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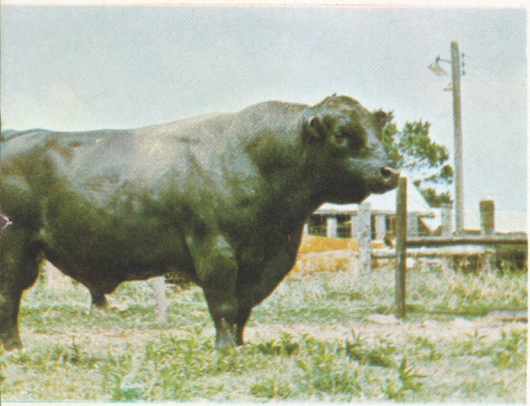

Crossbreeding British Beef Breeds

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Crossbreeding British Beef Breeds

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MUCH OF THE CROSSBREEDING of beef cattle has been conducted in the Southern United States. In the Gulf Coast Region, Brahman bulls have been crossed with native and British breed cows for improved production and greater tolerance to heat and insects. British bulls have been mated with native cows for increased production and improved quality. Recently these high grade cows have been bred to British bulls of a different breed and occasionally the two-breed cross females from these matings have been mated to a third breed.

Crossbred cattle have proven to be highly productive. Several workers have reported higher calving rates and a higher percentage calves weaned as a result of crossing British breeds *(6, 20, 22, 23, 26)*. Temple *et al. (22)* and Turner *et al. (23)* showed that crossbred females weaned a higher percentage of calves than straightbred females.

Many reports *(6, 8, 9, 10, 15, 20, 24)* showed that crossbred calves are heavier at birth than straightbred calves. Some *(9, 24)* have shown that three-breed calves were heavier at birth than either two-breed or purebreds.

Crossbred calves from purebred cows have been shown to be heavier at weaning than purebred calves *(6, 8, 9, 10, 15, 18, 19, 20)*. Reports *(9, 24)* also show the three-breed calves were heavier than either purebred or two-breed calves. Gaines *et al. (6)* found that three-breed calves out of purebred cows sired by crossbred bulls were heavier than straightbred calves.

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Slaughter or feeder grades at weaning have not been significantly affected by crossbreeding *(5, 6, 10, 20, 24).*

Previous results *(3, 4, 11, 12, 15, 16, 25)* indicated that crossbred calves gained faster from weaning to 15-18 months of age and had a heavier final weight and a higher weight per day of age. However, some specific crosses which were as heavy or heavier than straightbred calves at weaning gained slower post-weaning *(1, 2, 12, 25).*

Differences in carcass traits between purebreds and crossbreds tend to be small and non-significant unless the traits are associated with weight *(1, 2, 5, 7, 8, 13, 15, 24).*

This study was conducted to determine the effects of crossbreeding among the Angus, Hereford, and Shorthorn breeds on reproduction, growth, and carcass characteristics.

EXPERIMENTAL PROCEDURE

The data used in this study were obtained from performance records of cows assigned to crossbreeding research at Auburn University. These records began with calves born in the 1957-58 calving season and ended with the completion of the post-weaning performance test of steers born during the 1967-68 calving season.

Data collected during this period were divided into two phases:

Phase I: A 5-year period (1957 through 1961) in which purebred matings and all possible crosses were made among the purebred Angus, Hereford, and Shorthorn breeds.

Phase II: A 7-year period (1961 through 1967) in which the following matings were made:

(a) Angus bulls mated to Hereford, Shorthorn, Hereford-Shorthorn, and Shorthorn-Hereford cows.

(b) Hereford bulls mated to Angus, Shorthorn, Angus-Shorthorn, and Shorthorn-Angus cows.

(c) Shorthorn bulls mated to Angus, Hereford, Angus-Hereford, and Hereford-Angus cows.

The foundation cows were from the purebred Angus, Hereford, and Shorthorn herds of Auburn University. Both the purebred and crossbred cows used in Phase II were females produced in Phase I. Bulls used were selected from the purebred herds of Auburn University or were purchased from other breeders.

In Phase I, 24 females of each breed were used to produce the calf crop each year, Table 1. The first year, females of each breed were randomly assigned to sire sub-groups on the basis

of age, ancestry, and previous performance. In succeeding years, cows were reallotted. During the study, each cow was mated to bulls of all three breeds. Cows with poor calving records were removed from the experiment and replaced with cows that were similar in age, ancestry, and previous performance. The basic plan was to use two bulls of each breed per year, with each bull being bred to twice as many females of his own breed as to each of the other two breeds.

TABLE 1. EXPERIMENTAL DESIGN OF PHASE I

Breed of cows	Breed of bulls[1]			Total
	Angus	Hereford	Shorthorn	
	No.	*No.*	*No.*	*No.*
Angus	12	6	6	24
Hereford	6	12	6	24
Shorthorn	6	6	12	24
Total	24	24	24	72

[1] Two sires of each breed used each year.

All cows were maintained under practical conditions. During the winter months, cows were full fed grass hay and/or sorghum silage supplemented with 1 to 2 pounds of soybean or cottonseed meal daily. Summer pastures consisted of common bermuda, Coastal bermuda, and Dallisgrass. Clover or vetch furnished some early spring grazing in these pastures. Calves were not creep fed.

During the 1957-58 calving season, the first calf was born on September 13, 1957, and the last calf on March 22, 1958. The calving season was gradually shortened until in 1961-62, it extended from September 29, 1961 to February 13, 1962.

All cows were individually identified, and within 24 hours after birth all calves were ear tagged and dehorned if necessary. At this time, the following records were obtained: calving dates, dam number, dam weight, calf number, calf weight, and sex. Calving difficulties and death losses were noted. In 1957, male calves were castrated at approximately 180 days of age. In all succeeding years, they were castrated within 24 hours after birth.

Calves were weaned at approximately 250 days of age. At this time, the following records were obtained: cow weight, calf weight, slaughter score for steers, and slaughter and breeder scores for heifers.

As they were weaned, the steer calves were placed on permanent pasture until all calves were weaned. At least 2 weeks

were allowed for adjustment after weaning the youngest calf before the post-weaning performance feeding began. While on post-weaning performance test, they were full-fed a 30 per cent roughage ration. Steers were slaughtered when visual appraisal indicated the group had obtained an average grade of USDA Choice.

At slaughter, records were obtained for chilled carcass weight, fat thickness, rib eye area, conformation score, and USDA quality grade. Beginning in 1959, a wholesale rib was obtained and a tenderness score was determined by the Warner-Bratzler shear on a steak taken at the 12th rib.

The experimental design of Phase II showing the matings made and the total number of cows used during the 7-year period is given in Table 2. In this phase, the management practices and records taken for the cows and calves up to weaning were the same as in Phase I. Both the purebred and crossbred cows used were produced in Phase I. No purebred calves were produced in Phase II, and all possible crosses (including reciprocal matings) were made among the three pure breeds. In addition, the two-breed cows were mated to bulls of a third breed. This allowed comparisons of two-breed and three-breed crosses.

TABLE 2. EXPERIMENTAL DESIGN OF PHASE II

Breed of cows	Breed of bulls[1]			Seven-year total
	Angus	Hereford	Shorthorn	
	No.	*No.*	*No.*	*No.*
Angus	0	50	49	99
Hereford	50	0	50	100
Shorthorn	48	48	0	96
A x H and H x A	0	0	119	119
H x S and S x H	126	0	0	126
S x A and A x S	0	117	0	117
Seven-year total	224	215	218	657

[1] Two bulls of each breed used each season.

Steers produced in Phase II were placed on post-weaning performance test immediately after weaning with no adjustment period allowed.

In addition to the carcass data collected in Phase I, marbling scores and per cent kidney fat were taken beginning in 1962. This made it possible to use the revised USDA quality grades and to calculate USDA yield grades. The steers were individually removed from test and slaughtered when they reached approximately 1,000 pounds.

Analysis of Data

The breeds of cattle used in these experiments were not random samples of their breeds since they were selected from the existing herds of Angus, Hereford, and Shorthorn beef cattle at Auburn University. Analyses were made to compare appropriate breeding-group means to determine (1) the effect of crossbreeding on reproductive performance of the brood cows; (2) heterotic effects on pre-weaning, post-weaning, and carcass traits of the calves; and (3) the performance of the three breeds in crosses.

In Phase I, appropriate comparisons were made between purebred and two-breed calves and among calves grouped by breed of bulls and cows. In Phase II, comparisons were made between two-breed and three-breed calves and between calves from purebred and two-breed cows.

The data were analyzed by the method of least-squares *(14)*. Separate analyses were made for birth weight, average daily gain from birth to weaning, weight at 250 days of age, and condition score using the linear model shown in the Appendix.

The Chi-square method was used as the test of significance for differences in reproductive performance *(21)*. Kramer's *(17)* modification of Duncan's multiple range test was used to test significance between individual means.

RESULTS AND DISCUSSION

Phase I

Reproductive performance of the cows, expressed as percentages of calves born and weaned per cow bred, is shown in Table 3. A significantly higher ($P<0.05$) percentage of the Angus cows gave birth to and weaned calves than did either the Hereford or Shorthorn cows. The percentage of calves born dead or dying prior to weaning was slightly over 5 per cent for each of the three breeds of cows. The percentage of calves weaned was low for all breeds of cows for the calving season of 1960. During the 1959-60 calving and breeding season, all cows were fed Coastal bermudagrass hay *ad libitum*. A possible energy deficiency may have contributed to the poor reproductive performance.

