaning Traits

The amount of heterosis for postweaning traits is presented in Tables 31-35. Linecross females were superior to inbred females for rate of gain and feed per unit gain. Linecross males were younger than inbred males at 363 kg. Differences between linecross and inbred calves were very small for conformation and condition scores.

In Table 31 it can be seen that the amount of heterosis for ADG from 204-363 kg. was significant for the 1 × 3 and 3 × 1 males. Among the females, the 1 × 2 cross plus its reciprocal exhibited a highly significant advantage for ADG from 182-340 kg. The overall linecross minus inbred difference was 0.04 kg. ($P < .05$) among the females. The 1 × 2 and 2 × 1 cross females were significantly superior to their inbred contemporaries for feed per unit gain. Also, the overall linecross advantage was significant for feed per unit gain among the females. No significant linecross advantage was detected for feed per unit gain from 204-363 kg. in the males.

Differences in age at 363 kg. were highly significant in favor

Table 31. Heterosis of linecross calves by sex for postweaning average daily gain and feed efficiency.

Line		ADG 204-363 kg (Males)				ADG 182-340 kg (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	kg	kg	kg	%	kg	kg	kg	%
1	1	1.27	....	....	....	0.96	....	....	....
2	2	1.35	....	....	....	0.93	....	....	....
3	3	1.33	....	....	....	0.99	....	....	....
1 2	2 1	1.38	1.31	0.07	5.34	1.04	0.94	0.10**	10.64
1 3	3 1	1.37	1.30	0.07*	5.38	0.98	0.97	0.01	1.03
2 3	3 2	1.32	1.34	-0.02	-1.49	1.00	0.96	0.04	4.17
LC-SL		1.36	1.32	0.04	3.03	1.00	0.96	0.04*	4.17

Line		Feed Efficiency[1] 204-363 kg (Males)				Feed Efficiency[1] 182-340 kg (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	kg	kg	kg	%	kg	kg	kg	%
1	1	6.38	....	....	....	8.13	....	....	....
2	2	5.69	....	....	....	8.33	....	....	....
3	3	5.95	....	....	....	7.71	....	....	....
1 2	2 1	5.71	6.04	0.33	5.46	7.39	8.23	0.84*	10.21
1 3	3 1	6.00	6.16	0.16	2.60	7.76	7.92	0.16	2.02
2 3	3 2	5.88	5.82	-0.06	-1.03	7.46	8.02	0.56	6.98
LC-SL		5.86	6.01	0.15	2.50	7.54	8.06	0.52*	6.45

*P < .05, **P < .01.

[1] Expressed as feed per unit gain.

of the 1 × 2 and 2 × 1 males as shown in Table 32. Linecross males evinced an overall advantage of 12.04 days ($P < .05$) for age at 363 kg. A significant negative heterotic effect for age at 340 kg. was detected among 2 × 3 and 3 × 2 females. This negative heterosis for age at 340 kg. was likely the result of the poor suckling gains of the 2 × 3 and 3 × 2 females.

No significant differences between overall linecross and inbred means were found for conformation and condition scores of either males at 363 kg. or females at 340 kg. (Tables 32 and 33). However the 1 × 3 and 3 × 1 males exhibited negative heterosis for conformation score at 363 kg. ($P < .01$) and condition score at 363 kg. ($P < .05$).

Linecross advantages were not found for ADG from 204-454 kg., feed per unit gain from 204-454 kg., age at 454 kg., conformation at 454 kg. or condition at 454 kg. among the males (Tables 34 and 35). However, a significant heterotic advantage of 24.60 days was detected in 1 × 2 and 2 × 1 males for age at 454 kg. The overall linecross minus inbred differences were very similar for ages at 363 and 454 kg. among the males.

Using males and females from a diallel cross of five inbred lines of Herefords, Urick *et al.* (1968) conducted a similar study to determine the amount of heterosis exhibited for feedlot weights and gains of the males and for weights and gains of the females on the

Table 32. Heterosis of linecross calves by sex for age and conformation score at the end of the feed test.

Line		Age at 363 kg (Males)				Age at 340 kg (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	days	days	days	%	days	days	days	%
1	1	344.32	....	....	....	359.12	....	....	....
2	2	350.93	....	....	....	357.76	....	....	....
3	3	339.82	....	....	....	364.73	....	....	....
1 2	2 1	322.45	347.63	25.18**	7.24	357.56	358.44	0.88	0.24
1 3	3 1	338.03	342.07	4.04	1.18	358.17	361.93	3.76	1.04
2 3	3 2	338.50	345.38	6.88	1.99	381.44	361.25	-20.19*	-5.59
LC-SL		332.99	345.03	12.04*	3.49	365.72	360.54	- 5.18	-1.44

Line		Conformation at 363 kg (Males)				Conformation at 340 kg (Females)			
		Mean	Mid-parents	Difference	Cross Advantage	Mean	Mid-parents	Difference	Cross Advantage
Sire	Dam	units	units	units	%	units	units	units	%
1	1	12.67	....	....	....	12.72	....	....	....
2	2	12.22	....	....	....	11.58	....	....	....
3	3	12.10	....	....	....	12.23	....	....	....
1 2	2 1	12.67	12.44	0.23	1.85	12.60	12.15	0.45	3.70
1 3	3 1	11.80	12.39	-0.59**	-4.76	12.18	12.48	-0.30	-2.40
2 3	3 2	11.86	12.16	-0.30	-2.47	11.94	11.91	0.03	0.25
LC-SL		12.11	12.33	-0.22	-1.78	12.24	12.18	0.06	0.49

*P < .05, **P < .01.

Table 33. Heterosis of linecross calves by sex for condition score at the end of the feed test.

Line		Condition at 363 kg (Males)				Condition at 340 kg (Females)			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	units	units	units	%	units	units	units	%
1	1	12.03	....	....	....	12.50	....	....	....
2	2	11.83	....	....	....	11.63	....	....	....
3	3	11.74	....	....	....	12.17	....	....	....
1 2	2 1	12.12	11.93	0.19	1.59	12.45	12.06	0.39	3.23
1 3	3 1	11.51	11.89	-0.38*	-3.20	12.25	12.34	-0.09	-0.73
2 3	3 2	11.66	11.78	-0.12	-1.02	11.92	11.90	0.02	0.17
LC-SL		11.76	11.87	-0.11	-0.93	12.20	12.10	0.10	0.83

*P< .05.

Table 34. Heterosis of linecross males for rate and efficiency of gain from weaning to 454 kg body weight.

Line		ADG 204-454 kg				Feed Efficiency 204-454 kg			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	kg	kg	kg	%	kg	kg	kg	%
1	1	1.31	....	....	....	6.96	....	....	....
2	2	1.33	....	....	....	6.31	....	....	....
3	3	1.33	....	....	....	6.62	....	....	....
1 2	2 1	1.35	1.32	0.03	2.27	6.48	6.64	0.16	2.41
1 3	3 1	1.36	1.32	0.04	3.00	6.74	6.79	0.05	0.74
2 3	3 2	1.32	1.33	-0.01	-0.75	6.58	6.47	-0.11	-1.70
LC-SL		1.34	1.32	0.02	1.52	6.60	6.63	0.03	0.45

Table 35. Heterosis of linecross males for age at 454 kg, conformation score at 454 kg and condition score at 454 kg.

