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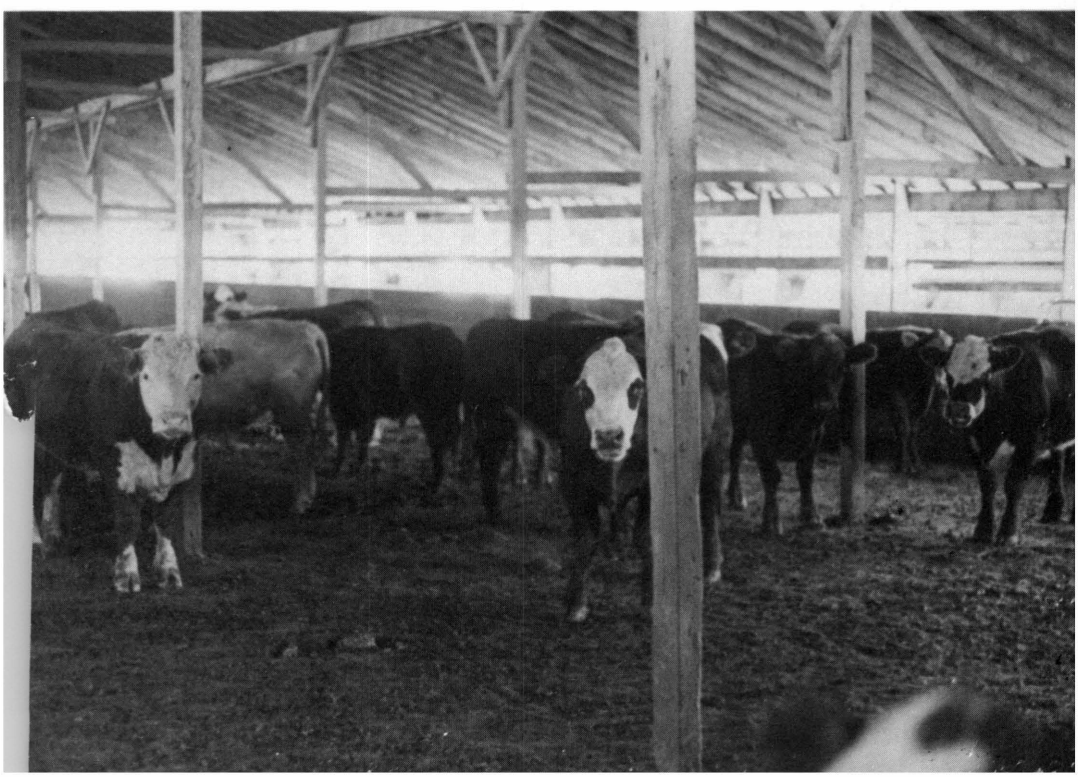

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The Virginia Agricultural and Mechanical College came into being in 1872 upon acceptance by the Commonwealth of the provisions of the Morrill Act of 1862 "to promote the liberal and practical education of the industrial classes in the several pursuits and professions of life." Research and investigations were first authorized at Virginia's land-grant college when the Virginia Agricultural Experiment Station was established by the Virginia General Assembly in 1886.

The Virginia Agricultural Experiment Station received its first allotment upon passage of the Hatch Act by the United States Congress in 1887. Other related Acts followed, and all were consolidated in 1955 under the Amended Hatch Act which states "It shall be the object and duty of the State agricultural experiment stations . . . to conduct original and other researches, investigations and experiments bearing directly on and contributing to the establishment and maintenance of a permanent and effective agricultural industry of the United States, including the researches basic to the problems of agriculture and its broadest aspects and such investigations as have for their purpose the development and improvement of the rural home and rural life and the maximum contributions by agriculture to the welfare of the consumer . . . "

In 1962, Congress passed the McIntire-Stennis Cooperative Forestry Research Act to encourage and assist the states in carrying on a program of forestry research, including reforestation, land management, watershed management, rangeland management, wildlife habitat improvement, outdoor recreation, harvesting and marketing of forest products, and "such other studies as may be necessary to obtain the fullest and most effective use of forest resources."

In 1966, the Virginia General Assembly "established within the Virginia Polytechnic Institute a division to be known as the Research Division . . . which shall encompass the now existing Virginia Agricultural Experiment Station . . . "

HETEROSIS FROM CROSSES AMONG BRITISH BREEDS OF BEEF CATTLE: STRAIGHTBRED VERSUS CROSSBRED COWS[1]

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ABSTRACT

The second phase of a long-term beef cattle crossbreeding experiment involving the Angus, Hereford and Shorthorn breeds was conducted at the Shenandoah Valley Research Station, Steeles Tavern, Virginia. Records of 604 matings and 567 births from 120 cows were collected over five successive calf crops. Comparisons were made between crossbred and straightbred dams, backcross and three-breed cross calves, three breeds of straightbred cows, six kinds of crossbred cows, various combinations within the backcross and three-breed cross calves, and the general combining abilities of the three breeds. Calves from crossbred cows were heavier at birth and weaning, and had higher weaning grades. Crossbred cows were 31.9 kg heavier than straightbred cows. There were 2.0% more calves born, but 0.2% fewer calves weaned from the crossbred cows. Crossbred cows weaned more kg of calf per year, but fewer units of calf per 100 units of cow, and fewer units of calf per 100 units of cow per cow year. There were increases of three-breed cross over backcross calves for all measures of growth, leading to the conclusion that three-breed crossing would increase production over backcrossing. Differences existed among the three breeds of cows for every calf performance trait, and for cow weight. Differences were found among the kinds of crossbred cows for all calf traits. Crossbred cows out of Hereford dams excelled over the reciprocal matings. The breeds did not differ in general combining ability.

