

TWO-, THREE- AND FOUR-BREED ROTATIONAL CROSSBREEDING OF BEEF CATTLE: REPRODUCTIVE TRAITS¹

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ABSTRACT

Reproductive data were collected on 4,596 cow exposures in a rotational crossbreeding study that spanned four generations (1970 through 1988). Angus (A), Brahman (B), Charolais (C) and Hereford (H) breeds were included in three two-breed (A-B, C-B and H-B), three three-breed (A-B-C, A-B-H and C-H-B) and one four-breed (A-B-C-H) rotational mating system. Contemporary straightbreds were produced each generation. Reproductive traits of interest were calving rate, calf survival, weaning rate, calf birth date and calving assistance. Overall means and standard errors for calving rate, calf survival, weaning rate, calf birth date and calving assistance were $82.1 \pm .6\%$, $92.8 \pm .4\%$, $76.2 \pm .6\%$, $50.4 \pm .3$ d and $4.2 \pm .3\%$, respectively. Rotational mating systems had similar calving and calf survival rates that were greater ($P < .01$) than those of straightbreds. Three- and four-breed rotation systems had similar weaning rates (81.5 ± 1.1 and $80.8 \pm 2.0\%$) that were higher than those for two-breed rotations ($77.1 \pm 1.2\%$). Two- and three-breed rotation systems had fewer assisted births ($3.5 \pm .6$ and $2.2 \pm .6\%$) than straightbreds ($5.5 \pm .6\%$) and the four-breed rotation ($5.4 \pm 1.0\%$). Three-breed rotation calves were born earlier in the calving season ($46.8 \pm .6$ d; $P < .05$) than straightbred, two-breed or four-breed rotation calves ($51.8 \pm .6$, $52.1 \pm .6$ and 51.1 ± 1.0 d). Hereford-Brahman two-breed rotation cows had higher ($P < .05$) calving and weaning rates than A-B or C-B two-breed rotation cows ($87 \pm .4$ vs 81.9 ± 1.9 and $81.5 \pm 1.8\%$; 81.7 ± 2.0 vs 76.4 ± 2.1 and $74.1 \pm 2.0\%$). All three-breed rotation combinations had similar calving, calf survival and weaning rates, assistance at calving and calf birth dates. Rotational combinations tended to be more superior ($P < .05$) to weighted purebred means for calving, calf survival and weaning rates than for calf birth date and calving assistance.

(Key Words: Beef Cattle, Mating Systems, Reproductive Performance.)

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Introduction

Mating systems designed to increase reproductive efficiency would be of direct benefit to beef cattle producers and to the industry. The use of first-cross females in crossbreeding systems has been found to increase reproduction and growth; its advantages are documented well (Mason, 1966; Cundiff, 1970; Long, 1980). The theoretical basis for crossbreeding to improve livestock production was discussed by Dickerson (1969, 1973) and Hill

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(1971). Gregory and Cundiff (1980) gave a detailed review of crossbreeding systems for beef cattle. They concluded that the basic objective of beef cattle crossbreeding systems is to optimize simultaneously the use of both additive and nonadditive effects of genes for traits of economic importance.

Most crossbreeding schemes in the industry involve first-cross cows, either backcrossed or mated to an unrelated sire breed, to increase breed complementarity and to maximize heterosis. Replacement first-cross heifers must be produced in an auxiliary herd or purchased from other producers; this is a major disadvantage to many producers.

Rotational crossbreeding systems have been recommended for the production of replacement females within the herd and for maintenance of a reasonable level of heterosis. Evaluations of several beef breed combinations in rotational crossbreeding systems have been discussed by Kidder et al. (1964), Chapman et al. (1970), Crockett et al. (1978) and Neville et al. (1984).

The objective of this study was to compare two-, three- and four-breed rotational crossbreeding systems and breed combinations within these systems for reproductive traits through four generations.

Materials and Methods

Source of Data. Data were collected at the Ben Hur Research Farm of the Louisiana Agricultural Experiment Station, Baton Rouge. Baton Rouge is located at latitude 30°31'N and longitude 90°08'W and is 10.6 m above sea level. The environment is subtropical with average maximum and minimum daily temperatures of 26° and 13°C, average maximum and minimum daily relative humidity of 88 and 54% and an average annual rainfall of 147 cm.

