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Breed Comparisons of Weight, Weight Adjusted for Condition Score, Height, and Condition Score of Beef Cows[1]

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Abstract

*Breeds were compared for differences in BW (n = 56,731), heights (n = 51,407) and body condition scores (**BCS**, n = 56,371) of 2- to 8-yr-old cows from four cycles of the Germplasm Evaluation (**GPE**) Program at the U. S. Meat Animal Research Center (**MARC**). Angus, Hereford, and topcross cows from 22 breeds of sires were produced. The mixed model for repeated measures of BW, height, and BCS included random additive genetic and permanent environmental effects of the cow. Differences among crosses were significant for all traits. In general, BW, within cycle, was greater for cows sired by breeds of large size and low milk production (Chianina and Charolais) than for those of large size and moderate milk production (Maine Anjou, Salers, and Shorthorn), moderate size and moderate milk production (Angus and South Devon), moderate size and low milk production (Hereford), and small size and low milk production (Galloway and Longhorn). Breeds of moderate size and moderately high milk production (Pinzgauer, Red Poll, and Tarentaise) were even lighter. Cows with Jersey sires were separated from all other breed groups because of light BW. Cows with sires of British origin tended to be lighter than those of continental European origin. Cows with Bos indicus sires (Brahman and Nellore) ranked between other breeds of large and moderate size for BW or for BW adjusted for BCS. In general, adjustment for BCS did not alter rankings of breed groups for differences in cow BW. Differences among breed groups for height closely followed differences for BW.*

(Key Words: Growth, Maturity, Breeds, *Bos taurus*, *Bos indicus*.)

Introduction

The many breeds varying in performance for economic traits represent a wide spectrum of biological types for beef production. Diverse climatic conditions and feed resources should be matched to genetic resources to optimize meat production. Important within- and between-breed variation exists for economic traits of beef cattle. This variation can be exploited by selection and crossbreeding programs. The Germplasm Evaluation (GPE) program at the U. S. Meat Animal Research Center (MARC) was designed to evaluate topcrossing with breeds of sires differing in genetic potential for diverse economic traits such as growth and mature size, milk production, lean-to-fat ratio, and carcass characteristics. Analyses of mature BW, height, and body condition score (BCS) were presented in previous reports separately for cows in Cycles I to IV of the GPE program (Arango et al., 2002b,c,d,e). Earlier reports from MARC presented ordinary least squares means and estimates of breed differences for some of these traits in heifers (Laster et al., 1976; Gregory et al., 1979; Thallman et al., 1999) and cows (Cundiff et al., 1986, 1988; Setshwaelo et al., 1990; Jenkins et al., 1991) using part of the

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data from some cycles of the GPE program or from special experiments involving breed groups included in the GPE (Dearborn et al., 1987; Green et al., 1991; Gregory and Maurer, 1991). This paper reports combined analyses to compare breeds for BW, BW adjusted for BCS, height, and BCS of cows from the first four cycles of the GPE program, comparing 22 breeds of sires mated to Angus and Hereford dams.

Materials and Methods

Data were from cows of the first four cycles of the GPE program including Hereford and Angus purebred cows (Cycles I, II, and IV). Each cycle was conducted as a separate experiment spanning an 8- to 9-yr period from the time AI matings were made to produce the females until they were evaluated for characteristics expressed at 7 or 8 yr of age. The F_1 cows for all cycles were produced by mating Angus and Hereford dams to 22 breeds of sires. Hereford-Angus (**H-A**) reciprocal crosses were produced in each cycle of the program to provide ties for analysis of data pooled over all cycles. The breeds and numbers of sires and cows by breed of sire are presented in Table 1. Some of the Angus and Hereford sires used in Cycle I were repeated as reference sires in the following cycles to provide genetic ties for data across all four cycles. In Cycle IV, in addition to semen from reference sires, a more current sample of Hereford and Angus bulls (born 1982 to 1984) accounting for the genetic trend that has occurred within the Hereford and Angus breeds were also used. Therefore, "reference" and "1980s" bulls were treated as representing different breed groups in analyses of Cycle IV. Charolais sires used in Cycle IV also represented a new sample, different from the Charolais bulls used in Cycle I (Arango et al., 2002b). Additionally, in Cycle IV, some Hereford, Angus, Charolais, Gelbvieh, and Pinzgauer bulls (born from 1983 to 1985) were also used by natural service following an AI period of about 45 d. These natural service bulls were mainly sampled from

TABLE 1. Number of sires and number of daughters by breed of sire for Cycles I to IV.

	Cycle I (1970–1972)		Cycle II (1973–1974)		Cycle III (1975–1976)		Cycle IV[a] (1986–1990)		Total	
Item	Sires	Daughters	Sires	Daughters	Sires	Daughters	Sires	Daughters	Sires	Daughters
Hereford	31	121	15	86	13	68	10	74	96	401
							27	*52*		
Angus	33	123	17	92	14	30	20	77	103	359
							19	*37*		
Jersey	32	106							32	106
South Devon	27	109							27	109
Simmental	27	151							27	151
Limousin	20	148							20	148
Charolais	26	123					22	35	48	158
Red Poll			16	87					16	87
Brown Swiss			11	127					11	127
Maine Anjou			17	86					17	86
Chianina			19	86					19	86
Gelbvieh			11	77					11	77
Brahman					17	101			17	101
Sahiwal					6	86			6	86
Pinzgauer					9	103			9	103
Tarentaise					6	80			6	80
Shorthorn							22	68	22	68
Galloway							27	70	27	70
Longhorn							24	81	24	81
Nellore							22	81	22	81
Piedmontese							18	83	18	83
Salers							25	6	25	86
Total	196	881	106	641	65	468	236	744	603	2735

[a]Reference sires (born from 1963 to 1971); *in italics: 1980s sires born from 1982 to 1985*.

MARC populations, especially from the Germplasm Utilization (**GPU**) project, in which relaxed selection for growth was practiced and in which Charolais, Gelbvieh, and Pinzgauer bulls were the result of a grading-up program. Consequently, clean-up sires were considered not to be a representative sample from the respective breed and were excluded from the analyses. Details of sampling of sires and experimental design have been presented by Cundiff et al. (1998).