Cows bred to produce purebred calves gave birth to and weaned approximately 5 per cent more calves than did cows bred to produce crossbred calves, Table 4. This difference was not

TABLE 3. REPRODUCTIVE PERFORMANCE BY BREED OF COW, PHASE I

Year	Angus			Hereford			Shorthorn		
	Cows	Calving	Weaning calves	Cows	Calving	Weaning calves	Cows	Calving	Weaning calves
	No.	*Pct.*	*Pct.*	*No.*	*Pct.*	*Pct.*	*No.*	*Pct.*	*Pct.*
1957	24	87.5	75.0	24	83.3	75.0	23	73.9	65.2
1958	24	87.5	79.2	24	79.2	70.8	24	87.5	83.3
1959	24	91.7	87.5	23	82.6	78.3	24	58.3	54.2
1960	24	70.8	66.7	24	58.3	58.3	24	70.8	62.5
1961	24	91.7	91.7	24	70.8	66.7	24	75.0	70.8
Total or average[1]	120	85.8a	80.0a	119	74.8b	69.7b	119	73.1b	67.2b

[1] Means followed by different letters differ at $P<0.05$.

TABLE 4. REPRODUCTIVE PERFORMANCE OF PUREBRED COWS PRODUCING PUREBRED OR CROSSBRED CALVES, PHASE I

Year	Purebreds mating			Crossbreds mating		
	Cows	Calving	Weaning calves	Cows	Calving	Weaning calves
	No.	*Pct.*	*Pct.*	*No.*	*Pct.*	*Pct.*
1957	35	88.6	77.1	36	75.0	66.7
1958	37	91.9	83.8	35	77.1	71.4
1959	36	77.8	72.2	35	77.1	74.3
1960	36	63.9	63.9	36	69.4	69.3
1961	36	80.1	77.8	36	77.8	72.2
Total or average	180	80.6	75.0	178	75.3	70.2

significant. Some published reports have indicated improved reproduction by cows bred to produce crossbred calves compared to cows bred to produce purebred calves *(6, 8, 16, 26)*.

Among the purebreds, the Hereford and Shorthorn calves were significantly ($P<0.01$) heavier at birth than were the Angus calves, Table 5. However, the Angus and Hereford calves had a higher average daily gain ($P<0.05$) and a heavier 250-day weight ($P<0.05$) than the Shorthorn calves. There were no significant differences among weaning scores of the purebred calves.

Differences in the birth weights of Hereford x Shorthorn and Shorthorn x Hereford calves were not significant. However, these two were significantly heavier at birth ($P<0.05$) than any of the other groups of calves. No significant differences existed among 250-day weights of the Hereford x Shorthorn, Shorthorn x Angus, and Shorthorn x Hereford calves. However, the Hereford x Shorthorn calves were heavier at 250 days of age ($P<0.05$) than the Hereford x Angus, Angus x Shorthorn, and Angus x Here-

TABLE 5. LEAST-SQUARES MEANS FOR PREWEANING PERFORMANCE, PHASE I[1]

Breeding of calf	Calves	Birth weight	250-day ADG	250-day WDA	250-day weight	Weaning score[2]
	No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	
A x A	49	59.5cd	1.54b	1.78b	445b	9.9ab
H x H	41	66.7b	1.52b	1.79b	448b	9.7b
S x S	42	66.0b	1.41c	1.67c	417c	9.4b
A x H	15	63.3bcd	1.53b	1.78b	445b	9.3b
A x S	19	60.7cd	1.52b	1.76b	441b	9.4b
H x A	22	63.6bcd	1.60ab	1.86ab	464b	10.6a
H x S	19	73.7a	1.67a	1.96a	490a	10.6a
S x A	25	63.7bcd	1.63ab	1.88ab	471ab	10.2ab
S x H	20	70.4ab	1.60ab	1.88ab	470ab	10.0ab

[1] Means followed by different letters differ at $P < 0.05$.
[2] Grade code: 9 = low Good; 10 = average Good; 11 = high Good, etc.

ford. There were small but significant ($P<0.05$) differences in weaning scores. The Hereford x Angus and Hereford x Shorthorn calves had the highest grades (10.6) and the Angus x Hereford the lowest (9.3). This difference represents slightly more than one-ninth of a grade.

Comparisons of pre-weaning traits of the reciprocal crosses with mid-parent averages are shown in Table 6. There was little evidence of heterosis in birth weight. Only the difference between the Hereford x Shorthorn reciprocal crosses and the mid-parental average was significant ($P<0.01$). Gregory *et al. (10),* Gaines *et al. (6)* and Rollins *et al. (20)* also reported greater heterosis for birth weight from the Hereford and Shorthorn crosses than from crosses of Angus and Hereford or Angus and Shorthorn.

Average daily gains from birth to weaning and 250-day weights were greater for crossbred than for straightbred calves in all comparisons, Table 6. The differences of 0.10 pound in average daily gain and 27 pounds in weaning weight between the crossbred and the straightbred calves were highly significant ($P<0.01$). In individual comparisons, the heterotic effects for these traits were greater for the Hereford x Shorthorn reciprocals than for the other two crossbred combinations. The greater heterosis in Hereford x Shorthorn crosses reported here agrees with findings of Gregory *et al. (10)* and Rollins *et al. (20).*

Differences in weaning scores were small and, for the most part, non-significant. However, the difference of 0.7 between the Hereford x Shorthorn reciprocals and the mid-parental average was highly significant ($P<0.01$). In addition, the difference of 0.3 between all crossbreds and all straightbreds was significant

TABLE 6. LEAST-SQUARES MEANS AND DIFFERENCES OF PREWEANING TRAITS, PHASE I

Breeding of calf	Calves	Birth weight	250-day ADG	250-day weight	Weaning score[1]
	No.	*Lb.*	*Lb.*	*Lb.*	
H x A & A x H	37	63.5	1.57	455	10.0
H and A[2]	90	63.1	1.53	447	9.8
Difference	----	0.4	0.04	8	0.2
H x S & S x H	39	72.1	1.64	480	10.3
H and S[2]	83	66.4	1.47	433	9.6
Difference	----	5.7**	0.17**	47**	0.7**
A x S & S x A	44	62.2	1.58	456	9.8
A and S[2]	91	62.8	1.48	431	9.7
Difference	----	−0.6	0.10**	25**	0.1
All crossbreds	120	65.9	1.59	464	10.0
All straightbreds	132	64.1	1.49	437	9.7
Difference	----	1.8	0.10**	27**	0.3*

[1] Grade code: 9 = low Good; 10 = average Good; 11 = high Good, etc.
[2] Mean of parental breeds.
* $P<0.05$.
** $P<0.01$.

at the 0.05 level of probability. These differences represent approximately one-fourth and one-ninth of a grade, respectively.

Calves by Hereford sires had significantly higher ($P<0.05$) average daily gains, 250-day weights, and weaning scores than calves by Angus and Shorthorn sires, Table 7. Angus cows produced calves that grew faster and had heavier weaning weights and higher weaning scores than calves produced by either the Hereford or Shorthorn cows. This is in general agreement with the report of Gregory *et al. (10).*

Post-weaning performance data for heifers are presented in Table 8. No significant differences were found among breed of

TABLE 7. LEAST-SQUARES MEANS FOR BREED OF SIRE AND BREED OF DAM, PHASE I[1]

	Calves	Birth weight	250-day ADG	250-day WDA	250-day weight	Weaning score[2]
	No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	
Breed of sire						
Angus	83	61.6b	1.53b	1.77b	443b	9.5b
Hereford	82	68.0a	1.60a	1.87a	469a	10.3a
Shorthorn	87	66.7a	1.55ab	1.81b	454b	9.9b
Breed of dam						
Angus	96	62.4b	1.60a	1.85	463a	10.2a
Hereford	76	67.4a	1.55ab	1.82	454b	9.7b
Shorthorn	80	66.6a	1.53b	1.80	449b	9.8b

[1] Means followed by different letters differ at $P<0.05$.
[2] Grade code: 9 = low Good; 10 = average Good; 11 = high Good, etc.

