December 2002

Comparisons of Angus-, Braunvieh-, Chianina-, Hereford-, Gelbvieh-, Maine Anjou-, and Red Poll-sired cows for weight, weight adjusted for body condition score, height, and body condition score

Jesus Arango
University of Nebraska-Lincoln, jarango2@unl.edu

L. V. Cundiff
USDA-ARS, Roman L. Hruska U.S. Meat Animal Research Center

L. Dale Van Vleck
University of Nebraska-Lincoln, dvan-vleck1@unl.edu

Comparisons of Angus-, Braunvieh-, Chianina-, Hereford-, Gelbvieh-, Maine Anjou-, and Red Poll-sired cows for weight, weight adjusted for body condition score, height, and body condition score[1]

J. A. Arango*[2], L. V. Cundiff†, and L. D. Van Vleck†‡[3]

*Department of Animal Science, University of Nebraska, Lincoln 68583-0908; and USDA-ARS, Roman L. Hruska U.S. Meat Animal Research Center, †Clay Center, NE 68933 and ‡Lincoln, NE 68583-0908

ABSTRACT: Data from Angus, Hereford, and topcross cows (n = 641) from 2- to 8-yr-old daughters of seven breeds of sires included in Cycle II of the Germplasm Evaluation Program at the U.S. Meat Animal Research Center, comprising cow weight (CW, n = 15,698), height (CH, n = 15,676), and condition score (CS, n = 15,667), were used to estimate breed-group differences. Data were recorded in four seasons of each year (1975 to 1982). The mixed model included cow age, season of measurement, and their interactions, year of birth, pregnancy-lactation code (PL), and breed-group as fixed effects for CW and CS. Analyses of weight adjusted for condition score included CS as covariate. The model for CH excluded PL. Random effects were additive genetic and permanent environmental effects. Differences among breed-groups were significant for all traits at different ages and were maintained across ages, with few interchanges in ranking through maturity. Cows were ranked (by breed of sire) in the following order for weight: Red Poll (lightest), Hereford-Angus (reciprocal), Braunvieh, Gelbvieh, Maine Anjou, and Chianina (heaviest). In general, cows sired by breeds of British origin were lighter and shorter than those of continental origin. Differences in weight due to differences in condition seemed to be of small magnitude because making an adjustment for condition score did not affect rankings of breed groups across ages. Differences among breed groups for height were consistent with differences for weight. Cows from Chianina sires were taller than Hereford-Angus cows by 14 to 15 cm across ages. In this study, breed of sire effects were significantly different for the mature size of their daughters.

Key Words: Beef Cattle, *Bos taurus*, Breeds, Growth, Maturity

 J. Anim. Sci. 2002. 80:3133–3141

Introduction

Many diverse breeds with important differences for economic traits are available for use in beef production systems. Crossbreeding offers a tool to create genetic improvement by exploiting heterosis and breed complementarity to match genetic resources with production systems, environmental and managerial conditions, and market requirements. The study of various breeds of sire for topcrosses is intended to determine the potential benefit of using exotic breeds for crossing with indigenous or local breeds (Dickerson, 1993). The Germplasm Evaluation (**GPE**) Program at the U.S. Meat Animal Research Center (**MARC**) was designed to evaluate topcrossing, using 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. The objective of this research was to evaluate breed of sire differences for cow weight, weight adjusted for condition score, height, and body condition score of cows in Cycle II of the GPE Program. Weight and height represent mature size, and previous reports from MARC have presented ordinary least squares means and breed differences for Cycle II heifers (Laster et al., 1979) and cows. Pooled results have also been summarized using partial data from the first three cycles of the GPE Program (Cundiff et al., 1986, 1988; Setshwaelo et al., 1990; Jenkins et al., 1991) or from special experiments involving breed groups included in the GPE (Dearborn et al., 1987; Gregory and Maurer, 1991). However, estimates from mixed models that appropriately account for random effects, such as

[1]Published as paper no. 13636, Journal Ser., Nebraska Agric. Res. Div., Univ. of Nebraska, Lincoln 68583-0908.