Details of the experimental design and postweaning management were presented by Laster et al. (1976) and Gregory et al. (1979) for Cycles I to III, by Cundiff et al. (1998) and Thallman et al. (1999) for Cycle IV, and for all cycles in previous reports of this series (Arango et al., 2002b,c,d,e). Reviews that have summarized and compared the first three cycles (Cundiff et al., 1986, 1988) and Cycle IV (Cundiff et al., 1998; Thallman et al., 1999) help to explain the breeding plan.

Yearling heifers were weighed at the beginning and end of the mating season and when palpated for pregnancy. Thereafter, cows were weighed, measured for hip height, and scored for BCS four times each year. One measurement was taken each season: 1) mid May (spring) at the start of the breeding season, 2) early August (summer) at the end of the breeding season, 3) end of October (fall) at palpation for pregnancy following weaning, and 4) early February (winter) prior to calving. The BCS was based on a subjective classification scale of nine points, from very emaciated (1) to very obese (9) (Spitzer, 1986; Wagner et al., 1988). Each record of a cow was assigned to one of four physiological codes composed of a combination of lactation (1 = not lactating; 2 = lactating) and pregnancy (1 = not pregnant; 2 = pregnant) codes. Data for the present study included records of cows from 2 to 6 yr of age (the oldest age allowed for any cow for this study).

Breed means and differences by age of cow (year) were presented in previous reports (Arango et al., 2002b,c,d,e) for Cycles I to IV. Estimates of genetic correlations among BW measurements taken at different seasons of the year as well as at different ages were large for the data used here (Arango et al., 2002a). Consequently, repeatability models, assuming constant variance, could be used with data from this study. To summarize results across cycles, breed group means and breed differences estimated using pooled data (all measurements) are presented in this report. The number of records and unadjusted means are summarized in Table 2. On average, unadjusted means for cow BW were 469, 500, 486, and 522 kg, and for cow height, unadjusted means were 125, 126, 126, and 132 cm in Cycles I to IV, respectively. Cows were heavier and taller in Cycle IV and shorter and lighter in Cycle I. Unadjusted means for BCS did not change much across cycles (maximum = 0.5 points).

TABLE 2. Number of records and unadjusted means (±SD) for BW, height, and body condition score by cycle.

	BW		Height		BCS	
Cycle	no.	Mean	no.	Mean	no.	Mean
	(kg)		(cm)		(points)	
I	19,851	469 ± 83	14,533	125 ± 5.2	19,536	6.1 ± 1.2
II	15,680	500 ± 81	15,676	126 ± 6.5	15,667	6.5 ± 1.0
III	9012	486 ± 71	9010	126 ± 5.2	8991	6.6 ± 0.9
IV	12,188	522 ± 72	12,188	132 ± 5.9	12,177	6.2 ± 0.8
Total	56,731		51,407		56,371	

Statistical analyses were conducted using single-trait animal models with a derivative-free restricted maximum likelihood algorithm using the MTDFREML computer programs (Boldman et al., 1995) to estimate variance components and to solve mixed model equations. Fixed effects were sire breed, dam breed, and their interactions; age and season of measurement and their interactions; year of birth; and pregnancy-lactation code in models for cow BW and BCS. For cow height, pregnancy-lactation code was excluded from the model. Analyses of BW adjusted for BCS included BCS as a covariate. Random effects were additive genetic and permanent environmental effects of the cow. Details about models and procedures for estimation of variance components were presented by Arango et al. (2002a) and will not be discussed here.

Estimates of (co)variances at convergence were used with mixed model equations to obtain solutions for fixed effects and to estimate linear contrasts for breed of sire comparisons. The standard breed group for comparison of breeds of sire (within and across cycles) was the H-A reciprocal cross. Three sets of contrasts were tested for each trait and age (year): 1) the difference between the average for cows of each breed of sire and the average of H-A cows, 2) the difference between Angus and Hereford purebred cows and the average of their reciprocal crosses, and 3) the difference between cows with Angus dams and cows with Hereford dams. In Cycle IV, the standard for comparison was the H-A cows with "reference" sires, to allow for comparisons with other cycles. Differences for the "1980s" sires were also studied for contrast. Differences among crossbred cows would be due to differences in additive genetic effects present in the specific two-

TABLE 3. Estimates of breed group means[a] using all measurements for BW (kg) of cows in Cycles I to IV.

	Cycle[b]			
Item[c]	I	II	III	IV[d]
Hereford (H)	440	469		485 (553)
Angus (A)	444	471		503 (524)
H-A-x	464	487	487	510 (544)
Ch-x	515			
Je-x	408			
Sd-x	476			
Si-x	487			
Li-x	474			
Rp-x		471		
Bs-x		497		
Gv-x		510		
Ma-x		540		
Ci-x		543		
Br-x			510	
Sh-x			447	
Pz-x			489	
Ta-x			486	
Ch-x				589
So-x				564
Ga-x				505
Lh-x				478
Ne-x				538
Pd-x				502
Sa-x				552

[a]Means were obtained by adding the unadjusted mean for H-A, the solution constrained to zero, to solutions for each breed-group.

[b]Cows were 2 to 7 (Cycle I), 2 to 8 (Cycle II), or 2 to 6 (Cycles III and IV) yr of age.

[c]-x = crosses (simple average of estimates with Hereford and Angus dams), Ch = Charolais, Je = Jersey, Sd = South Devon, Si = Simmental, Li = Limousin, Rp = Red Poll, Bs = Brown Swiss, Gv = Gelbvieh, Ma = Maine Anjou, Ci = Chianina, Br = Brahman, Sh = Sahiwal, Pz = Pinzgauer, Ta = Tarentaise, So = Shorthorn, Ga = Galloway, Lh = Longhorn, Ne = Nellore, Pd = Piedmontese, and Sa = Salers.