TABLE 8. LEAST-SQUARES MEANS FOR POSTWEANING PERFORMANCE OF HEIFERS, PHASE I[1]

Breed of heifer	Heifers	Pasture period				Feedlot period			
		Weaning weight[2]	Period	Final weight	ADG	Final weight	ADG	Final WDA	Age
	No.	*Lb.*	*Days*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Days*
A x A	27	419	103	464b	0.42	682b	1.70	1.42b	481
H x H	17	444	89	476b	0.42	714ab	1.85	1.53ab	467
S x S	18	404	107	461b	0.44	683b	1.73	1.45ab	475
A x H	9	407	95	466b	0.67	691b	1.76	1.46ab	473
A x S	12	422	95	475b	0.56	697b	1.73	1.47ab	473
H x A	10	447	103	496ab	0.51	728ab	1.80	1.51ab	482
H x S	9	460	94	506ab	0.53	739ab	1.82	1.59a	471
S x A	8	458	81	495ab	0.46	717ab	1.73	1.57a	462
S x H	8	463	98	528a	0.35	765a	1.85	1.61a	475

[1] Means followed by different letters differ at $P<0.05$.
[2] Unadjusted weaning weight at 250 ± 7 days of age.

calf for average daily gain during either the pasture or feedlot periods. However, as shown in the comparisons in Table 9, crossbred heifers gained as fast or faster than straightbred heifers. The differences in final weights between reciprocal crosses and their respective mid-parent average were positive for all comparisons. Hereford x Shorthorn reciprocal crosses showed the greatest difference (53 pounds) and the Hereford x Angus reciprocal crosses the least difference (12 pounds) in final weight. The difference for the Angus x Shorthorn reciprocals was 24 pounds. The combined effect of heavier weaning weight and slightly faster growth rate after weaning resulted in crossbred heifers being 30 pounds heavier than the straightbred heifers at the end of the feedlot period.

Least-squares means for post-weaning performance of steers are shown in Table 10. No significant differences among breed of calves existed in average daily gain on pasture. During the feedlot period, the Shorthorn x Hereford and reciprocal cross steers gained significantly faster ($P<0.05$) than the Shorthorn x Angus and the straightbred Angus steers. No significant differences in rate of gain during the feedlot period were found among any other breed groups.

All groups of crossbred steers gained more rapidly than straightbred steers during both the pasture and feedlot periods, Table 11. When compared to the mid-parent average, Hereford x Shorthorn and reciprocal cross steers had the greatest advantage (111 pounds) in final weight and Hereford x Angus and recipro-

TABLE 9. LEAST-SQUARES MEANS AND DIFFERENCES FOR HEIFERS, PHASE I

Breed of heifers	Heifers	Birth weight	250-day weight	Pasture ADG	Feedlot ADG	Final weight	Final WDA
	No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
H x A & A x H	19	63.3	431	0.59	1.78	710	1.49
H and A[1]	44	61.7	438	0.42	1.78	698	1.48
Difference	----	1.6	—7	0.17**	0.00	12	0.01
H x S & S x H	17	69.7	461	0.44	1.84	752	1.60
H and S[1]	35	66.8	438	0.43	1.79	699	1.49
Difference	----	2.9*	23*	0.01	0.05	53**	0.11**
A x S & S x A	20	61.1	438	0.51	1.73	707	1.52
A and S[1]	45	61.8	424	0.43	1.72	683	1.44
Difference	----	—0.7	14*	0.08*	0.01	24**	0.08**
All crossbreds	56	64.7	445	0.51	1.78	723	1.54
All straightbreds	62	63.4	433	0.43	1.76	693	1.47
Difference	----	1.3	12*	0.08*	0.02	30**	0.07*

[1] Mean of parent breeds.
* $P<0.05$.
** $P<0.01$.

TABLE 10. LEAST-SQUARES MEANS FOR POSTWEANING PERFORMANCE OF STEERS, PHASE I[1]

Breed of steers	Steers	Pasture period				Feedlot period			
		Weaning weight[2]	Period	Final weight	ADG	Final weight	ADG	Final WDA	Age
	No.	*Lb.*	*Days*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Days*
A x A	17	458	86	496bc	0.37	906b	1.83b	1.62b	561
H x H	22	431	89	489bc	0.60	911b	1.96ab	1.65b	554
S x S	20	418	103	461bc	0.38	899b	1.96ab	1.56b	577
A x H	5	450	102	523ab	0.63	956ab	1.92ab	1.66b	576
A x S	7	446	97	506bc	0.61	958ab	2.01ab	1.67b	571
H x A	12	480	106	530ab	0.43	955ab	1.91ab	1.64b	581
H x S	10	499	102	558a	0.56	1,024a	2.07a	1.78a	576
S x A	17	479	112	550ab	0.62	969a	1.86b	1.65b	586
S x H	12	472	89	538ab	0.64	1,008a	2.10a	1.80a	564

[1] Means followed by different letters differ at $P<0.05$.
[2] Unadjusted weaning weight at 250 ± 7 days of age.

cal steers the least (47 pounds). With the combined effects of heavier weaning weights and more rapid post-weaning gains, the average final weight of all crossbred steers was 73 pounds heavier than the average final weight of all straightbred steers. These results are in general agreement with these reported by other investigators *(6, 10, 25)*.

The greatest differences in steer carcass traits were among those associated with growth rate, carcass weight, and carcass weight per day of age, Table 12. The crossbred steer carcasses were significantly ($P<0.05$) heavier than those of the straight-

TABLE 11. LEAST-SQUARES MEANS FOR STEERS PERFORMANCE, PHASE I

Breed of steers	Steers	Birth weight	250-day weight	Pasture ADG	Feedlot ADG	Final weight	Final WDA
	No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*
H x A & A x H	17	63.7	479	0.53	1.92	956	1.65
H and A[1]	39	64.5	455	0.49	1.90	909	1.64
Difference	----	−0.8	24*	0.04	0.02	47**	0.01
H x S & S x H	22	74.4	495	0.60	2.09	1,016	1.79
H and S[1]	42	66.0	427	0.49	1.96	905	1.61
Difference	----	8.4**	68**	0.11**	0.13*	111**	0.18**
A x S & S x A	24	63.2	474	0.62	1.94	964	1.66
A and S[1]	37	63.8	438	0.38	1.90	903	1.59
Difference	----	−0.6	36**	0.24**	0.04	61**	0.07*
All crossbreds	63	67.1	482	0.58	1.98	978	1.70
All straightbreds	59	64.7	440	0.45	1.92	905	1.61
Difference	----	2.4*	42**	0.13**	0.06	73**	0.09**

[1] Mean of parent breeds.
* $P<0.05$.
** $P<0.01$.

TABLE 12. LEAST-SQUARES MEANS OF STEER CARCASS CHARACTERISTICS, PHASE I[1]

Breed of steers	Steers	Carcass weight	Dressing per cent[2]	Carcass WDA	Fat thickness	Ribeye area[3]	Quality grade[4]	Tenderness score[5]
	No.	*Lb.*	*Pct.*	*Lb.*	*In.*	*Sq. In.*		
A x A	17	557c	61.7ab	0.99b	0.67	11.3	13.3a	13.9
H x H	22	540c	59.8c	0.98b	0.66	11.1	11.4b	16.7
S x S	20	544c	60.5bc	0.94b	0.57	11.1	12.6b	17.6
A x H	5	597ab	61.7ab	1.04ab	0.77	10.3	12.5b	17.2
A x S	7	591ab	61.6ab	1.03ab	0.67	11.4	12.9b	20.3
H x A	12	582b	60.9ab	1.00b	0.68	11.9	12.3b	15.7
H x S	10	636a	61.9a	1.11a	0.66	11.5	12.8b	15.9
S x A	17	595ab	61.0abc	1.01b	0.67	11.5	13.5a	15.3
S x H	12	617ab	61.1ab	1.10a	0.65	11.5	12.6b	15.5

[1] Means followed by different letters differ at $P<0.05$.
[2] Regressed on live weight.
[3] Regressed on carcass weight.
[4] Grade code: 10 = average Good; 11 = high Good; 12 = low Choice, etc.
[5] Warner-Bratzler shear values—lower values more tender.

bred steers. When regressed on live weight, dressing percentages of straightbred Herefords were significantly lower than those of the Angus or any of the crossbreds. There were slight differences among carcass quality grades. However, these steers were slaughtered when it appeared the group would have an average grade of USDA Choice. When regressed on carcass weight, no significant differences were found among fat thickness measurements, ribeye areas, or tenderness scores. These results are similar to those reported by Gregory *et al. (12)* and Gaines *et al. (7)*.

TABLE 13. LEAST-SQUARES MEANS AND DIFFERENCES OF STEER CARCASS CHARACTERISTICS, PHASE I

Breed of steers	Steers	Carcass weight	Dressing per cent	Carcass WDA	Fat thickness	Ribeye area	Quality grade[1]	Tenderness score[2]
	No.	*Lb.*	*Pct.*	*Lb.*	*In.*	*Sq. In.*		
A x H & H x A	17	590	61.3	1.02	0.72	11.1	12.4	16.5
A and H[3]	39	549	60.8	0.98	0.67	11.2	12.4	15.3
Difference	----	41**	0.5	0.04**	0.05	—0.1	0.0	—1.2
H x S & S x H	22	627	61.5	1.10	0.65	11.5	12.7	15.7
H and S[3]	42	542	60.2	0.96	0.62	11.1	12.0	17.2
Difference	----	85**	1.3	0.14**	0.03	0.4	0.7	1.5
A x S & S x A	24	593	61.3	1.02	0.67	11.5	13.2	17.8
A and S[3]	37	551	61.1	0.96	0.62	11.2	13.0	15.8
Difference	----	42**	0.2	0.06**	0.05	0.3	0.2	—2.0
All crossbreds	63	603	61.4	1.05	0.68	11.4	12.7	16.7
All straightbreds	59	547	60.7	0.97	0.63	11.2	12.4	16.1
Difference	----	56**	0.7	0.08**	0.05	0.2	0.3	—0.6

[1] Grade code: 12 = low Choice; 13 = average Choice.
[2] Warner-Bratzler shear values—lower values more tender.
[3] Mean of parent breeds.
** $P<0.01$.

