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Effects of Crossbreeding on Growth Rate of Steers and Heifers, Feed Efficiency of Heifers and Carcass Characteristics of Steers

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EFFECTS OF CROSSBREEDING ON GROWTH RATE OF STEERS AND HEIFERS, FEED EFFICIENCY OF HEIFERS AND CARCASS CHARACTERISTICS OF STEERS

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser | Date

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INTRODUCTION

The future of the beef industry will be determined by the cost of production of edible product and the efficiency by which beef is produced. If the price of beef becomes excessively high in relation to other protein sources, an alteration in consumers' diets can be expected. Also, the world is ever more conscious of its limited resources and concerned about efficient use of available food sources.

The role of the animal breeder in the beef industry is to identify the most efficient methods of animal breeding. Crossbreeding is a potential method of improving production when heterosis exists and is important when combining effects are large and economically important or when combinations of several traits yield economically desirable results.

The purpose of this thesis is to evaluate the effects of crossbreeding on growth rate, feed efficiency and carcass characteristics. Increased growth rate, improved feed efficiency and improved carcass characteristics would decrease the growing and fattening period, reduce overhead costs, decrease feed requirements and increase the percentage yield of edible product.

REVIEW OF LITERATURE

Crossbreeding involves the mating of two or more breeds. The advantages of crossbreeding are the production of heterosis, the opportunity to incorporate desirable genetic material and the chance to combine several desirable traits in a market animal.

The definition of heterosis is in fact a definition of interaction, interaction being the failure of an additive scheme to describe the facts (Willham, 1970). Heterosis results from nonadditive gene action.

When crossbred offspring are used for meat production, efficiency of production is a function of three genotypes, that of the sire, the dam and the crossbred offspring. If specialized crosses are used, the sire breed may ignore female fertility without loss of efficiency; but in the dam breed progeny growth and carcass traits must be considered in addition to number of offspring or else a substantial loss in efficiency of improvement of overall net merit may be suffered (Smith, 1964). Moav (1966) concluded that, if the contribution of the sire and dam to profit is unequal, there is justification for the breeding and use of specialized lines even if the traits were genetically additive. He also concluded that multiple crosses may improve profit over a two-way cross only when there is heterosis in one or more of the component traits.

For most characteristics of size and growth there is a small but consistent amount of heterosis exhibited. The amount of heterosis usually will vary between 1 to 10% depending upon the experiment, trait and breed (Mason, 1966). In general the heterotic estimate expressed as a percent of the mid-parent will decrease with age after approximately 1 year of age in cattle. This is consistent with the observation by Willham (1970) that heterosis varies inversely with heritability.

Birth Weight

Heterosis as indicated by a significant ($P<.01$) interaction between breed of sire and breed of dam was reported by Gregory et al. (1965) for birth weight and had an average value of 2.7% for the crossbreds over the straightbreds of the Hereford, Angus and Shorthorn breeds. Both breed of sire and breed of dam had significant ($P<.01$) effects on birth weight. Gaines et al. (1966) using the same breeds found evidence for heterosis in birth weight which averaged 3.1%. Contrary to the results reported by Gregory et al. (1965), Gaines et al. (1966) found little, if any, evidence of maternal influence on birth weight. The mature size of these three breeds is similar and may be part of the reason for little demonstration of maternal influence in this experiment.

Charolais, Hereford and Angus breeds were studied in two experiments (Pahnish et al., 1969; Sagebiel et al., 1973) and researchers observed in both cases greater heterosis for birth weight in the male calves than the female calves. Pahnish et al. (1969) reported heterosis values of 4.4% for males and 1.4% for females, while Sagebiel et al. (1973) reported values of 2.0% for males and 1.0% for females. The calves by Charolais sires and Angus dams were larger than calves by Angus sires and Charolais dams in both experiments.

Maternal effects have been reported by some researchers to have an important effect, while others have reported no effect. In most instances where no significant maternal effects were observed, there was little difference in the average mature weight of the dams between breeds. When breeds of nearly the same size are crossed, there is generally some expression of heterosis; but, when breeds differ in size, the heterotic estimate is usually smaller and the calculated value is apparently influenced by the size of the dam.

Joubert and Hammond (1958) crossed Dexter and South Devon cattle which have average birth weights of 23.7 kg and 45.5 kg, respectively, and mature female weights of 318 kg and 635 kg, respectively. They observed that the calves born to Dexter dams averaged 26.8 kg and those born to South Devon dams averaged 33.3 kilograms. The data from two breeds very different in mature size actually show a negative heterosis for birth weight and a large degree of maternal influence.

Two British studies (Dickinson, 1960; Donald, Russell and Taylor, 1962) with Holstein, Jersey and Ayrshire also demonstrated that the size of the newborn calf may be affected by the size of the mother and that differences in birth weight may be due to factors other than genetic. Dickinson (1960) found that crossbred calves born of the larger breed were larger at birth in all cases. Also, the correlation between birth weight and mature weight was consistently larger for calves born to cows of the smaller breed. It was postulated that the maternal retardation of fetal growth resulted in phenotypes more closely related to their genotype, whereas the fetal environment provided by the larger breed obscured the genotype at birth. Dickinson (1960) also found that traits relatively more mature at birth such as height at withers were influenced the least by heterosis at birth.

Studies of Holstein and Guernsey crosses reported by Shreffler and Touchberry (1959) and Touchberry and Bereskin (1966a) indicated that breed of dam was a large source of variation. Calves from Holstein dams were 6.22 kg heavier than those born of Guernsey dams, where there was only a 2.50 kg birth weight difference associated with breed of sire (Touchberry and Bereskin, 1966a).

Gestation length has pronounced effects on birth weight, is significantly affected by the breed of sire and breed of dam and appears to be largely controlled by additive gene action (Haycock and Stewart, 1973; Sagebiel et al., 1973; Joubert and Hammond, 1958). Sagebiel et al. (1973), Touchberry and Bereskin (1966a) and Rollins et al. (1969) found the effect of heterosis on gestation length to be small and values were reported of 0.15%, -.17% and 0.3%, respectively.

Weaning Weight

Heterosis has consistently been demonstrated to have a positive influence on the weaning weight of crossbred calves. Table 1 lists the results of several studies.

The influence of sex on heterosis at weaning has not been established and in most studies the males and females have not been analyzed separately. Pahnish et al. (1969) and Gregory et al. (1965)

TABLE 1. HETEROSIS EFFECTS FOR WEANING WEIGHT OF SINGLE CROSS CALVES

Experiment	Breeds[a]	Sex	Purebred wt., kg	Crossbred wt., kg	Percent heterosis
Damon *et al.*, 1959	A,S,H,B, C,Br		187.7	195.0	4.3
Gaines *et al.*, 1966	A,S,H		178.7	186.4	4.1
Gregory *et al.*, 1965	A,S,H	Male	195.5	202.8	3.7
		Female	176.0	188.2	6.9
Klosterman *et al.*, 1968	H,C		263.5	273.1	3.4
Lawson and Peters, 1964	H,High		158.8	173.3	9.2
Pahnish *et al.*, 1969	H,A,C	Male	220.3	228.6	3.7
		Female	213.5	217.5	1.9
Rollins *et al.*, 1969	H,A,S		174.1	181.1	4.5

[a] A = Angus, B = Brahman, Br = Brangus, C = Charolais, H = Hereford, S = Shorthorn and High = Highland.

did analyze the sexes separately and reported opposite effects. Pahnish *et al.* (1969) found steers to have a higher heterosis value, while Gregory *et al.* (1965) found heifers to have a higher heterosis value. Brinks *et al.* (1967) crossing inbred lines of Herefords reported higher heterosis values for heifers on average daily gain to weaning and weaning weight.

Differences in the growth curves between reciprocal crosses are regularly observed and may be an indication of maternal ability, although as indicated by the dairy studies the differences involve more than just the postnatal environment provided by the dam. McDowell *et al.* (1969)

crossed three dairy breeds and found that, although the differences between reciprocal crosses varied as much as 5 kg at birth, the groups lighter at birth were equal to or slightly heavier than their reciprocals by 3 months of age. However, Touchberry and Bereskin (1966b) found no reversal in weight and the animals born of larger dams maintained their advantage throughout life.

Pahnish et al. (1969) observed that in Angus and Charolais crosses the calves from Angus cows were larger at birth. However, at weaning the steer calves from Charolais dams were larger and the reciprocal cross heifers were nearly equal in weight. Lawson and Peters (1964) reported the reversing in size advantage of reciprocal crosses from birth weight to weaning weight, although Gregory et al. (1965) found the larger reciprocals at birth to be the largest at weaning in all crosses.

Most studies indicate that both breed of sire and breed of dam are significant sources of variation in weaning weight. Gregory et al. (1965) reported data which are an exception to this general observation and found breed of sire to be a significant ($P < .01$) source of variation, while breed of dam was significant only at the 10% level.

Postweaning Growth - Heifers

Gregory et al. (1966a) evaluated postweaning growth traits of replacement heifers of the Hereford, Angus and Shorthorn breeds and their reciprocal crosses. Significant ($P < .01$) heterosis effects were found for 200-day weight, average daily gain from 200 to 396 days, average daily gain from 200 to 550 days, 396-day weight and 550-day weight but not for average daily gain from 396 to 550 days. Heterosis effects were larger in the winter when relatively low levels of gain were made than during the summer. This was interpreted to be due to diminished heterosis effects after 1 year of age and to smaller heterosis effects on feeding regimes that result in a relatively high level of gain.

Vogt et al. (1967) analyzed heifers of the same breeds which were put in the feedlot immediately following weaning and found that the crosses exceeded the purebreds by 3.9% in average daily gain and 4.4% in slaughter weight when approximately 420 days of age. Jain et al. (1971) reported heterotic estimates of 8.0% and 4.0% for slaughter weight of short and long fed heifers of Charolais, Hereford and Angus crosses at approximately 400 and 475 days of age. These values are less than those reported by Gregory et al. (1966a) of 10.3% and 6.8% at 369 days of age but would agree with Gregory's postulation that heterosis effects are less at higher levels of gain and decrease after 1 year of age.

No statistically significant differences between purebreds and crossbreds were found by Pahnish et al. (1971) when all crosses of the Hereford, Charolais and Angus breeds were analyzed together. The heterosis effects they obtained were smaller than most, 1.0% for 190-day weight, 2.0% for 361-day weight and 1.3% for 547-day weight with no significant differences for rate of gain. Statistically important differences between reciprocal crosses were confined to the British by Charolais crosses. Crossbreds by Charolais sires and Hereford or Angus dams excelled their reciprocal cross in rate of gain and were larger at 361 days and 547 days. Jain et al. (1971), studying the same cross under feedlot conditions, reported no statistically significant differences between reciprocal crosses.

McDowell et al. (1969) analyzed body measurements and body weight of Brown Swiss, Holstein and Ayrshire crosses and reported heterotic estimates at 6, 12, 18 and 24 months for body weight of 2.8%, 2.8%, 4.6% and 3.4%, respectively. However, Touchberry and Bereskin (1966b) found the effects of crossbreeding decreased linearly as age increased from 7.1% at 3 months to 1.5% at 48 months.

Variations due to breed of sire and breed of dam are highly significant ($P < .01$) in most experiments for yearling weight, 550-day weight and slaughter weight.

Postweaning Growth - Steers

Studies of hybrid vigor in feedlot cattle conducted more than 30 years ago (Shaw and MacEwan, 1938; Phillips et al., 1942) concluded that crossbreds had a definite advantage over purebreds in rate of gain, quality of carcass and weight at slaughter.

Studies of the influence of heterosis on beef steers conducted by Gregory et al. (1966b) and Vogt et al. (1967) with Hereford, Angus and Shorthorn showed the crossbreds had larger yearling and slaughter weights. Gregory et al. (1966b) found differences in average daily gain between straightbreds and crossbreds to be significant ($P < .01$) from weaning to 284 days of age, significant ($P < .05$) from 284 to 368 days of age and not significant for the last third of the feeding period from 368 to 452 days of age though the average daily gain was larger for the crossbred in each period. Vogt et al. (1967) found average daily gain to be significantly ($P<.01$) larger for the crossbreds from fall weaning to the following September. However, in the feedlot there was no difference in average daily gain between the purebreds and crossbreds. These two studies are in agreement in that after approximately 1 year of age there was little heterosis for average daily gain in beef steers, though the weight advantage the crossbreds obtained earlier in life was maintained.