Angus (A), Brahman (B), Charolais (C) and Hereford (H) breeds were chosen because of their unique contributions to the beef cattle industry in the Gulf Coast region and because a relatively large number of herds of these beef cattle breeds existed within the state. Combinations of these breeds formed three two-breed (A-B, C-B, H-B), three three-breed (A-C-B, A-H-B, C-H-B) and one four-breed (A-B-C-H) rotational crossbreeding system. Breed combinations were limited to those that contained B because earlier research with this breed documented its usefulness (Damon et al., 1961;

Turner and McDonald, 1969) over combinations not including B. Each rotation system was initiated with B first-cross cows. In the first generation, backcross calves were produced in the two-breed combination systems and three-breed cross calves were produced in the three- and four-breed combination systems. Only one breed of sire was used each generation in each breed combination to allow evaluation of more breed combinations. Brahman sires were used last in the rotation scheme within each system because it was thought that this would be most feasible for a commercial operation. Breed of sire × breed of dam matings and number of females and exposure records are given by generation in Table 1. Straightbred calves of the four breeds were produced each generation by the same sires that produced crossbred calves and were contemporary to the crossbred calves.

Four spring-born calf crops were produced each generation. Approximately 75% of the heifers that were weaned were retained as replacements. These heifers were managed separately and accumulated during the 4 yr for each generation. All unsound and unthrifty heifers were sold at weaning or prior to the breeding season. While being accumulated for the next generation, replacement females were used to evaluate early fertility (DeRouen and Franke, 1989) and ease of calving of certain sire breeds (Thrift et al., 1986). When the fourth calf crop in a generation was weaned, all cows in that generation were sold. Replacement heifers that had been accumulated during that generation were mated during the next breeding season to produce the first calf crop for the next generation. During the accumulation period, heifers were exposed to calve at 2 yr of age and all calved at 2 yr or 3 yr of age. This management scheme resulted in non-overlapping generations but animals entering the herd ranged from 2 to 5 yr of age at the start of each generation.

Management of Cattle. Cows were assigned randomly to a particular breeding herd on the basis of their age and breed-type. Each herd was composed of 25 to 30 straightbred and crossbred females for single-sire mating. Sires used for breeding were purchased from purebred producers in Louisiana on the basis of growth traits, structural soundness and fertility of their dams. Bulls were purchased at 1 to 2 yr of age and used for only two breeding seasons in order to sample as many bulls as

TABLE 1. BREED COMPOSITION AND NUMBER OF DAMS AND DAM EXPOSURE RECORDS BY SYSTEM OF MATING AND GENERATION^a

System of mating and breed combinations	Generation 1			Generation 2			Generation 3			Generation 4		
	Mating	No. of dams	No. of dam exposures	Mating	No. of dams	No. of dam exposures	Mating	No. of dams	No. of dam exposures	Mating	No. of dams	No. of dam exposures
Straightbreds												
Angus (A)	A × A	39	125	A × A	41	109	A × A	33	110	A × A	28	76
Brahman (B)	B × B	37	114	B × B	49	127	B × B	33	102	B × B	30	76
Charolais (C)	C × C	37	118	C × C	33	88	C × C	30	109	C × C	25	74
Hereford (H)	H × H	31	101	H × H	39	110	H × H	37	127	H × H	28	71
Two-breed rotation												
A-B	A × AB	28	96	B × A ₃ B ₁	34	110	A × B ₅ A ₃	28	96	B × A ₁₁ B ₅	26	88
C-B	C × CB	30	106	B × C ₃ B ₁	33	100	C × B ₅ C ₃	37	122	B × C ₁₁ B ₅	27	90
H-B	H × HB	31	104	B × H ₃ B ₁	34	113	H × B ₅ H ₃	37	130	B × H ₁₁ B ₅	26	86
Three-breed rotation												
A-B-C	C × AB	28	98	A × C ₂ A ₁ B ₁	32	110	B × A ₅ C ₂ B ₁	36	120	C × B ₉ A ₅ C ₂	28	96
H-B-A	A × HB	32	120	H × A ₂ H ₁ B ₁	34	112	B × H ₅ A ₂ B ₁	36	122	A × B ₉ H ₅ A ₂	28	109
H-B-C	C × HB	30	97	H × C ₂ H ₁ B ₁	33	108	B × H ₅ C ₂ B ₁	33	114	C × B ₉ H ₅ C ₂	28	97
Four-breed rotation												
A-B-H-C	H × AB	29	100	C × H ₂ A ₁ B ₁	33	98	B × C ₄ H ₂ A ₁ B ₁	33	117	A × B ₉ C ₄ H ₂ A ₁	29	100
Total		352	1,179		395	1,185		373	1,269		303	963

^aBreed codes for crossbreds indicate both breed combination and composition. AB represents 50% Angus and 50% Brahman; A₃B₁ represents 75% Angus and 25% Brahman; C₂A₁B₁ represents 50% Charolais, 25% Angus and 25% Brahman.

possible. All bulls were weighed, dewormed and required to pass a breeding soundness examination prior to the start of each breeding season. A 75-d breeding season was utilized, beginning April 15 and ending July 1 of each year.