[d]Reference sires (born from 1963 to 1971); in parenthesis 1980s sires (born from 1982 to 1985).

breed crosses and to any differences caused by heterosis for a particular cross (e.g., Frahm and Marshall, 1985). Overall heterosis was assumed to be of similar magnitude for *Bos taurus* × *Bos taurus* crosses; however, cows with Brahman and Sahiwal sires (Cycle III) and Nellore sires (Cycle IV) would be expected to express higher levels of heterosis, resulting from the *Bos indicus x Bos taurus* crosses (Koger, 1980).

Results and Discussion

Cow BW. The solutions for breed group means for Cycles I through IV from the analysis using all measurements are shown in Table 3. Contrasts between breed groups, their standard errors, and levels of significance are presented in Tables 4 and 5 for BW and BW adjusted for BCS, respectively. The BW means for Hereford cows with reference sires increased with cycle (Table 3), even though cows in Cycle IV were measured only to 6 yr of age. Hereford cows with 1980s sires (Cycle IV) were even heavier, indicating a positive genetic trend within the Hereford breed for cow BW in the 1980s compared with the 1960s and 1970s. The same pattern was found for Angus cows whose mean BW were slightly greater than those for Hereford cows in all cycles; however, daughters of 1980s Hereford sires outweighed Angus cows by 29 kg. At maturity, BW of Hereford cows (496 kg) have been reported to be 8 to 34 kg (average 25 kg) greater than BW of Angus cows in studies comparing both breeds (e.g., Fitzhugh et al., 1967; Urick et al., 1971; Johnston et al., 1996). Other estimates of asymptotic mature BW using different growth functions also have indicated that BW for Hereford cows (482 kg, on average) were, on average, 38 kg (6 to 82 kg) greater than those of Angus cows (e.g., Brown et al., 1972; Smith et al., 1976; Johnson et al., 1990).

Hereford-Angus reciprocal crosses were produced over all four cycles to be a base for comparing other F_1 groups. On average, BW of H-A cows (with reference sires) increased in each cycle and were 34 kg greater for cows with 1980s sires than for cows with reference sires in Cycle IV. On average, reciprocal H-A cows were heavier ($P<0.01$) than the purebred Hereford and Angus cows, with estimates of direct heterosis of 4.8 and 3.8% for Cycles I and II, respectively (Table 4). In Cycle IV, the difference was significant for cows with reference sires, but dropped ($P>0.05$) to 1.0% for cows with 1980s sires. The corresponding superiorities of H-A cows for BW adjusted for BCS (Table 5) were slightly less, but significance levels were the same as for actual BW. In literature reports, H-A cows have been heavier than purebred Angus and Hereford or their average (e.g., Cundiff, 1970; Morris et al., 1987; Kress et al., 1990) by differences that have ranged from 2 to 31 kg, averaging 18.3 kg, similar to

TABLE 4. Contrasts of breed group solutions (±SE) using all measurements for BW (kg) of cows[a] in Cycles I to IV.

Item[c]	Cycle[b] I	II	III	IV
H-A-x [d]	0.00	0.00	0.00	0.00
Je-x	–55.17 ± 5.82**			
Sd-x	12.83 ± 5.91**			
Li-x	10.67 ± 5.93**			
Si-x	22.98 ± 5.73**			
Ch-x	51.17 ± 5.87**			
Bs-x		9.08 ± 8.12		
Gv-x		22.88 ± 8.75*		
Ci-x		55.45 ± 7.63**		
Ma-x		52.98 ± 7.67**		
Rp-x		–16.74 ± 7.75*		
Br-x			23.00 ± 8.22**	
Sh-x			–39.91 ± 10.76**	
Pz-x			1.94 ± 9.45	
Ta-x			–0.43 ± 11.18	
Lh-x				–31.59 ± 7.89**
Sa-x				42.63 ± 7.93**
Ga-x				–4.57 ± 7.99
Ne-x				28.64 ± 8.06**
Pd-x				–8.07 ± 8.28
Ch-x				78.67 ± 9.42**
So-x				54.53 ± 8.37**
(H-A)-p[e]	21.29 ± 4.73** (4.82%)	17.67 ± 5.44** (3.76%)		15.61[f] ± 6.52* (3.16%)
H-x-A-x[g]	3.41 ± 2.86	9.39 ± 3.35**	12.51 ± 4.02**	1.98 ± 1.85

[a]Cows were 2 to 7 (Cycle I), 2 to 8 (Cycle II), or 2 to 6 (Cycles III and IV) yr of age.

[b]Means in the contrast are different: ***P*<0.01 or **P*<0.05.

[c]x = crosses, -p = pure breeds; H = Hereford, A = Angus, H-A = reciprocal crosses of H-A and A-H, Je = Jersey, Sd = South Devon, Li = Limousin, Si = Simmental, Ch = Charolais, Bs = Brown Swiss, Gv = Gelbvieh, Ci = Chianina, Ma = Maine Anjou, Rp = Red Poll, Br = Brahman, Sh = Sahiwal, Pz = Pinzgauer, Ta = Tarentaise, Lh = Longhorn, Sa = Salers; Ga = Galloway, Ne = Nellore, Pd = Piedmontese, and So = Shorthorn.

[d]Contrast: respective breed of sire group *vs* H-A (H-A-x).

[e]Contrast: H-A-p *vs* H-A-x; in parenthesis, heterosis as a percentage.

[f]For 1980s sires: 5.2 ± 9.02 kg (0.97%).

[g]Contrast: crosses with H dams *vs* crosses with A dams.

difference between those breed groups.