TABLE 14. LEAST-SQUARES MEANS BY SIRE AND BY DAM FOR STEER CARCASS CHARACTERISTICS, PHASE I[1]

	Steers	Carcass weight	Dressing per cent	Carcass WDA	Fat thickness	Ribeye area	Quality grade	Tenderness score
	No.	*Lb.*	*Pct.*	*Lb.*	*In.*	*Sq. In.*		
Breed of sire								
Angus	29	583	61.6	1.03	0.68	11.3	13.0a	17.1
Hereford	44	588	60.9	1.03	0.66	11.5	12.1b	16.1
Shorthorn	49	586	60.9	1.02	0.63	11.3	12.7a	16.1
Breed of dam								
Angus	46	581	61.2	1.01	0.67	11.6	12.8a	15.0
Hereford	39	586	60.9	1.04	0.66	11.1	12.2b	16.5
Shorthorn	37	590	61.4	1.03	0.64	11.4	12.8a	17.8

[1] Means followed by different letters differ at $P<0.05$.

Least-squares means of carcass traits and the difference between straightbreds and crossbreds are shown in Table 13. Only those traits directly related to growth, carcass weight, and carcass weight per day of age were significantly different ($P<0.01$). More heterosis was expressed in Hereford-Shorthorn crosses than in the Angus-Hereford and Angus-Shorthorn crosses. These results agree with those of Gaines *et al. (6)*, Gregory *et al. (13)*, and Rollins *et al. (19)*. No significant heterotic effects were found for the other carcass traits measured.

Differences existed among the carcass quality grades with carcasses from steers by either a Hereford bull or from a Hereford cow having significantly ($P<0.05$) lower carcass grades than those of the other breeds, Table 14.

Phase II

Among the purebred cows bred to produce crossbred calves, a higher percentage of the Angus cows calved than either the Hereford or Shorthorn cows, Table 15. However, there were no significant differences among purebred cows in the percentage of calves weaned since the Hereford and Shorthorn cows raised a higher percentage of calves that were born.

TABLE 15. REPRODUCTIVE PERFORMANCE OF COWS, PHASE II[1]

Year	Angus			Hereford			Shorthorn		
	Cows	Calving	Weaning calves	Cows	Calving	Weaning calves	Cows	Calving	Weaning calves
	No.	*Pct.*	*Pct.*	*No.*	*Pct.*	*Pct.*	*No.*	*Pct.*	*Pct.*
1961	3	66.7	66.7	7	85.7	85.7	6	66.7	33.3
1962	8	100.0	75.0	11	72.7	72.7	7	71.4	57.1
1963	14	57.1	42.9	12	50.0	50.0	13	92.3	84.6
1964	18	74.5	66.7	14	85.7	85.7	14	42.9	42.9
1965	20	80.0	75.0	20	60.0	60.0	21	76.2	76.2
1966	18	77.8	72.2	18	50.0	50.0	18	55.6	50.0
1967	18	94.4	88.9	18	88.9	88.9	17	94.1	88.2
Total or average	99	79.8b	70.7bc	100	69.0cd	69.0bc	94	71.9c	65.6cd
	(A x H) & (H x A)			(A x S) & (S x A)			(H x S) & (S x H)		
1961	5	100.0	100.0	8	87.5	87.5	9	88.9	88.9
1962	8	100.0	100.0	11	54.5	54.5	11	81.8	72.7
1963	12	58.3	50.0	15	86.7	86.7	15	93.3	93.3
1964	16	81.3	68.8	14	100.0	92.9	19	84.2	84.2
1965	27	29.6	29.6	24	91.7	91.7	23	60.9	60.9
1966	26	50.0	46.2	23	82.6	78.3	24	75.0	70.8
1967	25	80.0	80.0	22	90.9	90.9	25	84.0	80.0
Total or average	119	62.2d	58.8d	117	86.3a	84.6a	126	78.7b	76.4b

[1] Means followed by different letters differ at $P<0.05$.

Among the crossbreds, the Angus-Shorthorn cows dropped and weaned a significantly ($P<0.05$) higher percentage of calves than either the Angus-Hereford or Hereford-Shorthorn cows. The Hereford-Shorthorn cows calved and weaned a significantly ($P<0.05$) higher percentage of calves than did the Angus-Hereford cows.

Comparisons of reproductive performance between all cross-

bred and all purebred cows showed that crossbred cows calved 1.6 and weaned 4.8 per cent more calves than did the purebred cows, Table 16. However, these differences were not significant.

TABLE 16. REPRODUCTIVE PERFORMANCE OF PUREBRED AND CROSSBRED COWS, PHASE II

Year	Purebreds			Crossbreds		
	Cows	Calving	Weaning calves	Cows	Calving	Weaning calves
	No.	*Pct.*	*Pct.*	*No.*	*Pct.*	*Pct.*
1961	16	87.5	62.5	22	90.9	90.9
1962	26	80.8	69.2	30	76.7	73.3
1963	39	66.7	59.0	42	81.0	78.6
1964	46	69.6	65.2	49	87.8	81.6
1965	61	72.1	70.5	75	58.7	58.7
1966	54	61.1	57.4	73	68.5	64.4
1967	53	92.5	88.7	72	84.7	83.3
Total or average	295	74.2	68.5	363	75.8	73.3

Reproductive performance was poor for Angus and Hereford cows in 1963, for Shorthorn cows in 1964, 1965, and 1966, and for the Hereford, Angus-Hereford, and Hereford-Shorthorn cows in 1965 and 1966. Trichomoniasis was diagnosed in one Angus and two Shorthorn bulls during 1965 and in one Angus and one Shorthorn bull in 1966. It is believed that this disease was introduced by a Shorthorn bull in 1963, and by the rotation of bulls was spread to other bulls and cow groups. Among the two-breed calves, the Hereford x Angus, Hereford x Shorthorn, and Shorthorn x Hereford were significantly ($P<0.01$) heavier at birth than were the other two-breed crosses, Table 17. The Hereford x Angus and Hereford x Shorthorn calves were significantly ($P<0.01$) heavier at 250 days of age than any of the other two-breed crosses. In individual comparisons of the three-breed crosses, the A x (H x S) and S x (H x A) calves were significantly ($P<0.01$) lighter at birth and at 250 days of age than were the other three-breed cross calves.

Least-squares means and differences between two-breed and three-breed calves are shown in Table 18. In all comparisons, three-breed calves were significantly ($P<0.01$) heavier at birth, had a higher average daily gain, and were heavier at 250 days of age. All three-breed calves had a significantly ($P<0.01$) higher weaning score than did the two-breed calves. Three-breed calves from A x H cross dams had a significantly ($P<0.01$) higher weaning score than two-breed calves from purebred Angus and Hereford cows.

TABLE 17. LEAST-SQUARES MEANS FOR PREWEANING PERFORMANCE, PHASE II[1]

Breed of calf	Calves	Birth weight	250-day ADG	250-day WDA	250-day weight	Weaning score[2]
	No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	
A x H	35	62.5bc	1.49b	1.74	434c	9.6bc
A x S	30	58.1bc	1.47b	1.70	424c	9.8abc
H x A	42	67.5a	1.64a	1.91	478ab	10.4a
H x S	35	68.1ab	1.58a	1.86	464b	10.3ab
S x A	29	60.7bc	1.50b	1.74	436c	9.9abc
S x H	35	68.8a	1.43b	1.71	427c	9.3bc
A x (H x S)	52	62.3bc	1.47b	1.72	430c	9.6bc
A x (S x H)	45	67.2b	1.68a	1.95	488a	10.3ab
H x (A x S)	48	67.7ab	1.66a	1.93	482ab	10.5a
H x (S x A)	51	60.7a	1.67a	1.96	489a	10.3ab
S x (A x H)	28	68.7a	1.61a	1.88	470ab	10.4a
S x (H x A)	42	64.3bc	1.49b	1.74	436c	10.1ab

[1] Means followed by different letters differ at $P<0.01$.
[2] Grade code: 9 = low Good; 10 = average Good; 11 = high Good, etc.

TABLE 18. LEAST-SQUARES MEANS AND DIFFERENCES BETWEEN CALVES FROM CROSSBRED AND PUREBRED DAMS, PHASE II

Breed of bull	Breed of cow	Calves	Birth weight	250-day ADG	250-day weight	Weaning score[1]
		No.	*Lb.*	*Lb.*	*Lb.*	
S	A x H & H x A	70	66.5	1.55	453	10.3
S	A and H	64	64.8	1.47	432	9.6
	Difference	----	1.7**	0.08	21**	0.7**
H	A x S & S x A	99	69.2	1.67	486	10.4
H	A and S	77	67.8	1.61	471	10.4
	Difference	----	1.4**	0.06*	15**	0.0
A	H x S & S x H	97	64.8	1.58	459	10.0
A	H and S	65	60.3	1.48	429	9.7
	Difference	----	4.5**	0.10**	30**	0.3
----	Crossbred dams	266	66.8	1.60	466	10.2
----	Purebred dams	206	64.3	1.52	444	9.9
	Difference	----	2.5**	0.08**	22**	0.3**

[1] Grade code: 9 = low Good; 10 = average Good; 11 = high Good, etc.
** $P<0.01$.