Calves were born between January 15 and April 10 and were weighed, dehorned and identified at birth. All calves were weaned the 1st wk in October at an average age of 220 d. Cows were pregnancy-tested in October and were culled only for failing to produce a calf in two consecutive years, structural unsoundness or reproductive abnormalities. There was no deliberate selection pressure placed on heifers for growth performance or on mature females for productivity.

Cows were wintered on native hay, fortified blackstrap molasses (32% crude protein) and overseeded ryegrass (*Lolium multiflorum*). The diets were assumed to meet NRC requirements. Cows were grazed on common bermuda (*Cynodon dactylon*) and dallisgrass (*Paspalum dilatatum*) pastures during the summer with Louisiana S-1 white clover (*Trifolium repens*) available in the spring.

Reproductive Traits. The traits of interest in this study were calving rate (CR), calf survival (CS), weaning rate (WR), calf birth date (CBD) and assistance at birth (CA). Calving rate was defined as the proportion of cows exposed to breeding that gave birth to a calf. Cows that calved were given a score of 1 and those that failed to calve were given a score of 0. Pregnant cows lost before calving and cows that aborted were not included in the analysis for calving rate. Calf survival was defined as the proportion of calves born that survived to weaning (1 = survived, 0 = died before weaning). Weaning rate was the proportion of cows exposed to breeding that weaned a calf (1 = weaned, 0 = did not wean). Calf birth date was the day of birth counted in days starting from January 1 using the Julian calendar. Assistance at calving was designed to measure the proportion of calvings in which assistance was needed to save the cow and/or calf (0 = no assistance, 1 = assistance). Cows that gave birth to twins, aborted or had abnormal presentations were not included in the calving assistance analysis.

Statistical Methods. Data were analyzed utilizing ordinary least squares with the GLM procedure (SAS, 1985). The models used for the analysis of CR, CS, WR, CBD and CA

included system of mating (straightbreeding, two-breed, three-breed and four-breed rotational systems), breed or breed combination within system of mating, generation, year within generation, sex of calf, breed or breed combination within mating system \times generation, linear and quadratic effects of cow age and random error, with the exception that sex of calf was not included for CR and WR. Preliminary analyses indicated that most two-way interactions among fixed variables were nonsignificant; they were omitted from final analyses. Birth weight \times sex of calf interaction was found to significantly influence assistance at calving. Therefore, an additional analysis was conducted to obtain partial regression coefficients for the influence of birth weight on calving assistance within sex of calf.

Comparisons between mating systems and between breeds or breed combinations within mating systems were made using *t*-tests on the least squares means. Because a larger number of comparisons was made than the available degrees of freedom, the error over the entire set of comparisons may be greater than indicated by the probability level.

An estimate of crossbred superiority was made for each breed combination within mating system and generation by contrasting the breed combination-generation least squares mean to purebred least squares means weighted according to the breed composition in each breed combination-generation subgroup. This estimate of crossbred superiority may be thought of as a composite heterosis estimate because it includes heterosis expressed both in the cow and in the calf. Crossbred superiority estimates were calculated for CR and WR using expected breed composition of the cow and for CBD, CA and CS using expected breed composition of the calf.

Results and Discussion

Least squares analysis of variance mean squares and significance levels for reproductive traits are presented in Table 2. Least squares means for reproductive traits by mating system and breed combination within mating system are presented in Tables 3 and 4. All factors remaining in the final model significantly influenced variation in reproductive traits.