Different breeds of sires were used to produce F_1 cows in each cycle to be compared with H-A cows. The F_1 cows with Jersey, South Devon, Limousin, Simmental, and Charolais sires produced in Cycle I (Table 1) were, on average, heavier (P<0.01) than H-A cows, except for cows with Jersey sires that were 55 kg lighter (P<0.01) than H-A cows, as expected for crosses with this small British breed developed for milk production. In Cycle II, on average, F_1 cows with Red Poll sires were lighter than H-A cows (P<0.05). The other F_1 groups were heavier than the H-A cross cows by differences that were not significant for Brown Swiss, significant for Gelbvieh, and highly significant for Maine Anjou and Chianina. On average, in Cycle III, F_1 cows with Sahiwal sires were 40 kg lighter than H-A cows (P<0.01). The BW of cows with Pinzgauer and Tarentaise sires were not different from H-A cows, but cows with Brahman sires were heavier (P<0.01) than H-A cows. In Cycle IV, on average, F_1 cows with Longhorn, Piedmontese, and Galloway sires were lighter than H-A cows, but that difference was significant only for cows with Longhorn sires. The other F_1 groups were heavier (P<0.01) than H-A crosses. Charolais bulls represented a more current sample of sires and exceeded H-A reference cows by a greater difference (27.5 kg) than those used in Cycle I.

In general, means for cow BW for breed groups within cycle were greater for cows sired by bulls of breeds of large size and low milk production (Chianina and Charolais) than for cows by sired by bulls of breeds of large size and moderate milk production (Maine Anjou, Salers, and Shorthorn) and greater than for cows sired by bulls of breeds of moderate or small size and moderate or low milk production (Angus, Galloway, Hereford, Longhorn, and South Devon). Cows by breeds of sire of moderate size and moderately high milk production (Pinzgauer, Red Poll, and Tarentaise) were even

the average of Cycles I, II, and IV with reference sires (18.2 kg). The H-A cows weighed the same as Hereford cows in one study (Bailey and Moore, 1980) and were lighter than Angus cows in another study (Thompson et al., 1983). Morgan (1986) compared Herefords with H-A under three different stocking rates in Victoria (Australia) and reported that Hereford cows (439 kg) were, on average, 21 kg heavier than H-A cows. For BW adjusted for BCS, Smith et al. (1976) found that H-A cows were, on average, 9 kg heavier than the average of Angus and Herefords. Nelsen et al. (1982) reported that adjustment for BCS increased the estimate of the

TABLE 5. Contrasts of breed group solutions (±SE) using all measurements for BW (kg) adjusted for body condition score for cows[a] in Cycles I to IV.

	Cycle[b]			
Item[c]	I	II	III	IV
H-A-x [d]	0.00	0.00	0.00	0.00
Je-x	–44.47 ± 5.38**			
Sd-x	19.05 ± 5.46**			
Li-x	15.06 ± 5.49**			
Si-x	29.31 ± 5.30**			
Ch-x	52.78 ± 5.42**			
Bs-x		24.54 ± 7.09**		
Gv-x		34.35 ± 7.66**		
Ci-x		67.30 ± 6.70**		
Ma-x		62.61 ± 6.73**		
Rp-x		–3.87 ± 6.80		
Br-x			28.40 ± 7.22**	
Sh-x			–28.86 ± 9.47**	
Pz-x			17.27 ± 8.31*	
Ta-x			10.52 ± 9.83	
Lh-x				–14.98 ± 7.13*
Sa-x				51.00 ± 7.16**
Ga-x				–1.61 ± 7.21
Ne-x				37.00 ± 7.29**
Pd-x				7.84 ± 7.49
Ch-x				83.10 ± 8.47**
So-x				66.13 ± 7.55**
(H-A)-p[e]	19.39 ± 4.33** (4.36%)	13.99 ± 4.86** (2.97%)		12.13[f] ± 5.79* (2.44%)
H-x-A-x[g]	3.56 ± 2.62	6.02 ± 2.97	12.11 ± 3.51**	3.88 ± 1.66*

[a]Cows were 2 to 7 (Cycle I), 2 to 8 (Cycle II), or 2 to 6 (Cycles III and IV) yr of age.
[b]Means in the contrast are different: ***P*<0.01 or **P*<0.05.
[c]x = crosses, -p = pure breeds; H = Hereford, A = Angus, H-A = reciprocal crosses of H-A and A-H, Je = Jersey, Sd = South Devon, Li = Limousin, Si = Simmental, Ch = Charolais, Bs = Brown Swiss, Ci = Chianina, Ma = Maine Anjou, Rp = Red Poll, Br = Brahman, Sh = Sahiwal, Pz = Pinzgauer, Ta = Tarentaise, Lh = Longhorn, Sa = Salers; Ga = Galloway, Ne = Nellore, Pd = Piedmontese, and So = Shorthorn.
[d]Contrasts: respective breed of sire group *vs* H-A (H-A-x).
[e]Contrast: H-A-p *vs* H-A-x; in parenthesis, heterosis as a percentage.
[f]For 1980s sires: 3.05 ± 8.02 kg (0.56%).
[g]Contrast: crosses with H dams *vs* crosses with A dams.

lighter. Cows with Jersey sires stood out among all breed groups because of light BW, as was expected for a small British breed that has been heavily selected for milk production. Crossbred cows by breeds of British origin tended to rank below those of continental European origin in BW, except for Shorthorns. Cows by the Shorthorn sires sampled in Cycle IV, which were strongly influenced by relatively recent introductions of dual purpose (milk and meat) Shorthorns from Ireland, were the second heaviest breed in Cycle IV and were excelled only by cows with Charolais sires. Cows by Longhorn sires were lightest in Cycle IV, which might have been due to the history of adaptation to harsh nutritional environments by the Longhorn breed after introduction to the United States.

Cows with *Bos indicus* sires (Brahman and Nellore) constitute a separate group with BW that ranked between cows sired by *Bos taurus* breeds of large size and *Bos taurus* breeds of moderate size, possibly because they may exhibit more heterosis in crosses with *Bos taurus* breeds than that between crosses of *Bos taurus* breeds. The exception was for cows with Sahiwal sires (in Cycle III), which were lightest. The Sahiwal is a Zebu breed that has been selected for milk production rather than for beef production.

Cow BW reflects differences in size associated not only with skeletal size and lean growth, but also with fatness, which is associated indirectly and negatively with milk production (Cundiff et al., 1986). Therefore, adjustment for BCS caused some differences in estimates of breed differences for BW (Table 5). However, ranking of breed groups was generally the same as for actual BW. Those results might indicate that a portion of the differences in BW was due to differences in condition, but those differences were of moderate to small magnitude.