Line		Age at 454 kg				Conformation at 454 kg			
		Mean	Mid-parent	Difference	Cross Advantage	Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	days	days	days	%	units	units	units	%
1	1	411.58	....	....	....	12.82	....	....	....
2	2	424.61	....	....	....	12.42	....	....	....
3	3	409.37	....	....	....	12.49	....	....	....
1 2	2 1	393.53	418.10	24.60*	5.88	13.00	12.62	0.38	3.01
1 3	3 1	405.33	410.48	5.15	1.25	12.32	12.65	-0.33	-2.61
2 3	3 2	409.07	416.99	7.92	1.90	12.39	12.46	-0.07	-0.56
LC-SL		401.93	415.19	13.26	3.19	12.57	12.58	-0.01	-0.08

Line		Condition at 454 kg			
		Mean	Mid-parent	Difference	Cross Advantage
Sire	Dam	units	units	units	%
1	1	12.41	....	....	....
2	2	12.24	....	....	....
3	3	12.23	....	....	....
1 2	2 1	12.57	12.33	0.24	1.95
1 3	3 1	12.11	12.32	-0.21	-1.70
2 3	3 2	12.20	12.23	-0.03	-0.25
LC-SL		12.29	12.29	0.00	0.00

*P < .05.

range from weaning to 18-months of age. The feeding period for the males was divided into seven, 28-day periods with weights and gains calculated for each period. The linecross males showed a highly significant advantage over straightline males for all weights. The differences between the linecross and straightline means were highly significant for gain in the first 28-day period. Gains in all other periods were nonsignificant but a significant linecross advantage was detected for gain over the entire 196-day period. The linecross females generally showed a greater advantage over the straightline females than did the males. Highly significant differences in favor of the linecross females were found for weaning weight, 12-month weight, 18-month weight and 18-month score. Significant differences were detected in gain from weaning to 12-months and weaning to 18-months but differences in gain from 12- to 18-months were not significant. The authors used this as evidence to show that linecross calves can withstand the stress of weaning and being placed on feed better than straightline calves.

In the present study the data would indicate the same trend for heterosis in ability to withstand stress among the linecross males. No heterosis was detected for age at weaning (Table 29), but the linecross males exhibited a significant heterotic difference for age at 363 kg. (Table 32). Also the differences between the linecross and inbred males for ages at 363 and 454 kg. were very similar indicating that from 363 kg. to 454 kg. the inbreds gained at the same rate as the linecross males.

The significant heterosis for rate of gain and feed per unit gain from 182-340 kg. among the females was likely the result of compensation for the poor preweaning gains since the males did not exhibit significant heterotic effects for postweaning rate of gain or feed per unit gain. However, Urick et al. (1968), Gregory et al. (1966), Gregory et al. (1966b) and Vogt et al. (1967) concluded that females generally exhibited more heterosis for postweaning traits than males.

Damon et al. (1961) conducted an experiment to evaluate Angus, Brangus, Brahman, Charolais, Hereford and Shorthorn breeds of cattle in the Gulf Coast Region. Significant or highly significant heterotic effects were found for 180-day weight, slaughter grade, rate of gain on feed test and weight per day of age.

In the present study, linecross females were found to exhibit more heterosis for postweaning rate of gain and feed per unit gain than linecross males. However, the linecross males were significantly younger than inbred males at 363 kg. whereas the linecross females were actually older than the inbred females at 340 kg. Thus, the apparent homogametic heterosis for postweaning rate and efficiency of gain may be the result of compensation for low preweaning growth rates among the linecross females. Neither males nor females exhibited heterosis for postweaning conformation or condition scores. The results would imply that heterosis was not generally important for postweaning traits among linecross males or females included in the present study.

Heterosis of Blood Constituents, Carcass Traits and Endocrine Gland Weights

The difference between the linecross and inbred means were calculated as well as the significance of the difference for blood, carcass and endocrine traits. The traits included were: blood levels of creatinine, amino acids and urea nitrogen; dressing percentage; percent fat, lean and bone in the 12th rib separation; loin-eye area; fat depth over the 12th rib; percent weight loss in cooking; percent drip in cooking; tenderness, juiciness, flavor of lean, flavor of fat and overall score as determined by a taste panel; thyroid weight; pituitary weight; adrenal weight and testicle weight. Of all these traits, only testicle weight showed any significant difference between the linecross males and their inbred contemporaries. For testicle weight, a highly significant difference occurred between 1 × 2 and 2 × 1 linecross males and their inbred contemporaries (Table 36). The smaller testicle weight of the 1 × 2 and 2 × 1 linecross males was likely the result of their being 24.60 days younger than the inbreds at time of slaughter.

Table 36. Heterosis of linecross males for testicle weight.

Line		Total testicle weight			
		Mean	Mid-parent	Difference	Cross advantage
Sire	Dam	gms.	gms.	gms.	%
1	1	479.30	....	....	....
2	2	451.19	....	....	....
3	3	460.69	....	....	....
1 2	2 1	429.38	465.24	-35.86**	-7.71
1 3	3 1	478.95	470.00	8.95	1.90
2 3	3 2	462.48	455.94	6.54	1.43
LC-SL		456.94	463.73	- 6.79	-1.46

**P < .01

These results would generally indicate that heterotic effects are unimportant for later life traits such as carcass traits and endocrine gland weights. The only measurement in the present study that showed a significant heterotic effect was a measurement directly influenced by age, i.e. testicle weight.

The relative lack of heterosis for carcass traits has been reported by several workers. Gregory et al. (1966a) in a study of crosses of Angus, Hereford, and Shorthorn cattle, found significant interactions between breed of sire and breed of dam for many carcass traits associated with or affected by age. However, after adjusting these traits for the effect of weight, these interactions were not significant. Gaines et al. (1967) conducted a similar study among breed crosses of Angus, Hereford, and Shorthorn cattle and concluded that there was some evidence of heterosis for those traits associated directly with growth, namely carcass weight, rib-eye area and carcass length.

Considering all the traits in the present study, the data would indicate that heterotic effects of four to five percent can be expected for most postweaning growth traits. The poor maternal ability of the inbred dams likely prevented the linecross calves from exhibiting heterosis for preweaning growth. However, after weaning the genotypes of the calves were allowed to express themselves and significant heterotic effects for rate of gain and feed per unit gain were found among the females. Heterosis was found among the males for age at 363 kg. Conformation scores, condition scores and carcass traits did not show linecross superiority. It would appear that there was little or no influence of overdominance, linkage of desirable with undesirable genes, or epistasis on these traits.

Correlation Coefficients Among Production Traits, Blood Constituents, Carcass Traits and Endocrine Gland Weights

The simple phenotypic correlation coefficients among the various characters included in this study are presented in Tables 37-40. The correlation coefficients were calculated on a within-sex basis because of differences in management practices and differences in the characters measured. In Tables 37-39, the correlation coefficients among the various production traits and blood constituents are presented for both sexes. Table 37 includes correlations of traits only among the Hereford females while the correlations of both Hereford and Angus females are presented in Table 38. Correlations among the production traits and blood constituents for all Hereford and Angus males are presented in Table 39 whereas Table 40 contains the correlations among the production traits, blood constituents, carcass traits, organoleptic measurements and endocrine gland weights for all Hereford and Angus males that were slaughtered.

Among the males, birth date was positively correlated with birth weight (Table 39). The positive associations between birth date and birth weight in males may be an indication that later born calves were born after longer gestation periods than early born calves.

A negative relationship was found between birth date and suckling gains among both sexes (Tables 37-39). Many of the later born calves were born in early May with the result that a lush pasture period of only 60-80 days was available for these calves in which they could make excellent gains. On the other hand, the early born calves had an additional 40-50 days when the grass was growing rapidly in which they could be making rapid suckling gains. Generally, those calves not reaching weaning weights by the first of September were at a disadvantage compared to the earlier weaned calves. The negative association between birth date and suckling gain agrees with the results reported by Bogart _et al_. (1956) and Nelms and Bogart (1956).

Birth date was positively correlated with ADG from 204-340 kg. in the Hereford and Angus females (Tables 38) and with ADG from 204-363 kg. in the males (Table 39). Among the males, birth date was negatively correlated with feed per unit gain from body weights of 204-363 kg. (Table 39). Apparently, the relationship of rate and efficiency of gain with birth date was caused by compensatory growth on feed test since the later calves had lower suckling gains.