[2]Current address: Facultad de Ciencias Veterinarias, Universidad Central de Venezuela, Apartado 4563, Maracay 2101, Aragua, Venezuela.

[3]Correspondence: A218 Animal Sciences (phone: 402/472-6010; fax: 402/472-6362; E-mail: lvanvleck@unlnotes.unl.edu).

Received February 19, 2002.

Accepted July 25, 2002.

Table 1. Number of sires and daughters by breed of sire for Cycle I (Phase 2)

Breed of sire	Sires	Daughters
Hereford	15	86
Angus	17	92
Red Poll	16	87
Braunvieh	11	127
Maine Anjou	17	86
Chianina	19	86
Gelbvieh	11	77
Total	106	641

sires for weight, height, and condition score of cows from Cycle II for all ages, have not been reported. A separate report has presented such estimates for breed groups and breed differences for Cycle I cows (Arango et al., 2002b).

Materials and Methods

Purebred Angus and Hereford and F_1 cows were produced by mating Angus and Hereford dams with sires of seven breeds. The number of sires and daughters produced by each breed of sire are presented in Table 1. The GPE Program at MARC was designed to estimate breed-group effects for major economic traits by comparing the progeny of different breeds of sires with Hereford-Angus crosses. Cycle II included progeny from two calving seasons (1973 and 1974). Hereford and Angus cows from Cycle I were bred by AI to Hereford, Angus, Braunvieh (including seven imported from Switzerland and four domestic Braunvieh bulls selected for their "beef type," available from a commercial AI bull stud), Red Poll, Maine Anjou, Gelbvieh, and Chianina bulls. Details of the sampling of sires were presented by Gregory et al. (1978). General management was described in previous reports of this series (Arango et al., 2002a,b). Cows were managed to calve first as 2-yr-olds in the spring (mid-March through April). Details of postweaning management were presented by Laster et al. (1979). Animals were not removed from the experiment due to growth criteria. Cows were removed only for failure to conceive in two consecutive breeding seasons or for serious unsoundnesses. Cows were maintained on an improved pasture of cool- or warm-season grass. During winter months (late November through April), cows were fed supplemental grass hay and alfalfa hay on alternate days (about 11 to 14 kg of hay per head each day). Cows with the same birth year were assigned to the same contemporary group for nearly all measurements.

Yearling heifers were weighed at beginning and end of the mating season, and when palpated for pregnancy. Thereafter, cows were weighed, measured for hip height, and scored for body condition four times each year with one measurement 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. Body condition score was based on a subjective classification scale of nine points, from extremely thin (very emaciated) to extremely fat (very obese). 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. Records of cows from 2 to 8 yr of age (the oldest age allowed for any cow) were included in this study.

Statistical analyses were done using single trait animal models with a derivative-free REML algorithm using the MTDFREML computer programs (Boldman et al., 1995) to estimate variance components. Models included sire breed, dam breed, and their interactions; age and season of measurement, and their interactions; and year of birth and pregnancy-lactation code as fixed effects for cow weight and body condition score. For cow height, pregnancy-lactation code was excluded from that model. Analyses for weight adjusted for condition score included condition score as a covariate. For all traits, separate analyses by age (yr) of cow included age in days within each season of measurement as extra covariates. Random effects were additive genetic and permanent environmental effects of the cow. Details about models and estimation of variance components were presented in an article by Arango et al. (2002a), in which maternal effects were found to be unimportant and thus not considered in models for this report.

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, which will be reported here. Three sets of contrasts were tested for each trait and age at measurement (yr): 1) the difference between the average for cows of each breed of sire and the average of Hereford-Angus reciprocal (**HA**) 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. Differences among crossbred cows would be expected to be due to differences in additive genetic effects present in the specific two-breed crosses and to any difference due to specific combining ability (e.g., Frahm and Marshall, 1985).