On average, cows from Hereford dams were heavier than cows from Angus dams in all cycles, although the differences were highly significant only for Cycles II and III for actual weight. The difference was highly significant for Cycle III and significant in Cycle IV for BW adjusted for BCS.

Previous reports from the U.S. MARC summarized cow BW and differences between H-A cows and F_1 cows of other breeds of sire used in Cycles I, II, and III (Cundiff et al., 1986, 1988; Setshwaelo et al., 1990; Jenkins et al., 1991). Means of BW and breed group differences were not the same as in the present study, as expected, because those studies 1) included cows of either selected ages or all measurements up to 7 yr of age in all cycles in pooled analyses, 2) did not include Cycle IV cows, and 3) presented least squares estimates of breed effects, in contrast to generalized least squares means in the present study. Rankings, however, were the same as in the present study.

Cundiff et al. (1988) reviewed cow BW of different breeds of sire of large size used in research programs in Nebraska (GPE Cycles I to III), Montana, Oklahoma, and Canada. In agreement with this study, F_1 cows by breeds of sire of moderate size and low potential for milk production were lightest. Cows by sire breeds of large size and high potential for milk production were intermediate for BW, and cows by breeds of sire of large size and low milk production were heaviest within location. Barlow and Hearnshaw (1988) in a broad review of studies of size by environment interaction, including many studies that reported cow BW, in general, found little evidence of changes in rank across a diverse range of environments for maternal traits. In that study, Charolais cows and Charolais crosses were always heavier than contemporary British breeds and British crosses.

In Alberta (Canada), Jeffery and Berg (1972) compared two breeding systems 1) HEAG (Jeffery and Berg, 1972) with British genes (Hereford and Angus-Galloway) and 2) HYC, a hybrid with a continental breed (Charolais-Angus and Charolais-Galloway). The HYC (550 kg) cows were 22 kg heavier than HEAG cows. In Nevada, Bailey and Moore (1980) reported results from a diallel experiment between Hereford and Red Poll and other crossbred groups. Hereford and H-A cows (464 kg) had the same BW but exceeded Red Poll-Hereford cows (-5 kg) and F_1 Brahman cows (-23 kg) with Angus and Hereford dams, contrary to most reports and the present study in which crosses with Brahman were heavier. In Florida, Peacock et al. (1981) found Charolais-Angus (448 kg) and Brahman-Angus (444 kg) to be 40 and 36 kg heavier, respectively, than purebred Angus cows. In Indiana, Nelson et al. (1982) found that Charolais-Hereford (498, 504 kg) and Brown Swiss-Hereford (486, 494 kg) were 23, 23 and 11, 13 kg heavier than H-A cows after calving and at weaning of the calves. In South Dakota, Miller and Deutscher (1985) reported that Simmental-Angus cows (482 kg) were 28 kg heavier than H-A cows. In Australia (Victoria), Morgan (1986) reported that Charolais-Hereford and Brahman-Hereford cows were 59 and 20 kg heavier, respectively, than Hereford cows (469 kg). In Louisiana, Humes and Munyakazi (1989) found that crossbred cows with Hereford dams (533 kg) were 8 kg heavier than crossbred cows with Angus dams. When they compared cows by breed of sire, the ranking order was Maine Anjou (545 kg; heaviest), Chianina (543 kg), Brahman (528 kg), and Simmental (501 kg; lightest). In Australia, Pitchford et al. (1993) reported that Brahman-Hereford cows (396 kg) were 29 kg heavier than Hereford cows.

In Texas, Nelsen et al. (1982), from a five-breed diallel experiment, concluded that F_1 Brahman and Jersey cows (with Angus and Hereford dams) were 35 kg heavier and 60 kg lighter, respectively, than H-A cows (484 kg) for asymptotic mature BW using the Brody function. Weights adjusted for condition were greater than actual weights for H-A, Brahman-Angus, and Jersey-Hereford cows. Differences from H-A cows were less for F_1 Brahman cows (31 kg) and greater for F_1 Jersey cows (-67 kg). In Virginia, Nadarajah et al. (1984) reported that Charolais-Angus cows (511, 513 kg) were 58 and 56 kg heavier (not adjusted for BCS) at maturity than Angus cows using the Brody and the Richards growth functions, respectively. Differences for BW adjusted for BCS were greater (91 and 94 kg). In Ontario (Canada), McMorris and Wilton (1986) and Fiss and Wilton (1992) compared breeding systems including 1) a large beef rotation (**LRB**: Charolais, Maine Anjou, and Simmental), 2) a small dual purpose rotation (**SRD**: Angus, Gelbvieh, Pinzgauer, and Tarentaise), and 3) a small beef rotation (**SRB**: Hereford, Limousin, and Shorthorn) for BW and BW adjusted for BCS. Cows from LRB (701 kg) were heaviest, followed by Hereford cows (594 kg), SRD cows (589 kg), and SRB cows (588 kg) for actual BW. Rankings for BW adjusted for BCS were different; SRD cows were heavier than Hereford cows (Fiss and Wilton, 1992). Within systems, the rankings for breed of sire were Maine Anjou (686 kg), Charolais (684 kg), and Simmental (664 kg) for LRB and Pinzgauer (572 kg), Gelbvieh (571 kg), and Tarentaise (540 kg) for SRB (Fiss and Wilton, 1992). In Nebraska, Montaño-Bermudez et al. (1990) reported that actual BW of Shorthorn-Angus (high milk) and Red Poll-Angus (medium milk) were 34 and 60 kg less and 36 and 70 kg less than Angus-Hereford (low milk) cows (511, 528 kg) during gestation and lactation, respectively. Shorthorn-Angus and Red Poll-Angus cows were 8 and 17 kg lighter and 35 and 50 kg lighter, respectively, than H-A cows for BW adjusted for BCS. These differences were less than for actual BW, especially for Shorthorn-Angus cows.