INTRODUCTION

An experiment to estimate heterosis from crossing the Angus, Hereford, and Shorthorn breeds was started at the Virginia Agricultural Experiment Station in 1954. Previous papers have reported the results of the first phase of the experiment involving five calf crops born from 1957 through 1961. This bulletin reports the results through weaning of the second phase of the experiment which involved five calf crops born from 1963 through 1967. The primary objective was to arrive at estimates of heterosis for maternal performance when crossing the three breeds. Other objectives were to compare the performance of backcross and three-breed cross calves and to evaluate various breed combinations and general combining ability differences. Cow size was studied and an analysis made in order to estimate the percentage of the increased performance of the calf that was due to increased cow size.

MATERIALS AND METHODS

The accurate evaluation of heterosis for maternal performance involves making comparisons free from any confounding of genetic effects in the calf. These comparisons were made according to the mating design shown in Table 1, which gives the theoretical number of cows assigned to each pair of bulls each year, and shows that all calves were crossbreds, either backcrosses or three-breed crosses. There were 616 mating opportunities over the five years. Each year the breeding herd was randomly assigned to pairs of bulls to make up the numbers shown in Table 1.

Cows. One-half of the cow herd was crossbreds (reciprocal two-breed) and the other half straightbreds (of the Angus, Hereford, and Shorthorn breeds). These crosses resulted from contract matings made with six cattle breeders, two for each breed. In each herd, half the cows, chosen at random were mated to bulls of a different breed and the other half to bulls of their same breed, and a minimum of ten crossbred and ten straightbred heifers were purchased. The herds were high grade (but non-pedigreed) and believed to be representative of the commercial beef cow herds in Virginia.

Bulls. Most of the bulls were produced at the Beef Cattle Research Station (BCRS), Front Royal. Some, however,

were produced in Blacksburg and several were purchased from private breeders. All of them had completed a 168-day postweaning performance feeding test at the BCRS, Front Royal, and those selected for breeding were as close to the average of the breed as practical for conformation score and weight gain during the 168-day performance test. All bulls were two-year-olds, and all were changed each year. Two bulls were alternated every three weeks within each of the six breeding groups.

Management. Throughout the experiment, management was comparable with that of a commercial operation. No special practices were followed except for implementation of a specific weighing and grading schedule. The cows were bred to calve first as three-year-olds. Pasture breeding and calving programs were used with an early spring calving

TABLE 1. MATING DESIGN SHOWING THEORETICAL NUMBER OF COWS ASSIGNED TO EACH PAIR OF BULLS EACH YEAR

Bulls[a]	Cows[a]					
	A	H	S	AxH	AxS	HxS
A				5	5	10
H				5	10	5
S				10	5	5
AxH	5	5	10			
AxS	5	10	5			
HxS	10	5	5			
Backcross	10	10	10	10	10	10
3-way cross	10	10	10	10	10	10
Total	20	20	20	20	20	20

[a]A = Angus, H = Hereford, S = Shorthorn. Crossbred parent could be of either reciprocal mating.

schedule (most calves were born in February and March). Within 24 hours after birth, calves were ear-tagged and weighed. During the pre-weaning period, all cows and calves were grazed on permanent bluegrass-white clover pasture. Care was taken to avoid confounding of genetic and management effects in the pasture utilization. All calves were weaned, weighed, and graded in October every year. Feeder calf grade was the average of the scores of at least three graders using federal-state standards. Cows were culled if diagnosed open in the fall after failing to calve the previous spring, or if they sustained some type of permanent physical damage.

Analysis of Data. All analyses were conducted using the Least-squares and Maximum Likelihood General Purpose Program of Harvey (1968). Preliminary analyses were made to

TABLE 2. BIRTH WEIGHT MEANS AND STANDARD ERRORS (kg)

Source[a]	No.	Model A	Model B
SB cows	272	32.25 ± 0.21	32.45 ± 0.21
CB cows	273	33.15 ± 0.21	32.91 ± 0.22
BC calves	265	32.66 ± 0.22	32.62 ± 0.21
3BC calves	280	32.74 ± 0.21	32.75 ± 0.21
GCA Angus	96	31.12 ± 0.46	31.12 ± 0.45
GCA Hereford	87	33.78 ± 0.47	33.81 ± 0.46
GCA Shorthorn	85	33.09 ± 0.47	32.92 ± 0.46

[a]SB = straightbred, CB = crossbred, BC = backcross, 3BC = three breed cross, GCA = general combining ability.

test thirteen two-factor interactions. Only those with an F-ratio greater than one were included in the final analyses.