Calving rate. The overall mean calving rate

TABLE 2. LEAST SQUARES ANALYSIS OF VARIANCE MEAN SQUARES FOR REPRODUCTIVE TRAITS

Sources of variation	df	Calving rate	Calf survival	Weaning rate	Calf birth date	Assisted births
Mating system	3	5.074**	.445**	7.061**	6634**	.235**
Breed or breed combination:						
mating system	7	1.156**	.233**	1.610**	9204**	.079*
Generation	3	1.864**	.306**	1.280**	4897**	.161**
Year:generation	12	.663*	.136*	.731**	753**	.291**
Sex	1		.385*		6578**	1.048**
Line:mating system						
× generation	30	.232*	.109**	.375**	1498**	.099**
Cow age						
Linear	1	14.750**	1.271**	20.092**	4594**	1.885**
Quadratic	1	14.988**	1.335**	20.830**	4478**	1.532**
Error		.142	.067	.171	339	.034
Error df		4,538	3,670	4,538	3,670	3,639

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

TABLE 3. MATING SYSTEM AND BREED OR BREED COMBINATION LEAST SQUARES MEANS FOR REPRODUCTIVE TRAITS

Mating system and breed combination	Calving rate, %	Calf survival, %	Weaning rate, %	Assisted births, %	Calf birth date, d
Mating system					
Straightbreds	73.1 ± 1.0 ^c	89.6 ± .8 ^a	65.5 ± 1.0 ^a	5.5 ± .6 ^a	51.8 ± .6 ^a
Two-breed rotation	83.3 ± 1.1 ^b	92.6 ± .8 ^b	77.1 ± 1.2 ^b	3.5 ± .6 ^{bc}	52.1 ± .6 ^a
Three-breed rotation	86.9 ± 1.1 ^a	93.8 ± .8 ^b	81.5 ± 1.1 ^c	2.2 ± .6 ^b	46.8 ± .6 ^b
Four-breed rotation	85.0 ± 1.8 ^{ab}	95.1 ± 1.4 ^b	80.8 ± 2.0 ^c	5.4 ± 1.0 ^{ac}	51.1 ± 1.0 ^a
Breed or breed combination ^d					
A	76.1 ^x	94.2 ^x	71.4 ^x	5.3 ^x	45.0 ^x
B	62.0 ^y	84.3 ^z	52.4 ^y	2.6 ^y	65.0 ^y
C	78.2 ^x	90.6 ^{xy}	70.4 ^x	8.9 ^z	48.7 ^x
H	76.3 ^x	89.2 ^y	67.8 ^x	5.3 ^x	48.3 ^x
A-B	81.7 ^x	93.7 ^x	76.2 ^x	3.5 ^x	51.1 ^x
C-B	81.2 ^x	90.8 ^x	73.8 ^x	3.3 ^x	53.5 ^x
H-B	87.0 ^y	93.4 ^x	81.4 ^y	3.7 ^x	51.8 ^x
A-B-C	84.9 ^x	93.0 ^x	78.8 ^x	2.6 ^x	47.2 ^x
A-B-H	89.7 ^x	93.3 ^x	83.9 ^x	2.1 ^x	46.5 ^x
H-B-C	86.1 ^x	95.0 ^x	81.8 ^x	1.9 ^x	46.7 ^x
A-B-C-H	85.0	95.1	80.8	5.4	51.1
Approximate SE ^e	1.8	1.4	2.0	1.0	1.0

^{a,b,c}Superscripts indicate differences among mating systems. Means in the same column with no common superscript differ ($P < .05$).

^dA = Angus, B = Brahman, C = Charolais and H = Hereford.

^eStandard errors for breed or breed combination least squares means were similar, therefore an average standard error is given for each trait.

^{x,y,z}Superscripts indicate differences among breed combinations within mating system. Means in the same column within mating system with no common subscripts differ ($P < .05$).

for 4,596 cow exposures was 82.1%. Three- and four-breed rotation cows had similar CR of 86.9 and 85.0%. Straightbred cows had a lower CR (73.1%; $P < .01$) than two-breed (83.3%) and three- and four-breed rotation cows. These differences among mating systems were fairly consistent across generations; the mating system \times generation source of variation was not significant in preliminary analyses.

A higher CR for crossbred cows than for the straightbred group of cows is consistent with the majority of previous studies (Turner et al., 1968; Cundiff, 1970; Gaines et al., 1978; Long, 1980). However, Gotti et al. (1985) reported that CR for crossbred cows was 8.2% less than the average of straightbred Angus, Gelbvieh and Santa Gertrudis cows. Neville et al. (1984) found that the CR for two- and three-

breed rotation cows over three generations was similar to the CR of straightbred A and Polled Hereford cows.

Among straightbreds, B had a lower ($P < .01$) CR (62.0%) than A, C or H cows (76.1, 78.2 and 76.3%) over the four generations. This is in agreement with other studies in which the CR for A or H dams generally exceeded that for B (Cartwright et al., 1964; Crockett et al., 1978; Long, 1980; Comerford et al., 1987). However, in some studies CR for B cows was equal to or exceeded that of A, C or H cows (Turner et al., 1968; Peacock and Koger, 1980).