An experiment involving the Angus, Charolais and Hereford breeds was carried out by Lasley et al. (1973). Steer calves born in the fall were grazed on pasture following weaning until approximately 1 year of age in 2 years of the experiment and then put in the feedlot. In the other 2 years of the experiment they were put in the feedlot immediately following weaning. Each year half the steers were fed a short feeding period (less than 200 days) and half put on a long feeding period (more than 200 days). Weight gains on grass were between 0.30 and 0.64 kg per day and no significant heterosis effect was obtained in average daily gain nor did breed of sire or breed of dam have a significant effect. The conclusion was that possibly the steers were unable to consume enough nutrients per day to make sufficient gains which may be necessary for the expression of genetic differences among breed groups. In the experiment Charolais gained faster than Angus and had a heavier slaughter weight. The Angus by Charolais crosses were the only crosses which did not exhibit heterosis in average daily gain when on the long feeding period. However, for the short feeding period heterosis was 12.8% and was significant ($P<.01$). Heterosis for slaughter weight was significant ($P<.05$) for the Angus by Charolais crosses in both the short and long feeding periods with values of 4.1% and 4.4%, respectively. Differences between the reciprocal crosses were small except for slaughter weight on the long fed steers in which case the steers from Angus sires and Charolais dams were significantly ($P<.05$) larger.

Feed Efficiency

The heterosis values for feed required to produce gain are small and improved feed efficiency has not been associated with hybrid vigor in beef cattle (Gregory et al., 1966b; Phillips et al., 1942; Vogt et al., 1967).

Under feedlot conditions and using steers of the Hereford, Angus and Shorthorn breeds, Gregory et al. (1966b) found breed of sire by breed of dam interaction to be nonsignificant for feed efficiency. Crossbreds consumed more feed and the heterosis effects on average daily TDN consumed for the 252-day postweaning feeding period were significant ($P<.01$). When adjusted for the effects of mid-weight, the differences were small, indicating that increased TDN consumption was mainly due to the heavier weight of the crossbreds. It was concluded that the increase in average daily gain of the crossbreds was mainly due to increased consumption and not to efficiency of feed utilization, which was substantiated by small differences in TDN per unit of gain between crossbreds and purebreds. Vogt et al. (1967), using the same three breeds under feedlot conditions, drew the same conclusions and found no significant differences in feed efficiency of feedlot steers or heifers.

Charolais gained more rapidly and ate more feed per head per day than Herefords, but there was no significant difference between breeds in the amount of feed required per unit of gain (Klosterman, Cahill and Parker, 1968). When the maintenance requirements were subtracted from the total TDN, there was a very small difference between breeds in the amount of TDN per pound of gain. The data also indicated that the crossbreds required slightly more TDN per pound of gain than the average of the mid-parents.

Carcass Characteristics

Important, significant ($P<.01$) heterotic effects were found by Gregory et al. (1966c) for carcass weight, rib eye area, dressing percentage and actual cutability when both crossbred and purebred steers were slaughtered at the same age. However, the lack of hybrid vigor on traits associated with carcass composition after the data were adjusted for weight showed that heterosis effects on carcass composition are through growth rate. Heterosis increases slaughter weight of the crossbreds at the same slaughter age. Thus, on a weight constant basis there is little heterosis effect on carcass traits.

Gaines et al. (1967) also studied Hereford, Angus and Shorthorn and observed a heterosis effect in carcass weight of 3.1% in steers and 4.3% in heifers and a significant ($P<.05$) rib eye area advantage for the crossbred over the straightbred when the data were adjusted to a constant age. No significant differences were found in fat thickness, marbling score, conformation score or carcass grade.

Carroll and Rollins (1965) found no significant differences for the previously mentioned carcass traits between purebreds and crossbreds, although the trend of the carcass measurements indicated that the purebreds were higher in carcass grade and fatter. Lasley et al. (1971) found heterotic effects were negligible for carcass quality as determined by carcass conformation, marbling score, Warner-Bratzler shear value and carcass quality grade.

SOURCE OF DATA

The experiment was initiated in the fall of 1968 with the purchase of straightbred Angus heifers and Charolais heifers of no less than 75% Charolais breeding. Ninety head of each breed were obtained from South Dakota farmers and ranchers with no more than four Angus or eight Charolais from any breeder.

The foundation stock was bred artificially to an Angus or Charolais bull and calves were produced in the years 1970, 1971 and 1972. Only one bull of each breed was used and the same two bulls were used each year, in that the main purpose of the project was to produce crossbred and straightbred heifers of similar breeding. All cows were the same age and thus the calf crops were produced when the cows were 2, 3 and 4 year-olds. The number of calves produced in each year and of each genotype is given in tables 2 and 3.

Feeding and Management of Phase I Cows

The first 3 years of the experiment the phase I cows were kept at the experiment station at Brookings, South Dakota. The winter of 1968-69 they were fed hay, cracked shelled corn and silage in the drylot and gained at the rate of approximately 0.57 kg per day. During the summer of 1969 they were managed on pasture and in the drylot. The winters of 1969-70 and 1970-71 they were fed corn silage and hay in the drylot. All cows were put on pasture in the summer. However, because of the shortage of pasture, cows with bull calves were put in the drylot on August 6 in 1970 and July 27 in 1971, while cows with heifer calves were maintained on pasture until weaning. Some cracked

TABLE 2. NUMBER OF INDIVIDUALS PER YEAR-BREED GROUP-SEX SUBGROUP FOR BIRTH TRAITS

Year	Genotype	Birth weight		Heart girth		Width at shoulders		Height at withers	
		Bull	Heifer	Bull	Heifer	Bull	Heifer	Bull	Heifer
1970	AA	22	23			22	23	22	23
	AC	22	24			22	24	22	24
	CA	10	13			10	13	10	13
	CC	10	9			10	9	10	9
1971	AA	19	16	19	16	19	16	19	16
	AC	12	9	12	9	12	9	12	9
	CA	24	19	24	19	24	19	24	19
	CC	19	15	19	15	19	15	19	15
1972	AA	10	10	10	10				
	AC	9	10	9	10				
	CA	14	15	14	15				
	CC	12	11	12	11				
Totals		183	174	119	105	138	128	138	138

TABLE 3. NUMBER OF INDIVIDUALS PER YEAR-BREED GROUP-SEX SUBGROUP FOR POSTWEANING TRAITS

		Weaning weight		365-day weight	550-day weight	Slaughter weight	Feed efficiency	
Year	Genotype	Steer	Heifer	Heifer	Heifer	Steer	Weaning-yearling Heifer	Yearling-550 days Heifer
1970	AA	18	22	22	22	15	22	13
	AC	16	21	21	21	14	21	12
	CA	10	13	13	13	9	13	7
	CC	9	8	8	8	9	8	5
1971	AA	19	16	16	16	17	9	9
	AC	12	9	8	8	12	5	5
	CA	24	19	18	18	22	10	10
	CC	17	15	15	15	11	10	10
1972	AA	10	10	10	10	10	5	5
	AC	9	10	10	10	8	5	5
	CA	13	15	15	15	13	6	6
	CC	12	11	11	11	11	6	6
Totals		169	169	167	167	151	120	93

shelled corn was fed the cows prior to and during the breeding season.

The cows were shipped to the Antelope Range Field Station in Harding County in the fall of 1971. They were wintered there and the 1972 calf crop was raised under range conditions.

Pertinent management dates are given in table 4.

Feeding and Management of Phase I Calves

The heifers were managed under two systems. One group of heifers was fed individually in the barn and will be referred to as the drylot heifers. Those heifers put on pasture during the summer but wintered in the lots will be referred to as pasture heifers. The steers were fed as a group and received the same feed and management throughout the growing and feedlot stages.

Drylot Heifers. The heifers born in 1970 were fed 2.3 kg of corn silage daily plus a pelleted feed *ad libitum* which contained 24.7% corn cobs, 24.7% oats, 24.7% alfalfa hay, 7.4% corn, 9.1% soybean oil meal, 7.4% molasses and 1.2% Durabond. On May 6, 1971, the ration was changed. The corn silage was replaced by 1.4 kg of hay and the composition of the pelleted feed was changed to 24% corn cobs, 27% corn, 29% oats, 7% molasses, 12% alfalfa hay and 1% Durabond. The ration was changed on November 9, 1971, to alfalfa pellets *ad libitum* and 1.4 kg of chopped alfalfa hay daily.

The 1971 heifers were fed shelled corn, alfalfa pellets and chopped alfalfa hay. Corn was fed daily at levels of 1.4 kg from

TABLE 4. PERTINENT MANAGEMENT DATES

Management	1969	1970	1971	1972	1973
Start of breeding season	July 1	July 1	June 11		
End of breeding season	Sept. 12	Sept. 18	Aug. 23		
First calf born		April 4	April 5	Mar. 15	
Last calf born		June 16	June 26	June 1	
Castrated bulls		Oct. 22	Oct. 9	At birth	
Weaning date		Nov. 11	Sept. 20 M[a] Oct. 19 F	Nov. 1	
Delivered steers to feedlot		Nov. 25	Nov. 13	Nov. 18	
Started individual feeding		Dec. 4	Nov. 19	Dec. 15	
Yearling weigh date for heifers			May 5	May 5	April 6
550-day weigh date for heifers			Nov. 19	Nov. 17	Nov. 2
Slaughter date for steers			Aug. 16	July 19	July 20

[a] M = males, F = females.

December 22, 1971, to January 29, 1972, 1.8 kg from January 30, 1972, to June 6, 1972, and 0.9 or 1.8 kg depending upon the condition of the heifer from June 7, 1972, to August 29, 1972. Alfalfa pellets were fed _ad libitum_ and 1.4 kg of chopped alfalfa hay were fed daily from the start of the feeding period to February 10, 1972, after which 2.7 kg of chopped hay were fed daily.

The ration of alfalfa pellets, shelled corn and chopped hay was also fed the 1972 heifers. The alfalfa pellets were fed _ad libitum_, chopped alfalfa hay was fed at the rate of 1.4 kg daily and from July 4, 1973, to October 4, 1973, 0.9 kg of corn was fed daily.

All the 1970 heifers were fed individually until a year of age at which time half of the heifers were put on pasture. Approximately half of the 1971 and 1972 heifers were allotted to each of the drylot and pasture management groups at weaning.

Pasture Heifers. The pasture heifers were raised and fed under a management system similar to local farm and ranch conditions. They were wintered in the lots on hay, corn silage and shelled corn and pastured during the summer from approximately the middle of May to the end of October. A conscientious attempt was made to simulate good commercial management.

Steers. The steers were backgrounded by the Jorgensen Bros., Ideal, South Dakota. The growing ration through the winter consisted of corn silage, hay, grain and protein supplement. Finishing of the steers was at a commercial feedlot and marketing took place in late summer.

Traits Studied

Growth traits from birth to 550 days for the heifers and to slaughter weight for the steers were studied. Other traits related to growth were included in the analysis when available and applicable. Carcass data were available for the steers only. The feed efficiency data involved only the postweaning period of the drylot heifers.

Preweaning Growth Traits. Birth weight, width at shoulders, height at withers and heart girth circumference of the calf were obtained within 24 hours after birth. Data were available for birth weight each year, for width at shoulders and height at withers in 1970 and 1971 and for heart girth circumference in 1971 and 1972.

Weight of dam at parturition was taken within 24 hours after parturition in 1970 and 1971.

Weaning weights (WW) were obtained and adjusted for age of calf. Age of calf adjustment was obtained by the following formula:

$$\text{205-day WW} = \frac{\text{actual WW} - \text{birth weight}}{\text{days of age}} \times 205 + \text{birth weight}$$

Average daily gain from birth to weaning was calculated by dividing the actual weaning weight by days of age at weaning.

<u>Postweaning Growth and Feed Efficiency of Heifers</u>. Yearling weight (YW) and 550-day weight (5W) were adjusted by the following formulas:

$$\text{Adjusted YW} = \frac{\text{actual YW} - \text{actual WW}}{\text{days between WW and YW}} \times 160 + \text{adjusted WW}$$

$$\text{Adjusted 5W} = \frac{\text{actual 5W} - \text{actual YW}}{\text{days between YW and 5W}} \times 185 + \text{adjusted YW}$$

Average daily gain weaning to yearling, weaning to 550 days and yearling to 550 days was calculated as the total kilograms gained for the period divided by the number of days in the period.

Feed efficiency weaning to yearling, weaning to 550 days and yearling to 550 days was calculated as the total digestible nutrients required per unit of gain from the start to the end of each feeding period. The trait feed efficiency weaning to yearling was not from the day of weaning to 365 days. There was an adjustment period of several weeks immediately following weaning before individual feed records were recorded. The dates are given in table 4.