Post-weaning performance results of heifers are listed by breeding groups in Table 19. There were no significant differences in average daily gain during the pasture period. The significant differences in final pasture weights are due to the differences that existed in actual weaning weight and the slight differences in average daily gain.

During the feedlot period, the Hereford x Shorthorn and Shorthorn x Hereford heifers gained significantly ($P<0.01$) faster than did the S x (H x A). There were no significant differences in average daily gain for other individual comparisons. Because of small differences in average age of the heifers at the completion

TABLE 19. LEAST-SQUARES MEANS FOR POSTWEANING PERFORMANCE OF HEIFERS, PHASE II[1]

Breed of heifer	Heifers	Pasture period				Feedlot period				
		Weaning weight[2]	Period	Final weight	ADG	Final weight	ADG	Final WDA	Score[3]	Age
	No.	*Lb.*	*Days*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*		*Days*
A x H	24	417	67	464bc	0.70	671bc	1.69ab	1.54abc	12.2ab	436
A x S	18	407	68	444c	0.55	629c	1.51ab	1.44bc	12.1ab	437
H x A	23	452	81	501ab	0.61	704ab	1.66ab	1.56a	12.5a	451
H x S	17	432	64	468bc	0.56	682ab	1.75a	1.58a	12.8a	432
S x A	15	399	77	464bc	0.83	659bc	1.61ab	1.47bc	12.5a	448
S x H	16	406	84	481abc	0.89	693ab	1.74a	1.52ab	11.8b	456
Ax(HxS)	23	405	82	455c	0.62	656bc	1.64ab	1.45bc	12.1ab	452
Ax(SxH)	24	458	74	504ab	0.64	707ab	1.66ab	1.61a	12.3ab	439
Hx(AxS)	23	465	63	498ab	0.53	704ab	1.68ab	1.63a	12.7a	432
Hx(SxA)	24	463	81	519a	0.70	729a	1.72ab	1.62a	12.7a	450
Sx(AxH)	13	447	76	497ab	0.65	703ab	1.69ab	1.58a	12.8a	445
Sx(HxA)	16	395	75	444c	0.74	623c	1.46b	1.40b	11.6b	445

[1] Means followed by different letters differ at $P<0.05$.
[2] Unadjusted weaning weight.
[3] Grade Code: 11 = high Good; 12 = low Choice.

of the feedlot period, weight per day of age is the best estimate of total growth. The weights per day of age of Angus x Shorthorn, Shorthorn x Angus, A x (H x S), and S x (H x A) were similar to the Angus x Hereford and Shorthorn x Hereford, but were significantly ($P<0.01$) lower than any other group. The significant differences in final feedlot weights were due to cumulative effect of differences in initial feedlot weight and the differences in average daily gain. There were small but significant ($P<0.01$) differences among breeding groups for conformation scores at the end of the feedlot period. However, there was no specific pattern and the difference from high to low amounted to only one-third of a grade.

Post-weaning means and their differences for two-breed and three-breed cross heifers are shown in Table 20. The two-breed heifers sired by Shorthorn bulls gained faster on pasture than the three-breed heifers by Shorthorn bulls. This difference was large enough to result in almost equal weights at the end of the pasture period. Although the three-breed cross heifers gained faster on the average than the two-breed cross heifers during the pasture period, the difference was not significant. The average final pasture weight of all three-breed heifers was significantly ($P<0.01$) heavier than the final weight of the two-breed heifers.

TABLE 20. LEAST-SQUARES MEANS AND DIFFERENCES IN POSTWEANING PERFORMANCE OF HEIFERS FOR CROSSBRED AND PUREBRED DAMS, PHASE II

Breed of bull	Breed of cows	Heifers	Pasture period			Feedlot period			
			Weaning weight	Final weight	ADG	Final weight	ADG	Final WDA	Score[1]
		No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	
S	A x H & H xA	29	421	471	.70	663	1.65	1.49	12.2
S	A and H	31	403	472	.86	676	1.68	1.49	12.2
	Difference	----	18	−1	−0.16	−13	−0.03	0.00	00.0
H	A x S & S x A	47	464	509	0.62	716	1.70	1.63	12.7
H	A and S	40	442	485	0.59	693	1.71	1.57	12.7
	Difference	----	22	24**	0.03	23*	−0.01	.06	00.0
A	H x S & S x H	47	432	479	0.63	682	1.65	1.53	12.2
A	H and S	42	412	454	0.56	650	1.60	1.49	12.2
	Difference	----	20	25**	0.07	32**	0.05	0.04	00.0
----	Crossbred dams	123	439	486	0.63	687	1.64	1.55	12.3
----	Purebred dams	113	418	470	0.69	673	1.66	1.52	12.3
	Difference	----	21	16**	−0.06	14**	−0.02	0.03	00.0

[1] Grade code: 9 = low Good; 10 = average Good; 11 = high Good, etc.
* $P<0.05$.
** $P<0.01$.

Differences in average daily gain, weight per day of age, and conformation score at the conclusion of the feedlot period were not significant. The three-breed heifers sired by Angus bulls were significantly ($P<0.05$) heavier than the two-breed heifers sired by Angus bulls. The significant difference in final feedlot weights between three-breed and two-breed crosses was primarily due to the difference in weaning weights.

Post-weaning performance by breed of steer is shown in Table 21. The Hereford x Shorthorn and Shorthorn x Hereford steers had the highest average daily gain (1.86 pounds) of any group. The Shorthorn x Angus and Angus x Shorthorn had the lowest daily gain, 1.59 and 1.60 pounds, respectively.

The Hereford x Angus, Hereford x Shorthorn, and H x (S x A) made the most rapid gain throughout the entire experiment and thereby reached 1,000 pounds at average ages of 527, 527, and 530 days, respectively. Due to their slow growth rate in the feedlot, the Angus x Shorthorn, Angus x Hereford, Shorthorn x Angus, and A x (H x S) steers had lower weights per day of age than other breed groups. There were small but significant ($P<0.05$) differences among conformation scores.

Least-squares means for post-weaning performance for two-breed and three-breed steers are shown in Table 22. When all three-breed steers were compared with all two-breed steers, there

TABLE 21. LEAST-SQUARES MEANS FOR POSTWEANING PERFORMANCE OF STEERS, PHASE II

Breed of steers	Steers	Weaning weight[2]	Final weight	ADG	WDA	Score[3]	Age
	No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*		*Days*
A x H	11	436	989	1.70ab	1.71b	14.0ab	578b
A x S	11	449	991	1.60b	1.68b	14.2a	590b
H x A	19	483	991	1.84a	1.88a	13.9ab	527a
H x S	16	476	991	1.86a	1.88a	13.7b	527a
S x A	14	458	998	1.59b	1.69b	14.8a	590b
S x H	19	415	997	1.86a	1.77ab	13.5b	563ab
A x (H x S)	29	439	991	1.65b	1.69b	14.3a	586b
A x (S x H)	21	498	997	1.71ab	1.83ab	13.3b	545ab
H x (A x S)	25	481	994	1.66b	1.77ab	14.2a	562ab
H x (S x A)	27	503	1,002	1.79a	1.89a	13.7b	530a
S x (A x H)	15	477	999	1.68ab	1.78ab	14.5a	561ab
S x (H x A)	25	466	993	1.69ab	1.76ab	14.7a	564ab

[1] Means followed by different letters differ at $P<0.05$.
[2] Unadjusted weaning weight.
[3] Grade code: 13 = average Choice; 14 = high Choice, etc.

TABLE 22. LEAST-SQUARES MEANS AND DIFFERENCES IN POSTWEANING PERFORMANCE OF STEERS FROM CROSSBRED AND PUREBRED DAMS, PHASE II

Breed of bull	Breed of cow	Steers	Weaning weight[1]	Final weight	ADG	WDA	Score[2]	Age
		No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*		*Days*
S	A x H & H x A	40	471	996	1.69	1.77	14.6	562
S	A and H	33	437	998	1.73	1.73	14.2	576
	Difference	---	34**	−2	−0.04	.04	0.4	−14
H	A x S & S x A	52	492	998	1.73	1.83	14.0	546
H	A and S	35	479	991	1.85	1.88	13.8	527
	Difference	---	13	7*	−0.12*	−0.05	0.2	19
A	H x S & S x H	50	489	994	1.68	1.75	13.8	565
A	H and S	22	442	990	1.65	1.70	14.1	584
	Difference	---	47**	4	0.03	0.05	−0.3	−19
---	Crossbred dams	142	477	996	1.70	1.79	14.1	558
---	Purebred dams	90	453	993	1.74	1.77	14.0	563
	Difference	---	24**	3	−.04	0.02	0.1	−5

[1] Unadjusted weaning weight.
[2] Grade code: 13 = average Choice; 14 = high Choice, etc.
* Significant at $P<0.05$.
** Significant at $P<0.01$.

were no significant differences in average daily gain, weight per day of age, conformation score, or age at slaughter. However, the two-breed steers sired by Hereford bulls gained significantly faster ($P<0.05$) than did the three-breed steers sired by Hereford bulls.