The H-B two-breed rotation group had a higher CR (87.0%; $P < .01$) than the A-B or C-B two-breed rotation combinations (81.7 and 81.2%). Crockett et al. (1978) found no difference between A-B and H-B two-breed

TABLE 4. LEAST SQUARES MEANS FOR REPRODUCTIVE TRAITS BY BREED OR BREED COMBINATION AND GENERATION

Reproductive trait and generation	Straightbreds ^a				Two-breed rotation			Three-breed rotation			Four-breed rotation
	A	B	C	H	AB	CB	HB	ABC	ABH	CBH	ACBH
Calving rate, %											
1	76.9	63.6	76.2	63.6	82.1	87.5	92.3	82.1	94.7	85.9	83.6
2	69.0	57.9	79.4	67.5	69.7	78.5	78.5	85.2	90.8	89.3	78.0
3	79.0	64.0	79.9	79.8	87.8	78.0	91.1	82.8	80.9	80.8	86.5
4	79.5	62.5	77.2	84.3	87.2	80.8	86.2	89.3	92.4	88.3	91.8
SE ^b	3.7	3.8	3.9	3.7	3.8	3.7	3.7	3.7	3.6	3.7	3.7
Calf survival, %											
1	93.0	95.8	94.1	87.6	98.0	95.0	99.2	91.5	98.4	98.6	96.0
2	94.9	79.5	91.0	87.9	92.9	86.7	90.9	96.4	90.1	96.6	92.9
3	94.5	90.5	88.8	92.1	92.9	91.6	94.6	92.8	89.9	94.7	92.5
4	94.5	90.5	88.7	89.1	90.8	89.8	88.8	91.5	94.7	90.1	99.0
SE	3.0	3.3	3.1	3.0	2.9	2.8	2.8	2.7	2.6	2.7	2.8
Weaning rate, %											
1	71.6	59.8	71.6	64.5	80.8	83.1	91.6	74.9	93.1	85.3	80.3
2	65.1	46.0	72.2	58.5	63.8	68.0	71.1	82.2	81.5	86.2	72.7
3	74.3	47.3	70.7	73.3	81.4	71.5	86.3	76.7	72.6	76.3	79.6
4	74.7	56.5	67.1	74.8	78.7	72.5	76.5	81.6	88.4	79.5	90.6
SE	4.2	4.3	4.4	4.3	4.2	4.3	4.2	4.1	4.0	4.2	4.1
Assisted births, %											
1	2.1	4.1	5.0	7.0	1.8	.1	.5	1.2	.5	.9	1.7
2	8.9	3.9	12.8	4.3	9.2	.9	9.3	.2	.0	.0	12.8
3	5.6	2.7	9.6	3.5	.5	3.5	1.1	7.8	8.5	4.7	6.6
4	4.5	.0	8.2	6.5	2.4	8.5	4.1	1.2	.3	3.0	.7
SE	2.1	2.3	2.1	2.1	2.1	2.0	1.8	1.9	1.8	1.9	2.0
Calf birth date, d											
1	45.3	63.7	47.9	51.3	45.0	46.1	44.5	42.3	42.5	43.7	46.3
2	43.8	63.6	46.5	44.6	55.1	57.8	56.9	44.8	45.9	42.1	49.1
3	43.0	62.8	49.3	49.7	49.4	55.6	48.3	54.9	54.2	55.0	58.7
4	47.9	70.0	51.1	47.6	55.0	54.4	57.5	46.7	43.3	46.1	50.4
SE	2.1	2.3	2.3	2.1	2.0	2.0	2.0	2.0	2.0	1.9	2.0

^aA = Angus, B = Brahman, C = Charolais and H = Hereford.

^bStandard errors for least squares means were similar, therefore an average standard error is presented.

rotation cows for pregnancy rate. Peacock and Koger (1980) reported no difference between C-B and A-B first-cross cows for calving rate when mated to produce backcross and three-breed cross calves. Bailey and Moore (1980) found first-cross A-B cows to have a 5% greater ($P > .05$) CR than H-B first-cross cows.

Calving rates for three-breed rotation combinations were similar, being 84.9, 89.7 and 86.1% for A-B-C, A-B-H and C-B-H. Four-breed rotation cows had a 85.0% CR. These results are comparable to the 88.1% CR for Angus-Polled Hereford-Santa Gertrudis rotation cows over three generations (Neville et al., 1984).