<u>Feedlot and Carcass Traits of Steers</u>. Average daily gain was calculated as slaughter weight minus weaning weight divided by the number of days from weaning to slaughter.

Slaughter weight was the shrunk weight on the day of slaughter, chilled carcass weights were obtained 24 hours post-mortem and weight of retail cuts was estimated by multiplying cutability by carcass weight. These three traits were adjusted for age effects to 452 days (mean slaughter age) by least squares regression computed from sum of squares and cross-products for each breed group pooled across years.

Carcass weight had significant ($P<.01$) effects on weight of retail cuts and rib eye area. In order to study the effect of heterosis on the composition of the carcass, these two traits were adjusted to the mean carcass weight (286.2 kg) in the same manner as age adjustments.

Dressing percent equals the chilled carcass weight divided by actual slaughter weight.

Cutability is equal to an estimate of boneless retail cuts from round, loin, rib and chuck by the following regression equation (Murphey et al., 1960):

Percent retail cuts = 52.56 - 4.95 (single thickness of fat over rib eye, in.) - 1.06 (percent kidney fat) + 6.82 (area of rib eye, sq. in.) - 0.008 (carcass weight, lb.)

Fat thickness was measured by a U.S.D.A. grader between the 12th and 13th ribs. Marbling and carcass quality scores were assigned by a U.S.D.A. grader. Marbling was classified from devoid to abundant using codes from 1 through 10. Carcass quality scores were coded 13 to 15, standard; 16 to 18, good; 19 to 21, choice and 22 to 24, prime. Rib eye area was measured in square centimeters from an acetate tracing with a polar compensatory planimeter at the 12th rib.

ANALYSIS OF DATA

The data were analyzed by least squares procedures. The main effects were breed of sire, breed of dam and year (confounded with age of dam) and were cross-classified. Management (drylot or pasture) was a fourth main effect present only in the analysis of postweaning traits of the heifers and was cross-classified. Inclusion of age of dam was unnecessary since all dams in a given year were the same age. Only single births were analyzed and male and female data were analyzed separately.

Only one bull of each breed was used in this experiment. Therefore, variation due to breed of sire also includes variation due to sire and this variation cannot be separated.

The complete model for the analysis of preweaning traits, feed efficiency of the heifers and steer feedlot and carcass traits is as follows:

$$Y_{ijkl} = \mu + S_i + D_j + Y_k + SD_{ij} + SY_{ik} + DY_{jk} + SDY_{ijk} + e_{ijkl}$$

where Y_{ijkl} is the observation on the l^{th} individual in the k^{th} year from the j^{th} breed of dam and i^{th} breed of sire.

μ is the population mean

S_i is the effect common to all animals of the i^{th} breed of sire

D_j is the effect common to all animals of the j^{th} breed of dam

Y_k is the effect common to all animals in the k^{th} year

SD_{ij} refers to the interaction of the i^{th} breed of sire and the j^{th} breed of dam

SY_{ik} refers to the interaction of the i^{th} breed of sire and the k^{th} year

DY_{jk} refers to the interaction of the j^{th} breed of dam and the k^{th} year

SDY_{ijk} refers to the interaction of the i^{th} breed of sire, the j^{th} breed of dam and the k^{th} year

e_{ijkl} is the random effect particular to the i^{th} breed of sire, j^{th} breed of dam and k^{th} year that causes the l^{th} observation to deviate from the expected mean.

The complete model for yearling weight, 550-day weight, average daily gain from weaning to 365 days, weaning to 550 days and 365 days to 550 days for the heifers is as follows:

$$Y_{ijkml} = \mu + S_i + D_j + Y_k + M_m + SD_{ij} + SY_{ik} + SM_{im} + DY_{jk} + DM_{jm} + YM_{km} + SDY_{ijk} + SDM_{ijm} + SYM_{ikm} + DYM_{jkm} + SDYM_{ijkm} + e_{ijkml}$$

where Y_{ijkml} is the observation on the l^{th} individual from the m^{th} management group in the k^{th} year from the j^{th} breed of dam and the i^{th} breed of sire.

μ is the population mean

S_i is the effect common to all animals of the i^{th} breed of sire

D_j is the effect common to all animals of the j^{th} breed of dam

Y_k is the effect common to all animals in the k^{th} year

M_m is the effect common to all animals in the m^{th} management group

SD_{ij} refers to the interaction of the i^{th} breed of sire and the j^{th} breed of dam

SY_{ik} refers to the interaction of the i^{th} breed of sire and the k^{th} year

SM_{im} refers to the interaction of the i^{th} breed of sire and the m^{th} management group

DY_{jk} refers to the interaction of the j^{th} breed of dam and the k^{th} year

DM_{jm} refers to the interaction of the j^{th} breed of dam and the m^{th} management group

YM_{km} refers to the interaction of the k^{th} year and the m^{th} management group

SDY_{ijk} refers to the interaction of the i^{th} breed of sire, j^{th} breed of dam and the k^{th} year

SDM_{ijm} refers to the interaction of the i^{th} breed of sire, j^{th} breed of dam and m^{th} management group

SYM_{ikm} refers to the interaction of the i^{th} breed of sire, k^{th} year and the m^{th} management group

DYM_{jkm} refers to the interaction of the j^{th} breed of dam, k^{th} year and the m^{th} management group

$SDYM_{ijkm}$ refers to the interaction of the i^{th} breed of sire, j^{th} breed of dam, k^{th} year and m^{th} management group

e_{ijkml} is the random effect particular to the i^{th} breed of sire, j^{th} breed of dam, k^{th} year and m^{th} management group that causes the l^{th} observation to deviate from the expected mean.

All main effects were considered fixed and the mean square expectations are given in tables 5 and 6.

TABLE 5. ANALYSIS OF VARIANCE WITH EXPECTED MEAN SQUARES FOR PREWEANING TRAITS, FEED EFFICIENCY OF HEIFERS AND STEER FEEDLOT AND CARCASS TRAITS

Source of variation	df	E M S
Breed of sire (BS)	S-1	$\sigma_e^2 + k_7\sigma_s$
Breed of dam (BD)	D-1	$\sigma_e^2 + k_6\sigma_d$
Years (Y)	Y-1	$\sigma_e^2 + k_5\sigma_y$
BS x BD	(S-1)(D-1)	$\sigma_e^2 + k_4\sigma_{sd}$
BS x Y	(S-1)(Y-1)	$\sigma_e^2 + k_3\sigma_{sy}$
BD x Y	(D-1)(Y-1)	$\sigma_e^2 + k_2\sigma_{dy}$
BS x BD x Y	(S-1)(D-1)(Y-1)	$\sigma_e^2 + k_1\sigma_{sdy}$
Within	N-(SDY)	σ_e^2

Breed group means were used to estimate heterosis, to estimate performance of breed groups and to make breed group comparisons. Breed group means are the least squares means constructed from the overall mean and breed of sire, breed of dam and breed of sire x breed of dam interaction constants. The means presented for each breed group are free of year effects including age of dam x year interaction effects and effects of disproportionate subclass frequencies. Coefficients for orthogonal comparisons are given in table 7.

TABLE 6. ANALYSIS OF VARIANCE WITH EXPECTED MEAN SQUARES FOR POSTWEANING TRAITS OF HEIFERS

Source of variation	df	E M S
Breed of sire (BS)	S-1	$\sigma_w^2 + k_{15}\sigma_s^2$
Breed of dam (BD)	D-1	$\sigma_w^2 + k_{14}\sigma_d^2$
Years (Y)	Y-1	$\sigma_w^2 + k_{13}\sigma_y^2$
Management (M)	M-1	$\sigma_w^2 + k_{12}\sigma_m^2$
BS x BD	(S-1)(D-1)	$\sigma_w^2 + k_{11}\sigma_{sd}^2$
BS x Y	(S-1)(Y-1)	$\sigma_w^2 + k_{10}\sigma_{sy}^2$
BD x Y	(D-1)(Y-1)	$\sigma_w^2 + k_9\sigma_{dy}^2$
BS x M	(S-1)(M-1)	$\sigma_w^2 + k_8\sigma_{sm}^2$
BD x M	(D-1)(M-1)	$\sigma_w^2 + k_7\sigma_{dm}^2$
Y x M	(Y-1)(M-1)	$\sigma_w^2 + k_6\sigma_{ym}^2$
BS x BD x Y	(S-1)(D-1)(Y-1)	$\sigma_w^2 + k_5\sigma_{sdy}^2$
BS x Y x M	(S-1)(Y-1)(M-1)	$\sigma_w^2 + k_4\sigma_{sym}^2$
BD x Y x M	(D-1)(Y-1)(M-1)	$\sigma_w^2 + k_3\sigma_{dym}^2$
BS x BD x M	(S-1)(D-1)(M-1)	$\sigma_w^2 + k_2\sigma_{sdm}^2$
BS x BD x Y x M	(S-1)(D-1)(Y-1)(M-1)	$\sigma_w^2 + k_1\sigma_{sdym}^2$
Within	N-(SDYM)	σ_w^2

TABLE 7. COEFFICIENTS FOR ORTHOGONAL COMPARISONS

Comparisons	Breed groups[a] AA	AC	CA	CC
Straightbred vs. crossbred	-1	+1	+1	-1
Angus vs. Charolais dams	+1	-1	+1	-1
Angus vs. Charolais sires	+1	+1	-1	-1
Angus-Char. vs. Char.-Angus	0	+1	-1	0
Angus vs. Charolais	-1	0	0	+1
Crossbreds vs. Angus	+2	-1	-1	0
Crossbreds vs. Charolais	0	-1	-1	+2

[a] AA = Angus, AC = Angus-Charolais, CA = Charolais-Angus and CC = Charolais.

More comparisons are made using these means than there are independent degrees of freedom. Therefore, not all of the comparisons are independent and the confidence level may not be as reliable as implied by the level of probability. The student's two tailed t test was used to test the level of significance between group means.

Heterosis, the genetic interaction resulting from crossbreeding, is defined as the difference between the mean of the crossbreds and the mean of the parent breeds. In this study heterosis is expressed as a percent of the mean of the parents.

Combining effect is defined as one-half the difference between the two straightbreds and therefore by definition will increase as the differences between two breeds increase.

The comparison of the mean of the crossbreds and the superior parent gives a statistical test of the difference between combining and heterotic effects.

RESULTS

Analysis of Variance

Preweaning Traits and Gestation Length. Analyses of variance for both steers and heifers for preweaning traits and gestation length are presented in tables 8, 10 and 12. Least squares means for breed groups are given in tables 9, 11 and 13.

The main effects of breed of sire, breed of dam and year are significant for most traits ($P<.01$). Year had no effect on gestation length or width at shoulders of calf. A notable exception was the lack of significance of breed of sire on weaning weight of steer calves and average daily gain of steer and heifer calves. Most studies have shown breed of sire to have an important effect on weaning weight, although Schreffler and Touchberry (1959) found no significant breed of sire effect until after 12 months of age in Holstein and Guernsey crosses. Breed of dam had no significant effect on gestation length which may be explained in part by the fact that Angus dams bred to the Angus sire had shorter gestation periods than Charolais dams bred to the Charolais sire, while Angus dams bred to the Charolais sire had longer gestation periods than Charolais dams bred to the Angus sire.

Interactions between breed of sire and breed of dam were significant ($P<.01$) only for weaning weight and preweaning gain of the steers. The interaction of breed of sire x breed of dam indicates the presence of heterosis.

Effects due to breed of sire, breed of dam and the interaction between breed of sire and breed of dam are again discussed when specific comparisons are made.