Results and Discussion

Cow Weights

Numbers and means by age of cow are shown in Table 2. Cows continued gaining weight until 7 yr of age. The largest yearly gain was from 2 to 3 yr of age and accounted for 37% of the total gain. By 4 yr of age, cows had accumulated most (89%) of their final weight. Unadjusted means for height did not change much across ages, which indicates that height reaches maturity earlier than weight. In fact, cows had attained 96%

Table 2. Numbers of cows (N), observations (n), and unadjusted means (± SD) for weight (kg), hip height (cm), and body condition score (points) by age of cows

		Weight		Height		Condition score	
Age (yr)	N	n	Mean	n	Mean	n	Mean
2	641	2564	399 ± 51	2563	123 ± 6.1	2563	6.1 ± 0.99
3	641	2562	459 ± 56	2562	125 ± 6.4	2562	6.3 ± 0.97
4	629	2515	502 ± 57	2514	125 ± 6.6	2510	6.6 ± 0.93
5	617	2464	520 ± 59	2446	127 ± 6.4	2440	6.4 ± 0.98
6	594	2352	550 ± 63	2351	128 ± 6.2	2352	6.8 ± 1.0
7	560	2225	562 ± 63	2224	128 ± 6.0	2224	6.6 ± 1.1
8	377	1016	561 ± 65	1016	128 ± 5.7	1016	6.6 ± 0.80

of their final height as 3 yr-olds. Changes for condition score were minor over ages (0.7 points), which is expected for a trait that reflects fatness and that changes more within ages (due to differences in physiological status) than across ages.

Estimates of breed means for weight by age in years are presented in Table 3. In general, cows of all breed groups showed similar growth patterns, and continued gaining weight to 7 yr of age, but at decreasing rates at later ages. The fraction of total weight (at 8 yr of age) gained during the 7 yr period ranged from 28 to 32%, the same range as found in Cycle I cows to 7 yr of age (Arango et al., 2002b). Rankings of F_1 cows were consistent across ages (except that F_1 cows with Maine Anjou sires were heavier than F_1 cows with Chianina sires after 5 yr of age) in the following order by breed of sire: Red Poll (lightest), Hereford-Angus (reciprocal), Braunvieh, Gelbvieh, Chianina, and Maine Anjou. Cows tended to cluster into three groups by weight with Chianina- and Maine Anjou-sired cows being heavier than the other breed groups. Cows with Gelbvieh and Braunvieh sires (continental breeds with greater milk production) had intermediate weights, while cows with sire breeds of British origin and their crosses were lighter than crosses with sires with continental European origin. Estimates of breed-group contrasts are presented in Table 4. The first set of contrasts represents deviations of each sire-breed group from the average solution for HA reciprocal cross-cows. All F_1 cows of other breeds were heavier than the HA crosses, except for F_1 cows with Red Poll sires, which were lighter by differences that ranged from 12 to 21 kg, and which were significant at 2 ($P < 0.01$), 3, and 7 ($P < 0.05$) yr of age. Cows with sires of other breeds outweighed HA cows by differences that varied with breed and age of cow. Chianina and Maine Anjou F_1 cows were heavier ($P < 0.01$) than HA cows at every age. Those differences (34 to 66 kg) were twice or more as large as the difference by which the next heaviest (Gelbvieh-sired) cows exceeded HA after 3 yr of age. Gelbvieh cross cows were heavier (22 to 25 kg, $P < 0.05$) than HA at each age, and at 2 yr of age the superiority was highly significant. Cows with Braunvieh sires were about 5 kg heavier than HA at all ages, but the differences were never significant. Purebred Hereford and Angus cows were lighter (12 to 25 kg) than the average of reciprocal HA

Table 3. Estimates of breed-group means for weight (kg) of cows by age[a]

	Age of cow, yr						
Breed group[b]	2	3	4	5	6	7	8
H	366	428	469	485	514	531	534
A	374	420	475	491	526	533	527
H-A	384	439	476	492	521	530	526
A-H	393	458	494	513	543	560	571
Rp-H	371	438	477	494	512	523	530
Rp-A	371	423	470	485	516	525	528
Bs-H	398	467	500	518	534	556	564
Bs-A	401	450	489	505	535	550	545
Gv-H	413	481	514	531	555	573	573
Gv-A	413	466	504	519	553	564	572
Ma-H	426	494	545	564	597	613	618
Ma-A	429	488	536	562	597	609	610
Ci-H	417	509	546	569	586	611	613
Ci-A	427	496	543	561	589	608	607

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

[b]H = Hereford, A = Angus, Rp = Red Poll; Bs = Braunvieh; Gv = Gelbvieh; Ma = Maine Anjou; Ci = Chianina.