Because a detailed description of the six models used in this study would be too lengthy, we will present only a summary. Model A (Table 3) included comparisons of straightbred vs crossbred cows (type of dam), breeds within straightbred cows, two breed crosses within crossbred cows (kind/CB), backcross calves vs 3-breed cross calves (mating system), backcross calves within backcross types (kind/BC), 3-breed cross calves within 3-breed cross types (kind/3BC), general combining ability of the three breeds in backcross

TABLE 3. ANALYSES OF VARIANCE OF BIRTH WEIGHT

Source[a]	D.F.[b]	Model A MS	Model A F	Model B MS	Model B F
SB vs CB cows (D)	1	110.76	9.07**	24.85	2.11
Breed/SB cows	2	53.78	4.41*	15.76	1.34
Kind/CB cows	2	35.63	2.92	25.55	2.17
BC vs 3BC calves (M)	1	0.73	0.06	2.15	0.18
Kind/BC calves	2	0.81	0.07	2.85	0.24
Kind/3BC calves	2	49.69	4.07*	50.18	4.26*
GCA/BC	2	92.73	7.60**	90.16	7.69**
Years (Y)	4	273.33	22.39**	230.48	19.56**
Sex (S)	1	480.16	39.33**	538.43	45.70**
D x Y	4	11.01	0.90	10.97	0.93
M x Y	4	22.50	1.84	21.44	1.82
Y x S	4	15.78	1.29	14.16	1.20
b (cow wt.)[c]	(1)			231.44	19.64**
Remainder	(514)515	12.21		11.78	
Total	545				

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

[a]SB = straightbred, CB = crossbred, BC = backcross, 3BC = three-breed cross

[b]Values in parentheses are for the analysis that included cow weight.

[c]Linear.

combinations, (GCA/BC), year - age of dam - parity, sex of calf, type of dam (D) by year (Y) interaction, system of mating (M) by year (Y) interaction, sex of calf (S) by year (Y)interaction, and regression on calf's age in days. Model B was the same as Model A except it included the regression on cow weight taken at approximately six weeks after weaning the calf. In an effort to further study the effect of cow weight and to separate the reciprocal crosses, Models C and D (Table 4) were applied to the two subsets composed of data from straightbred and crossbred cows. Model C included comparisons of breeds or crosses of dams (kind of cow), system of mating (M), year-age of dam-parity (Y), sex of calf (S), sex of calf by year, and system of mating by year; Model D included all of these plus the regression on cow weight. With the four models just mentioned, the dependent variables were data taken on the calves. With Models E and F, the dependent variable was unadjusted cow weight; main effects in Model E (Table 12) were straightbred or crossbred cow (D), breeds within straightbred cows, two-breed crosses within crossbred cows (kind/CB), year-age of dam-parity, and type of cow by year interaction (to test for possible differences in rate of maturity between the straightbred and crossbred cows). Model F was applied to subsets the same as Models C and D, to get a within-type-of-cow variance estimate that was free of year and breeding effects. Comparisons of the error mean squares were expected to provide information on the variability of weight of

TABLE 4. ANALYSES OF VARIANCE OF BIRTH WEIGHT

Source[a]	D.F.	Straightbred cows				Crossbred cows			
		Model C		Model D		Model C		Model D	
		MS	F	MS	F	MS	F	MS	F
Kind of cow	2[b]	213.35	17.84**	63.45	5.65*	55.38	4.50*	48.57	3.96**
BC vs 3BC calves (M)	1	7.14	0.59	21.23	1.89	5.71	0.38	6.23	0.51
Years (Y)	4	149.97	12.29**	136.84	12.18**	131.23	10.66**	108.90	8.88**
Sex (S)	1	264.61	21.68**	327.20	29.12**	248.15	20.16**	258.64	21.09**
M x Y	4	20.48	1.68	13.19	1.17	13.36	1.09	14.74	1.20
Y x S	4	11.98	0.98	9.23	0.82	21.89	1.78	22.06	1.80
b (cow wt.)[c]	(1)			257.51	22.92**			22.55	1.84
Remainder	(254)255[d]	12.20		11.24		12.31		12.27	
Total	272/273								

*P < .05; **P < .01.
[a]BC = backcross, 3BC = three-breed cross.
[b]CB cows = 5.
[c]Linear.
[d]CB cows = (252)253.

straightbred and crossbred cows. The main effects in Model F were kind of cow (breeds in the straightbred cow subset and crosses in the crossbred cow subset), year-age of dam-parity, and kind of cow by year interaction.

Chi-square analysis was used to test for differences in numbers of calves born and weaned.

RESULTS AND DISCUSSION

Birth Weight. Table 2 shows the means and standard errors of birth weight from Models A and B. With Model A, the calves from crossbred cows averaged 0.90 kg (2.8%) heavier than those from straightbred cows ($P<.01$). The difference between calves from crossbred cows and calves from straightbred cows was reduced to 0.46 kg (1.4%) with Model B. Thus, it appears that half of the increase is associated with the larger weight of the crossbred cow. The small differences of .08 kg and .13 kg between backcross (BC) and three-breed cross (3BC) calves were not significant, indicating that the 3BC calves did not show sufficient increased heterosis to be of concern when considering the two breeding plans. With respect to general combining ability (GCA), the Hereford breed ranked slightly higher (0.69 kg) than the Shorthorn and definitely higher (2.66 kg) than the Angus.