Means of steer post-weaning performance traits by sires are shown in Table 23. Steers sired by Hereford bulls had a higher

average daily gain and weight per day of age than did steers sired by either Angus or Shorthorn bulls. Because of their heavier weaning weights and more rapid post-weaning gains, steers by Hereford bulls were younger than steers by Angus (39 days) and Shorthorn (34 days) bulls at the slaughter weight of 1,000 pounds.

The dressing percentage for Angus x Shorthorn steers (63.3) was significantly ($P<0.05$) higher than Angus x Hereford (61.3), H x (S x A) (61.4), and Shorthorn x Hereford (61.5), Table 24. Other differences were not significant.

Carcass weight per day of age was significantly ($P<0.05$) greater for the H x A, H x S, and H x (S x A) steers than for the A x H, A x S, S x A, and A x (H x S) steers. Other differences were not significant.

TABLE 23. LEAST-SQUARES MEANS FOR POSTWEANING PERFORMANCE OF STEERS BY SIRES, PHASE II[1]

Breed of sire	Calves	Weaning weight[2]	Final weight	ADG	WDA	Score[3]	Age
	No.	*Lb.*	*Lb.*	*Lb.*	*Lb.*		*Days*
Angus	72	456	992	1.66	1.73	13.9	575
Hereford	87	486	995	1.79	1.86	13.9	536
Shorthorn	73	454	996	1.71	1.75	14.3	570

[1] Means followed by different letters differ at $P<0.05$.
[2] Unadjusted weaning weight.
[3] Grade code: 13 = average Choice; 14 = high Choice, etc.

TABLE 24. LEAST-SQUARES MEANS OF STEER CARCASS CHARACTERISTICS, PHASE II[1]

Breed of steers	Steers	Carcass weight	Dressing per cent	Carcass WDA	Fat thickness	Ribeye area	Quality grade[2]	Yield grade[3]	Tenderness score[4]
	No.	*Lb.*	*Pct.*	*Lb.*	*In.*	*Sq. In.*			
A x H	11	606	61.3b	1.05b	0.79	10.6ab	13.9ab	4.3	19.0
A x S	11	627	63.3a	1.06b	0.85	10.3ab	14.2a	4.8	19.1
H x A	19	614	61.9ab	1.16a	0.73	11.0a	13.9ab	4.0	17.4
H x S	16	613	61.9ab	1.16a	0.75	10.1b	13.0b	4.3	17.2
S x A	14	625	62.6ab	1.06b	0.87	10.5ab	15.0a	4.8	18.3
S x H	19	613	61.5b	1.08ab	0.76	9.9b	13.7ab	4.4	16.6
A x (H x S)	29	618	62.4ab	1.06b	0.76	10.7a	14.3a	4.4	16.5
A x (S x H)	21	621	62.3ab	1.14ab	0.79	10.5ab	13.1b	4.6	17.4
H x (A x S)	25	617	62.0ab	1.11ab	0.78	10.6ab	14.0ab	4.3	17.8
H x (S x A)	27	615	61.4b	1.16a	0.68	10.9a	13.4b	3.9	18.9
S x (A x H)	15	618	62.2ab	1.10ab	0.83	10.0b	14.4a	4.6	16.0
S x (H x A)	25	616	62.1ab	1.09ab	0.88	10.5ab	14.7a	4.7	16.7

[1] Means followed by different letters differ at $P<0.05$.
[2] Grade code: 13 = average Choice; 14 = high Choice, etc.
[3] The lower the yield grade the better the carcass.
[4] Warner-Bratzler shear values—lower values more tender.

The ribeye area of carcasses from Hereford x Angus, H x (S x A), and A x (H x S) were significantly larger ($P<0.05$) than the ribeye area from Shorthorn x Hereford, S x (A x H), and Hereford x Shorthorn. Other differences were not significant.

There were small but significant ($P<0.05$) differences in carcass quality grades. Shorthorn x Angus had the highest grading carcasses (15.0) and Hereford x Shorthorn the lowest (13.0). There were no significant differences in fat thickness, steak tenderness scores, or yield grades.

When all carcasses from two-breed and three-breed steers were compared, no significant differences were found in any of the traits measured, Table 25.

TABLE 25. LEAST-SQUARES MEANS AND DIFFERENCES IN CARCASS CHARACTERISTICS OF STEERS FROM CROSSBRED AND PUREBRED DAMS, PHASE II

Breed of dam	Steers	Carcass weight	Dressing per cent	Carcass WDA	Fat thickness	Ribeye area	Quality grade[1]	Yield grade[2]	Tenderness score[3]
	No.	*Lb.*	*Pct.*	*Lb.*	*In.*	*Sq. In.*			
A x H & H x A	40	617	62.2	1.10	0.86	10.3	14.6	4.7	16.4
A and H	33	619	62.1	1.07	0.82	10.2	14.4	4.6	16.6
Difference	----	—2	0.1	.03	.04	0.1	0.2	0.1	—0.2
H x S & S x H	52	620	62.4	1.10	0.78	10.6	13.7	4.5	16.9
H and S	35	617	62.3	1.06	0.82	10.5	14.0	4.5	19.0
Difference	----	3	0.1	.04	—.04	0.1	—0.1	0.0	—2.1
A x S & S x A	50	616	61.7	1.14	0.73	10.7	13.7	4.1	18.4
A and S	22	614	61.9	1.16	0.74	10.6	14.0	4.5	17.8
Difference	----	2	—0.2	—.02	—.01	0.1	—0.3	—0.4	0.6
Crossbred dams	142	617	62.1	1.11	0.79	10.5	14.0	4.4	17.2
Purebred dams	90	616	62.1	1.10	0.79	10.3	14.0	4.4	17.9
Difference	----	1	0.0	.01	.00	0.2	0.0	0.0	—0.7

[1] Grade code: 13 = average Choice; 14 = high Choice, etc.
[2] The lower the yield grade the better the carcass.
[3] Warner-Bratzler shear values—lower values more tender.

SUMMARY

Angus, Hereford, and Shorthorn beef cattle were used in a cross-breeding program from 1957 through 1967. The following results were obtained:

(1) There were no significant differences in the percentage of calves dropped or weaned by purebred cows producing purebred calves and those producing crossbred calves.

(2) There were no significant differences between reproductive performance of purebred cows producing crossbred calves and two-breed cows producing three-breed calves.

(3) Purebred Angus cows gave birth to and weaned a higher percentage of calves than either the purebred Hereford or Shorthorn cows.

(4) Angus-Shorthorn cows dropped and weaned a higher percentage of calves than either the Hereford-Shorthorn or the Angus-Hereford cows. Hereford-Shorthorn cows dropped and weaned a higher percentage of calves than did the Angus-Hereford cows.

(5) Two-breed calves gained more rapidly from birth to weaning, were heavier at 250 days of age, and had higher weaning scores than purebred calves.

(6) Three-breed calves were heavier at birth, gained more rapidly from birth to weaning, were heavier at 250 days of age, and had higher scores at weaning than did the two-breed calves.

(7) Purebred Angus cows produced calves that were lighter at birth but grew more rapidly from birth to weaning, weighed more at 250 days of age, and graded higher at weaning than the calves from either Hereford or Shorthorn cows.

(8) Hereford bulls sired calves which were heavier at birth, gained more rapidly during pre-weaning and post-weaning, and had higher weaning scores than calves sired by either Angus or Shorthorn bulls.

(9) Two-breed heifers had a higher post-weaning average daily gain while on pasture and a higher final weight per day of age than purebred heifers.

(10) Differences between post-weaning average daily gain of two-breed and three-breed heifers were not significant. However, because they were heavier at weaning, the three-breed heifers had heavier final weights.

(11) Two-breed steers gained faster during the post-weaning pasture periods and had a heavier slaughter weight and a higher final weight per day of age than the purebred steers.

(12) Differences between the post-weaning performance traits of two-breed and three-breed steers were not significant.

(13) Two-breed steers produced heavier carcasses and had a higher carcass weight per day of age than purebred steers. Differences in other carcass traits were small and non-significant.

(14) The differences between carcass traits of two-breed and three-breed steers were not significant.

LITERATURE CITED

(1) BUTLER, O. D., B. L. WARRICK, AND T. C. CARTWRIGHT. 1956. Slaughter and Carcass Characteristics of Shortfed Yearling Hereford and Brahman x Hereford Steers. J. Ani. Sci. 15:93.

(2) CARROLL, F. D., W. C. ROLLINS, AND N. R. ITTNER. 1955. Brahman x Hereford Crossbreds – Gains, Carcass Yields and Carcass Differences. J. Ani. Sci. 14:218.

(3) CLYBURN, T. M., W. C. MCCORMICK, R. L. SAFFLE, AND B. L. SOUTHWELL. 1961. Effects of Breed and Cross on Growth Rate and Carcass Characteristics of Beef Steers. J. Ani. Sci. 20:392 (Abstract).

(4) DAMON, R. A., JR., S. E. MCCRAINE, R. M. CROWN, AND C. B. SINGLETARY. 1959. Performance of Crossbred Beef Cattle in The Gulf Coast Region. J. Ani. Sci. 18:437.