TABLE 8. MEAN SQUARES FOR GESTATION LENGTH, BIRTH WEIGHT, WIDTH AT SHOULDERS, HEIGHT AT WITHERS AND HEART GIRTH CIRCUMFERENCE OF BULL CALVES

Source of variation	df	Gestation length	Birth weight	df	Width at shoulders	Height at withers	df	Heart girth circum-ference
Breed of sire (BS)	1	344.78**	5968.3**	1	23.752**	837.82**	1	256.18**
Breed of dam (BD)	1	130.97*	5077.2**	1	25.805**	293.30**	1	172.86**
Years (Y)	2	40.45	1217.8**	1	4.112	20.31	1	244.56**
BS x BD	1	3.50	1.6	1	2.522	2.54	1	14.82
BS x Y	2	27.62	112.5	1	0.849	0.12	1	6.29
BD x Y	2	29.84	142.5	1	1.025	3.24	1	3.98
BS x BD x Y	2	67.92	145.4	1	1.583	3.18	1	0.66
Within	171	25.89	101.7	130	2.084	8.21	111	9.96

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

TABLE 9. LEAST SQUARES MEANS FOR BULL CALVES BY BREED GROUPS

Breed group	Gestation length days	Birth weight kg	Width at shoulders cm	Height at withers cm	Heart girth circum-ference cm
Angus	281.60	29.98	18.33	60.44	72.04
Angus-Charolais	283.11	35.15	19.54	63.82	75.32
Charolais-Angus	284.23	35.57	19.50	65.95	75.88
Charolais	286.31	40.56	20.13	68.75	77.67

TABLE 11. LEAST SQUARES MEANS FOR HEIFER CALVES BY BREED GROUPS

Breed group	Gestation length days	Birth weight kg	Width at shoulders cm	Height at withers cm	Heart girth circum-ference cm
Angus	280.15	28.35	17.84	59.69	70.54
Angus-Charolais	279.06	32.84	18.38	63.70	72.62
Charolais-Angus	283.02	34.06	19.05	64.92	74.43
Charolais	283.96	36.70	19.14	67.78	75.12

TABLE 10. MEAN SQUARES FOR GESTATION LENGTH, BIRTH WEIGHT, WIDTH AT SHOULDERS, HEIGHT AT WITHERS AND HEART GIRTH CIRCUMFERENCE OF HEIFER CALVES

Source of variation	df	Gestation length	Birth weight	df	Width at shoulders	Height at withers	df	Heart girth circumference
Breed of sire (BS)	1	588.26**	4335.0**	1	27.515**	612.53**	1	251.10**
Breed of dam (BD)	1	0.18	2402.1**	1	2.804	332.60**	1	47.26*
Years (Y)	2	74.70	732.0**	1	3.834	58.43**	1	74.28**
BS x BD	1	40.10	163.6	1	1.474	9.38	1	11.93
BS x Y	2	14.91	182.3	1	0.379	0.00	1	41.23*
BD x Y	2	11.10	186.8	1	5.473	7.53	1	7.33
BS x BD x Y	2	37.53	156.1	1	6.703	3.20	1	10.29
Within	162	32.39	87.0	120	1.747	6.04	97	10.35

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

TABLE 12. MEAN SQUARES FOR WEANING WEIGHT AND AVERAGE DAILY GAIN BIRTH TO WEANING

		Steers		Heifers	
Source of variation	df	Weaning weight	Average daily gain birth to weaning	Weaning weight	Average daily gain birth to weaning
Breed of sire (BS)	1	1647	0.0306	12541**	0.0415
Breed of dam (BD)	1	28095**	0.2211**	28776**	0.3163**
Years (Y)	2	76289**	1.4414**	45864**	0.8886**
BS x BD	1	16871*	0.4451**	2369	0.0375
BS x Y	2	609	0.0039	1327	0.0263
BD x Y	2	960	0.0594	716	0.0453
BS x BD x Y	2	3144	0.0602	254	0.0045
Within	157	2544	0.0557	1597	0.0352

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

TABLE 13. LEAST SQUARES MEANS FOR BREED GROUPS

	Steers		Heifers	
Breed group	Weaning weight kg	Average daily gain birth to weaning kg	Weaning weight kg	Average daily gain birth to weaning kg
Angus	170.73	0.686	166.72	0.675
Angus-Charolais	192.50	0.767	182.77	0.731
Charolais-Angus	183.21	0.720	178.53	0.704
Charolais	185.97	0.708	187.42	0.732

<u>Postweaning Growth Traits of Heifers</u>. Mean squares and degrees of freedom for postweaning gain and weight of heifers are given in table 14 and least squares means for postweaning gain and weight of heifers are given in table 15.

Main effects of breed of dam on average daily gain weaning to yearling and management on yearling weight failed to show significance.

Breed of sire x breed of dam interaction was significant ($P < .05$) for average daily gain from weaning to yearling and yearling weight and significant ($P < .01$) for average daily gain weaning to 550 days, average daily gain yearling to 550 days and 550-day weight. This is indicative of the presence of heterosis.

Year by management interaction was significant for all post-weaning growth traits of heifers and several of the interactions involving year or management were also significant for specific traits.

<u>Feed Efficiency of Heifers</u>. Only years (table 16) had a significant effect on postweaning feed efficiency. Effects of years were significant ($P < .01$) on feed efficiency from weaning to yearling and feed efficiency yearling to 550 days. There were no significant effects due to breed of sire, breed of dam and the interaction between breed of sire and breed of dam. Gregory <u>et al</u>. (1966b) reported that the effects of breed of sire and breed of dam on feed efficiency were generally significant ($P < .01$). The least squares means for feed efficiency of breed groups are given in table 17.

TABLE 14. MEAN SQUARES FOR YEARLING WEIGHT, 550-DAY WEIGHT, AVERAGE DAILY GAIN WEANING TO YEARLING, AVERAGE DAILY GAIN WEANING TO 550 DAYS AND AVERAGE DAILY GAIN YEARLING TO 550 DAYS FOR HEIFERS

Source of variation	df	Yearling weight	550-day weight	Average daily gain: Weaning to yearling	Average daily gain: Weaning to 550 days	Average daily gain: Yearling to 550 days
Breed of sire (BS)	1	10828*	79343**	0.08003**	0.1132**	0.2283**
Breed of dam (BD)	1	23768	58615**	0.01122	0.1079**	0.1284**
Years (Y)	1	72324**	64920**	0.47716**	0.2643**	2.1835**
Management (M)	1	5025	252714**	0.20423**	2.0725**	4.8588**
BS x BD	1	10762*	43105**	0.11500*	0.1011**	0.2222**
BD x Y	1	2285	8199	0.02798	0.0363	0.1024*
BS x Y	1	802	3719	0.00650	0.0148	0.0493
BD x BS x Y	1	1240	1699	0.04350	0.0259	0.0179
BD x M	1	857	924	0.00360	0.0001	0.0000
BS x M	1	2448	2467	0.00000	0.0004	0.0034
BD x BS x M	1	7	10550	0.00006	0.0288	0.1743*
Y x M	1	9962*	26090*	0.16227**	0.7236**	0.4939**
BD x Y x M	1	88*	1114	0.07815	0.0588*	0.0234
BS x Y x M	1	60	2356	0.00050	0.0426	0.0857
BD x BS x Y x M	1	1029	6403	0.00268	0.0524*	0.0675
Within	87	2472	4198	0.01770	0.0123	0.0311

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

TABLE 15. LEAST SQUARES MEANS FOR BREED GROUPS FOR POSTWEANING TRAITS OF HEIFERS

Breed group	Yearling weight kg	550-day weight kg	Average daily gain: Weaning to yearling kg	Average daily gain: Yearling to 550 days kg	Average daily gain: Weaning to 550 days kg
Angus	257.38	336.82	0.563	0.429	0.492
Angus-Charolais	279.50	370.97	0.605	0.494	0.547
Charolais-Angus	281.08	371.99	0.638	0.491	0.559
Charolais	286.23	378.96	0.617	0.501	0.555

TABLE 16. MEAN SQUARES FOR FEED EFFICIENCY

Source of variation	df	Feed efficiency: Weaning to yearling	Feed efficiency: Yearling to 550 days	Feed efficiency: Weaning to 550 days
Breed of sire (BS)	1	0.5560	0.1216	0.2574
Breed of dam (BD)	1	0.6536	0.4917	0.0236
Years (Y)	2	8.0221**	71.2602**	0.5170
BS x BD	1	1.9404	2.3103	0.0043
BD x Y	2	0.4385	2.7615	0.6495
BS x Y	2	0.0941	1.5311	0.5756
BD x BS x Y	2	0.2579	0.6205	0.3666
Within	81	0.6617	4.0040	0.8780

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

TABLE 17. LEAST SQUARES MEANS FOR BREED GROUPS FOR FEED EFFICIENCY

	Feed efficiency		
Breed group	Weaning to 550 days TDN per unit of gain	Weaning to yearling TDN per unit of gain	Yearling to 550 days TDN per unit of gain
Angus	7.91	6.44	9.48
Angus-Charolais	7.93	6.32	9.66
Charolais-Angus	8.00	6.30	9.89
Charolais	8.05	6.76	9.40

Steer Feedlot and Carcass Traits. One degree of freedom was used for the adjustment of traits affected by age or weight. Therefore, the error degrees of freedom were reduced from 139 to 138.

Breed of sire (sire), breed of dam, years and the interaction between breed of sire and breed of dam (table 18) all had significant ($P<.01$) effects on feedlot daily gain and slaughter weight of the steers.

Analyses of variance for all carcass traits are given in table 12. Main effects were significant ($P<.05$) or highly significant ($P<.01$) for most carcass traits. The only exceptions were breed of dam on dressing percentage and weight adjusted rib eye area.

Breed of sire x breed of dam interactions had significant ($P<.01$) effects on carcass traits associated with quantity, while no significant effects were observed on carcass traits associated with carcass quality. The effects of genotype and heterosis on carcass

TABLE 18. MEAN SQUARES FOR STEER FEEDLOT AND CARCASS TRAITS

Source of variation	df	Average daily gain weaning to slaughter	Age adjusted slaughter weight[a]	Dressing percent	Rib eye area	Fat thickness	Marbling
Breed of sire (BS)	1	2.0978**	254260**	15.762*	127.17**	0.62832**	8.4740**
Breed of dam (BD)	1	0.9732**	194043**	0.642	9.34*	0.27055**	8.8102**
Years (Y)	2	1.2829**	348237**	24.212**	7.70*	0.69045**	23.4937**
BS x BD	1	0.6969**	86210**	3.050	6.55	0.00090	0.5783
BS x Y	2	0.0124	2394	4.447	1.21	0.02479	1.7286
BD x Y	2	0.0139	1181	0.067	1.52	0.01098	5.6569**
BS x BD x Y	2	0.0607	10796	7.008	4.80	0.12000**	1.5251
Within	139	0.0626	7751	2.924	2.16	0.01880	0.7814

Source of variation	df	Cutability	Carcass quality grade	Age adjusted carcass weight[a]	Age adjusted retail cuts[a]	Weight adjusted retail cuts[a]	Weight adjusted rib eye area[a]
Breed of sire (BS)	1	0.01040**	14.353**	133050**	59984**	4751.8**	52.045**
Breed of dam (BD)	1	0.00100**	34.162**	89704**	29477**	429.4*	1.326
Years (Y)	2	0.00589**	53.255**	190113**	41544**	2574.5**	34.527**
BS x BD	1	0.00006	0.720	32447**	6726**	1.8	0.180
BS x Y	2	0.00001	2.783	328	202	5.9	0.715
BD x Y	2	0.00014	8.302**	812	223	76.4	1.368
BS x BD x Y	2	0.00068	5.308	4121	900	344.7*	1.432
Within	139	0.00020	1.495	2869	855	82.4	1.341

[a] One hundred thirty-eight degrees of freedom were allowed for error term because trait was adjusted by linear regression.

* $P < .05$.

** $P < .01$.

traits is discussed in greater detail when comparisons of specific crosses are presented.

The least squares means for steer feedlot and carcass traits are given in table 19.

Breed Group Comparisons

Birth Traits and Gestation Length. Heterosis (table 20) for birth weight was greater for heifer calves than for bull calves. Crossbred and straightbred bull calves were nearly equal for birth weight (35.27 kg for the mid-parent vs. 35.36 kg for the crossbreds) and crossbred heifers were 0.93 kg heavier than straightbred heifers, although the difference was nonsignificant. These results disagree with those of Pahnish et al. (1969) and Sagebiel et al. (1973) who reported that estimates of heterosis were higher for males than females of the Charolais and Angus cross. However, Brinks et al. (1967) reported a higher heterotic estimate for females than males when inbred lines of Herefords were crossed. The percentage heterosis estimates of 0.3% for males and 2.9% for heifers are small and consistent with the review by Pearson and McDowell (1968).