Tables 3 and 4 show the analyses of variance for Models A, B, C, and D. In Table 3, the most striking difference between the two analyses is in the mean squares for straightbred vs crossbred cows. A similar reduction occurred in the mean square for breed of cow within straight breeds for Model A and B, and for Models C and D with straightbred cows (Table 4).

Sex and year were the two largest sources of variation in all of the analyses. In Table 3, with Model B (b = .014 ± .003), and Table 4 with Model D, straightbred cows (b = .022 ± .005), the linear regression of birth weight on cow weight was highly significant (P<.01). In Table 4, Model D, crossbred cows, the regression (b = .007 ± .005) was significant at P<.10, showing the effect of cow weight was larger within the straightbred cows than within the crossbred cows. The birth weight means in kg from Model D, Table 4 were: Angus, 31.3; Hereford, 33.1; Shorthorn, 32.3; H x A, 34.4; H x S, 34.0; S x H, 33.1; S x A, 32.7; A x S, 32.0; and A x H, 31.9. Later sections will discuss cow weight in more detail.

Weaning Weight. Table 5 shows the means and standard errors of weaning weight resulting from Models A and B.

TABLE 5. WEANING WEIGHT MEANS AND STANDARD ERRORS (kg)

Soruce[a]	No.	Model A	Model B
SB cows	260	198.65 ± 1.15	199.40 ± 1.17
CB cows	253	206.81 ± 1.17	205.99 ± 1.19
BC calves	252	200.27 ± 1.17	200.14 ± 1.15
3BC calves	261	205.19 ± 1.15	205.25 ± 1.14
GCA Angus	93	197.98 ± 2.48	197.65 ± 2.45
GCA Hereford	85	203.59 ± 2.51	203.43 ± 2.47
GCA Shorthorn	76	199.24 ± 2.58	199.34 ± 2.55

[a]SB = straightbred, CB = crossbred, BC = backcross, 3BC = three-breed cross, GCA = general combining ability.

With Model A the calves from crossbred cows averaged 8.16 kg (4.1%) heavier at weaning than those from straightbred cows ($P<.01$). The difference between calves from crossbred cows and calves from straightbred cows was reduced to 6.59 kg (3.3%) with Model B ($P<.01$); in this case 81% of the increase in weaning weight was due to heterosis in the cow on a weight constant basis. Cundiff et al. (1974) reported a similar advantage (4.99%) in weaning weight of calves from crossbred cows. The 3BC calves averaged 5.0 kg (2.5%) heavier than the BC calves ($P<.01$), similar to many other reports. GCA did not appear to be a significant source of variation in weaning weight.

Tables 6 and 7 show the analyses of variance for Models A, B, C and D. In Table 6, holding cow weight constant (Model B) changed the results somewhat, but not conclusively. Both tables show an increase in breed of cow differences (within the straight breeds) when the breeds were compared on an equal cow weight basis (Model B). The breed means from Model C ranked Angus (204.3 kg), Shorthorn (199.2 kg), and Hereford (191.3 kg). The Angus is the lightest breed of cow, and the Hereford is the heaviest, so holding cow weight constant would increase the differences in the means. The superiority of the Angus cow in producing heavy calves at weaning has been mentioned in several experiments, among them Gerlaugh et al. (1951), Gregory et al. (1965), Gaines et al. (1966), Rollins et al. (1969). Table 6 shows that the interaction of mating system with

years was significant. Inspection of the means showed that in three of the five years the 3BC calves were definitely heavier, and in the other two years (1963 and 1965) BC calves and 3BC calves had very similar weaning weights.

In Table 6, with Model B, the quadratic effect of age of calf in days was found to provide the best fitting curve. Within the crossbred cows (Table 7, Models C and D), however, the regression coefficients were about equal with b = 0.40 kg; even when the quadratic effect was significant, its regression coefficient was quite small.

TABLE 6. ANALYSES OF VARIANCE OF WEANING WEIGHT (kg)

Source[a]	D.F.[b]	Model A MS	Model A F	Model B MS	Model B F
SB vs CB cows (D)	1	8,331	24.9**	4,789	14.7**
Breed/SB cows	2	3,775	11.3**	4,506	13.8**
Kind/CB cows	2	2,131	6.4**	2,114	6.5**
BC vs 3BC calves (M)	1	3,032	9.1**	3,279	10.1**
Kind/BC calves	2	455	1.4	480	1.5
Kind/3BC calves	2	367	1.1	475	1.4
GCA/BC	2	392	1.2	401	1.2
Years (Y)	4	20,889	62.4**	13,873	42.6**
Sex (S)	1	14,866	44.4**	15,927	48.9**
D x Y	4	798	2.4[c]	720	2.2[c]
M x Y	4	1,176	3.5**	1,045	3.2*
Y x S	4	424	1.3	468	1.4
b (age of calf)[d]	1	17,230	51.5**	17,596	54.0**
b (age of calf)[e]	1	1,562	4.7*	1,802	5.5*
b (cow wt.)[d]	(1)			1,792	5.5*
b (cow wt.)[e]	(1)			3,514	10.8**
Remainder	(479)481	335		326	
Total	513				

*P <.05; **P < .01.
[a]SB = straightbred, CB = crossbred, BC = backcross, 3BC = three-breed cross, GCA = general combining ability.
[b]Values in parentheses are for the analysis that included cow weight.
[c]P < .10.
[d]Linear.
[e]Quadratic.