(5) DAMON, R. A., JR., R. M. CROWN, C. B. SINGLETARY, AND S. E. MCCRAINE. 1960. Carcass Characteristics of Purebred and Crossbred Beef Steers in the Gulf Coast Region. J. Ani. Sci. 19:820.

(6) GAINES, J. A., W. H. MCCLURE, D. W. VOGT, R. C. CARTER, AND C. M. KINCAID. 1966. Heterosis from Crosses Among British Breeds of Beef Cattle: Fertility and Calf Performance to Weaning. J. Ani. Sci. 25:5.

(7) GAINES, J. A., G. V. RICHARDSON, W. H. MCCLURE, D. W. VOGT, AND R. C. CARTER. 1967. Heterosis from Crosses Among British Breeds of Cattle: Carcass Characteristics. J. Ani. Sci. 26:1217.

(8) GERLAUGH, PAUL, L. E. KUNKLE, AND D. C. RIFE. 1951. Crossbreeding Beef Cattle. Ohio Agr. Exp. Sta. Res. Bull. 703.

(9) GODLEY, W. C., E. G. GODBEY, E. D. KYZER, AND R. F. WHEELER. 1960. Crossbred and Purebred Dams for Production of Slaughter Calves. J. Ani. Sci. 19:203.

(10) GREGORY, K. E., L. A. SWIGER, R. M. KOCH, L. J. SUMPTION, W. W. ROWDEN, AND J. E. INGALLS. 1965. Heterosis in Preweaning Traits of Beef Cattle. J. Ani. Sci. 24:21.

(11) GREGORY, K. E., L. A. SWIGER, R. M. KOCH, L. J. SUMPTION, AND J. E. ROTHLISBERGER. 1966. Heterosis Effects on Growth Rate of Beef Heifers. J. Ani. Sci. 25:290.

(12) GREGORY, K. E., L. A. SWIGER, L. J. SUMPTION, R. M. KOCH, J. E. INGALLS, W. W. ROWDEN, AND J. A. ROTHLISBERGER. 1966. Heterosis Effects on Growth Rate and Feed Efficiency of Beef Steers. J. Ani. Sci. 25:299.

(13) GREGORY, K. E., L. A. SWIGER, L. J. SUMPTION, R. M. KOCH, J. E. INGALLS, W. W. ROWDEN, AND J. A. ROTHLISBERGER. 1966. Heterosis Effects on Carcass Traits of Beef Steers. J. Ani. Sci. 25:311.

(14) HARVEY, WALTER R. 1960. Least-Squares Analyses of Data with Unequal Subclass Numbers. USDA, ARS. 20-8.

(15) KINCAID, C. M. 1962. Breed Crosses with Beef Cattle in the South. Texas Agr. Exp. Sta. Southern Coop. Series Bull. 81.

(16) KNAPP, BRADFORD, JR., A. L. BAKER, AND R. T. CLARK. 1949. Crossbred Beef Cattle for the Northern Great Plains. USDA Cir. 810.

(17) KRAMER, C. Y. 1957. Extension of Multiple Range to Group Correlated Adjusted Means. Biom. 13:13.

(18) PAHNISH, O. F., J. S. BRINKS, J. J. URICK, W. B. KNAPP, AND T. M. RILEY. 1969. Results from Crossing Beef x Beef and Beef x Dairy Breeds: Calf Performance to Weaning. J. Ani. Sci. 28:291.

(19) PHILLIPS, RALPH W., W. H. BLACK, B. KNAPP, JR., AND R. T. CLARK. 1942. Crossbreeding for Beef Production. J. Ani. Sci. 1:23.

(20) ROLLINGS, W. C., R. G. LOY, F. D. CARROLL, AND K. A. WAGNON. 1969. Heterotic Effects in Reproduction and Growth to Weaning in Crosses of the Angus, Hereford and Shorthorn Breeds. J. Ani. Sci. 28:431.

(21) STEELE, ROBERT G. D. AND JAMES H. TORRIE. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York, N.Y.

(22) TEMPLE, R. S. AND D. D. MILLER. 1961. A Comparison of Calving Percentages and Preweaning Performance of Various Breeds of Beef Cattle in a Crossbreeding Program. J. Ani. Sci. 20:392 (Abstract).

(23) TURNER, J. W., B. R. FATHERING, AND G. L. ROBERTSON. 1968. Heterosis in Reproductive Performance of Beef Cows. J. Ani. Sci. 27:336.

(24) TURNER, J. W. AND R. P. MCDONALD. 1969. Mating-Type Comparisons Among Crossbred Beef Cattle for Preweaning Traits. J. Ani. Sci. 29:389.

(25) VOGT, D. W., J. A. GAINES, R. C. CARTER, W. H. MCCLURE, AND C. M. KINCAID. 1967. Heterosis from Crosses Among British Breeds of Beef Cattle. Postweaning Performance to Slaughter. J. Ani. Sci. 26:443.

(26) WILTBANK, J. N., K. E. GREGORY, J. A. ROTHLISBERGER, J. E. INGALLS, AND C. W. KASSON. 1967. Fertility in Beef Cows Breed to Produce Straightbred and Crossbred Calves. J. Ani. Sci. 26:1005.

APPENDIX

The mathematical model used for analysis is as follows:

$$X_{ijklmn} = \alpha + Y_i + A_j + B_k + S_l + YB_{(ik)} + YS_{(il)} + BS_{(kl)} + W/BY_{(mki)} + b_1(BD) - b_2(BD)^2 + b_3(BD)^3 + E_{ijklmn}.$$

Where:

α = the overall mean for the X_{ijklm} when equal frequencies exist in each of the subclasses and birth date equals 0.
Y_i = the effect of the i-th year.
A_j = the effect of the j-th age of dam.
B_k = the effect of the k-th breed of calf.
S_l = the effect of the l-th sex of calf.
$YB_{(ik)}$ = the effect of the interaction of the i-th year and the k-th breed of calf.
$YS_{(il)}$ = the effect of the interaction of the i-th year and the l-th sex of calf.
$BS_{(kl)}$ = the effect of the interaction of the k-th breed of calf and the l-st sex of calf.
$W/BY_{(mki)}$ = the effect of the m-th sire within the k-th breed of calf and the i-th year subclass.
b_1 = partial regression of the dependent variable (X) on the linear form of BD.
b_2 = partial regression of the dependent variable (X) on the quadratic form of BD.
b_3 = partial regression of the dependent variable (X) on the cubic form of BD.
BD = date of birth of calf.
E_{ijklmn} = the random error.

Because of computer capacity limitations, the breed of sire and breed of dam effects were analyzed using the following linear model:

$$X_{ijklmn} = \alpha + Y_i + M_j + F_k + A_l + S_m + YM_{(ij)} + YF_{(ik)} + YS_{(im)} + MF_{(jk)} + MS_{(jm)} + FS_{(km)} - b_1(BD) + b_2(BD)^2 + b_3(BD)^3 + E_{ijklmn}.$$

The components of this equation are defined as in the previous equations with the following additions:

M = the effect of the j-th breed of sire.
F = the effect of the k-th breed of dam.

Various linear functions of these subgroup least-squares means were used to determine heterotic effects of specific crosses. Standard errors of the linear functions of these means were calculated, as described by Gregory *et al. (10)* from the least-squares variance – covariance matrix for these subgroup means and from the error mean square for each trait from the analyses of variance.

A least-squares analysis of weight changes and conformation sources from weaning through both post-weaning periods was made for both heifers and steers. As a result of length of calving season and method of management during Phase I, the number of days calves were in the post-weaning pasture period depended on date of birth. Because of this varia-

tion, number of days during the pasture period and initial age of calf at beginning of feedlot period were included as dependent variables in the post-weaning analysis. The following model was used for post-weaning performance analysis:

$$X_{ijkl} = \alpha + Y_i + B_j + YB_{(ij)} + W/BY_{(mji)} + E_{ijkl}.$$

Where

Y_i = the effect of the i-th year.
B_j = the effect of the j-th breed of calf.
$YB_{(ij)}$ = the effect of the interaction of the i-th year and the j-th breed of calf.
$W/BY_{(mji)}$ = the effect of the m-th sire within the k-th breed of calf and the i-th year subclass.
E_{ijkl} = the random error.

The results of the analyses are summarized in Appendix Tables 1 through 10.

APPENDIX TABLE 1. LEAST-SQUARES CONSTANTS FOR AGE OF DAM AND SEX OF CALF AND REGRESSIONS ON DATE OF BIRTH, PHASE I

Effect	Birth weight	250-Day weight	Daily gain, Birth—250 days
Age of dam[1]			
3	—8.01	—47.63	—0.158
4	—3.58	—14.92	—0.045
5	0.17	— 4.25	—0.018
6	—0.33	— 2.15	—0.008
7	1.33	13.30	0.049
8	0.14	— 1.72	—0.008
9	—0.73	8.13	0.034
10	2.46	28.04	0.102
11 & older	8.55	21.18	0.051
Sex of calf			
Heifer	—1.03	—13.64	—0.050
Steer	1.03	13.64	0.050
Regression on date of birth			
Linear	0.00086593	0.03285865	0.00012377
Quadratic	—0.00016739	0.00942919	0.00003829
Cubic	0.00000881		—0.00000025
Average	65.39	454.63	1.557

[1] Age of dam expressed in years.