Negative correlations between birth date and conformation scores were detected at all weights in both sexes (Tables 37-39).

Birth date was negatively associated with condition score at 227 kg. among Hereford and Angus females (Table 38) and with condition score at 363 kg. among the males (Table 39). The negative association of birth date with conformation and condition scores was probably caused by the lower suckling gains of later born calves.

Birth date was positively correlated with age at 227 kg. only among the Hereford and Angus females (Table 38). Apparently, date of birth had no effect on ages at the end of the feed test because of compensatory growth of the later born calves subsequent to their being placed on feed test. A negative correlation existed between date of birth and blood levels of creatinine at 204 kg. among the Hereford and Angus females (Table 38).

Birth weight was more highly correlated with ages at weaning and at the end of the feed test than with any other trait in both sexes as can be seen in Tables 37-39. The large, negative association between these traits can partially be explained on the basis that age at a particular weight is the result of the birth weight of the calf plus the rate of gain from birth to the weight with which one is concerned.

Birth weight was not correlated with either preweaning or post-weaning gains in calves of either sex when both Hereford and Angus breeds were included (Tables 38 and 39). However, a large positive correlation existed between birth weight and suckling gain among the Hereford females (Table 37). Why the association between birth weight and suckling gain is so important in these lines of Hereford cattle, but not in the Angus cattle is unknown. The positive correlation between birth weight and suckling gain in the Hereford females agrees with the findings of Bogart et al. (1956), Koch and Clark (1955) and Nelms and Bogart (1956).

Birth weight was positively correlated with conformation score at 227 kg. among the Hereford females (Table 37) probably as a result of the increased suckling gains of the heavier Hereford female calves. Birth weight was negatively correlated with feed per unit gain from 204-454 kg. among the males (Table 39) and with amino acids at 340 kg. among the males and the Hereford females (Tables 37 and 39).

Large, negative relationships were found between suckling gain and postweaning ADG in both males and females as shown in Tables 37-39. The magnitude of the correlation was less between suckling gain and postweaning ADG from 204-363 kg. This decrease in magnitude would indicate that compensatory effects on postweaning ADG were occurring. However, it is possible that fast gain in the feedlot may be associated with poor milking ability of the dams. Whether this relationship is genetic or environmental cannot be determined without obtaining genetic correlations. Koch and Clark (1955) found a negative phenotypic correlation of - .36 between gain from birth to weaning and gain from weaning to yearling age but a genetic correlation of only -.05 between the two traits. Carter and Kincaid (1959) obtained genetic correlations of .69 for steers and .51 for heifers between preweaning growth rate and subsequent rate of gain. From the results of these studies it would seem likely that the large, negative associations between suckling gain and postweaning ADG in the present study were due to compensatory effects and were not genetic.

Suckling gain was positively correlated with feed per unit gain among the males (Table 39) and with conformation and condition scores in both sexes (Tables 37-39). This would imply that selection for heavier weaning weights in cattle will also result in selecting for higher scoring cattle, not only at weaning but in later life as well. These results agree with those reported by Bogart and Frischknecht (1967), Brinks et al. (1964), Carter and Kincaid (1959), Koch and Clark (1955) and Marlowe and Vogt (1965).

Large, negative correlations existed between suckling gain and ages at weaning and at the end of the feed test in both sexes as shown by Tables 37-39. These correlations point out the importance of high preweaning performance in the overall scheme of beef production and agree with the report of Bogart and Frischknecht (1967).

Among the male calves, positive correlations between suckling gains and blood levels of amino acids at 204 and 340 kg. were detected (Table 39). The higher level of amino acids at 204 kg. among the faster gaining males may have been caused by an excess of amino acids being supplied by the better milking dams. Slower gaining calves would therefore have lower levels of amino acids in the blood than the faster gaining calves. These associations were likely not detected in the female calves because they were weaned at 170 kg. and blood samples were not collected until they reached 204 kg. By this time, the differences in amino acid content caused by differences in the milking ability of the dams would have been removed. The positive correlation between suckling gain and amino acid content at 340 kg. in the males was likely caused by the increased growth rate of males from poor milking dams. Thus, calves with low suckling gains would be expected to have low levels of amino acids in the blood at 340 kg. Hornbeek (1964) found that among Hereford calves, suckling gain was positively correlated with amino acids at 204 kg.

Postweaning ADG was negatively correlated with feed per unit gain in both sexes (Tables 37 and 39). The magnitude of the correlations between ADG and feed efficiency agree with those reported by Hornbeek (1964) and Bogart et al. (1956).

The associations between postweaning ADG and conformation and condition scores were generally not important. Postweaning ADG was correlated with condition at 340 kg. among the females (Tables 37 and 38). This lack of relationship between postweaning ADG and conformation scores does not agree with the results of Bogart and Frischknecht (1967), Carter and Kincaid (1959) or Koch and Clark (1955). In the present study, the large compensatory effects on postweaning gains likely caused this lack of relationship between postweaning ADG and conformation and condition scores.

Positive correlations between age at 227 kg. and postweaning ADG were detected in both sexes (Tables 37-39). These correlations were likely caused by compensation for poor suckling gains. A negative relationship between postweaning ADG and age at 454 kg. was found among the males (Table 39), but correlations between postweaning ADG and age at the smaller weight increments were not detected among either sex. ADG from 182-340 kg. was positively correlated with blood content of creatinine at 340 kg. among the Hereford females (Table 37). Among the males, ADG from 204-363 kg. was positively correlated with creatinine at 204 and 454 kg. (Table 39). These correlations are evidence that faster gaining calves likely have a higher proportion of lean tissue in the body than do slower gaining calves. A negative correlation between ADG from 204-363 kg. and urea at 204 kg. was detected in the males (Table 39).

Feed per unit gain was negatively related with conformation and condition scores at 340 kg. among the Hereford females indicating the more efficient Hereford females were higher scoring with respect to conformation and condition at the end of the feed test (Table 37). Among the males, negative associations were detected between feed per unit gain at both weight intervals and age at 227 kg. as shown in Table 39. This correlation was likely caused by compensatory growth following weaning since the more efficient males were older at 227 kg.

Among the males (Table 39) feed per unit gain was positively correlated with amino acids at 204 and 340 kg. The size of the correlations would indicate that blood levels of amino acids are better indicators of efficiency of feed utilization than of rate of gain. The positive correlations between feed per unit gain and amino acids agree with those reported by Bogart et al. (1963) and Price et al. (1956).

Conformation and condition scores at one weight were positively correlated with conformation and condition scores at other weights in each sex (Tables 37-39). In addition, conformation and condition scores were highly associated with each other. These associations between conformation and condition scores point out how estimates of conformation are likely influenced by the degree of finish that the animal possesses. Bogart and Frischknecht (1967), Carter and Kincaid (1959) and Koch and Clark (1955) also found high relationships between scores at different weights.

Conformation and condition scores at all weights in each sex were negatively correlated with age at 227 kg. (Tables 37-39). Similar correlations were found by Bogart and Frischknecht (1967) and Koch and Clark (1955). Conformation scores at 227 and 340 kg. were negatively associated with age at 340 kg. in the females (Tables

37 and 38). Among the males, conformation and condition scores at 227, 363, and 454 kg. were negatively correlated with age at 363 and 454 kg.

Positive correlations of conformation and condition scores with levels of amino acids at 340 kg. were detected among the males (Table 39). This positive association was likely an indication that higher scoring calves had larger fat deposits in the body since less efficient males also had higher levels of amino acids. Condition scores at 204 and 363 kg. were positively correlated with amino acid content at 204 kg. while a negative relationship existed at 454 kg. among the males (Table 39).