Calving rates for individual straightbreds and two-, three- and four-breed rotation combinations by generation are given in Table 4. Differences among generations could be due to differences in genetic potential and in environmental trends (generations did not overlap). The CR means by generation for H cows suggest improvement over the course of the study; however, no trends were observed in the other straightbreds. There is no reasonable explanation for this difference. A trend over generations is more difficult to assess in the rotation systems because of changes in expected degree of average heterozygosity and breed composition as generations progressed. In the two-breed rotation system, one would expect 100, 50, 75 and 62.5% heterozygosity in dams for generations 1 through 4. Thus, differences in apparent heterozygosity, dam breed composition and sire breed each generation could influence variation in generation means in combination with environmental effects.

Calf Survival to Weaning. The overall mean CS for 3,729 calves was 92.8%. The CS of two-, three- and four-breed rotation calves (92.6, 93.8 and 95.1%) were similar and higher ($P < .05$) than the CS of straightbred calves (89.6%). Approximately 40% of the calf losses in this study were due to stillbirths. In other studies conducted in the Gulf Coast region, stillbirths and drownings were found to account for a high percentage of calf losses (DeRouen et al., 1967; Turner et al., 1968).

Heifer calves had a higher ($P < .05$) CS to weaning than male calves (93.8 vs 91.7%). Comerford et al. (1987) found that heifer calves had a 13% greater 24-h survival than did male calves, and Gregory et al. (1978)

reported a 3.2% survival advantage for females in the first 24 h. However, when survival from birth to weaning was considered, Reynolds et al. (1980) found contrasting results, with male calves having a 4.4% higher ($P < .01$) survival rate than heifers.

Among straightbreds, B calves had a lower CS (84.3%) than A, H or C (94.2, 90.6 and 89.2%) calves. Angus calves had a higher ($P < .05$) CS than H calves. Other reports are in agreement with the lower CS of B calves (DeRouen et al., 1967; Koger et al., 1967; Cundiff, 1970; Reynolds et al., 1980). Gotti et al. (1985) noted that straightbred Santa Gertrudis calves had less viability at birth than other mating types.

The survival rates for A-B, C-B and H-B two-breed rotation calves were similar. Also, the CS of A-B-C, A-B-H and C-B-H calves were not different and were similar to survival rates of two-breed and four-breed (95.1%) rotation calves. Koger et al. (1967), Cundiff (1970) and Gotti et al. (1985) reported a higher CS for crossbred calves than for purebred calves. Frahm and Marshall (1985) and Reynolds et al. (1986) found no differences among crossbred cow groups for CS.

Variation among generation means for CS followed no particular pattern except that B-sired two-breed rotation calves in generations 2 and 4 appeared to have slightly lower CS than calves by other sire breeds. This trend was not observed for B-sired three-breed rotation calves in generation 3.

Weaning Rate. The overall mean WR was 76.2%. Three- and four-breed rotation cows had similar and higher ($P < .05$) weaning rates (81.5 and 80.8%) than two-breed rotation (77.1%) and straightbred (65.5%) cows. Two-breed rotation cows had a higher WR than straightbred cows ($P < .01$). These differences could be due to the factors discussed earlier for CR. Neville et al. (1984) did not find a difference between three-breed and two-breed rotation systems for WR. He also found that the WR of straightbred A and Polled Hereford cows were similar to the WR of two- and three-breed rotation cows. Crockett et al. (1978) found that two-breed rotation cows had a higher WR over three generations than straightbred cows (80.3 vs 74.4%).

The weaning rates for A, C, and H cows were similar (71.4, 70.4 and 67.8%) but higher than the WR for B (52.4%) cows. The lower WR of B cows relative to that of A or H cows

has been reported in other studies (Cartwright et al., 1964; Crockett et al., 1978); however, Peacock et al. (1971, 1977) and Turner et al. (1968) reported WR of B to be similar to or superior to WR of British cows.

Hereford-Brahman two-breed rotation cows had a higher WR (81.4%) than A-B or C-B two-breed rotation cows (76.2 and 73.8%) over the four generations. Crockett et al. (1978) found A-B and H-B two-breed rotation cows to have similar but lower WR (80.8 and 77.5%) than A-H two-breed rotation cows (82.7%). Neville et al., (1984) found no differences among two-breed rotation cows for WR.

Three- and four-breed rotation cows had similar WR over the four generations. These results are in agreement with a WR of 84.2% reported by Neville et al. (1984) for Angus-Polled Hereford-Santa Gertrudis three-breed rotation cows.