Table 4. Contrasts between breed groups (± standard errors) and variance component estimates (VCE) for weight (kg) of cows

Breed group[a]	Age of cow, yr						
	2	3	4	5	6	7	8
HA-x[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bs-x	10.96 ± 6.39	9.18 ± 8.32	9.40 ± 9.14	9.34 ± 9.23	2.00 ± 9.43	7.79 ± 9.12	6.25 ± 10.18
Gv-x	24.12 ± 6.94**	24.60 ± 9.10*	24.20 ± 9.85*	22.64 ± 9.97*	21.69 ± 10.35*	23.86 ± 10.02*	24.03 ± 11.51*
Ci-x	33.60 ± 6.10**	53.39 ± 8.10**	59.43 ± 8.60**	62.82 ± 8.72**	55.37 ± 9.18**	64.44 ± 8.87**	61.32 ± 10.17**
Ma-x	38.70 ± 6.13**	42.27 ± 8.12**	55.64 ± 8.63**	60.53 ± 8.82**	64.71 ± 9.29**	66.05 ± 9.00**	65.59 ± 10.12**
Rp-x	−17.55 ± 6.18**	−18.20 ± 8.17*	−12.03 ± 8.72	−12.58 ± 8.88	−18.27 ± 9.34	−20.90 ± 9.01*	−19.34 ± 10.20
(H,A)-p[c]	18.70 ± 4.60**	24.95 ± 6.43**	13.39 ± 6.16*	14.60 ± 6.44*	12.17 ± 7.45	13.37 ± 7.05	17.70 ± 10.02
	(5.05)	(5.89)	(2.84)	(2.99)	(2.34)	(2.52)	(3.33)
Hx-Ax[d]	−0.93 ± 2.82	14.05 ± 3.87**	9.60 ± 3.79*	10.76 ± 3.91**	2.53 ± 4.48	8.10 ± 4.21	13.67 ± 5.09*
VCE[e]							
σ_p	37.49	48.41	47.50	47.94	53.31	49.17	48.78
σ_g	26.38	32.21	39.55	38.92	35.24	35.48	36.31
σ_c	15.13	22.46	22.23	20.71	23.74	22.24	23.60
h^2	0.50	0.44	0.69	0.66	0.44	0.52	0.55
$2R/\sigma_g$[f]	4.26	4.45	3.61	3.87	4.71	4.90	4.68

*$P < 0.05$.
**$P < 0.01$.
[a]x = crosses, p = pure breeds, H = Hereford, A = Angus, HA = mean of reciprocal crosses of HA and AH, Bs = Braunvieh, Gv = Gelbvieh, Ci = Chianina, Ma = Maine Anjou, Rp = Red Poll.
[b]Contrasts: respective breed of sire group vs Hereford-Angus crosses (HA-x).
[c]Contrast: H-A pure breeds vs HA-x (the heterosis percentage).
[d]Contrast: crosses with Hereford dams vs crosses with Angus dams.
[e]σ_p = phenotypic standard deviation, σ_g = genetic standard deviation, and σ_c = permanent environmental standard deviation, h^2 = heritability.
[f]Twice the range (R) in sire breed differences divided by genetic standard deviation.

crosses by differences that were greater at early ages (2 and 3 yr, $P < 0.01$), than at intermediate (4 and 5 yr, $P < 0.05$) and later ages (>5 yr, not significant). That pattern disagreed with Cycle I, in which the superiority of the reciprocal crosses was highly significant at all ages and increased with age (Arango et al., 2002b). Consequently, estimates of heterosis were less in Cycle II (2.3 to 5.9%) than in Cycle I (4.2 to 5.7%). Cows with Hereford dams were heavier than cows with Angus dams (except at 2 yr of age, $P > 0.05$), by differences that varied across ages (3 to 14 kg) and were significant at 3, 5 ($P < 0.01$), and 4 ($P < 0.05$) yr of age.