Cow Height. Estimates of breed group means for cow height using all measurements are presented in Table 6. On average, Hereford cows with reference sires had the same stature in Cycles I and II but were taller in Cycle IV. Cows with 1980s sires were even taller; Angus cows were similar. The H-A reciprocal cows were about 1 cm taller than the average of the purebred (Table 7) cows, but the differences were significant only in Cycles II and IV. Estimates of direct heterosis were about 1%. The H-A cows with 1980s sires did not differ from the average of the purebreds.

The average height of Angus cows has been reported to be 122 cm (Brown et al. 1956b; Thompson et al., 1983; Northcutt et al., 1992), the same as an estimate reported for asymptotic mature height using the Brody function (Nelsen et al., 1982). In addition, Archer et al. (1998) reported estimates of 119, 116, and

108 cm for three lines of Angus selected for growth rate (high, control, and low, respectively) using the Gompertz function. Height of Hereford cows has tended to be greater than for Angus cows, averaging 126 cm (Brown et al., 1956a; Williams et al., 1979; Meyer, 1995). Estimates of asymptotic mature heights of Hereford cows include 124 cm using the Brody function (Nelsen et al., 1982) and 121 cm using the Gompertz function (Pitchford et al., 1993). The H-A cows (120 and 123 cm) also were reported to be 1 cm taller than purebred (Angus, Hereford) cows in two studies, one in Nebraska (Cundiff, 1970) and the other in Minnesota (Thompson et al., 1983).

TABLE 6. Estimates of breed group means[a] using all measurements for height (cm) for cows in Cycles I to IV.

	Cycle[b]			
Item[c]	I	II	III	IV[d]
Hereford (H)	121	121		126 (133)
Angus (A)	120	119		126 (131)
H-A-x	121	122	122	127 (132)
Ch-x	128			
Je-x	122			
Sd-x	127			
Si-x	128			
Li-x	127			
Rp-x		123		
Bs-x		127		
Gv-x		127		
Ma-x		129		
Ci-x		136		
Br-x			131	
Sh-x			126	
Pz-x			126	
Ta-x			127	
Ch-x				138
So-x				136
Ga-x				128
Lh-x				131
Ne-x				139
Pd-x				131
Sa-x				136

[a]Means were obtained by adding the unadjusted mean for H-A, which solution was constrained to zero, to solutions for each breed-group.

[b]Cows were 2 to 7 (Cycle I), 2 to 8 (Cycle II), or 2 to 6 (Cycles III and IV) yr of age.

[c]x = crosses (simple average of estimates with H and A dams); Ch = Charolais, Je = Jersey, Sd = South Devon, Si = Simmental, Li = Limousin, Rp = Red Poll, Bs = Brown Swiss, Gv = Gelbvieh, Ma = Maine Anjou, Ci = Chianina, Br = Brahman, Sh = Sahiwal, Pz = Pinzgauer, Ta = Tarentaise, So = Shorthorn, Ga = Galloway, Lh = Longhorn, Ne = Nellore, Pd = Piedmontese, and Sa = Salers.

[d]Reference sires (born from 1963 to 1971); in parenthesis 1980s sires (born from 1982 to 1985).

In Cycle I, F_1 cows of all breeds of sire were, on average, taller (P<0.01) than H-A cows (Table 7), except for cows with Jersey sires, which had the same stature as the H-A cows. In Cycle II, F_1 cows from all breeds of sire were taller than H-A cows; the differences, however, ranged from 2 cm (P<0.05) for cows with sires of a small British breed (Red Poll) to 14 cm (P<0.01) for cows from Chianina sires. The F_1 cows from the other sire breeds (Brown Swiss, Gelbvieh, and Maine Anjou) ranked in between (P<0.01). On average, all F_1 cows in Cycle III were taller (P<0.01) than H-A cows. In Cycle IV, H-A cows did not differ (P>0.05) in stature from F_1 cows with Galloway sires. The other F_1 groups were taller (P<0.01) than H-A. Cows with Charolais sires in Cycle IV, representing a more current sample of the breed, exceeded H-A cows by about twice as much as they exceeded H-A cows in Cycle I, indicating an effect of the genetic trend for stature within the Charolais breed. On average, cows with Hereford dams were taller than cows with Angus dams in all cycles; differences were highly significant in Cycles II and III and significant in Cycle IV.

Within cycle, some breed groups stood out for height because of 1) selection history for size, such as for cows with Chianina sires (tallest in Cycle II) and Galloway and Longhorn sires (smallest in Cycle IV); 2) selection history for milk production, such as for cows with Jersey sires (smallest in Cycle I) and Sahiwal sires (smallest in Cycle III); and 3) greater heterosis for size of cows with *Bos indicus* sires, such as Brahman and Nellore, which were tallest in Cycles III and IV, respectively.

Jenkins et al. (1991) reported mature heights (7 yr of age) for H-A and other F_1 cows from GPE Cycles I to III. Ranks for breed differences were as in the present study. In Texas, Nelsen et al. (1982), using the Brody function, reported asymptotic mature heights of cows from a five-breed diallel experiment involving Angus, Brahman, Hereford, Holstein, and Jersey. On average, cows with Brahman sires (Angus and Hereford dams) were 8 cm taller than H-A cows (125 cm). The corresponding F_1 cows by Jersey sires were 1 cm shorter than H-A cows. In Australia, Pitchford et al. (1993), using the Gompertz function,

TABLE 7. Contrasts of breed group solutions (±SE) using all measurements for height (cm) for cows[a] in Cycles I to IV.