Among the Hereford and Angus female calves, positive correlations of conformation and condition scores at 227 kg. with blood levels of creatinine at 204 and 340 kg. were detected (Table 38). This association might have been caused by an increased muscle mass in the faster growing calves up to weaning. Negative correlations of condition at 227 kg. with urea at 204 and 340 kg. among the Hereford and Angus females would tend to support this hypothesis (Table 38). A negative correlation between condition at 227 kg. and urea at 204 kg. was found among the Hereford females as is shown in Table 37.

Ages at one weight were highly correlated with ages at other weights (Tables 37-39). Age was generally not associated with creatinine and urea levels but a negative association between age at

Table 37. Correlation coefficients involving performance and blood traits of Hereford female calves (N = 80).

	Birth Weight	Suckling Gain	ADG (182-340 kg)	Feed Efficiency (182-340 kg)	Conformation (227 kg)	Conformation (340 kg)	Condition (227 kg)	Condition (340 kg)	Age at 227 kg	Age at 340 kg	Creatinine (204 kg)	Creatinine (340 kg)	Amino Acids (204 kg)	Amino Acids (340 kg)	Urea (204 kg)	Urea (340 kg)
Birth Date	-.06	-.25*	.16	-.05	-.33**	-.25*	-.17	-.15	.19	.09	-.17	-.15	.04	.12	.20	.03
Birth Weight		.43**	-.20	.14	.23*	.07	.09	-.06	-.50**	-.55**	.06	-.11	.03	-.22*	-.02	.00
Suckling Gain			-.43**	.21	.44**	.31**	.27*	.25*	-.91**	-.80**	.03	-.10	.12	-.11	.03	.00
ADG (182-340kg)				-.83**	-.06	.17	.05	.37**	.22*	.15	.07	.27*	.18	-.02	-.10	.04
Feed Efficiency[1] (182-340 kg)					-.01	-.25*	-.11	-.51**	-.02	-.13	-.03	-.15	-.17	.02	.02	-.13
Conformation (227 kg)						.64**	.72**	.38**	-.48**	-.33**	.17	.19	.15	.05	-.12	-.07
Conformation (340 kg)							.43**	.64**	-.40**	-.26*	.13	.17	.12	.05	-.08	.10
Condition (227 kg)								.48**	-.36**	-.12	.21	.25*	.06	.20	-.26*	-.21
Condition (340 kg)									-.34**	-.10	.11	.10	.08	.05	-.20	.12
Age at 227 kg										.84**	-.11	.06	-.19	.14	.00	.02
Age at 340 kg											.00	.03	-.11	.21	-.04	-.06
Creatinine (204 kg)												.19	.15	.00	-.29**	-.40**
Creatinine (340 kg)													.14	.04	-.38**	-.18
Amino Acids (204 kg)														.37**	.02	.07
Amino Acids (340 kg)															.00	.09
Urea (204 kg)																.29*

* $P < .05$, ** $P < .01$

[1] Expressed as feed per unit gains.

Table 38. Correlation coefficients involving performance and blood traits of Hereford and Angus female calves. (N = 109).

	Birth Weight	Suckling Gain	ADG (182-340 kg)	Conformation (227 kg)	Conformation (340 kg)	Condition (227 kg)	Condition (340 kg)	Age at 227 kg	Age at 340 kg	Creatinine (204 kg)	Creatinine (340 kg)	Amino Acids (204 kg)	Amino Acids (340 kg)	Urea (204 kg)	Urea (340 kg)
Birth Date	.05	-.26**	.28**	-.40**	-.29**	-.19*	-.11	.20*	-.03	-.19*	-.11	.00	.02	.12	.14
Birth Weight		.18	.03	.05	.01	.02	.02	-.31**	-.42**	.04	-.07	-.03	-.18	-.07	-.02
Suckling Gain			-.44**	.53**	.35**	.31**	.11	-.92**	-.72**	.10	-.02	.17	-.03	-.03	-.05
ADG (182-340 kg)				-.19*	.12	-.05	.36**	.25**	-.04	-.03	.14	.05	-.03	-.12	.07
Conformation (227 kg)					.63**	.70**	.25**	-.53**	-.33**	.20*	.20*	.17	.07	-.14	-.16
Conformation (340 kg)						.41**	.58**	-.43**	-.29**	.18	.19	.14	.13	-.07	.03
Condition (227 kg)							.39**	-.37**	-.15	.22*	.23*	.10	.17	-.20*	-.19*
Condition (340 kg)								-.22*	-.08	.13	.07	.03	.09	-.16	.13
Age at 227 kg									.77**	-.15	-.02	-.24*	.07	.05	.04
Age at 340 kg										.00	-.02	-.09	.15	.08	-.05
Creatinine (204 kg)											.22*	.21*	.06	-.29**	-.25**
Creatinine (340 kg)												.29**	.05	-.30**	-.20*
Amino Acids (204 kg)													.35*	-.01	.05
Amino Acids (340 kg)														.05	.08
Urea (204 kg)															.26**

* P < .05, ** P < .01

Table 39 Correlation coeffieients involving performance records and blood constituents of Hereford and Angus males (N = 135).

	Birth Weight	Suckling Gain	ADG(204-363 kg)	ADG(204-454 kg)	Feed Efficiency (204-363 kg)	Feed Efficiency (204-454 kg)	Conformation (227 kg)	Conformation (363 kg)	Conformation (454 kg)	Condition (227 kg)	Condition (363 kg)	Condition (454 kg)	Age at 227 kg	Age at 363 kg	Age at 454 kg	Creatinine (204 kg)	Creatinine (340 kg)	Creatinine (454 kg)	Amino Acids(204 kg)	Amino Acids(340 kg)	Amino Acids(454 kg)	Urea (204 kg)	Urea (340 kg)	Urea (454 kg)
Birth Date	.25**	-.29**	.27**	.16	-.24	-.11	-.23**	-.24	-.25**	-.02	-.20*	-.16	.11	.00	.03	-.10	-.08	-.10	-.04	-.12	.11	.00	.15	-.06
Birth Weight		.09	.00	.13	-.08	-.19*	-.14	-.05	-.04	-.13	-.05	-.14	-.19*	-.22**	-.23**	-.13	.00	-.12	-.14	-.24**	-.02	.05	.08	-.02
Suckling Gain			-.44**	-.27**	.44**	.29**	.39**	.45**	.50**	.15	.48**	.40**	-.95**	-.86**	-.79**	-.09	-.11	-.11	.22**	.27**	-.05	.14	-.10	.11
ADG(204-363 kg)				.81**	-.80**	-.63**	-.03	-.03	.09	.02	-.03	.10	.34**	.03	-.01	.18*	.15	.17*	-.10	-.08	.05	-.19*	.14	.05
ADG(204-454 kg)					-.67**	-.80**	-.02	-.02	.14	-.02	-.07	.05	.18*	-.11	-.28**	.02	.07	.10	-.13	-.11	.04	-.07	.08	.08
Feed Efficiency[1] (204-363 kg)						.77**	.11	.09	-.02	.13	.14	.00	-.41**	-.13	-.07	-.12	-.08	-.07	.30**	.34**	.10	.09	-.11	.04
Feed Efficiency[1] (204-454 kg)							.09	.03	-.04	.12	.14	.07	-.27**	-.04	.11	-.10	-.16	-.07	.30**	.35**	-.09	.00	-.13	-.04
Conformation(227kg)								.60**	.60**	.62**	.49**	.49**	-.38*	-.38*	-.31*	.10	.14	.15	.17*	.20*	.00	-.08	-.14	.11
Conformation(363kg)									.68**	.31**	.83**	.56**	-.45**	-.44**	-.39**	.04	.02	.05	.15	.17*	.01	-.05	-.10	.17*
Conformation(454kg)										.33**	.60**	.73**	-.52**	-.57**	-.55**	-.03	-.02	.09	.11	.18*	-.11	-.07	-.13	.07
Condition (227 kg)											.32**	.32**	-.18*	-.19*	-.14	.13	.18*	.15	.32**	.30**	.11	-.16	-.10	.07
Condition (363 kg)												.62**	-.50**	-.49**	-.41**	-.02	-.05	-.05	.19*	.27*	.00	-.14	-.08	.12
Condition (454 kg)													-.43**	-.47**	-.40**	.08	-.01	.08	-.18*	.31**	-.09	-.22**	-.09	.02
Age at 227 kg														.93**	.86**	.10	.10	.09	-.30**	-.30**	.05	-.10	.08	-.13
Age at 363 kg															.94**	.10	.11	.10	-.22**	-.25**	.04	-.08	.03	-.13
Age at 454 kg																.15	.12	.09	-.16	-.19*	.07	-.13	.07	-.12
Creatinine(204kg)																	.69**	.51**	.12	.05	.15	-.08	.08	.11
Creatinine(340kg)																		.68**	.13	.00	.18*	-.08	.12	.00
Creatinine(454kg)																			.16	.18*	.05	-.17*	-.05	-.08
Amino Acids(204kg)																				.52**	.20*	-.13	-.08	.10
Amino Acids(340kg)																					.27**	-.31**	-.12	.13
Amino Acids(454kg)																						-.10	.29**	.26**
Urea (204 kg)																							.13	.07
Urea (340 kg)																								.24*