The crossbred steer and heifer calves by Angus dams were 0.42 and 1.22 kg larger than the crossbred calves produced by Charolais dams (table 13) which was also true in the studies by Pahnish et al. (1969) and Sagebiel et al. (1973). The first 2 years of this experiment Angus cows weighed approximately 56.8 kg less at parturition than did Charolais. The maternal influence of the Charolais and Angus on birth weight does not conform with results of other experiments in which the

TABLE 19. LEAST SQUARES MEANS FOR BREED GROUPS FOR CARCASS TRAITS

Breed group	Age adjusted carcass weight kg	Age adjusted slaughter weight kg	Age adjusted retail cuts kg	Weight adjusted retail cuts kg	Weight adjusted rib eye area cm^2	Rib eye area cm^2
Angus	251.94	414.86	125.26	141.55	79.08	73.08
Angus-Charolais	288.77	471.23	144.74	143.04	77.35	79.22
Charolais-Angus	293.78	476.13	150.37	146.74	86.49	88.19
Charolais	302.95	487.41	157.25	148.44	85.70	88.74

Breed group	Fat thickness cm	Average daily gain feedlot kg	Dressing percent	Marbling score	Cutability	Quality grade score
Angus	1.35	0.95	60.93	4.98	0.497	18.76
Angus-Charolais	1.14	1.09	61.36	4.35	0.501	17.63
Charolais-Angus	1.03	1.13	61.89	4.36	0.513	17.98
Charolais	0.79	1.14	61.73	3.98	0.520	17.13

TABLE 20. LEAST SQUARES MEANS, DIFFERENCES AND STANDARD ERRORS FOR BREED GROUP COMPARISONS OF BIRTH WEIGHT AND WIDTH AT SHOULDERS

	Birth weight				Width at shoulders			
	Males		Females		Males		Females	
Breed group comparison	kg	SE	kg	SE	cm	SE	cm	SE
Crossbred vs. straightbred								
AC and CA	35.36		33.45		19.52		18.72	
AA and CC	35.27		32.52		19.23		18.49	
Difference	0.09	1.437	0.93	1.355	0.29	0.521	0.23	0.497
Percent heterosis	0.26		2.86		1.51		1.24	
Angus vs. Charolais dams								
AA and CA	32.78		31.21		18.92		18.45	
AC and CC	37.85		34.77		19.83		18.76	
Difference	-5.07*	1.437	-3.56**	1.355	-.92**	0.521	-.31**	0.497
Angus vs. Charolais sire								
AA and AC	32.56		30.60		18.94		18.11	
CA and CC	38.06		35.38		19.81		19.10	
Difference	-5.50**	1.437	-4.78**	1.355	-.88**	0.521	-.99**	0.497
Angus-Char. vs. Char.-Angus								
AC	35.15		32.84		19.54		18.38	
CA	35.57		34.06		19.50		19.05	
Difference	-.42	1.026	-1.22	0.945	0.04	0.375	-.67*	0.351
Angus vs. Charolais								
AA	29.98		28.35		18.33		17.84	
CC	40.56		36.70		20.13		19.14	
Difference	-10.58**	1.005	-8.35**	0.972	-1.80**	0.361	-1.30**	0.352
Crossbred vs. Angus								
Cross	35.36		33.45		19.52		18.72	
AA	29.98		28.35		18.33		17.84	
Difference	-5.33**	1.702	5.10**	1.591	1.19**	0.586	0.88**	0.555
Crossbred vs. Charolais								
Cross	35.36		33.45		19.52		18.72	
Charolais	40.56		36.70		20.13		19.14	
Difference	-5.20**	1.803	-3.24**	1.741	-.61*	0.677	-.42	0.659

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

dams of the larger breed gave birth to heavier crossbred calves (Hilder and Fohrman, 1948; Donald et al., 1962; Touchberry and Bereskin, 1966a; Dickinson, 1960; McDowell et al., 1969). The Angus cows bred to the Charolais sire had a longer gestation period than the Charolais dam bred to the Angus sire, which may explain some of the reason for the differences in birth weight. Sagebiel et al. (1973) also reported a longer gestation length for crossbred calves from Angus dams than for crossbred calves from Charolais dams.

Angus calves, Angus-sired calves and calves born to Angus dams weighed significantly ($P < .01$) less at birth than their Charolais counterparts (table 20) and this is supported by data presented by Pahnish et al. (1969) and Sagebiel et al. (1973). The crossbred calves were intermediate for birth weight and were larger ($P < .01$) than Angus by 5.4 kg for bulls and 5.1 kg for heifers and smaller ($P < .01$) than Charolais by 5.2 kg for bulls and 3.2 kg for heifers, as might be expected when heterotic estimates are small. The combining effect of the two breeds was significantly ($P < .05$) larger than heterosis for birth weight (5.3 and 4.2 for combining effect vs. 0.09 and 0.93 for heterotic effect for males and females, respectively). The differences between the crossbreds and the Charolais that were observed for birth weight were not demonstrated at subsequent weaning, yearling, 550-day and slaughter weights.

Heterosis for the linear measurements (tables 20 and 21) of height at withers, width as shoulders and heart girth circumference were small and not significant for any measurement. The heterosis estimates were positive in all cases but did not exceed 1.5% for any

TABLE 21. LEAST SQUARES MEANS, DIFFERENCES AND STANDARD ERRORS FOR BREED GROUP COMPARISONS OF HEIGHT AT WITHERS AND HEART GIRTH CIRCUMFERENCE

	Height at withers				Heart girth circumference			
	Males		Females		Males		Females	
Breed group comparison	cm	SE	cm	SE	cm	SE	cm	SE
Crossbred vs. straightbred								
AC and CA	64.88		64.31		75.60		73.52	
AA and CC	64.59		63.74		74.86		72.83	
Difference	0.29	1.034	0.57	0.924	0.74	1.218	0.69	1.298
Percent heterosis	0.45		0.89		0.99		0.95	
Angus vs. Charolais dams								
AA and CA	63.19		62.31		73.96		72.48	
AC and CC	66.28		65.74		76.50		73.87	
Difference	-3.09**	1.034	-3.43**	0.924	-2.54**	1.218	-1.39*	1.298
Angus vs. Charolais sire								
AA and AC	62.13		61.70		73.68		71.58	
CA and CC	67.35		66.35		76.77		74.77	
Difference	-5.22**	1.034	-4.65**	0.924	-3.09**	1.218	-3.19**	1.298
Angus-Char. vs. Char.-Angus								
AC	63.82		63.70		75.32		72.62	
CA	65.95		64.92		75.88		74.43	
Difference	-2.13**	0.745	-1.22*	0.653	-.56	0.875	-1.81*	0.925
Angus vs. Charolais								
AA	60.44		59.69		72.04		70.54	
CC	68.75		67.78		77.67		75.12	
Difference	-8.31**	0.719	-8.09**	0.655	-5.63**	0.848	-4.58*	0.910
Crossbred vs. Angus								
Cross	64.88		64.31		75.60		73.52	
AA	60.44		59.69		72.04		70.54	
Difference	4.44**	1.166	4.62**	1.033	3.56**	1.512	2.98*	1.593
Crossbred vs. Charolais								
Cross	64.88		64.31		75.60		73.52	
Charolais	63.75		67.78		77.67		75.12	
Difference	-3.87**	1.345	-3.47**	1.225	-2.07**	1.456	-1.60*	1.577

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

of the three traits. As was true for birth weight, combining effects on height at withers, width at shoulders and heart girth circumference were several times larger than heterosis.

Heterosis had no significant effect on the length of gestation of either the female or male calves (table 22). The small nonsignificant effect on gestation is in agreement with studies by Touchberry and Bereskin (1966a) and Sagebiel et al. (1973).

Charolais bull and heifer calves had 4.7 and 3.8 days longer ($P<.01$) gestation periods than did the Angus calves and agrees with data published by Sagebiel et al. (1973). Differences between sires were significant ($P<.01$) for both male and female calves, while the differences between breed of dam were significant ($P<.05$) for the male calves only, indicating that the genotype of the fetus played an important role in determining the gestation length.

Combining effect had a significantly ($P<.01$) greater influence on length of gestation than did the small heterotic effect.

The combining effect was 2.35 days for males and 1.90 days for females, while heterotic effects were 0.29 days and 1.01 days. The inclusion of Charolais breeding increased the length of gestation of crossbred calves by 2.07 days for the bulls and 0.89 days for the heifers over the average gestation length of the Angus.

Weaning Weight and Preweaning Gain. Heterotic effects on preweaning gain and weaning weight were higher for steers than for heifers (table 23) and the differences between crossbred and mid-parent were significant ($P<.05$) only for the steers. These results are in close

TABLE 22. LEAST SQUARES MEANS, DIFFERENCES AND STANDARD ERRORS FOR BREED GROUP COMPARISONS OF GESTATION LENGTH

Breed group comparison	Gestation length			
	Males		Females	
	Days	SE	Days	SE
Crossbred *vs.* straightbred				
AC and CA	283.67		281.04	
AA and CC	283.96		282.05	
Difference	-.29	1.594	-1.01	1.823
Percent heterosis	-.10		-.36	
Angus *vs.* Charolais dams				
AA and CA	282.91		281.58	
AC and CC	284.71		281.51	
Difference	-1.80*	1.594	0.07	1.823
Angus *vs.* Charolais sire				
AA and AC	282.35		279.60	
CA and CC	285.27		283.49	
Difference	-2.92**	1.594	-3.89**	1.823
Angus-Char. *vs.* Char.-Angus				
AC	283.11		279.06	
CA	284.23		283.02	
Difference	-1.12	1.139	-3.96**	1.271
Angus *vs.* Charolais				
AA	281.60		280.15	
CC	286.31		283.96	
Difference	-4.71**	1.115	-3.81**	1.307
Crossbred *vs.* Angus				
Cross	283.67		281.04	
AA	281.60		280.15	
Difference	2.07*	1.889	0.89	2.140
Crossbred *vs.* Charolais				
Cross	283.67		281.04	
Charolais	286.31		283.96	
Difference	-2.64**	2.001	-2.92*	2.342

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

TABLE 23. LEAST SQUARES MEANS, DIFFERENCES AND STANDARD ERRORS FOR BREED GROUP COMPARISONS OF WEANING WEIGHT AND AVERAGE DAILY GAIN BIRTH TO WEANING

	Weaning weight				Average daily gain birth to weaning			
	Males		Females		Males		Females	
Breed group comparison	kg	SE	kg	SE	kg	SE	kg	SE
Crossbreed *vs.* straightbred								
AC and CA	187.85		180.65		0.744		0.718	
AA and CC	178.35		177.07		0.697		0.704	
Difference	9.50*	7.38	3.58	5.87	0.047**	0.034	0.014	0.028
Percent heterosis	5.33		2.02		6.74		1.99	
Angus *vs.* Charolais dams								
AA and CA	176.97		172.62		0.703		0.690	
AC and CC	189.23		185.09		0.738		0.721	
Difference	-12.26**	7.38	-12.47**	5.87	-.035*	0.034	-.041**	0.028
Angus *vs.* Charolais sire								
AA and AC	181.62		174.74		0.727		0.703	
CA and CC	184.59		182.97		0.714		0.718	
Difference	-2.97	7.38	-8.23**	5.87	0.013	0.034	-.015	0.028
Angus-Char. *vs.* Char.-Angus								
AC	192.50		182.77		0.767		0.731	
CA	183.21		178.53		0.720		0.704	
Difference	9.29	5.26	4.24	4.08	0.047	0.024	0.027	0.019
Angus *vs.* Charolais								
AA	170.73		166.72		0.686		0.675	
CC	185.97		187.42		0.708		0.732	
Difference	-15.24**	5.18	-20.70**	4.23	-.022	0.024	-.057**	0.020
Crossbred *vs.* Angus								
Cross	187.85		180.65		0.744		0.718	
AA	170.73		166.72		0.686		0.675	
Difference	17.12**	8.72	13.93**	6.85	0.058**	0.041	0.043**	0.032
Crossbred *vs.* Charolais								
Cross	187.85		180.65		0.744		0.718	
Charolais	185.97		187.42		0.708		0.732	
Difference	1.88	9.31	-6.77	7.61	-.036	0.044	-.014	0.036

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

agreement with a study by Pahnish et al. (1969) involving Angus, Hereford and Charolais, which found higher heterosis for preweaning traits of steers than of heifers and the heterosis to be significant ($P<.01$) only for steers. Brinks et al. (1967) and Gregory et al. (1966b) reported higher heterotic effects for preweaning gain and weaning weight of heifer calves than for preweaning gain and weaning weight of bull calves.

The percentage heterosis estimated for weaning weight of the steer calves (5.3%) is above the weighted average heterosis calculated by Warwick (1968) of 4.9% from 13 experiments. The percentage heterosis for the heifers (2.0%) is below average.

There was no significant difference between reciprocal crosses (table 13), although the crossbred steer and heifer calves weaned by Charolais dams were 9.2 and 4.2 kg heavier than crossbred steer and heifer calves weaned by Angus dams. Pahnish et al. (1969) found reciprocally crossed steer calves from Charolais dams were 19.7 kg ($P<.05$) larger than steer calves from Angus dams, although the heifers of the two reciprocal crosses were nearly equal in weight. This indicates that there may be differences in maternal ability between the two breeds and the Charolais may have an advantage.