	Cycle[b]			
Item[c]	I	II	III	IV
H-A-x[d]	0.00	0.00	0.00	0.00
Je-x	–0.10 ± 1.32			
Sd-x	4.89 ± 1.31**			
Li-x	4.97 ± 1.21**			
Si-x	6.35 ± 1.21**			
Ch-x	6.18 ± 1.28**			
Bs-x		6.03 ± 0.77**		
Gv-x		6.00 ± 0.83**		
Ci-x		14.37 ± 0.71**		
Ma-x		7.32 ± 0.72**		
Rp-x		1.57 ± 0.73*		
Br-x			9.12 ± 0.69**	
Sh-x			4.02 ± 0.92**	
Pz-x			3.99 ± 0.80**	
Ta-x			4.56 ± 0.95**	
Lh-x				4.29 ± 0.65**
Sa-x				8.96 ± 0.65**
Ga-x				1.04 ± 0.65
Ne-x				11.88 ± 0.67**
Pd-x				4.41 ± 0.69**
Ch-x				11.13 ± 0.75**
So-x				9.07 ± 0.69**
(H-A)-p[e]	1.18 ± 1.28 (0.98%)	1.19 ± 0.48* (0.99%)		0.99[f] ± 0.48* (0.78%)
H-x-A-x[g]	1.23 ± 0.74	1.65 ± 0.30**	2.09 ± 0.33**	0.31 ± 0.14*

[a]Cows were 2 to 7 (Cycle I), 2 to 8 (Cycle II), or 2 to 6 (Cycles III and IV) yr of age.

[b]Means in the contrast are different: ***P*<0.01 or **P*<0.05.

[c]x = crosses, -p = pure breeds; H = Hereford, A = Angus, H-A = reciprocal crosses of H-A and A-H, Je = Jersey, Sd = South Devon, Li = Limousin, Si = Simmental, Ch = Charolais, Bs = Brown Swiss, Gv = Gelbvieh, Ci = Chianina, Ma = Maine Anjou, Rp = Red Poll, Br = Brahman, Sh = Sahiwal, Pz = Pinzgauer, Ta = Tarentaise, Lh = Longhorn, Sa = Salers, Ga = Galloway, Ne = Nellore, Pd = Piedmontese, and So = Shorthorn.

[d]Contrasts: respective breed of sire group *vs* H-A (H-A-x).

[e]Contrast: H-A-p *vs* H-A-x; in parenthesis, heterosis as a percentage.

[f]For 1980s sires: -0.19 ± 0.67 cm (-0.14%).

[g]Contrast: crosses with H dams *vs* crosses with A dams.

reported that Brahman-Hereford cows (127 cm) were 6 cm taller than Hereford cows for asymptotic mature height. Meyer (1995) reported that cows from a synthetic breed, Wokalups (with genes of Angus, Brahman, Charolais, Hereford, and Holstein), were 9 cm taller than purebred Hereford cows (130 cm).

BCS. Estimated means for BCS for cows in Cycle I to IV are presented in Table 8. On average, Hereford cows had similar BCS in Cycles I, II, and IV. Angus cows had slightly greater scores in Cycles I and II (6.5 and 6.8, respectively), but about the same in Cycle IV (6.4), as Hereford cows. Reciprocal H-A crosses exceeded (*P*<0.05) the purebreds in Cycles I, II, and IV (Table 9). That difference was not significant for cows with reference and 1980s sires in Cycle IV. Cundiff (1970) reported that H-A cows (BCS = 10.5) had a slightly greater BCS (5- to 14-point scale) than the average of Angus and Hereford cows (BCS = 10.2), but that difference was not significant. Thompson et al. (1983) reported that BCS (1- to 9-point scale) of H-A cows (BCS = 5.5) was slightly greater than that of Angus cows (BCS = 5.4) at maturity. In Australia, Morgan (1986) reported that Hereford cows (BCS = 2.6) were heavier and had a slightly greater condition (0- to 5-point scale) than H-A cows (BCS = 2.4), when averaged over three stocking rates.

On average, H-A cows had greater BCS (*P*<0.01) than F_1 cows of all breeds of sire in Cycle I (Table 9), except for cows with Charolais sires, which were not statistically different from H-A cows. Cows with Jersey sires had the least BCS, 1.0 points less than for H-A cows. That difference would be expected for crosses of a breed selected for milk production with less fat deposition than for the typical beef breeds. In Cycle II, the BCS of all F_1 cows were exceeded, on average, by those of H-A cows (*P*<0.01) within a narrow range from 0.5 (Maine Anjou) to 0.8 (Brown Swiss) points. Cows with sires of a dairy breed (Brown Swiss) had the least BCS, as in Cycle I. On average, the F_1 cows with Brahman, Sahiwal, Pinzgauer, and Tarentaise sires produced in Cycle III had lesser BCS than H-A cows (*P*<0.01). On average, H-A cows did not differ (*P*>0.05) for BCS from F_1 cows with Galloway sires (BCS = 0.14) in Cycle IV. Cows with Charolais sires averaged 0.22 point less (*P*<0.05) than H-A cows. The other F_1 had lesser BCS (*P*<0.01) than H-A. On average, cows with Hereford dams had the same BCS as cows with Angus dams in Cycles I and III; although BCS of cows with Hereford

TABLE 8. Estimates of breed group means[a] using all measurements for body condition score (points) for cows in Cycles I to IV.

	Cycle[b]			
Item[c]	I	II	III	IV[d]
Hereford (H)	6.28	6.73		6.44 (6.31)
Angus (A)	6.46	6.81		6.43 (6.24)
H-A-x	6.65	6.95	7.04	6.61 (6.36)
Ch-x	6.40			
Je-x	5.55			
Sd-x	5.96			
Si-x	5.95			
Li-x	6.15			
Rp-x		6.30		
Bs-x		6.17		
Gv-x		6.38		
Ma-x		6.47		
Ci-x		6.35		
Br-x			6.76	
Sh-x			6.46	
Pz-x			6.27	
Ta-x			6.48	
Ch-x				6.39
So-x				6.05
Ga-x				6.47
Lh-x				5.83
Ne-x				6.21
Pd-x				5.86
Sa-x				6.22

[a]Means were obtained by adding the unadjusted mean for HA, which solution was constrained to zero, to solutions for each breed-group.

[b]Cows were 2 to 7 (Cycle I), 2 to 8 (Cycle II), or 2 to 6 (Cycles III and IV) yr of age.