Cundiff et al. (1986) reported estimates of $2R/\sigma_g$, where R is the range of difference among sire breed means and σ_g is the additive genetic standard deviation within breeds, to assess genetic variation among breeds relative to that within breeds. The R is doubled in the ratio because differences among means from topcross progeny estimate half of the breed difference. When $2R/\sigma_g = 6$, the range between breeds is expected to equal the range in breeding value for individuals within breeds with the assumption that a range of $\pm 3\sigma_g$ represents the practical range in breeding values within breed. Table 4 shows that estimates of this ratio range from 3.61 for Chianina vs Red Poll cow weights at 4 yr of age, to 4.90 for Maine Anjou vs Red Poll cow weights at 7 yr of age. Thus, considerable variation is found both among and within breeds for cow weight.

Laster et al. (1979) reported weights of heifers (550 d) from Cycle II. Their ranking of breed groups was the same, but the magnitudes of the differences were less than in the recent study, which is expected with weights at an earlier age. On average, in that study, heifers with Red Poll sires were 10 kg lighter than HA, whereas heifers with Braunvieh, Gelbvieh, Chianina, and Maine Anjou sires outweighed HA females by 15, 23, 28, and 30 kg, respectively. Those differences were similar to those in the present study for 2-yr-old cows.

Reports from the literature for weights of Angus and Hereford cows up to 7 yr of age, which were discussed in a previous report (Arango et al., 2002b), compared well with the weights of Cycle II cows. Montaño-Bermudez (1987) studied HA (low milking) and Red Poll-Angus (medium milking) cows to compare crosses with different potentials for milk production. As in the present study, cows with Red Poll sires were lighter than HA cows at each age, by differences of 32, 42, and 48 kg at 2, 3, and 4 yr of age, respectively. These differences are greater than the differences in the present study. Morrison et al. (1989) reported weights of cows with Chianina (377 kg) and Maine Anjou (369 kg) sires and Angus and Hereford cows at 3 yr of age in Louisiana, in a study that also included crosses with Brahman and Simmental sires. The lower weights in their study compared with the weights reported in the present study may be due to environmental and managerial differences between Louisiana and Nebraska. The cows with Chianina sires were 8 kg heavier than those with Maine Anjou sires, which was similar to the difference of 12 kg in the present study at 3 yr of age.

Table 5 presents estimates of breed group contrasts for weight adjusted for condition score. Rankings of

Table 5. Contrasts between breed-groups (± standard errors) and variance component estimates (VCE) for weight of cows adjusted for condition score (kg)

Breed group[a]	Age of cow, yr						
	2	3	4	5	6	7	8
HA-x[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bs-x	25.30 ± 5.64**	28.37 ± 6.89**	20.98 ± 8.17*	20.54 ± 8.15*	12.53 ± 8.64	24.36 ± 7.84**	20.42 ± 8.50*
Gv-x	33.18 ± 6.11**	38.29 ± 7.50**	32.62 ± 8.80**	31.86 ± 8.81**	28.35 ± 9.43**	34.91 ± 8.59**	32.54 ± 9.59**
Ci-x	46.88 ± 5.38**	66.39 ± 6.66**	66.21 ± 7.69**	72.71 ± 7.74**	65.54 ± 8.34**	75.63 ± 7.60**	69.38 ± 8.50**
Ma-x	47.33 ± 5.39**	55.16 ± 6.68**	62.48 ± 7.72**	66.38 ± 7.81**	69.36 ± 8.43**	74.55 ± 7.71**	72.53 ± 8.45**
Rp-x	−4.33 ± 5.44	−3.02 ± 6.73	−4.96 ± 7.80	−5.57 ± 7.86	−9.91 ± 8.49	−4.72 ± 7.74	−7.24 ± 8.53
(H,A)-p[c]	14.14 ± 4.02** (3.78)	18.44 ± 5.19** (4.31)	10.38 ± 5.54 (2.19)	14.01 ± 5.82* (2.87)	13.07 ± 6.58 (2.52)	10.61 ± 6.01 (2.00)	17.33 ± 8.41* (3.31)
Hx-Ax[d]	−3.97 ± 2.47	7.01 ± 3.15*	6.68 ± 3.40	9.75 ± 3.51**	4.21 ± 3.99	7.44 ± 3.59*	6.02 ± 2.97
VCE[e]							
σ_p	31.86	39.04	42.69	43.19	48.28	42.17	41.36
σ_g	23.39	27.23	31.14	33.56	33.42	30.58	29.51
σ_c	13.58	21.86	13.38	19.19	25.85	21.45	19.42
h^2	0.54	0.49	0.68	0.60	0.48	0.53	0.51
$2R/\sigma_g$[f]	4.42	5.10	4.57	4.66	4.74	5.25	5.41