Table 6, with Model B, shows that the linear regression on cow weight (b = .041 ± .018) was significant (P<.05). Table 7, Model D, shows the significant effect to be in the straightbred cows (b = .095 ± .026), with little or no effect in the crossbred cows (b = -.029 ± .030). Several estimates of regression coefficients from straightbred cows are available in the literature, and a range of b = .05 to .10 kg has been reported by Benyshek and Marlowe (1973).

Finally, Table 7 shows that kind of crossbred cow was a highly significant source of variation. The means, comparing reciprocal crosses, showed the following (sire of the cow listed first in each case): calves out of A x H cows (213.8 kg) were 12.7 kg heavier than those from H x A cows (201.1 kg); calves out of S x H cows (210.5 kg) were 18.8 kg heavier than those from H x S cows (191.7 kg); and calves from S x A cows (218.4 kg) were 6.5 kg heavier than those from A x S cows (211.9 kg). The differences between reciprocal crosses appear to be real.

Feeder Grade at Weaning. Table 8 shows the means and standard errors of weaning grade resulting from Models A and B, and Table 9 shows the corresponding analyses of variance. There are a number of statistical significances between the means in Table 8, but the differences are not large enough to be of any practical significance. Tables 9 and 10, straightbred cows, show breed of cow to be a highly significant source of variation. Calves from Angus cows (Model A) graded 0.4 points higher than those from Shorthorn

TABLE 7. ANALYSES OF VARIANCE OF WEANING WEIGHT (kg)

Source[a]	D.F.	Straightbred cows				Crossbred cows			
		Model C		Model D		Model C		Model D	
		MS	F	MS	F	MS	F	MS	F
Kind of cow	2[b]	3,848	12.7**	5,840	20.4**	4,191	13.0**	3,607	11.6**
BC vs 3BC (M)	1	2,296	7.6**	3,101	10.8**	1,506	4.7*	1,552	5.0*
Years (Y)	4	11,497	38.0**	6,029	21.1**	9,299	28.8**	8,358	26.8**
Sex (S)	1	8,501	28.1**	9,573	33.4**	5,517	17.1**	5,526	17.7**
M x Y	4	634	2.1[c]	544	1.9	745	2.3[c]	699	2.2*
Y x S	4	1,292	4.3**	1,098	3.8**	224	0.7	171	0.5
b (calf age)[d]	1	10,731	35.5**	10,714	37.4**	9,707	30.1**	9,134	29.3**
b (calf age)[e]	1	1,273	4.2*	1,504	5.2*				
b (cow wt.)[d]	(1)			4,154	14.5**			283	0.9
b (cow wt.)[e]	(1)							2,046	6.6*
Remainder	(240)241[f]	302		286		323		312	
Total	260/253								

*P < .05; **P < .01.
[a]BC = backcross, 3BC = three-breed cross.
[b]CB cows = 5.
[c]P < .10.
[d]Linear.
[e]Quadratic.

TABLE 8. MEANS AND STANDARD ERRORS OF WEANING GRADE[a]

Source[b]	No.	Model A	Model B
SB cows	260	12.0 ± 0.1	12.0 ± 0.1
CB cows	253	12.2 ± 0.1	12.3 ± 0.1
BC calves	252	12.1 ± 0.1	12.1 ± 0.1
3BC calves	261	12.1 ± 0.1	12.1 ± 0.1
GCA Angus	93	12.0 ± 0.2	12.0 ± 0.2
GCA Hereford	85	12.4 ± 0.2	12.3 ± 0.2
GCA Shorthorn	76	12.0 ± 0.2	12.0 ± 0.2

[a]Grade code: Low Choice, 12; Choice, 13.
[b]SB = straightbred, CB = crossbred, BC = backcross, 3BC = three-breed cross, GCA = general combining ability.

TABLE 9. ANALYSES OF VARIANCE OF WEANING GRADE

Source[a]	D.F.[b]	Model A MS	Model A F	Model B MS	Model B F
SB vs CB cows (D)	1	8.7	5.7*	9.8	6.5*
Breed/CB cows	2	24.4	16.0**	20.1	12.3**
Kind/CB cows	2	3.6	2.3[c]	3.7	2.5[c]
BC vs 3BC calves (M)	1	0.1	0.1	0.1	0.1
Kind/BC calves	2	4.4	2.9[c]	5.1	3.4[c]
GCA/BC	2	1.7	1.1	1.5	1.0
Kind/3BC calves	2	13.7	9.0**	14.7	9.7**
Years (Y)	4	10.2	6.7**	11.3	7.5**
Sex (S)	1	1.2	0.7	1.0	0.7
D x Y	4	6.1	4.0**	6.6	4.4**
M x Y	4	4.1	2.7*	3.8	2.5*
Y x S	4	1.7	1.1	1.6	1.1
b (age of calf)[d]	1	2.9	1.9	2.6	1.7
b (cow wt.)[d]	(1)			2.0	1.3
b (cow wt.)[e]	(1)			9.7	6.4*
Remainder	(480)482			1.5	
Total	513				

*P < .05; **P < .01.
[a]SB = straightbred, CB = crossbred, BC = backcross, 3BC = three-breed cross, BCA = general combining ability.
[b]Values in parentheses are for the analysis that included cow weight.
[c]P < .10. [d]Linear. [e]Quadratic.