Variation in WR means for two- and three-breed rotation cows appeared to be influenced more by the use of B sires than by variation due to differences in apparent breed heterozygosity of crossbred cows. This result possibly could have been more easily explained if all rotation matings had been made each generation rather than by restricting matings to one sire breed.

Calving Assistance. Of 3,698 calves born in this study, 4.2% required some form of assistance during the birth process. Straightbred and four-breed rotation calves required more ($P < .05$) calving assistance than three-breed (2.2%) rotation calves. Male calves required more assistance at birth (5.9%) than female calves (2.5%). Dam breed, sire breed, sex of calf and the environment to which the calf was exposed have been found to influence the degree of assistance at birth (Laster and Gregory, 1973; Burfening et al., 1978; Bailey and Moore, 1980; Comerford et al., 1987). Bellows et al. (1971) and Laster (1974) indicated that birth weight was the most important single factor contributing to difficulty at calving.

Among straightbreds, C calves required more ($P < .01$) assistance (8.9%) at birth than other straightbreds, whereas A and H calves required more ($P < .05$) assistance at calving (5.3 and 5.3%) than B calves (2.6%). Two-breed rotation calves required an amount of assistance at calving (3.3 to 3.7%) similar to that of three-breed rotation calves (1.9 to

2.6%). A relatively high degree of calving difficulty has been found for C and C-sired calves in other studies (Cundiff, 1970; Smith et al., 1976; Nelson and Beavers, 1982).

Least squares means for calving assistance by generation indicated several patterns of interest for rotational crossbred calves. Higher levels of calving assistance were required for A-B and H-B two-breed rotation calves in generation 2, C-B two-breed rotation calves in generation 4 and for all three-breed rotation calves in generation 3. These calves were B-sired. Charolais-sired two-breed rotation calves in generation 3 and four-breed rotation calves in generation 2 also tended to require a greater amount of assistance at birth. Comerford et al. (1987) found that B-sired crossbred calves required more assistance at calving ($P < .05$) than H-sired crossbred calves. Gregory et al. (1979) reported B sires to reduce calving ease when bred to Angus and Hereford cows. Thus, the data in this study and the literature suggest that Brahman-sired crossbred calves require more assistance at calving. The reason for this is not entirely clear; however, Wyatt and Franke (1986) reported that the Brahman direct additive genetic effect and the direct heterosis effects of Brahman crosses contribute to larger birth weights.

Birth weight had a significant influence on assistance of male calves but not on assistance of heifer calves. Each kilogram increase in birth weight of male calves resulted in .127% greater incidence in assistance ($P < .01$), whereas a kilogram increase in birth weight of heifer calves caused no real difference in incidence of assistance ($b = .015\%$; $P > .15$). Inclusion of birth weight in the model did not reduce the significance of mating systems but did cause breed or breed combination within mating system to be nonsignificant.

Calf Birth Date. Cows that calve late in a restricted calving season often do not return to estrus prior to the end of the next breeding season. Thus calf birth date (CBD) could influence reproduction. The overall mean CBD in this study was $50.4 \pm .3$ d. Three-breed rotation calves were born earlier (46.8 d; $P < .05$) than straightbred, two-breed or four-breed rotation calves (51.8, 52.1 and 51.1 d), all of which had similar CBD. Heifer calves were born 2.7 d earlier ($P < .01$) than male calves (49.1 vs 51.8 d). The effect of sex of calf agrees with differences reported by Reynolds et al. (1980) and McElhenney et al., (1986);

however, Gotti et al. (1985) found no sex of calf effect on CBD.

Straightbred B calves were born later (65.0 d; $P < .01$) than A, C or H straightbred calves (45.0, 48.7 and 48.3 d). This difference is larger than the 11-d difference in gestation length of the B and *Bos taurus* breeds reported by Reynolds et al. (1980). A slower return to estrus of B cows after the start of the breeding season and/or reduced libido in B males early in the breeding season could contribute to the difference in CBD. The data from this study could not be used to determine which of these factors was more important.

Three-breed rotation calves had similar CBD, and these were earlier ($P < .05$) than CBD of two-breed rotation and four-breed rotation calves. Means by generation indicate similar trends. Brahman-sired two-breed rotation calves in generations 2 and 4 and B-sired three-breed rotation calves in generation 3 also were born later than two- and three-breed

rotation A-, C- or H-sired calves, but not as late as straightbred B calves. These data again indicate that certain biological factors other than gestation length contributed to a later CBD for calves when the sire was B. Chapman and England (1965) and Reynolds et al., (1980) suggested that B sires were not as aggressive early in a spring breeding season as British sires because of cooler temperatures.