A significant ($P<.01$) maternal advantage in weaning weight was found in favor of the Charolais dams when all dams of each breed were compared. The Charolais dams weaned 12.26 kg heavier steer calves and 12.47 kg heavier heifer calves than Angus dams.

The paternal difference in weaning weight was smaller than the maternal difference and significant ($P<.01$) for the weaning weight of only the females. Charolais-sired steer and heifer calves excelled Angus-sired steer and heifer calves by 2.97 and 8.23 kg, respectively. This indicates a growth advantage in favor of the Charolais-sired calves. These results agree with studies by Damon et al. (1959) and Hidiroglou et al. (1966) which found Charolais-sired calves to be larger than Angus-sired calves at weaning.

A comparison of the breed groups reveals that the Charolais were larger than Angus at weaning (table 15). The Charolais steer calves were 15.2 kg ($P<.01$) and the heifer calves were 20.7 kg ($P<.01$) heavier than Angus. The crossbreds exceeded the Angus in weaning weight by 17.12 kg and 13.93 kg ($P<.01$) and in average daily gain from birth to weaning by 0.058 and 0.043 kg ($P<.01$) for steers and heifers. However, differences between the crossbreds and Charolais for weaning weight and preweaning gain were not significant. The crossbred and Charolais steers were nearly equal in weight at weaning and the Charolais heifers 6.77 kg heavier than crossbred heifers at weaning. This suggests that the crossbred calf more closely resembled the Charolais than the Angus calf in rate of gain from birth to weaning and that the differences between combining and heterotic effects were not significant (7.64 kg and 10.35 kg for steers and heifers for combining effect vs. 9.50 and 3.58 for steers and heifers for heterosis effect), although the heterotic effect exceeded the combining effect for steers and the combining effects exceeded the heterotic effect for heifers.

Postweaning Growth of Heifers. Heterotic effects on postweaning growth traits (table 24) increased with age and were greatest at the oldest weight studied. The percentage estimate of heterosis for average daily gain from 205 days to 365 days was 5.2% and increased to 6.1% for the period from 365 days to 550 days. Crossbreds weighed 8.5 kg and 13.6 kg more than straightbreds at yearling weight and 550-day weight and heterotic estimates of 3.1% and 3.8% were obtained for yearling weight and 550-day weight. The heterotic effects were significant ($P<.05$) for average daily gain from weaning to 365 days, average daily gain from weaning to 550 days, yearling weight and 550-day weight but not for average daily gain from 365 days to 550 days. These results parallel those of Gregory et al. (1966a) who found no significant heterosis for growth rate from 396 to 500 days. Pahnish et al. (1971) reported small nonsignificant heterotic estimates of 2.0% for 365-day weight and 1.1% for 547-day weight of Charolais and Angus crosses raised for replacement heifers.

The values for heterosis for yearling and 550-day weights indicate that heterosis for body weight did not decline after 12 months as reported by Touchberry and Bereskin (1966b), Gregory et al. (1966a) and Pahnish et al. (1971) but increased from yearling to 550-day weight as it did from weaning weight to yearling weight. These results do agree with data reported by McDowell et al. (1969) in which heterosis increased from 2.8% at 12 months to 4.6% at 18 months. Vogt et al.

TABLE 24. LEAST SQUARES MEANS, DIFFERENCES AND STANDARD ERRORS FOR BREED GROUP COMPARISONS OF YEARLING WEIGHT, 550-DAY WEIGHT AND AVERAGE DAILY GAIN WEANING TO YEARLING, YEARLING TO 550 DAYS AND WEANING TO 550 DAYS FOR HEIFERS

	Yearling weight		550-day weight		Average daily gain					
					Weaning to yearling		Yearling to 550 days		Weaning to 550 days	
Breed group comparison	kg	SE	kg	SE	kg	SE	kg	SE	kg	SE
Crossbred vs. straightbred										
AC and CA	280.29		371.48		0.621		0.493		0.553	
AA and CC	271.80		357.89		0.590		0.465		0.524	
Difference	8.49*	7.455	13.59*	11.739	0.031*	0.025	0.028	0.039	0.029*	0.028
Percent heterosis	3.12		3.80		5.25		6.02		5.53	
Angus vs. Charolais dams										
AA and CA	269.23		354.41		0.601		0.460		0.526	
AC and CC	282.86		374.97		0.611		0.498		0.551	
Difference	-13.63**	7.455	-20.56**	11.739	-.010	0.025	-.038*	0.039	-.025*	0.028
Angus vs. Charolais sire										
AA and AC	268.44		353.89		0.584		0.462		0.520	
CA and CC	283.65		375.48		0.628		0.496		0.557	
Difference	-15.21**	7.455	-21.59**	11.739	-.044**	0.025	-.034*	0.039	-.037**	0.028
Angus-Char. vs. Char.-Angus										
AC	279.50		370.97		0.605		0.494		0.547	
CA	281.08		371.99		0.638		0.491		0.559	
Difference	-1.58	5.220	-1.02	8.220	-.033*	0.018	0.003	0.028	-.012	0.020
Angus vs. Charolais										
AA	257.38		336.82		0.563		0.429		0.492	
CC	286.23		378.96		0.617		0.501		0.555	
Difference	-28.85**	5.323	-42.14**	8.382	-.054**	0.018	-.072*	0.028	-.063**	0.020
Crossbred vs. Angus										
Cross	280.29		371.48		0.621		0.493		0.553	
AA	257.38		336.82		0.563		0.429		0.492	
Difference	22.91**	8.677	34.66*	13.660	0.058*	0.029	0.064*	0.046	0.061*	0.033
Crossbred vs. Charolais										
Cross	280.29		371.48		0.621		0.493		0.553	
Charolais	286.23		378.96		0.617		0.501		0.555	
Difference	-5.94	9.619	-7.48	15.147	0.004	0.033	-.008	0.051	-.002	0.036

* P<.05.

** P<.01.

(1967) reported a significant ($P < .05$) advantage for crossbreds over straightbreds up to approximately 18 months of age in slaughter steers and heifers.

The Charolais excelled Angus in average daily gain for each period studied (average daily gain weaning to yearling, 0.617 kg *vs*. 0.563 kg; average daily gain yearling to 550 days, 0.505 kg *vs*. 0.429 kg; average daily gain weaning to 550 days, 0.555 kg *vs*. 0.492 kg) and exceeded Angus in 365-day and 550-day weights by 28.8 kg and 42.1 kg (table 17). The differences were significant ($P < .01$) for each trait.

There were no significant differences for any of the postweaning traits except average daily gain weaning to yearling ($P < .05$) between the reciprocal crosses and at 550 days the reciprocal crosses differed in weight by only 1 kilogram. Jain *et al*. (1971) found no significant differences between reciprocal crosses in postweaning traits, although Pahnish *et al*. (1971) reported heifers by Charolais sires and Angus dams excelled the reciprocal cross in average daily gain from 190 to 361 days and from 190 to 547 days. This study would, in part, support the findings of Pahnish *et al*. (1971).

The crossbreds had significantly ($P < .01$) larger 365-day and 550-day weights and significantly ($P < .01$) greater average daily gains than the Angus, but no significant differences were found between the crossbred and Charolais for the same traits. The combining effects of 14.42 kg and 21.07 kg and heterotic effects of 8.49 kg and 13.59 kg for yearling and 550-day weights were not significantly different. As was true for weaning weight, postweaning heterosis resulted in larger differences between Angus, the smallest breed group and the crossbreds than between Charolais, the largest breed group and the crossbreds.

Feed Efficiency of Heifers. All linear contrasts (table 25) were nonsignificant for TDN required per unit of gain except for the comparison of crossbreds and Charolais from weaning to yearling. Crossbreds required 6.31 kg of TDN per kg of gain compared to 6.75 kg of TDN per kg of gain for the Charolais. There was essentially no difference in average daily gain between the crossbreds and Charolais from weaning to yearling and the 6.00 kg advantage of the Charolais at the 365-day weight was not significantly different from the crossbreds. The difference in feed efficiency between crossbreds and Charolais cannot be explained by the high genetic correlation between feed efficiency and average daily gain (Koch et al., 1963).

Heterotic effects on feed efficiency approached significance ($P < .05$) from weaning to 365 days and the estimated percentage heterosis was 4.6% in favor of the more efficient crossbreds. The data of Gregory et al. (1966b) showed no significant difference between the crossbreds and straightbreds in TDN required per unit of gain for feedlot steers, although the heterosis value was the largest for the 84-day period immediately following weaning. The crossbreds required more feed per unit of gain than straightbreds for the period from 365 days to 550 days, although the differences were nonsignificant. These results are also similar to the results of Gregory et al. (1966b) which revealed crossbreds to require more TDN per unit of gain the final 84 days of the feeding period. Although nonsignificant, t values

TABLE 25. LEAST SQUARES MEANS, DIFFERENCES AND STANDARD ERRORS FOR BREED GROUP COMPARISONS OF FEED EFFICIENCY FOR HEIFERS

Breed group comparison	Feed efficiency					
	Weaning to 550 days		Weaning to yearling		Yearling to 550 days	
	TDN per unit of gain	SE	TDN per unit of gain	SE	TDN per unit of gain	SE
Crossbred vs. straightbred						
AC and CA	7.97		6.31		9.77	
AA and CC	7.98		6.60		9.44	
Difference	-.01	0.413	-.29	0.336	0.33	0.882
Percent heterosis	-.01		-4.39		+3.50	
Angus vs. Charolais dams						
AA and CA	7.96		6.37		9.68	
AC and CC	7.99		6.54		9.53	
Difference	-.03	0.413	-.17	0.336	0.15	0.882
Angus vs. Charolais sire						
AA and AC	7.92		6.38		9.57	
CA and CC	8.03		6.53		9.65	
Difference	-.11	0.413	-.15	0.336	-.08	0.882
Angus-Char. vs. Char.-Angus						
AC	7.93		6.32		9.66	
CA	8.00		6.30		9.89	
Difference	-.07	0.295	0.02	0.241	-.23	0.630
Angus vs. Charolais						
AA	7.91		6.44		9.48	
CC	8.05		6.76		9.40	
Difference	-.14	0.289	-.32	0.235	0.08	0.617
Crossbred vs. Angus						
Cross	7.97		6.31		9.77	
AA	7.91		6.44		9.48	
Difference	0.06	0.488	-.13	0.404	0.29	0.043
Crossbred vs. Charolais						
Cross	7.97		6.31		9.77	
Charolais	8.05		6.76		9.40	
Difference	-.08	0.519	-.45*	0.416	0.37	1.108

* P <.05.

for all comparisons were larger for the period from weaning to yearling than for the period from yearling to 550 days, indicating that, if any difference in feed efficiency exists, it will likely be exhibited at a young age.

These results are in general agreement with experiments by Phillips et al. (1942), Klosterman et al. (1968) and Vogt et al. (1967) which all showed no statistically significant differences between the crossbreds and straightbreds for feed required per unit of gain, though all found a slight advantage in favor of the crossbreds. Warwick (1968) reported a weighted average of 0.7% advantage for the crossbreds in six time-constant trials which were summarized.

Feedlot Performance of Steers. The crossbreds gained 0.07 kg per day faster and had 22.6 kg larger age adjusted slaughter weights than the average of the straightbreds (table 26). The differences were both significant ($P<.01$) and heterotic estimates of 5.00% and 6.73% were obtained for average daily gain and slaughter weight, respectively. This advantage in favor of the crossbreds in feedlot performance agrees with studies by Gregory et al. (1966b), Damon et al. (1961), Lasley et al. (1973), Phillips et al. (1942) and Vogt et al. (1967), all of which showed a consistent advantage in average daily gain and slaughter weight for the crossbreds. The percentage heterosis estimates of this study are higher than the 2 to 4% suggested by Warwick (1968).