*$P < 0.05$.
**$P < 0.01$.
[a]x = crosses, p = pure breeds, H = Hereford, A = Angus, HA = mean of reciprocal crosses of HA and AH, Bs = Braunvieh, Gv = Gelbvieh, Ci = Chianina, Ma = Maine Anjou, Rp = Red Poll.
[b]Contrasts: respective breed of sire group vs Hereford-Angus crosses (HA-x).
[c]Contrast: H-A pure breeds vs HA-x; in parenthesis, the heterosis percentage.
[d]Contrast: crosses with Hereford dams vs crosses with Angus dams.
[e]σ_p = phenotypic standard deviation, σ_g = genetic standard deviation and σ_c = permanent environmental standard deviation, h^2 = heritability.
[f]Twice the range (R) in sire breed differences divided by genetic standard deviation.

crossbred cows were the same as for actual weight. However, breed differences were not of the same magnitude and contrasts and significance levels were somewhat different for cow weight adjusted for condition score compared with actual weight. Cows with Red Poll sires were the only group lighter (3 to 10 kg) than HA, but the differences were not significant, and were much smaller than for actual weight (Table 4) at each age as expected because Red Poll is the breed with lowest lean to fat ratio among Cycle II breeds. Cows with sires of other breeds outweighed HA cows by differences that varied with breed and age of cow, and which were greater than for actual weight. Gelbvieh-, Chianina-, and Maine Anjou-sired cows were heavier ($P < 0.01$) than HA crosses at every age. Differences from HA for Chianina (47 to 76 kg) and Maine Anjou (47 to 75 kg) were similar, and were about twice as great as the difference for the next heaviest cross (Gelbvieh, 28 to 38 kg) after 3 yr of age. The cows with Braunvieh sires were heavier than HA at every age by differences (13 to 28 kg) that were highly significant when exceeding 20 kg, at 2, 3, and 7 yr of age, and significant at 4, 5, and 8 yr of age. These differences for Braunvieh-sired cows were at least twice as large as corresponding differences for actual weight, which were not significant at any age. Purebred (Hereford, Angus) cows were lighter (10 to 18 kg) than the average of the reciprocal HA crosses by differences that were highly significant when greater than 14 kg at 2 and 3, and significant at 5 and 8 yr of age. In Cycle I, the superiority of the reciprocal crosses was always highly significant and increased with age (Arango et al., 2002b). Consequently, estimates of heterosis were less in Cycle II (2.0 to 4.3%) than in Cycle I (3.7 to 5.1%) for weight adjusted for condition score. The cows with Hereford dams were always heavier than cows with Angus dams after 2 yr of age by differences that ranged from 3 to 10 kg, which were significant at 3, 7 ($P < 0.05$), and 5 ($P < 0.01$) yr of age.

The range for differences among breeds relative to the genetic standard deviation within breeds ($2R/\sigma_g$) was slightly greater for weight adjusted for condition score than for actual weight at all ages (Table 5 vs Table 4).

Dearborn et al. (1987) reported cow weights adjusted for condition score at 2, 3, 5, and 7 yr of age from the diallel experiment within Cycle II. On average, adjustment for condition score decreased the magnitude of direct heterosis similar to results from this study. The HA cows were always heavier than the purebreds. The differences were less than for actual weight at each age and were somewhat less than the differences in the present study. In their study, rankings of cows with Red Poll sires and HA dams changed with adjustment for condition score. The Red Poll sired cows were lighter than HA cows only at 2 and 7 yr. Cows with Braunvieh sires were heavier than HA cows by 31, 37, 32, and 29 kg at 2, 3, 5, and 7 yr of age (Dearborn et al., 1987). Those differences followed the same pattern, but were slightly greater than the differences in the present study.