[c]x = crosses (simple average of estimates with H and A dams); Ch = Charolais, Je = Jersey, Sd = South Devon, Si = Simmental, Li = Limousin, Rp = Red Poll, Bs = Brown Swiss, Gv = Gelbvieh, Ma = Maine Anjou, Ci = Chianina, Br = Brahman, Sh = Sahiwal, Pz = Pinzgauer, Ta = Tarentaise, So = Shorthorn, Ga = Galloway, Lh = Longhorn, Ne = Nellore, Pd = Piedmontese, and Sa = Salers.

[d]Reference sires (born from 1963 to 1971); in parenthesis 1980s sires (born from 1982 to 1985).

dams exceeded (P<0.01) those with Angus dams in Cycle II. The opposite occurred in Cycle IV: cows with Angus dams had greater BCS (P<0.01) than cows with Hereford dams.

Spelbring et al. (1977), from a diallel experiment with Angus and Milking-Shorthorn cattle, concluded that Angus cows (BCS = 10.7) had greater BCS (5- to 15-point scale) than Shorthorn-Angus cows (BCS = 10.3). On average, cows with Angus sires had greater (P<0.01) BCS than cows with Shorthorn sires. The estimate of heterosis for BCS (0.29 points) was also significant. Peacock et al. (1981), from rotation and inter se crosses in Florida, found that Brahman-Angus and Charolais-Angus cows (and reciprocals) had the same BCS (5.8), which exceeded the BCS for purebred Angus cows by 0.5 point. Nadarajah et al. (1984) reported that Angus cows (BCS = 3.4) had greater BCS (1- to 5-point scale) than Charolais-Angus cows (3.1 points) from a study that also involved crosses with Friesians. On average, Angus cows also had significantly greater BCS than all crossbred cows (0.36 point). Miller and Deutscher (1985) found than H-A and Simmental-Angus did not differ for BCS for a range of nutrition levels. Montaño-Bermudez et al. (1990), who compared crosses with different milk production potential, reported that H-A (low milk) cows exceeded (P<0.01) Red Poll-Angus (medium milk) and Shorthorn-Angus cows (high milk) for BCS (1- to 9-point scale) during gestation and lactation. McMorris and Wilton (1986) and Fiss and Wilton (1992) reported significant differences for BCS, with the following rank order: Hereford (greatest), SRB, SRD, and LRB (least). Within the rotation systems, Fiss and Wilton (1992) found differences for backfat thickness, with the following rankings for breeds of sire: Tarentaise (greatest, 8.0 mm), Pinzgauer (7.0 mm), and Gelbvieh (6.3 mm) for SRD and Charolais (3.6 mm), Maine Anjou (3.1 mm), and Simmental (2.9 mm, least) for LRB. Meyer (1995) reported that Hereford cows (BCS = 3.6 to 4.0) had 0.3 to 0.7 point greater BCS (1- to 5-point scale) than Wokalups, a synthetic breed with genes of Angus, Brahman, Charolais, Hereford, and Holstein breeds.

Implications

Results from breed comparisons for mature height, mature BW, and BCS between purebred (Angus and Hereford) and crossbred (F_1 crosses from 22 breeds of sire) cows in this study confirm information in the literature: a variety of biological types of cattle exists for beef production. This fact provides for great flexibility for matching breeding systems and cattle genotypes to a wide range of production systems, environmental and managerial conditions, and specific market demands to optimize beef production.

TABLE 9. Contrasts of breed group solutions (±SE) using all measurements for body condition score for cows[a] in Cycles I to IV.

	Cycle[b]			
Item[c]	I	II	III	IV
H-A-x [d]	0.00	0.00	0.00	0.00
Je-x	–1.00 ± 0.09**			
Sd-x	–0.59 ± 0.09**			
Li-x	–0.40 ± 0.09**			
Si-x	–0.59 ± 0.09**			
Ch-x	–0.14 ± 0.09			
Bs-x		–0.79 ± 0.11**		
Gv-x		–0.57 ± 0.12**		
Ci-x		–0.61 ± 0.10**		
Ma-x		–0.49 ± 0.10**		
Rp-x		–0.65 ± 0.10**		
Br-x			–0.28 ± 0.10**	
Sh-x			–0.58 ± 0.12**	
Pz-x			–0.76 ± 0.11**	
Ta-x			–0.56 ± 0.13**	
Lh-x				–0.78 ± 0.08**
Sa-x				–0.39 ± 0.08**
Ga-x				–0.14 ± 0.08
Ne-x				–0.39 ± 0.08**
Pd-x				–0.75 ± 0.08**
Ch-x				–0.22 ± 0.09*
So-x				–0.56 ± 0.08**
(H-A)-p[e]	0.18 ± 0.08*	0.18 ± 0.08*		0.17[f] ± 0.07*
H-x-A-x[g]	–0.02 ± 0.05	0.17 ± 0.05**	0.00 ± 0.05	–0.09 ± 0.02**

[a]Cows were 2 to 7 (Cycle I), 2 to 8 (Cycle II), or 2 to 6 (Cycles III and IV) yr of age.

[b]Means in the contrast are different: ***P*<0.01 or **P*<0.05.

[c]-x = crosses, -p = pure breeds H = Hereford, A = Angus, H-A = reciprocal crosses of H-A and A-H, Je = Jersey, Sd = South Devon, Li = Limousin, Si = Simmental, Ch = Charolais, Bs = Brown Swiss, Gv = Gelbvieh, Ci = Chianina, Ma = Maine Anjou, Rp = Red Poll, Br = Brahman, Sh = Sahiwal, Pz = Pinzgauer, Ta = Tarentaise, Lh = Longhorn, Sa = Salers, Ga = Galloway, Ne = Nellore, Pd = Piedmontese, and So = Shorthorn.

[d]Contrasts: respective breed of sire group *vs* H-A (H-A-x).

[e]Contrast: H-A-p *vs* H-A-x.

[f]For 1980s sires: 0.09 ± 0.09 points.

[g]Contrast: crosses with H dams *vs* crosses with A dams.

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