* $P < .05$, ** $P < .01$

[1] Expressed as feed per unit gains.

227 kg. and amino acids at 204 kg. was detected among the Hereford and Angus females (Table 38). Among the males, age at 227 and 363 kg. was negatively correlated with levels of amino acids at 204 and 340 kg. (Table 39). These results do not agree with those reported by Bogart _et al._ (1963). Perhaps in these calves, the older ones had lower blood levels of amino acids than the younger ones because of compensatory effects on rate of gain. If the older calves gained faster on feed test (compensatory growth), it might be expected that they would have lower blood levels of amino acids at 340 kg. body weight.

Blood levels of creatinine and amino acids at one weight were generally correlated with levels of corresponding blood constituents at other weights in both males and females (Tables 38 and 39). A few correlations among blood constituents were detected but no consistent pattern was noted.

In Table 40, the correlations of various production traits, slaughter traits, organoleptic measurements and endocrine gland weights are presented among the Hereford and Angus males. Birth date was negatively correlated with dressing percentage, carcass maturity, percent weight loss in cooking and total testicle weight. A positive correlation occurred between date of birth and juiciness as determined by a taste panel.

Birth weight was negatively correlated with carcass conformation, marbling and carcass grade (Table 40). The negative association between birth weight and these three traits was likely caused by a decreased fat deposition in the calves with heavier birth weights since heavier calves at birth reached 454 kg. at an earlier age than the calves with smaller birth weights (Table 39).

Positive correlations of suckling gain with dressing percentage, carcass grade, percent bone in the 12th rib cut, thyroid gland weight and testicle weight were found (Table 40). Suckling gain was negatively correlated with percent lean in the 12th rib cut and pituitary weight. From these correlations, it was noted that calves that had higher suckling gains had more fat and less lean in the carcasses than calves with lower suckling gains.

ADG from 204-363 kg. and from 204-454 kg. were negatively associated with dressing percentage (Table 40). These negative correlations could have been caused by differences in fat deposition. Rapidly gaining males would likely have a higher lean-to-fat ratio and would therefore have lower dressing percentages than slowly gaining males.

ADG from 204-454 kg. was positively correlated with carcass maturity and negatively correlated with marbling, fat thickness, percent fat in the 12th rib cut, percent drip in cooking and testicle weight (Table 40). Carcass maturity was expressed on a scale such that the younger the carcass the higher the score. ADG from 204-363 kg. and from 204-454 kg. were positively correlated with percent lean in the 12th rib cut. However, no correlation existed between ADG and loin-eye area so the correlations between ADG and percent lean in the 12th rib cut were likely caused by the differences in fat deposition of rapidly and slowly gaining males and not an association of rapid gain and muscling.

The correlations of feed per unit gain with carcass traits generally agreed with the correlations for ADG but were opposite in sign because of the way feed efficiency was expressed (Table 40). Also, the associations between feed per unit gain and the indicators of fatness in the carcass were larger, indicating that a larger amount of the variation in fatness could be explained by differences in efficiency of feed utilization than by differences in ADG. Therefore, feed per unit gain appears to be a better indicator of fat deposition than rate of gain. Feed per unit gain was positively correlated with dressing percentage, carcass conformation, marbling, carcass grade, fat thickness, percent fat in the 12th rib cut, percent drip in cooking, and testicle weight. Negative relationships of feed per unit gain with loin-eye area and with percent lean in the 12th rib cut were detected.

Conformation scores of the live animal at all weights were positively correlated with dressing percentage, carcass conformation, marbling and carcass grade (Table 40). Conformation score at 227 kg. was negatively associated with percent bone in the 12th rib cut.

Conformation scores at 227 and 454 kg.were positively associated with loin-eye area indicating that visual estimates of increased conformation scores were associated with increased muscling as evidenced by the larger loin-eye area of the higher scoring calves. Live animal conformation scores were not correlated with fat thickness, percent fat or percent drip. Therefore, from these correlations it would appear that visual estimates of increased conformation were associated with higher grading, more heavily muscled carcasses that did not have excessive amounts of fat deposited in the carcass.

Condition scores at 363 and 454 kg. were positvely correlated with dressing percentage and carcass conformation (Table 40). Likewise, condition scores at 227, 363 and 454 kg. were positively correlated with marbling and carcass grade. Condition score at 454 kg. was positively associated with loin-eye area and percent fat in the 12th rib cut. Negative correlations of condition at 227 and 454 kg. with percent bone in the 12th rib cut were found. A negative association occurred between condition at 227 kg. and adrenal weight. The results of the present study on the relation of conformation and condition scores with fatness and carcass grade agrees with those reported by Kidwell et al. (1959). They found a high relation between slaughter grade and carcass score; dressing percentage; and percent bone, muscle and fat in the 9-10-11 rib separation.

Age at 227 and at 454 kg. was negatively correlated with dressing percentage; similar correlations of age at 363 and at 454 kg. with carcass maturity were found as shown in Table 40. Negative correlations of age at 227 and 363 kg. with carcass grade were found while age at 227 kg. was positively associated with percent lean in the 12th rib cut (Table 40). From these correlations, younger calves had higher dressing percentages and more youthful appearing carcasses. Also, calves that were younger at weaning had a higher percentage of lean in the 12th rib cut.

Ages at 227 and 363 kg. were negatively correlated with thyroid and testicle weight. Age at 454 kg. was negatively correlated with percent bone in the 12th rib cut and with thyroid weight (Table 40). The consistent negative relationship of age at 227, 363 and 454 kg. with thyroid weight would imply that the younger (faster gaining) animals had larger thyroid glands than the older (slower gaining) calves. Thus, it would appear that thyroid output was partially regulating growth in these calves.

A positive relation of creatinine at 204 kg. with carcass maturity occurred and creatinine at 454 kg. was positively correlated with loin-eye area as presented in Table 40. No significant correlations between creatinine and percentages of fat, lean and bone in the 12th rib cut were detected. These results are in opposition to those found by Lofgreen and Garrett (1954). They obtained a correlation of .67 between creatinine excretion in the urine and percent lean in the

9-10-11 rib cut. Wuthier and Stratton (1957) likewise found positive correlations of creatinine levels in the serum with percent lean (r = .55) and with loin-eye area (r = .52).