Table 6. Estimates of breed-group means for hip height (cm) of cows by age[a]

	Age of cow, yr						
Breed group[b]	2	3	4	5	6	7	8
H	118	119	120	121	123	123	123
A	116	118	119	120	122	121	122
H-A	118	119	120	121	123	122	122
A-H	119	120	121	122	124	124	124
Rp-H	121	122	122	124	125	125	125
Rp-A	119	121	122	123	124	124	124
Bs-H	125	126	127	129	130	130	130
Bs-A	124	125	126	127	128	128	128
Gv-H	126	127	127	129	130	130	131
Gv-A	124	125	126	127	128	128	128
Ma-H	126	128	129	130	131	131	132
Ma-A	125	127	127	129	130	130	130
Ci-H	133	135	136	137	138	139	139
Ci-A	131	134	134	135	137	136	136

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

[b]H = Hereford, A = Angus, Rp = Red Poll; Bs = Braunvieh, Gv = Gelbvieh, Ma = Maine Anjou, Ci = Chianina.

Cow Height

Estimates of breed means for height by age (yr) are presented in Table 6. Cows from all breed groups gained about 1 cm in height per year from 2 to 6 yr of age, when they reached a plateau. The increase in height from 2 to 8 yr accounted for only 3.1 to 4.9% of the total height at 8 yr of age in the various breed groups, indicating that height reaches maturity earlier in life than weight for these breed groups. Breed groups tended to cluster in three groups for height. British breeds (Hereford, Angus) and crosses (HA reciprocal crosses and Red Poll crosses) tended to have similar heights, which were less than the corresponding heights for crosses with continental breeds. The highest height in the British cluster (Red Poll at 8 yr of age) was equal to the lowest height for continental crosses (Braunvieh sired cows at 2 yr of age). A second cluster was formed by F_1 cows with Braunvieh, Gelbvieh (with similar heights at each age) and Maine Anjou sires. A third cluster was formed by cows with Chianina sires, which were tallest and, on average, had heights (132 to 138 cm) that exceeded the second tallest group (F_1 Maine Anjou, 131 cm at 8 yr). Rankings of breed groups for height were consistent across ages, for all breed groups.

Estimates of breed group contrasts are presented in Table 7. The F_1 cows of all breeds were taller than HA cross cows by differences that were highly significant except for cows with Red Poll sires, which were significant from 2 to 6 yr of age. The cows with Chianina sires were taller than HA cross cows by a difference (14 to 15 cm) that was about twice as great as the difference by which the second tallest cross (F_1 Maine Anjou, 7 to 8 cm) surpassed HA cows at every age. Cows with Braunvieh and Gelbvieh sires exceeded HA cross cows by about 6 cm at each age. The cows with Red Poll sires were less than 2 cm taller than HA cross cows. The reciprocal HA crosses were about 1 cm taller than the average of the purebred Hereford and Angus at each age, but that superiority was significant only at 2 yr of age. Therefore, heterosis was only from 0.5 to 1.1% across ages, similar to the 0.1 to 1.1% found for Cycle I (Arango et al., 2002b). Cows with Hereford dams were taller ($P < 0.01$) at all ages than cows with Angus dams by differences (1.1 to 2.0 cm) that increased with age. The ratio of $2R/\sigma_g$ was greatest for Chianina vs HA at all ages, ranging from 8.60 at 5 yr of age to 10.23 at 8 yr of age. The ratios of $2R/\sigma_g$ for cow heights were approximately twice as large as corresponding estimates for actual weight or weight adjusted for condition score (see Tables 4, 5, and 7). When both between- and within-breed genetic variations are considered, the range in breeding values from the smallest HA to the largest Chianina was 14.6 (i.e., 6 + 8.60 where the 6 represents a range of ± 3 genetic standard deviations within breed) at 5 yr of age and 16.23 at 8 yr of age. More than half of the total range in breeding value was found between the means for breeds sampled in this experiment for this highly heritable trait.