Charolais were 72.5 kg ($P<.01$) heavier at slaughter and gained 0.19 kg per day ($P<.01$) faster than did the Angus. In

TABLE 26. LEAST SQUARES MEANS, DIFFERENCES AND STANDARD ERRORS FOR BREED GROUP COMPARISONS OF AGE ADJUSTED SLAUGHTER WEIGHT AND AVERAGE DAILY GAIN FEEDLOT FOR STEERS

Breed group comparison	Age adjusted slaughter weight		Average daily gain feedlot	
	kg	SE	kg	SE
Crossbred vs. straightbred				
AC and CA	473.68		1.11	
AA and CC	451.13		1.04	
Difference	22.55**	13.47	0.07**	0.039
Percent heterosis	5.00		6.73	
Angus vs. Charolais dams				
AA and CA	445.50		1.04	
AC and CC	479.32		1.11	
Difference	-33.82**	13.47	-.07**	0.039
Angus vs. Charolais sire				
AA and AC	443.05		1.02	
CA and CC	481.77		1.13	
Difference	-38.72**	13.47	-.11**	0.039
Angus-Char. vs. Char.-Angus				
AC	471.23		1.09	
CA	476.13		1.13	
Difference	-4.90	9.50	-.04	0.027
Angus vs. Charolais				
AA	414.86		0.95	
CC	487.41		1.14	
Difference	-72.55**	9.55	-.19**	0.027
Crossbred vs. Angus				
Cross	473.68		1.11	
AA	414.86		0.95	
Difference	58.82**	15.78	0.16**	0.045
Crossbred vs. Charolais				
Cross	473.68		1.11	
Charolais	487.41		1.14	
Difference	-13.73	17.22	-.03	0.049

** $P<.01$.

experiments which included Charolais, the Charolais have excelled the British breeds (Angus, Hereford and Shorthorn) in growth rate in the feedlot (Damon et al., 1960; Carroll and Rollins, 1965; Lasley et al., 1973). The difference between combining effect and heterotic effect on slaughter weight was nonsignificant, although the combining effect was approximately one and one-half times larger than the heterotic effect (36.21 kg vs. 22.55 kg) as was true of the postweaning traits of the heifers.

Differences in reciprocal crosses were small (4.90 kg for slaughter weight and 0.04 kg for average daily gain) and nonsignificant which indicates maternal influences on slaughter weight and feedlot performance are negligible. This agrees with data reported by Lasley et al. (1973), though Gregory et al. (1966b) found significant ($P < .05$) differences between reciprocal crosses in two of the three crosses studied.

Carcass Characteristics. Breed group comparisons for carcass traits are given in tables 27 and 28. Age adjusted carcass weight and age adjusted weight of retail cuts were the only carcass traits to demonstrate significant ($P < .01$) heterotic effects. The crossbreds produced 13.83 kg larger carcasses and 6.3 more kg of retail cuts than the mid-parent when all were adjusted to the overall mean of 452 days of age at slaughter. All other carcass traits studied demonstrated no significant heterotic effect, although the percentage estimate of heterosis for rib eye area was 3.5%. Significant heterotic effects have been reported for carcass traits associated with growth such as

TABLE 27. LEAST SQUARES MEANS, DIFFERENCES AND STANDARD ERRORS FOR BREED GROUP COMPARISONS OF AGE ADJUSTED CARCASS WEIGHT AND RETAIL CUTS, WEIGHT ADJUSTED RETAIL CUTS AND RIB EYE AREA AND RIB EYE AREA

	Age adjusted				Weight adjusted					
	Carcass weight		Retail cuts		Retail cuts		Rib eye area		Rib eye area	
Breed group comparisons	kg	SE	kg	SE	kg	SE	cm^2	SE	cm^2	SE
Crossbred vs. straightbred										
AC and CA	291.28		147.56		144.89		81.92		83.71	
AA and CC	277.45		141.26		144.99		82.39		80.91	
Difference	13.83**	8.20	6.30**	4.48	-.10	1.39	-.47	2.52	2.80	3.21
Percent heterosis	4.98		4.46		-.07		-.60		3.46	
Angus vs. Charolais dams										
AA and CA	272.85		137.82		144.15		82.79		80.64	
AC and CC	295.86		151.00		145.74		81.53		83.98	
Difference	-23.00**	8.20	-13.18**	4.48	-1.59*	1.39	1.26	2.52	-3.34*	3.21
Angus vs. Charolais sire										
AA and AC	270.36		135.00		142.30		78.22		76.15	
CA and CC	298.37		153.81		147.59		86.10		88.47	
Difference	-28.01**	8.20	-18.81**	4.48	-5.29**	1.39	-7.88**	2.52	-12.32**	3.21
Angus-Char. vs. Char.-Angus										
AC	288.77		144.74		143.04		77.35		79.22	
CA	293.78		150.37		146.74		86.49		88.19	
Difference	-5.01	5.78	-5.63	3.16	-3.70**	0.98	-9.14**	1.77	-8.97**	2.26
Angus vs. Charolais										
AA	251.94		125.26		141.55		79.08		73.08	
CC	302.95		157.25		148.43		85.70		88.74	
Difference	-51.01**	23.14	-31.99**	3.17	-6.88**	0.98	-6.62**	1.79	-15.66**	2.27
Crossbred vs. Angus										
Cross	291.28		147.56		144.89		81.92		83.71	
AA	251.94		125.26		141.55		79.08		73.08	
Difference	39.34**	9.60	22.30**	5.24	3.34**	1.63	2.84	2.95	10.63**	3.76
Crossbred vs. Charolais										
Cross	291.28		147.56		144.89		81.92		83.71	
Charolais	302.95		157.25		148.43		85.70		88.74	
Difference	-11.67*	10.47	-9.69**	5.72	-3.54**	1.77	-3.78*	3.22	-5.03*	4.10

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

TABLE 28. LEAST SQUARES MEANS, DIFFERENCES AND STANDARD ERRORS FOR BREED GROUP COMPARISONS OF FAT THICKNESS, DRESSING PERCENT, MARBLING, CUTABILITY AND QUALITY GRADE

Breed group comparison	Fat thickness cm	SE	Dressing percent %	SE	Marbling score	SE	Cutability %	SE	Quality grade score	SE
Crossbred vs. straightbred										
AC and CA	1.09		61.63		4.35		0.507		17.80	
AA and CC	1.07		61.33		4.48		0.509		17.95	
Difference	0.02	0.117	0.30	0.579	-.13	0.299	-.002	0.005	-.15	0.414
Percent heterosis	1.87		0.49		-2.90		-.39		-.84	
Angus vs. Charolais dams										
AA and CA	1.19		61.41		4.67		0.505		18.37	
AC and CC	0.97		61.55		4.17		0.511		17.38	
Difference	0.22**	0.117	-.14	0.579	0.50**	0.299	-.006*	0.005	0.99**	0.414
Angus vs. Charolais sire										
AA and AC	1.25		61.14		4.66		0.499		18.20	
CA and CC	0.91		61.81		4.17		0.517		17.55	
Difference	0.34**	0.117	-.67*	0.579	0.49**	0.299	-.018**	0.005	0.65**	0.414
Angus-Char. vs. Char.-Angus										
AC	1.14		61.36		4.35		0.501		17.63	
CA	1.03		61.89		4.36		0.513		17.98	
Difference	0.11	0.084	-.53	0.408	-.01	0.211	-.012**	0.003	-.35	0.292
Angus vs. Charolais										
AA	1.35		60.93		4.98		0.497		18.76	
CC	0.79		61.73		3.98		0.520		17.13	
Difference	0.56**	0.084	-.80	0.410	1.00**	0.212	-.023**	0.003	1.63**	0.293
Crossbred vs. Angus										
Cross	1.09		61.63		4.35		0.507		17.80	
AA	1.35		60.93		4.98		0.497		18.76	
Difference	-.26**	0.137	0.70*	0.678	-.63**	0.351	0.010**	0.006	-.96**	0.485
Crossbred vs. Charolais										
Cross	1.09		61.63		4.35		0.507		17.80	
Charolais	0.79		61.73		3.98		0.520		17.13	
Difference	0.30**	0.150	-.10	0.740	0.37	0.382	-.013**	0.006	0.67*	0.529

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

carcass weight, rib eye area (Gregory et al., 1966c; Hedrick et al., 1970; Gaines et al., 1967) and trimmed retail cuts (Gregory et al., 1966c; Hedrick et al., 1970; Klosterman et al., 1968). The results of this study indicate no heterosis for dressing percentage, marbling score, carcass quality grade or cutability. Other studies have indicated that heterosis on carcass traits not directly related to growth such as marbling, carcass grade (Gregory et al., 1966c; Gaines et al., 1967; Kincaid, 1962; Carroll and Rollins, 1965; Lasley et al., 1971) and cutability (Gregory et al., 1966c; Gaines et al., 1967) were negligible. Urick et al. (1974) fed Angus, Hereford, Charolais and reciprocal crosses to a constant weight and reported heterosis was small and not important for both quantity and quality traits and significant only for carcass weight per day of age.

No significant heterosis was found when the weight of the retail cuts and rib eye area were adjusted to the mean carcass weight, indicating that heterosis had little effect on the composition of the carcass. This is in agreement with results reported by Gregory et al. (1966c).

Differences between reciprocal crosses were significant ($P < .05$) for cutability, rib eye area, weight adjusted rib eye area and weight adjusted retail cuts, in which cases the steers of Angus sires and Charolais dams exceeded steers of Charolais sires and Angus dams. Hedrick et al. (1970) and Lasley et al. (1971) found no significant differences between reciprocal crosses of the Charolais and Angus breeds.

Charolais and Angus were significantly ($P<.01$) different in all traits except dressing percentage. Angus carcasses had greater fat thickness, a higher marbling score and higher carcass quality grade, while Charolais were higher in traits associated with quantity, carcass weight, weight of retail cuts, rib eye area and cutability. This supports other reports which indicate that Charolais carcasses have lower quality grades, less fat and larger rib eye areas (Damon et al., 1960; Urick et al., 1974) and higher percent cutability and more trimmed retail cuts (Urick et al., 1974) than Angus. Hedrick et al. (1970) reported that the Charolais produced larger carcasses, more pounds of retail cuts and larger rib eye areas than did Angus. Lasley et al. (1971) comparing the same Charolais and Angus reported higher marbling and carcass quality scores and greater fat thickness for Angus.

Crossbred carcasses were intermediate between the two breeds except for those traits associated with weight per day of age, in which case the crossbreds more closely resembled the Charolais. The crossbred carcasses graded significantly lower ($P<.05$) than the Angus carcasses by nearly one-third of a grade (17.80 vs. 18.76) and significantly higher ($P<.05$) than the Charolais, although the difference was less than a third of a grade (17.80 vs. 17.13). However, the crossbreds produced 22.30 more kg of retail cuts ($P<.01$) than did the straightbred Angus and 9.69 less kg of retail cuts ($P<.01$) than did the Charolais. This complementary influence of quality and quantity carcass characteristics may be economically advantageous in specific instances.

Discussion

Growth Rate. Growth rate was affected by heterotic and combining effects for all growth traits studied. Combining effects were greater than heterotic effects for all of the growth traits except average daily gain from birth to weaning and weaning weight of the steers. Thus, the crossbred individuals were intermediate for all growth traits except the two previously mentioned traits.

In this study combining effects played a greater role in increasing growth rate of the crossbreds over the inferior parent than heterotic effects. This is supported by studies by Pahnish et al. (1969, 1971) and Jain et al. (1971) which showed that, when Charolais, the breed with the fastest growth rate, were crossed with Hereford or Angus, breeds with slower growth rates, the crossbred was intermediate for most growth traits. The review of literature also shows that, when breeds nearly equal in growth rate and mature weights (Hereford, Angus and Shorthorn) were crossed, the crossbreds generally excelled both of the parents in growth rate (Pahnish et al., 1969, 1971; Jain et al., 1971; Gaines et al., 1966; Vogt et al., 1966; Gregory et al., 1965, 1966a,b). Thus, it appears that, as differences between two breeds crossed increase, the combining effects become more important than the heterotic effects.

Further evidence of the importance of combining effect when two breeds differ greatly in growth rate is indicated by the negative correlation between combining effects and heterotic effects. Indeed, simple correlations of combining effects and heterotic effects calculated from 25 crosses for birth weight, 23 crosses for weaning weight and 23 crosses for yearling weight (tables 29, 30 and 31) were -.41 for birth weight, -.36 for weaning weight and -.37 for yearling weight. The linear regressions of heterotic effect on combining effect were -.33 for birth weight, -.13 for weaning weight and -.33 for yearling weight. Thus, it appears that as differences for growth traits between two breeds crossed increase the heterotic effects on growth decrease.

The growth rate of the Charolais exceeded the crossbreds and the Angus in this study. Thus, crossbreeding did not produce enough hybrid vigor such that the crossbred animal was able to excel its superior parent and crossbreeding solely to obtain increased growth rate may not be justified when Charolais and Angus breeds are crossed. However, the crossbred did approach the Charolais in growth rate and this, in combination with increased reproduction and livability, would make the crossbred more economically desirable.

Feed Efficiency. No significant heterotic or combining effects were found for feed efficiency nor was there any significant difference between the size of the heterotic effect and the combining effect. The heifers in this study were raised for maternal reproduction and not for slaughter. Therefore, they were not fed for maximum growth. Under these conditions this study found no difference between the breeds nor between the crossbreds and the straightbreds for feed required per unit of gain. Thus, neither breed nor heterosis had any significant effect on feed efficiency of growing replacement heifers.