TABLE 10. ANALYSES OF VARIANCE OF WEANING GRADE

Source[a]	D.F.	Straightbred cows				Crossbred cows			
		Model C		Model D		Model C		Model D	
		MS	F	MS	F	MS	F	MS	F
Kind of cow	2[b]	27.5	20.1**	17.9	13.4**	22.9	14.8**	20.9	13.7**
BC vs 3BC (M)	1	0.9	0.7	0.9	0.7	0.7	0.5	1.2	0.8
Years (Y)	4	5.9	4.5**	5.5	4.1**	9.0	5.8**	10.9	7.2**
Sex	1	0.1	0.1	0.1	0.1	0.6	0.4	0.2	0.1
M x Y	4	2.6	2.0[c]	2.6	2.0[c]	3.4	2.2[d]	3.6	2.3[d]
b (calf age)[e]	1	1.0	0.8	1.0	0.8	1.4	0.9	0.7	0.4
b (cow wt.)[e]	(1)			0.1	0.1			7.7	5.1*
Remainder	(241)242[f]			1.3				1.5	
Total	260/253[f]								

**P < .01.
[a]BC = backcross, 3BC = three-breed cross.
[b]CB cows = 5
[c]P < .10.
[d]P < .10.
[e]Linear.
[f]CB cows = (231) 232.
[g]SB = 260 and CB = 253.

cows, and 1.5 points higher than those from Hereford cows. These results are similar to those for weaning weight, and support the statement that the calves that grew fastest also graded highest. Table 9 also shows differences between crosses within three-breed crosses to be highly sigificant. Inspection of the means showed 1/2 Hereford (12.5) and 1/2 Shorthorn (12.6) calves one grade point above 1/2 Angus calves (11.4). In this comparison, the breed which represents one-half of the genotype was the purebred parent, either sire or dam, whereas the breed-of-cow effect mentioned previously averaged the results of the breeds as straightbred cows.

Table 10, crossbred cows, shows the kind of crossbred cow source to be highly significant, showing again the same pattern between reciprocal crosses as was shown for weaning weight.

Cow Weight. The cows all calved first as three-year-olds in 1963. The weights reported here are the three- through seven-year-old weights for the herd (five successive calf crops). All weights were taken approximately six weeks after calf weaning. The means in Table 11 show that over the five-year period crossbred cows averaged 31.9 kg heavier than straightbred cows. The analysis of variance (Table 12) shows that this difference was highly significant ($P<.01$), and remained relatively constant during the five years.

Knapp et al. (1949) reported that, at five years of age, crossbred cows averaged approximately 45 kg heavier

TABLE 11. MEANS AND S.E. OF COW WEIGHT (kg) - MODEL E

Year	Straightbred cows			Crossbred cows		
	No.	Mean	S.E.	No.	Mean	S.E.
1963	58	415.7	5.8	56	442.5	5.9
1964	55	422.1	5.9	58	449.8	5.8
1965	57	448.4	5.8	54	489.1	6.0
1966	54	456.9	6.0	52	486.7	6.1
1967	48	488.3	6.4	53	522.9	6.1
Total	272	446.3	2.7	273	478.2	2.7

than straightbred cows of the Angus, Hereford, and Shorthorn breeds. Cundiff (1974b) reported that at six to nine years of age, crosses of Angus, Hereford, and Shorthorn cattle averaged 21.6 kg heavier than the straightbreds. The value of 31.9 kg in this study falls between these. Cundiff reported, further, that when condition score was held constant, the difference dropped 12.5 kg. No condition scores were available on the cows in this study.

Breed effects on cow weight within the straightbred cows were highly significant ($P<.01$) with Model E (Table 12) and also with Model F, straightbred cows (Table 13). The Herefords averaged 486.2 kg, the Angus 437.4 and the Shorthorns 414.7 (Table 14). Similarly, kind of cow effects within the crossbred cows were highly significant ($P<.01$) with Model E and Model F, crossbred cows. The means in Table 15 show that S x A cows were the heaviest (501.3 kg)

TABLE 12. ANALYSIS OF VARIANCE OF COW WEIGHT - MODEL E

Source [a]	D.F.	M.S.	F
Years (Y)	4	101,405	52.3**
SB vs CB cows (D)	1	136,959	70.6**
Breed/SB cows	2	117,770	60.8**
Kind/CB cows	5	42,704	22.0**
Y x D	4	921	0.5
Remainder	528	1,939	
Total	545		

**P < .01).
[a]SB = straightbred, CB = crossbred.

and A x S cows were the lightest (425.5 kg) of the crossbred groups. The means in Tables 14 and 15 show that all cows were gaining weight throughout the five years.