Crossbred Superiority. Differences between individual two-, three- and four-breed rotations by generation and weighted straightbred means from the same generation gave an indication of crossbred superiority or overall heterosis (Table 5). These differences may be thought of as that proportion of performance in the rotational crossbred individual (cow and/or calf) that was due to nonadditive genetic effects. This assumption can be made if the average breed composition and breed heterozygosity expected in the rotation systems are correct based on the mating design.

TABLE 5. CROSSBRED SUPERIORITY FOR REPRODUCTIVE TRAITS BY BREED COMBINATION AND GENERATION

Reproductive trait and generation	Two-breed rotation ^a			Three-breed rotation			Four-breed rotation
	AB	CB	HB	ABC	ABH	CBH	ABCH
Calving rate, %							
1	11.9**	17.6**	23.7**	11.8**	26.1**	17.3**	13.3**
2	3.5	4.4	13.4**	13.8**	25.0**	18.3**	12.6**
3	18.2**	8.1	21.2**	5.5	3.3	3.0	8.7*
4	13.0*	8.2	8.7	19.7**	20.9**	17.1**	20.9**
Calf survival, %							
1	4.7	1.0	10.1**	-2.2	6.5*	6.2	5.5
2	7.7*	3.0	8.3*	4.4	1.5	9.0**	3.7
3	5.0	7.6*	8.4*	10.8**	8.0*	13.5**	11.2**
4	-1.1	-1	-1.2	1.4	2.2	.8	6.6
Weaning rate, %							
1	15.1**	17.4**	29.5**	9.2	31.0**	23.1**	14.6**
2	3.5	2.3	15.8**	18.3*	22.8*	24.0**	15.7**
3	24.0**	15.4**	29.3**	6.6	2.3	6.9	10.1*
4	9.7	8.7	7.4	18.0**	23.9**	15.9**	27.0**
Assisted birth, %							
1	-8	-4.7	-5.8*	-2.8	-3.4	-4.3	-3.4
2	3.4	-6.3*	5.2	-9.0**	-6.4**	-7.2**	3.8
3	-4.2	-3.9	-2.2	-3.3	5.2*	.9	2.6
4	1.0	5.8*	2.1	-4.1	-3.2	-2.5	-3.0
Calf birth date, d							
1	-4.9	-5.7*	-10.0**	-8.9**	-9.0**	-9.0**	-6.7**
2	-1.1	.6	.4	-2.1	-.8	-5.4*	1.3
3	.3	2.1	-4.8*	.1	-2.0	-2.1	2.1
4	-7.5**	-9.1**	-4.8	-9.3**	-10.8**	-9.7**	-4.0

^aA = Angus, B = Brahman, C = Charolais, H = Hereford.

* $P < .05$.

** $P < .01$.

Several interesting trends emerged in the estimates of crossbred superiority. All the estimates for CR and WR and most of those for CS were positive, indicating that the rotational crossbred combinations generally were more reproductive than the respective weighted straightbred average. The majority of crossbred superiority differences for CA and CBD were negative, indicating that rotational crossbred calves required less assistance at birth and were born earlier in the calving season than their respective weighted parental breeds.

Two-breed rotation cows in generations 2 and 4 and three- and four-breed rotation cows in generation 3 had less advantage for CR and WR over their respective weighted parental breeds than other contemporary cows in the respective rotation system. Possible reasons for these trends are the degree of breed heterozygosity in crossbred cows unique to each generation, an incompatibility for mating between B sires and predominately non-B females, or other unknown factors.

Most estimates of crossbred superiority in the scientific literature are based on contrasting first-cross cows to the average of parental breeds. Peacock et al. (1971) reported a 16.3% WR advantage for first-cross and reciprocal backcross cows over the average parental breed performance. Crockett et al. (1978) found a 13.6 and 7.6% WR advantage over three generations for A-B and H-B rotational crossbred cows over contemporary parental means. These values compare favorably to those found in this study. Cartwright et al. (1964) reported WR advantages for first-cross and first and second backcross H-B crossbred groups that were similar to those found for the first three generations in this study.

Implications

Two-, three- and four-breed rotational crossbreeding systems, when managed in the manner described, were more productive than contemporary parental breeds. Three- and four-breed rotation systems had a slight advantage over the two-breed rotational system for weaning rate. The H-B two-breed rotation system and A-B-H three-breed rotation system tended to be superior to other two- and three-breed rotation systems for weaning rate.

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