Amino acids at 340 and 454 kg. were positively associated with carcass maturity as shown in Table 40. Amino acid levels at 204, 340 and 454 kg. were positively correlated with marbling, carcass grade, percent fat in the 12th rib cut and percent drip. Amino acids were therefore good indicators of fat deposition in the carcass. Apparently the animals with high blood levels of amino acids are unable to utilize the amino acids for muscle development. Instead they increase their weight by utilizing fats and carbohydrates in the diet to increase the deposition of fat in the body. Further evidence for this hypothesis was the negative association of amino acids at 454 kg. with loin-eye area and the positive correlation of amino acids at 454 kg. with fat thickness.

A negative correlation of amino acids at 204, 340 and 454 kg. with percent bone in the 12th rib cut was found mostly because of the positive relationship between percent fat and amino acids at all three weights (Table 40). The blood level of amino acids at 454 kg. was positively correlated with tenderness whereas amino acids at 340 kg. was negatively correlated with juiciness. The positive relation of blood levels of amino acids at 204 and 340 kg. with pituitary weight might be an indication that levels of amino acids in the blood are controlled by the pituitary gland. A negative correlation was obtained between amino acid content at 454 kg. and testicle weight.

Correlations between urea and the various traits were quite variable depending upon the weight when the blood sample was collected (Table 40). Therefore, in the present study the importance of the correlations involving blood levels of urea are questionable. Urea at 204 kg. was negatively associated with marbling, carcass grade, tenderness and pituitary weight. Positive correlations of urea at 204 kg. with percent bone, thyroid weight and testicle weight were found. At 340 kg. urea was positively correlated with fat thickness and percent fat in the 12th rib while negative associations were detected between urea at 340 kg. and loin-eye area, percent lean in the 12th rib cut and thyroid weight. Urea levels in the blood at 454 kg. were positively correlated with carcass maturity, tenderness and flavor of fat. A negative relationship occurred between urea levels at 454 kg. and loin-eye area.

Dressing percentage was positively correlated with carcass conformation and loin-eye area (Table 40). A negative correlation was found between dressing percentage and tenderness.

Carcass conformation was positively associated with marbling, carcass grade, flavor of fat and overall organoleptic score (Table 40). A negative association occurred between carcass conformation and percent lean in the 12th rib cut. These correlations are all indicators that carcass conformation scores were influenced by the amount of fat in the carcass.

Carcass maturity was expressed in terms of higher scores for more youthful appearing carcasses. Carcass maturity was negatively correlated with loin-eye area and juiciness while positive relationships of carcass maturity occurred with percent fat in the 12th rib cut and tenderness (Table 40).

Marbling was highly correlated with grade (Table 40). This is good evidence that carcass grade of cattle of excellent beef type and uniform age is determined almost completely by the degree of marbling in the loin-eye. Therefore, the ability of cattle to marble is of great economic importance based on present grading standards. Marbling was also positively associated with fat thickness, percent fat in the 12th rib cut, percent drip and tenderness. Marbling was negatively correlated with percent lean and bone in the 12th rib cut. Although a large degree of marbling in the loin-eye is desirable from a grading standpoint, it is undesirable in other aspects because of the high association of marbling with carcass fat. The present experiment would indicate that, among young animals, marbling contributes little to eating quality. Tuma et al. (1962) found that among 18-month old animals, marbling had no influence on tenderness.

Carcass grade was positively correlated with fat thickness, percent fat in the 12th rib cut, percent drip and tenderness (Table 40).

A negative relationship was found between carcass grade and percent lean and bone in the 12th rib cut. Therefore, selecting for higher grading carcasses will likely result in selecting for fatter carcasses. Dubose, Cartwright and Cooper (1967) found that the most highly correlated trait with carcass grade was fat thickness over the 12th rib. Kidwell et al. (1959) reported that carcass grade was largely a function of the percent fat in the carcass.

Loin-eye area was negatively correlated with fat thickness, percent fat in the 12th rib cut, percent drip in cooking and tenderness (Table 40). A positive relationship existed between loin-eye area and percent lean in the 12th rib cut.

Fat thickness over the 12th rib was positively correlated with percent fat in the 12th rib cut and percent drip as presented in Table 40. Negative associations were found for fat thickness with percent lean in the 12th rib cut, percent bone in the 12th rib cut and thyroid weight.

Percent fat in the 12th rib was negatively correlated with percent lean and bone in the 12th rib cut and positively correlated with percent drip in cooking (Table 40). Percent lean in the 12th rib cut was negatively associated with percent drip in cooking and with testicle weight. Percent bone was negatively correlated with percent drip. From the lack of relationship of percent fat and lean with tenderness, juiciness, flavor of lean or overall organoleptic score it

Table 40. Correlation coefficients involving performance traits, blood constituents, carcass traits, organoleptic measurements and endocrine gland weights (N = 119).