Fertility and Livability. The values in Table 16 show the reproductive performance by breed or cross of cow for the five calf crops. Records were available on 604 matings. A total of 567 births was recorded, giving an overall calving percentage of 93.9. The primary trait of interest was fertility, the basic consideration being whether or not a cow conceived and had a calf (carried through the gestation period and born, dead or alive). Thus, five stillbirths and nine calves which died within 48 hours of birth were included.

TABLE 13. ANALYSES OF VARIANCE OF COW WEIGHT - MODEL F

Source	D.F.	Straightbred cows		Crossbred cows	
		MS	F	MS	F
Years (Y)	4/4	42,680	20.2**	56,846	30.4**
Breed or kind (B)	2/5	119,650	56.5**	42,898	23.0**
Y x B	8/20	848	0.4	934	0.5
Remainder	257/243	2,118		1,867	
Total	272/273				

**P<.01.

The figures for calves weaned represent only live individuals. The discrepancy between the 567 birth records in Table 16 and the 545 in the birth weight analysis (Tables 2, 3, 4) is due to the fact that 18 of the cows (carried for the first year as possible replacements) were transferred out of the experiment without cow weights being recorded, and four of the cows gave birth to premature, light calves.

TABLE 14. MEANS OF COW WEIGHT BY YEAR (kg) - MODEL F

Year	Angus			Hereford			Shorthorn		
	N	Mean	S.E.	N	Mean	S.E.	N	Mean	S.E.
1963	20	406.3	10	19	452.7	11	19	388.1	11
1964	18	414.3	11	19	453.4	11	18	399.1	11
1965	20	442.2	10	20	488.0	10	17	414.8	11
1966	18	445.1	11	19	499.7	11	17	425.8	11
1967	18	479.2	11	17	537.4	11	13	445.4	13
Total	94	437.4	5	94	486.2	5	84	414.7	5

The crossbred cows in this study had a 2.0% higher calving rate than the straightbred cows. None of the comparisons in Table 16 was significantly different when tested by Chi-square. Cundiff et al. (1974b) reported a value of 6.8% more calves born from the crossbred cows in the Nebraska experiment. Warwick (1968) averaged Nebraska, Montana, Virginia, Louisiana and Georgia results and found a 4.6% advantage of the crossbred cow. Patterson (1971) reported 1.6% more calves born from crossbred cows in Alabama. The overall high reproductive performance which characterizes the Virginia experiment may have resulted from the fact that the Virginia cows were located in a very favorable environment (minimum stress) in the Shenandoah Valley.

More variability existed between the straight breeds than between the crosses for calving percentage (the range was 89.9 to 96.3%). Considering the reciprocal crosses, the same relationships existed as have been mentioned for other traits. A x H cows gave birth to 3.6% more calves than H x A cows, S x H exceeded H x S by 6.0%, and A x S exceeded S x A by 5.7%.

With respect to weaning performance, the differences are even smaller than those for calving performance. The straightbred cows weaned 0.2% more calves than the crossbred cows, a negligible difference, whereas Cundiff et al. (1974) reported crossbred cows weaned 6.8% more calves than straightbred cows.

TABLE 15. MEANS OF COW WEIGHT BY YEAR (kg) - MODEL F

Year	A x H[a]			H x A			S x H			H x S			A x S			S x A		
	N	$\bar{X}$	SE	N	$\bar{X}$	SE	N	$\bar{X}$	SE	N	$\bar{X}$	SE	N	$\bar{X}$	SE	N	$\bar{X}$	SE
1963	9	460.7	14	10	433.6	14	8	445.0	15	10	441.6	14	10	404.5	14	9	470.8	14
1964	9	462.1	14	10	436.5	14	7	449.4	16	12	473.2	13	10	400.0	14	10	476.3	14
1965	8	530.4	15	10	471.7	14	7	489.8	16	10	513.4	14	9	430.5	14	10	502.9	14
1966	9	502.2	14	9	470.2	14	6	484.9	18	9	513.7	14	10	430.9	14	9	518.5	14
1967	10	546.9	14	8	516.2	15	6	515.5	18	10	557.9	14	10	461.5	14	9	538.1	14
Total	45	500.5	7	47	465.6	6	34	476.7	8	51	499.9	6	49	425.5	6	47	501.3	6

[a]The sire breed is listed first in each cross: A = Angus, H = Hereford, S = Shorthorn.

TABLE 16. COW REPRODUCTIVITY AND CALF LIVABILITY[a]

Cows	No. of matings	Cows calving		Calves weaned	
		No.	%	No.	%
Angus	108	104	96.3	101	93.5
Hereford	102	94	92.1	90	88.2
Shorthorn	99	89	89.9	81	81.8
Total	309	287	92.9	272	88.0
A x H[b]	47	46	97.9	44	93.6
A x S	50	49	98.0	43	86.0
H x S	57	52	91.2	50	87.7
H x A	53	50	94.3	47	88.7
S x A	52	48	92.3	42	80.8
S x H	36	35	97.2	33	87.8
Total	295	280	94.9	259	87.8
Overall	604	567	94.9	531	87.9

[a]Includes 22 matings not included in birth weight analysis.
[b]The sire breed is listed first.