TABLE 29. STRAIGHTBRED, CROSSBRED AND MID-PARENT MEANS FOR BIRTH WEIGHT AND ACTUAL COMBINING AND HETEROTIC EFFECTS

Source[a]	Sex	Straightbred parents kg		Mid-parent kg	Crossbred average kg	Combining effect kg	Heterotic effect kg[b]
		Angus	Hereford				
1		29.4	35.3	32.4	33.5	3.0	1.1nt
2	M	30.2	34.6	32.4	33.2	2.2	0.8nt
2	F	27.9	32.3	30.1	30.9	2.2	0.8nt
3		28.6	32.9	30.8	31.4	2.2	0.6nt
4	M	32.0	35.3	33.6	35.7	1.6	2.1nt
4	F	31.6	34.6	33.1	33.2	1.5	0.1nt
		Hereford	Shorthorn				
1		35.3	32.7	34.0	36.1	1.3	2.1*
3		32.9	32.5	32.7	34.5	0.2	1.8nt
		Angus	Shorthorn				
1		29.4	32.7	31.0	31.5	1.6	0.5nt
3		28.6	32.5	30.6	31.1	2.0	0.5nt
		Hereford	Charolais				
2	M	34.5	41.4	38.0	39.0	3.4	1.0nt
2	F	32.3	39.6	35.9	35.7	3.6	-.2nt
4	M	35.3	42.3	38.8	40.6	3.5	1.8nt
4	F	34.6	39.7	37.2	43.2	2.6	6.0nt
5		31.8	37.8	34.8	35.1	3.0	0.3nt
		Angus	Charolais				
2	M	30.2	41.4	35.8	36.1	5.6	0.3nt
2	F	27.9	39.6	33.7	34.1	5.8	0.4nt
4	M	32.0	42.3	37.2	38.1	5.1	0.9nt
4	F	27.9	39.6	33.7	34.1	5.8	0.4nt
8	M	30.0	40.5	35.3	35.4	5.3	0.1**
8	F	28.4	36.7	32.5	33.4	4.2	0.9**
		Ayrshire	Friesian				
6	F	33.2	39.5	36.4	36.5	3.1	0.1nt
		Ayrshire	Jersey				
6	F	33.2	22.5	27.8	31.0	5.4	3.2nt
		Friesian	Jersey				
6	F	39.5	22.5	31.0	28.1	8.5	-2.9nt
		Hereford	Highlanders				
7		32.1	28.9	30.5	32.6	1.6	2.1nt

[a] Source code: 1, Gregory *et al.*, 1965; 2, Sagebiel *et al.*, 1973; 3, Gaines *et al.*, 1966; 4, Pahnish *et al.*, 1969; 5, Klosterman *et al.*, 1968; 6, Donald *et al.*, 1962; 7, Lawson and Peters, 1964; and 8, Concurrent study.

[b] Test of significant differences between combining and heterotic effects: nt, not tested; ns, not significant; and * $P < .05$, ** $P < .01$.

TABLE 30. STRAIGHTBRED, CROSSBRED AND MID-PARENT MEANS FOR WEANING WEIGHT AND ACTUAL COMBINING AND HETEROTIC EFFECTS

Source[a]	Sex	Straightbred parents kg		Mid-parent kg	Crossbred average kg	Combining effect kg	Heterotic effect kg[b]
		Hereford	Angus				
1		190.1	190.4	190.2	200.1	0.2	9.9**
2		175.7	188.0	181.8	188.9	6.2	7.1nt
3	M	208.2	199.2	203.7	216.8	4.5	13.1nt
3	F	198.0	202.5	200.2	205.4	2.3	5.2nt
8	M	172.0	171.0	171.5	180.4	0.5	8.9nt
8	F	157.2	163.2	160.2	170.1	3.0	9.9nt
		Hereford	Shorthorn				
1		190.1	188.8	189.4	200.3	0.6	10.9**
2		175.7	190.2	183.0	187.0	7.2	4.0nt
		Angus	Shorthorn				
1		190.4	188.8	189.6	195.4	0.8	5.8*
2		188.0	190.2	189.1	200.2	1.1	11.1nt
		Hereford	Charolais				
3	M	199.2	253.4	226.3	234.3	27.1	8.0nt
3	F	198.0	239.9	219.0	221.7	21.0	2.7nt
4		235.2	292.8	264.0	273.3	28.8	9.3nt
8	M	172.0	201.9	187.0	190.9	14.9	3.9nt
8	F	157.2	188.9	173.0	174.8	15.6	1.8nt
		Angus	Charolais				
3	M	208.2	253.4	230.8	234.6	22.6	3.6nt
3	F	202.5	239.9	221.2	224.9	18.7	3.7nt
5	M	170.7	186.0	178.3	187.8	7.6	9.5ns
5	F	166.7	187.4	177.1	180.6	10.4	3.6ns
8	M	171.0	201.9	186.4	191.0	15.4	4.6nt
8	F	163.2	188.9	176.0	183.5	12.8	7.5nt
		Hereford	Highlanders				
6		163.4	153.9	158.6	173.2	4.8	14.6nt
		Holstein	Guernsey				
7	F	171.9	136.5	154.2	162.5	17.7	8.5nt

[a] Source code: 1, Gregory et al., 1965; 2, Gaines et al., 1966; 3, Pahnish et al., 1969; 4, Klosterman et al., 1968; 5, Concurrent study; 6, Lawson and Peters, 1964; 7, Touchberry and Bereskin, 1966b; and 8, Sagebiel et al., 1974.

[b] Test of significant differences between combining and heterotic effects: nt, not tested; ns, not significant; and * P<.05, ** P<.01.

TABLE 31. STRAIGHTBRED, CROSSBRED AND MID-PARENT MEANS FOR YEARLING WEIGHT AND ACTUAL COMBINING AND HETEROTIC EFFECTS

Source[a]	Sex	Straightbred parents kg		Mid-parent kg	Crossbred average kg	Combining effect kg	Heterotic effect kg[b]
		Hereford	Angus				
1	F	239.9	252.5	246.2	252.4	6.3	6.2nt
2	F	338.4	327.6	333.0	363.1	5.4	30.1nt
3	F	208.2	216.4	212.3	233.2	4.1	20.9**
3	F	287.6	270.3	279.0	298.0	8.6	19.0ns
4	M	332.0	324.3	328.4	343.8	3.8	15.4*
5		346.2	350.2	348.2	371.2	2.0	23.0nt
		Charolais	Angus				
1	F	296.4	252.5	274.4	279.8	22.0	5.4nt
2	F	378.7	327.6	353.2	374.0	25.6	20.8nt
6	F	286.2	257.4	271.8	280.3	14.4	8.5ns
		Charolais	Hereford				
1	F	296.4	239.9	268.2	272.3	28.2	4.1nt
2	F	378.7	338.4	358.6	387.8	20.2	29.2nt
		Angus	Shorthorn				
3	F	216.4	205.9	210.9	229.5	5.2	18.6**
3	F	270.3	273.5	272.2	288.5	1.6	16.3**
4	M	324.3	333.8	329.3	332.0	4.8	2.7ns
5		350.2	360.2	355.2	374.2	5.0	19.0nt
		Hereford	Shorthorn				
3	F	208.2	205.9	206.8	232.2	1.2	25.4**
3	F	287.6	273.5	280.3	302.1	7.0	21.8*
4	M	332.0	333.8	332.9	354.3	0.9	21.4**
5		346.2	360.2	353.2	367.2	7.0	14.0nt
		Holstein	Guernsey				
7	F	309.7	249.7	279.7	295.9	30.0	16.2nt
		Ayrshire	Holstein				
8	F	269.0	322.0	295.5	297.5	26.5	1.0nt
		Ayrshire	Brown Swiss				
8	F	269.0	294.0	281.5	292.5	12.5	11.5nt
		Brown Swiss	Holstein				
8	F	294.0	322.0	308.0	313.5	14.0	5.0nt

[a] Source code: 1, Pahnish *et al.*, 1971; 2, Jain *et al.*, 1971; 3, Gregory *et al.*, 1966a; 4, Gregory *et al.*, 1966b; 5, Vogt *et al.*, 1967; 6, Concurrent study; 7, Touchberry and Bereskin, 1966b; and 8, McDowell *et al.*, 1969.

[b] Test of significant differences between combining and heterotic effects: nt, not tested; ns, not significant; and * P<.05, ** P<.01.

Carcass Characteristics. Only those carcass traits directly associated with growth, age adjusted carcass weight, age adjusted retail cuts and rib eye area showed a larger heterotic effect, though breed effects were large and significant for all carcass traits. The combining effects were significantly larger ($P < .01$) than heterotic effects for all the carcass traits studied except dressing percent, indicating that carcass characteristics of Angus and Charolais crosses are affected more by the combining effects than the heterotic effects.

The Charolais excelled in traits associated with pounds of red meat, while the Angus excelled in traits associated with carcass quality, namely, marbling and carcass quality grade. In all traits the crossbreds were intermediate between the two breeds.

Values were not assigned to individual traits and dollar values of the carcasses were not calculated. However, because of the complementary effects of the two breeds, Charolais superiority in carcass quantity and Angus superiority in carcass quality, the crossbred steer may be superior to either of the two parent breeds in dollar value of edible product produced.

SUMMARY

Straightbred Angus, Charolais and their reciprocal crosses were used to study heterosis and breed effects on growth, feed efficiency and carcass characteristics. Data were collected over a 3-year period and calves were produced from 2-, 3- and 4-year-old Angus and Charolais cows bred artificially to either an Angus or Charolais bull. Feeding and management practices were typical of good commercial cow-calf management. Steer and heifer data were analyzed separately. The steers were put in the feedlot immediately following weaning and heifers were grown out for replacement heifers. Approximately one-half of the heifers were fed individually each year to obtain feed efficiency data. Data were available for 183 bulls and 174 heifers at birth, 169 steers and 169 heifers at weaning, 167 heifers at 365 and 550 days of age and 151 steers at slaughter age. All weights were adjusted for age effects. Records were also obtained on the feed efficiency of 120 heifers from weaning to yearling and 93 heifers from yearling to 550 days.

Least squares analyses of variance showed breed of dam, breed of sire, years and breed of dam x breed of sire interaction to have significant effects ($P<.05$) on most traits studied. Notable exceptions were breed of dam, breed of sire and breed of dam x breed of sire interaction effect on feed efficiency and breed of dam x breed of sire interaction effects on carcass quality traits. Year x breed of dam and year x breed of sire interactions were significant ($P<.05$) for only

five of the traits studied. Management (drylot or pasture) had a significant effect ($P<.01$) on postweaning growth traits of heifers.

Least squares breed group means were constructed from the overall mean and breed of sire, breed of dam and breed of sire x breed of dam interaction constants. These means were used to estimate the size of heterosis and make breed group comparisons. Linear comparisons were made between straightbreds and crossbreds, Angus dams and Charolais dams, Angus sire and Charolais sire, Angus-Charolais and Charolais-Angus, Angus and Charolais, crossbreds and Angus and crossbreds and Charolais.

Heterosis was small and nonsignificant for traits measured at birth and ranged between -.10 to 2.86%. At weaning heterosis for growth traits was significant ($P<.05$) for steers but not heifers. Heterosis estimates of 5.3% for the steers and 2.0% for the females were obtained for weaning weight. Heterotic effects on postweaning growth traits of the heifers and steers were significant ($P<.01$) in most instances and ranged between 3.12 to 6.02%. No significant heterosis was found for feed efficiency, though the heterotic value for feed efficiency from weaning to yearling was 4.39% and approached significance. Estimates for heterosis of carcass quantity traits were between 3.5 to 5.0% and were generally significant ($P<.01$), while those dealing with carcass quality were lower and nonsignificant.

Combining effects were significant ($P<.01$) for all growth traits studied and were larger than heterotic effects in most cases. Combining effects had no significant effect on feed efficiency.

Breeds were significantly different ($P<.01$) for all carcass traits except dressing percent and combining effects were greater than heterotic effects for all carcass traits studied.

Charolais were larger and gained faster than did the Angus for all growth traits studied, and there was generally no significant difference between reciprocal crosses. The growth performance of the crossbreds was always greater than the Angus and in most cases less than the Charolais. Differences between the crossbreds and Charolais were generally not significant and indicate that the crossbreds more closely resembled the Charolais than the Angus and that the combining effects and heterotic effects were not significantly different.

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