	Dressing Percentage	Carcass Conformation	Carcass Maturity	Marbling	Carcass Grade	Loin-Eye Area	Fat Thickness	Percent Fat	Percent Lean	Percent Bone	Percent Loss	Percent Drip	Tenderness	Juiciness	Flavor of Lean	Flavor of Fat	Over-all Organoleptic Score	Pituitary Weight	Thyroid Weight	Adrenal Weight	Testicle Weight
Birth Date	-.18*	-.01	-.21*	.00	-.09	-.07	.04	.12	-.07	-.10	-.20*	.04	.05	.26**	.01	.00	-.05	.12	-.08	.08	-.21*
Birth Weight	-.07	-.19*	.07	-.32**	-.30**	-.20*	-.14	-.08	.00	.15	.16	-.12	.17	.00	.03	-.09	.01	-.11	-.02	.10	.08
Suckling Gain	.39**	.04	.15	.13	.21*	.00	.07	.05	-.19*	.20*	.13	.10	-.03	-.04	.05	-.16	.01	-.19*	.21*	-.14	.30**
ADG (204-363 kg)	-.29**	.02	.14	-.07	-.07	.06	-.13	-.08	.21**	-.17	-.11	-.20*	.06	.05	-.02	.03	.05	.12	-.09	.13	-.26**
ADG (204-454 kg)	-.34**	-.09	.22*	-.20*	-.13	.05	-.24**	-.18*	.24**	-.04	-.11	-.31**	.07	.00	-.10	-.03	.00	.07	.00	.10	-.23*
Feed Efficiency (204-363 kg)[1]	.21*	.08	.00	.32**	.32**	-.20*	.28**	.23*	-.28**	.01	.15	.36**	.08	-.07	.04	.03	.02	-.10	.11	-.10	.26**
Feed Efficiency (204-454 kg)[1]	.24**	.20*	-.22*	.40**	.32**	-.08	.26**	.27**	-.30**	-.02	.05	.35**	.00	.01	.05	.11	.11	.04	.06	-.04	.27**
Conformation (227 kg)	.29**	.34**	.11	.29**	.40**	.18*	.00	.09	.07	-.25**	.16	.09	.05	-.01	.14	.10	.03	-.10	.14	-.13	-.03
Conformation (363 kg)	.36**	.34**	.13	.22*	.32**	.13	-.06	.05	-.04	-.04	.05	-.03	.08	-.09	.11	.12	-.08	-.14	.09	-.05	.05
Conformation (454 kg)	.30**	.41**	.12	.24**	.35**	.24**	-.11	.07	.01	-.13	.00	-.06	-.06	-.02	.11	.12	.03	-.05	.12	-.06	.07
Condition (227 kg)	.11	.16	.03	.28**	.34**	.13	.08	.13	.09	-.34**	.16	.16	.13	.02	.02	-.02	.16	.05	.03	-.20*	-.17
Condition (363 kg)	.24**	.27**	.14	.30**	.35**	.05	.07	.13	-.16	.01	.12	.14	.09	-.14	.11	.04	-.07	-.09	.04	-.01	.11
Condition (454 kg)	.27**	.31**	.15	.38**	.41**	.23*	.13	.22*	-.10	-.22*	-.12	-.02	.00	-.02	.06	.09	-.06	-.07	.03	-.04	.12
Age at 227 kg	-.33**	-.09	-.17	-.20*	-.27**	.02	-.07	-.08	.20*	-.15	-.11	-.09	-.02	.03	-.05	.09	.01	.12	-.19*	.07	-.29**
Age at 363 kg	-.24**	-.09	-.23**	-.16	-.23**	.03	-.02	-.05	.15	-.14	-.05	.00	-.03	.01	-.03	.10	-.02	.12	-.19*	.04	-.21*
Age at 454 kg	-.14	-.03	-.25**	-.04	-.13	-.01	.06	.05	.09	-.21*	.00	.12	-.01	.03	.02	.11	.00	.10	-.23*	.02	-.17
Creatinine (204 kg)	-.02	.03	.20*	.02	.05	-.03	.15	.09	.00	-.15	.13	.11	-.05	.10	-.05	.00	.02	.02	-.05	.09	-.06
Creatinine (340 kg)	-.06	-.07	.15	.01	.04	.03	.06	.02	.05	-.11	.15	.10	-.06	.07	.01	.02	.01	-.04	.01	.03	-.15
Creatinine (454 kg)	-.06	-.10	.03	.13	.14	.21*	-.12	-.10	.19	-.10	.14	.06	.10	-.01	.12	.08	-.01	.01	.02	.12	-.16
Amino Acids (204 kg)	.12	.03	.09	.44**	.39**	.01	.13	.22*	-.09	-.25**	.07	.30**	.12	.03	.03	.10	.07	.18*	.06	-.02	.11
Amino Acids (340 kg)	.11	.14	.18*	.59**	.53**	-.04	.16	.23*	-.09	-.25**	-.08	.22*	.19	-.19*	.07	.10	.08	.26**	.03	-.07	.03
Amino Acids (454 kg)	-.10	.06	.25**	.28**	.27**	-.22*	.31**	.25**	-.13	-.24**	.00	.33**	.21*	.01	.04	.09	.00	.03	-.11	-.12	-21*
Urea (204 kg)	.16	.12	-.07	-.27**	-.25**	-.09	-.01	-.14	-.03	.29**	.05	-.17	-.20*	-.04	-.07	.08	-.11	-.27**	.40**	.02	.22**
Urea (340 kg)	.07	.11	.08	.05	.04	-.18*	.32**	.24**	-.26**	-.04	-.09	.03	.08	.10	.03	.07	.01	-.09	-.18*	.13	.01
Urea (454 kg)	.00	.14	.34**	.06	.14	-.24**	.13	.09	-.06	-.07	.04	.10	.24**	-.04	-.04	.18*	.05	-.07	-.12	-.01	.01
Dressing Percentage		.19*	-.16	.06	.07	.28**	-.07	-.07	.11	-.05	.10	.04	-.24**	.02	.14	.06	-.01	.01	-.04	-.15	.12
Carcass Conformation			.02	.31**	.42**	.07	.13	.25**	-.20*	-.13	-.05	.05	-.12	-.07	.07	.28**	.22*	-.03	.01	-.01	.11
Carcass Maturity				.03	.16	-.32**	.08	.19*	-.16	-.08	.09	-.01	.27**	-.18*	-.13	.01	-.01	-.11	.01	-.08	.08
Marbling					.92**	-.15	.33**	.47**	-.26**	-.42**	-.14	.35**	.21*	-.03	.09	.08	-.08	.09	-.04	-.01	.01
Carcass Grade						-.14	.27**	.46**	-.37**	-.40**	-.01	.35**	.24**	-.08	.08	.06	-.07	.11	-.03	-.05	.06
Ribeye Area							-.43**	-.37**	.47**	-.06	-.02	-.31**	-.22*	.03	.13	.06	.05	.02	.09	.08	-.15
Fat Thickness								.67**	-.62**	-.23*	-.08	.45**	-.01	.17	-.09	-.02	-.02	-.10	-.19*	-.14	.08
Percent Fat									-.81**	-.53**	-.04	.54**	.08	.08	-.10	.10	-.10	-.08	-.16	-.11	.12
Percent Lean										-.08	.08	-.43**	.02	.00	.12	-.06	.10	.08	.08	.08	-.21*
Percent Bone											-.05	-.29**	-.16	-.15	.00	-.08	.03	.01	.14	.08	.10
Percent Loss (Cooking)												.43**	.17	.09	.12	-.06	-.03	-.25**	.03	-.06	-.08
Percent Drip (Cooking)													.02	.19*	.08	.05	-.05	-.02	-.13	-.10	.05
Tenderness														-.03	-.06	-.10	-.24**	-.04	-.02	-.04	-.03
Juiciness															.09	-.04	.06	.11	.10	-.03	-.08
Flavor of Lean																.15	-.03	-.06	.12	.10	.01
Flavor of Fat																	-.05	.02	-.05	.06	-.02
Over-all Organoleptic Score																		.22*	-.10	-.06	.00
Pituitary Weight																			.02	.05	.16
Thyroid Weight																				.07	.15
Adrenal Weight																					.05

* P < .05, ** P < .01

[1] Expressed as feed per unit gains.

would appear that leaner animals could be produced without lowering eating quality so long as extremes in leanness are not encountered.

Percent weight loss and percent drip in cooking were positively correlated (Table 40). This positive association was expected since percent drip would make up a large portion of the weight loss in cooking. Percent drip was positively correlated with juiciness indicating that increased fatness of the roast was associated with increased juiciness. A significant negative relationship occurred between tenderness and overall organoleptic score. Overall organoleptic score was positively correlated with pituitary weight.

From the results of the entire study it would appear that rather large compensatory effects for poor suckling gains occur during the early part of the postweaning period. These compensatory effects would indicate that perhaps a longer period of adjustment would be desired before the feed trial was initiated. In this manner, the differences in maternal environment could be removed and true genetic differences in growth rate could be measured.

Birth weight was highly associated with preweaning growth rates and ages in Hereford females but was not associated with preweaning growth rates in the Angus females. Perhaps the large quantities of milk produced by the Angus dams were responsible for removing the effect of lighter birth weights on preweaning performance.

The relationship between suckling gain and conformation and condition scores at all weights were important but no relationship between postweaning ADG and conformation and condition scores were found. Therefore, selecting for heavier weaning weights would apparently result in improving the conformation of the animals even up to the time of slaughter.

Rather consistent positive correlations were detected between blood levels of amino acids and feed efficiency. This tends to indicate that less efficient animals cannot withdraw the amino acids for muscle development but use the carbonaceous fractions of amino acids to produce fat in the carcass to give increased body weights. The positive correlations of amino acids at all weights with carcass indicators of fat deposition lends additional support to this hypothesis.

Conformation scores of the live animals were positively associated with carcass conformation, marbling, carcass grade and loin-eye area. However, no correlations were found for conformation scores with percent fat, lean and bone. These correlations are used as evidence that, by placing emphasis on muscle development in the live animal, heavily muscled cattle that grade well without having excess fat can be selected.

Younger calves at slaughter were found to have more youthful appearing carcasses as was evidenced by the correlations between ages and carcass maturity. Also, marbling and carcass grade had little or no effect on eating quality of roasts from the 10-11 rib section. Whether this lack of association of marbling with tenderness and juiciness would still occur for older animals is not known.