APPENDIX TABLE 2. MEAN SQUARES OF PREWEANING TRAITS, PHASE I

Source of variation	d.f.	Birth weight	250-day ADG	250-day weight	Weaning score
Year	4	232**	0.152**	10863**	26.84**
Age of dam	8	135*	0.047	4187*	2.73
Breed	8	433**	0.130**	9427**	3.96**
Sex	1	147*	0.356**	25957**	0.02
Year x breed	32	66	0.021	1521	1.62
Year x sex	4	83	0.022	1121	3.85**
Breed x sex	8	39	0.041	2995	0.92
Sire/(year x breed)	43	83*	0.015	1247	0.83
Regression on date of birth					
Linear	1	0	0.001	74	5.50**
Quadratic	1	1	0.069*	4235	1.82
Cubic	1	52	0.043	2010	1.46
Error	140	54	0.030	2145	1.45

* $P<0.05$.
** $P<0.01$.

APPENDIX TABLE 3. MEAN SQUARES FOR HEIFER POSTWEANING PERIODS FROM LEAST-SQUARES ANALYSES, PHASE I

Source of variation	d.f.	Initial age	Days on pasture	Days in feedlot	Final age
Breed	8	548	600	0	459
Year	4	3958**	3937**	397**	4830**
Breed x year	27	969	954	0	1185
Sire/(breed x year)	22	1319	1287	0	1319
Error	56	882	905	0	883

** $P<0.01$.

APPENDIX TABLE 4. MEAN SQUARES FOR STEER POSTWEANING PERIODS FROM LEAST-SQUARES ANALYSES, PHASE I

Source of variation	d.f.	Initial age	Days on pasture	Days in feedlot	Final age
Breed	8	1039	1087	167	1640
Year	4	6278**	6069**	15214**	3430**
Breed x year	30	912	911	95	941
Sire/(breed x year)	30	1221*	1239*	69	1384*
Error	49	694	655	145	790

* $P<0.05$.
** $P<0.01$.

APPENDIX TABLE 5. MEAN SQUARES FOR CARCASS CHARACTERISTICS, PHASE I

Source of variation	d.f.	Dressing per cent	Carcass WDA	Fat thickness	Ribeye area	Quality grade	Shear value
Breed	8	3.425	0.033**	0.176**	1.370	6.051**	17.854
Year	4	3.587	0.093**	0.725**	13.393**	6.261**	23.054
Year x breed	30	1.050	0.009	0.667**	1.778	1.607	11.777
Sire/(year x breed)	30	1.347	0.007	0.018	1.278	0.847	14.418
Error	48	2.043	0.007	0.013	1.245	1.347	21.948

* P<0.01.
** P<0.05.

APPENDIX TABLE 6. LEAST-SQUARES CONSTANTS FOR AGE OF DAM AND SEX OF CALF AND REGRESSIONS ON DATE OF BIRTH, PHASE II

Effect	Birth weight	250-day weight	Daily gain, birth—250 days
Age of dam[1]			
3	−4.59	−30.72	−0.105
4	−0.43	− 9.17	−0.035
5	0.17	8.61	0.034
6	2.57	10.00	0.029
7	0.85	11.69	0.043
8	1.27	10.90	0.040
9	0.26	− 3.98	−0.017
10	−0.11	2.64	0.011
Sex of calf			
Heifer	−1.80	−16.15	−0.058
Steer	1.80	16.15	0.058
Regression on date of birth			
Linear	−0.01689012	0.66272819	0.00274906
Quadratic	0.00121071	−0.00591787	−0.00002929
Cubic	−0.00000849	0.00002720	0.00000015
Average	65.55	454.88	1.558

[1] Age of dam expressed in years.

APPENDIX TABLE 7. MEAN SQUARES OF PREWEANING TRAITS, PHASE II

Source of variation	d.f.	Birth weight	250-day ADG	250-day weight	Weaning score
Year	6	49	0.136**	7976**	42.32**
Age of dam	7	221**	0.124**	10185**	4.92**
Breed	11	512**	0.338**	26096**	5.56**
Sex	1	1169**	1.195**	93937**	0.33
Year x sex	6	51	0.014	864	4.80**
Year x breed	65	54	0.020	1350	1.55
Breed x sex	11	58	0.018	1242	1.19
Sire/(year x breed)	54	83	0.024	1847	1.25
Regression on date of birth					
Linear	1	13	0.338**	19627**	21.80**
Quadratic	1	72	0.042	1722	7.77*
Cubic	1	50	0.015	508	5.56*
Error	307	64	0.025	1824	1.34

* P<0.05.
**< P0.01.

APPENDIX TABLE 8. MEAN SQUARES FOR HEIFER POSTWEANING PERFORMANCE, PHASE II

Source of variation	d.f.	Days on pasture	Pasture ADG	Feedlot ADG	Final weight	Final WDA
Breed	11	853	0.449	0.092	15136**	0.078**
Year	6	20790**	1.465*	2.354**	29184**	0.047*
Breed x year	60	627	0.784	0.057	2960	0.019
Sire/(year x breed)	41	486	0.743	0.054	3713	0.021
Error	117	535	0.562	0.048	3300	0.019

* $P<0.05$.
** $P<0.01$.

APPENDIX TABLE 9. MEAN SQUARES FOR STEER POSTWEANING PERFORMANCE, PHASE II

Source of variation	d.f.	Average daily gain	Final weight	Final WDA	Conformation score
Breed	11	0.118**	225	0.083**	3.38**
Year	6	0.460**	391*	0.359**	10.53**
Breed x year	56	0.055	262**	0.030	1.63
Sire/(year x breed)	41	0.052	323**	0.030	1.25
Error	117	0.041	151	0.027	1.34

* $P<0.05$.
** $P<0.01$.

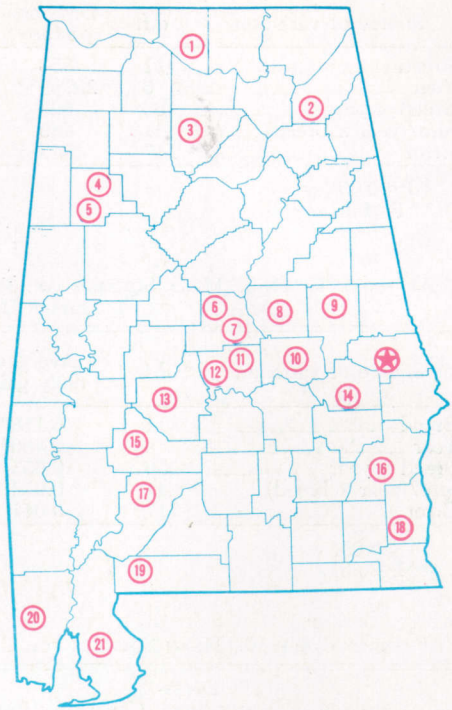
APPENDIX TABLE 10. MEAN SQUARES FOR CARCASS CHARACTERISTICS, PHASE II

Source of variation	d.f.	Dressing per cent	Carcass WDA	Fat thickness	Ribeye area	Quality grade	Yield grade[1]	Shear value[1]
Breed	11	0.820	0.026*	0.054	1.703**	4.858**	1.02	12.3
Year	6	1.081	0.132**	0.226**	3.346**	6.162**	2.93**	20.3
Year x breed	56	0.570	0.011	0.077*	0.885	1.393	0.99*	11.9
Sire/(year x breed)	41	0.529	0.010	0.041	0.789	1.276	0.54	10.4
Error	116	0.551	0.009	0.052	0.672	1.426	0.70	9.9

[1] Yield grade and shear values not obtained for 1961.
* $P<0.05$.
** $P<0.01$.

AGRICULTURAL EXPERIMENT STATION SYSTEM OF ALABAMA'S LAND-GRANT UNIVERSITY

With an agricultural research unit in every major soil area, Auburn University serves the needs of field crop, livestock, forestry, and horticultural producers in each region in Alabama. Every citizen of the State has a stake in this research program, since any advantage from new and more economical ways of producing and handling farm products directly benefits the consuming public.



Research Unit Identification

★ Main Agricultural Experiment Station, Auburn.

1. Tennessee Valley Substation, Belle Mina.
2. Sand Mountain Substation, Crossville.
3. North Alabama Horticulture Substation, Cullman.
4. Upper Coastal Plain Substation, Winfield.
5. Forestry Unit, Fayette County.
6. Thorsby Foundation Seed Stocks Farm, Thorsby.
7. Chilton Area Horticulture Substation, Clanton.
8. Forestry Unit, Coosa County.
9. Piedmont Substation, Camp Hill.
10. Plant Breeding Unit, Tallassee.
11. Forestry Unit, Autauga County.
12. Prattville Experiment Field, Prattville.
13. Black Belt Substation, Marion Junction.
14. Tuskegee Experiment Field, Tuskegee.
15. Lower Coastal Plain Substation, Camden.
16. Forestry Unit, Barbour County.
17. Monroeville Experiment Field, Monroeville.
18. Wiregrass Substation, Headland.
19. Brewton Experiment Field, Brewton.
20. Ornamental Horticulture Field Station, Spring Hill.
21. Gulf Coast Substation, Fairhope.