Yields and production efficiencies at weaning time are extremely important in the cow-calf industry. Table 17 shows three ways of comparing the cow groups on the basis of yield at calf weaning time. The column headed BxC is "Units Calf/Cow Year" and is the product of weaning percent and weaning weight. The column headed C/A is "Units Calf/100 Units Cow" and is the ratio of calf weaning weight to cow weight times 100. The last column, gives the product of weaning percent and "Units Calf/100 Units Cow." and therefore takes into account the weight of the calf, the weight of the cow, and the efficiency of the cow. Large breed and cross differences exist in the last column, in terms of total return to the cow-calf producer, even though

there was little difference (0.6%) between straightbred and crossbred cows. The highest individual cow group in the last column was Angus.

TABLE 17. COMPARISONS OF YIELD AT WEANING

Cows[a]	No.	Cow wt. kg, A	Percent weaned, B	W. wt. kg, C	B x C	C/A	B(C/A)
Angus	92	437	93.5	204	190.7	46.7	43.7
Hereford	90	486	88.2	191	168.5	39.3	34.7
Shorthorn	78	415	81.8	199	162.8	47.9	39.2
Total	260	446	88.0	199	175.1	44.6	39.2
A x H	44	501	93.6	214	200.3	42.7	40.0
A x S	43	425	86.0	212	182.3	49.9	42.9
H x S	49	500	87.7	192	168.4	38.4	33.7
H x A	44	466	88.7	201	178.3	43.1	38.2
S x A	41	501	80.8	218	176.1	43.5	35.1
S x H	32	477	87.8	211	193.5	44.2	40.5
Total	253	478	87.8	207	181.7	43.3	38.0
Overall	513	462	87.9	203	178.4	43.9	38.6

[a]A = Angus, H = Hereford, S = Shorthorn. Sire breed is listed first.

SUMMARY AND CONCLUSIONS

The second phase of a long-term beef cattle crossbreeding experiment involving the Angus, Hereford, and Shorthorn breeds was conducted at the Shenandoah Valley Research Station, Steeles Tavern, Virginia. Records of 604 matings and 567 births from 120 cows were collected over five successive calf crops. Comparisons were made between crossbred and straightbred dams and between their backcross and three-breed cross calves. Differences among the three breeds of straightbred cows and the six kinds (distinguishing reciprocals) of crossbred cows, the various combinations within the backcross and three-breed cross groups, and the general combining abilities of the three breeds were also tested.

Comparisons of the various cow classifications were accomplished in three ways: (1) through differences in cow weight from the ages of three to nine years of age; (2) through differences in reproduction efficiency (calving and weaning percentages); and (3) through differences in calf performance from birth through weaning. Calf performance traits were analyzed with and without the regression on cow weight, in order to distinguish other heterosis for maternal effects from that due to cow weight.

Calves from crossbred cows were heavier at birth and weaning and had higher weaning grade. Including the regression on cow weight reduced the differences among calf types.

The crossbred cows were 31.9 kg heavier than the straightbred cows. There were 2.0% more calves born, but 0.2% fewer calves weaned from the crossbred cows. Crossbred cows did wean more kilograms of calf per year, but fewer units of calf per 100 units cow, and fewer units of calf per 100 units of cow per cow year.

There were increases of three-breed cross over backcross calves for all measures of growth, leading to the conclusion that systematic three-breed crossing would increase production over backcrossing.

Differences existed among the three breeds of cows for every calf performance trait, and for cow weight. In general, calves from Angus cows performed better than calves from Hereford or Shorthorn cows. When differences in calf performance, cow reproductive performance, and cow size were all combined (units of calf/100 units cow/cow year), the Angus cows ranked first among all breeds and crosses. Differences were found among the kinds of crossbreds for all calf traits. Crossbred cows resulting from matings involving Hereford dams usually excelled over the reciprocal matings.

General combining ability was estimated within the backcross calves according to the method of Gaines et al. (1970). Generally speaking, the three breeds did not differ in additive genetic effects.

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Virginia's Agricultural Experiment Station

1 —— Blacksburg
Virginia Tech
Main Station

2 —— Steeles Tavern
Shenandoah Valley Research Station
Beef, Sheep, Fruit, Forages, Insects

3 —— Orange
Piedmont Research Station
Small Grains, Corn, Alfalfa, Crops

4 —— Winchester
Winchester Fruit Research Laboratory
Fruit, Insect Control

5 —— Middleburg
Virginia Forage Research Station
Forages, Beef

6 —— Warsaw
Eastern Virginia Research Station
Field Crops

7 —— Suffolk
Tidewater Research and Continuing Education Center
Peanuts, Swine, Soybeans, Corn, Small Grains

8 —— Blackstone
Southern Piedmont Research and Continuing Education Center
Tobacco, Horticulture Crops, Turfgrass, Small Grains, Forages

9 —— Critz
Reynolds Homestead Research Center
Forestry, Wildlife

10 —— Glade Spring
Southwest Virginia Research Station
Burley Tobacco, Beef, Sheep

11 —— Hampton
Seafood Processing Research

Seafood