SUMMARY AND CONCLUSIONS

A complete diallel cross among three inbred lines of Hereford cattle was conducted over a four year period, 1963-1966. Performance measurements consisting of birth date, birth weight, preweaning average daily gain, postweaning average daily gain, feed per unit gain, age at weaning, age at the end of the feed test, conformation scores and condition scores were collected on 102 males and 80 females of the Hereford breed. In addition, records of 33 males and 29 females of the Angus breed were included to obtain more accurate estimates of environmental effects on the various traits included in the study.

Measurements of blood levels of creatinine, amino acid nitrogen and urea nitrogen were obtained at 204 and 340 kg. body weight among the females and at 204, 340 and 454 kg. body weight among the males. In addition, carcass traits, organoleptic measurements and endocrine gland weights were collected on 119 males. The carcass traits consisted of carcass conformation, maturity, marbling and grade; dressing percentage; percent fat, lean and bone in the 12th rib cut; loin-eye area and fat thickness over the 12th rib. Cooking and organoleptic measurements consisted of percent weight loss and percent drip in cooking as well as taste panel evaluations of tenderness, juiciness, flavor of the lean, flavor of the fat and overall organoleptic score. Endocrine gland weights consisting of the thyroid gland, adrenal glands, pituitary gland and testicles were obtained.

The data on these traits were analyzed to obtain estimates of general combining ability, specific combining ability and reciprocal differences among the lines. Heterotic effects were estimated by comparing each linecross plus its reciprocal with the appropriate mid-parent. Phenotypic correlation coefficients among all the traits were obtained to determine the relationship between the various performance traits, blood constituents, carcass traits, organoleptic measurements and endocrine gland weights. All traits were analyzed on a within-sex basis because of management differences between the sexes.

Males had larger birth weights and reached 227 kg. at younger ages than the females but no differences existed between sexes for preweaning rate of gain or conformation and condition scores at 227 kg. Angus calves had earlier birth dates, smaller birth weights, higher preweaning rates of gain, were younger at 227 kg. and had higher conformation and condition scores at 227 kg. than the Hereford calves.

Among the males, general combining ability effects were nonsignificant for all preweaning and weaning traits except conformation score at 227 kg. Among the females, significant general combining ability effects were detected for preweaning rate of gain, age at 227 kg.

and condition score at 227 kg. body weight. Line 1 was superior to lines 2 and 3 in general combining ability for these traits in both males and females. Specific combining ability effects were nonsignificant among both sexes except for birth weights of the 2×3 and 3×2 linecross females.

Although the general and specific combining ability differences for preweaning and weaning traits were generally nonsignificant among the males, those crosses with line 1 involved were generally superior to other crosses. The inbreeding of dam effects on the males may have prevented general combining ability differences in growth rate to be detected since the milk production of the inbred dams may have been too low for the males to express their genetic differences in growth potential whereas among the females, the level of milk production was sufficient to detect general combining ability differences.

Heterotic effects were small or nonexistent for most of the preweaning traits. However, a significant difference in favor of the linecross calves was obtained for percent stillbirths. No differences were detected for percent calves born, but the linecross calves were more vigorous at birth than the inbred calves. The Angus exceeded the Herefords in percent calves born and percent calves weaned ($P < .01$). No overall linecross superiority was detected among the six preweaning and weaning traits in either sex. However negative heterosis was found for condition score at 227 kg. among the 2×3

and 3 × 2 linecross males and for birth weight among the 2 × 3 and 3 × 2 linecross females.

The Angus calves were lower in postweaning rate and efficiency of gain, were younger at the end of the feed test and had higher conformation and condition scores at the end of the feed test than the Hereford calves. General combining ability effects were significant or highly significant for feed efficiency, conformation score at 363 kg. and condition score at 363 kg. among the males. Among the females, significant or highly significant general combining ability differences were exhibited for conformation and condition scores at 340 kg. Significant specific combining ability effects were detected for postweaning rate of gain in both sexes. Reciprocal effects were unimportant for the postweaning traits. The line 2 males were superior in general combining ability for feed efficiency while line 3 was inferior in general combining ability for conformation and condition scores. The lack of significant general combining ability effects for rate of gain would indicate that the lines were genetically very similar for this trait.

Heterotic effects were significant for postweaning rate of gain and feed per unit gain among the females and for age at 363 kg. among the males. Heterosis was not found for conformation and condition scores in either sex.

Blood levels of creatinine were quite similar at all weights and for both sexes. Amino acids and urea were higher in females than in males and increased in both sexes with increasing age. Angus calves had higher levels of amino acids and urea than Hereford calves. Apparently as the animal increases in age, protein anabolism decreases and fat deposition increases resulting in higher levels of urea and amino acids in the blood. General combining ability, specific combining ability and heterotic effects were nonsignificant for all the blood constituents.

Angus males excelled the Hereford males in carcass conformation, marbling, carcass grade, thyroid gland weight and testicle weight. However the Herefords had larger loin-eyes, less fat over the 12th rib, a higher percentage of lean in the 12th rib cut separation and a lower percent drip in the 10-11 rib roast than the Angus. General combining ability differences were significant or highly significant for carcass conformation, marbling, carcass grade, percent drip, tenderness, juiciness and thyroid gland weight. Line 1 excelled in carcass conformation, marbling, grade and thyroid gland weight whereas Line 3 had a higher percent drip and excelled in juiciness and tenderness.

Significant heterotic differences were detected only for testicle weight among the 1 × 2 and 2 × 1 linecross males. All other carcass traits, organoleptic measurements and endocrine gland weights did not exhibit heterosis. Thus it would appear that most of the genetic variation is additive in nature for these traits.

For the entire study, it was concluded that line 1 was superior to lines 2 and 3 in general combining ability for most of the growth and carcass traits. Line 2 excelled in feed efficiency whereas line 3 was the poorest combining line for conformation and condition scores. Crosses of line 1 with the other lines generally resulted in larger heterotic effects for most of the growth traits. This might have been expected based on the history of the three lines. The development of three lines selected for the same traits and subjected to the same environmental influences likely prevented sufficient divergence among the lines for many significant combining ability or heterotic effects to be detected.

From the magnitude of the correlation coefficient of preweaning rate of gain with postweaning rate of gain and feed per unit gain, it was concluded that large compensatory effects occurred for poor preweaning rate of gain. The effect of poor preweaning rate of gain decreased as the length of the feed trial was lengthened. To avoid these compensatory effects it might be desirable to have a longer adjustment period prior to the initiation of the feed test.

Birth weight was highly associated with preweaning growth rates and ages among the Hereford females, but was not associated with preweaning growth among Angus females. It was concluded that the larger quantities of milk produced by the Angus dams might have been responsible for removing the effect of differences in birth weights among the Angus calves.

The association between suckling gain and conformation or condition scores was large whereas no relationship was found between postweaning rate of gain and conformation or condition scores. Therefore, by selecting for heavier weaning weights, an improvement in conformation scores even up to the time of slaughter could be expected.

Rather consistent positive correlation coefficients were detected between blood levels of amino acids and feed per unit gain among the males. This would tend to indicate that less efficient animals cannot withdraw the amino acids for muscle development and must utilize carbonaceous fractions of the amino acids to produce fat in the body to give increased body weights.

Conformation of the live animals was positively associated with carcass conformation, marbling, carcass grade and loin-eye area. However, no correlations of conformation scores with percent fat, lean and bone in the 12th rib cut were detected. These correlations were used as evidence to support the contention that by placing emphasis on muscle development in the live animal, heavily muscled cattle that grade well without having excess fat can be selected.

Younger calves at slaughter were found to have more youthful appearing carcasses as was evidenced by the correlation between ages and carcass maturity. Marbling and carcass grade had little or no effect on eating quality of roasts from the 10-11 rib section. It was concluded that among young animals marbling is not important for eating qualities but among older animals the association of marbling with juiciness and tenderness might be of greater importance.

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