Laster et al. (1979) reported heights of heifers (550 d) from the Cycle II. The ranking of breed groups was the same, but the heights were less than in this study, as expected from measures at an earlier age. On average, HA heifers (117 cm) were smallest, exceeded by heifers with Red Poll (1 cm), Braunvieh, Gelbvieh and Maine Anjou (6 cm), and Chianina (12 cm) sires. Heifers with Hereford dams were 1 cm taller than heifers with Angus dams, similar to results found in this study. Dearborn et al. (1987) reported cow heights at 2, 3, 5 and 7 yr of age from the diallel experiment within Cycle II with breed means and contrasts similar to those in the present study.

Table 7. Contrasts between breed-groups (± standard errors) and variance component estimates (VCE) for hip height (cm) of cows

Breed group[a]	Age of cow, yr 2	3	4	5	6	7	8
HA-x[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bs-x	6.18 ± 0.70**	6.11 ± 0.74**	5.94 ± 0.77**	6.21 ± 0.78**	5.81 ± 0.77**	5.71 ± 0.74**	5.95 ± 0.77**
Gv-x	6.52 ± 0.76**	6.06 ± 0.80**	5.88 ± 0.83**	6.02 ± 0.84**	5.84 ± 0.83**	5.70 ± 0.81**	6.16 ± 0.86**
Ci-x	13.84 ± 0.67**	14.87 ± 0.70**	14.42 ± 0.73**	14.50 ± 0.74**	14.10 ± 0.72**	14.18 ± 0.71**	14.06 ± 0.76**
Ma-x	7.28 ± 0.67**	7.52 ± 0.70**	7.46 ± 0.73**	7.58 ± 0.75**	7.34 ± 0.73**	7.13 ± 0.72**	7.70 ± 0.76**
Rp-x	1.68 ± 0.67*	1.86 ± 0.71*	1.54 ± 0.74*	1.62 ± 0.75*	1.54 ± 0.74*	1.20 ± 0.72	1.36 ± 0.77
(H,A)-p[c]	1.28 ± 0.49*	1.02 ± 0.51	0.89 ± 0.55	1.03 ± 0.53	0.77 ± 0.53	1.06 ± 0.53	0.61 ± 0.70
	(1.09)	(0.86)	(0.74)	(0.85)	(0.63)	(0.87)	(0.50)
Hx-Ax[d]	1.25 ± 0.30**	1.26 ± 0.32**	1.12 ± 0.33**	1.57 ± 0.33**	1.48 ± 0.33**	1.99 ± 0.32**	2.01 ± 0.38**
VCE[e]							
σ_p	3.86	3.93	4.10	3.96	3.86	3.68	3.53
σ_g	2.98	3.10	3.33	3.37	3.24	3.05	2.75
σ_c	1.50	1.72	1.83	1.34	1.51	1.68	1.94
h^2	0.60	0.62	0.60	0.72	0.70	0.69	0.61
$2R/\sigma_g$[f]	9.29	9.59	8.66	8.60	8.70	9.30	10.23

*$P < 0.05$.
**$P < 0.01$.
[a]x = crosses, p = pure breeds, H = Hereford, A = Angus, HA = mean of reciprocal crosses of HA and AH, Bs = Braunvieh, Gv = Gelbvieh, Ci = Chianina, Ma = Maine Anjou, Rp = Red Poll.
[b]Contrasts: respective breed of sire group vs Hereford-Angus crosses (HA-x).
[c]Contrast: H-A pure breeds vs HA-x; in parenthesis, the heterosis percentage.
[d]Contrast: crosses with Hereford dams vs crosses with Angus dams.
[e]σ_p = phenotypic standard deviation, σ_g = genetic standard deviation and σ_c = permanent environmental standard deviation, h^2 = heritability.
[f]Twice the range (R) in sire breed differences divided by genetic standard deviation.

Body Condition Score

Unadjusted breed means for body condition score by age (yr) are presented in Table 8. Condition scores increased to 4 yr of age, then generally, but with many exceptions, fluctuated slightly up and down at every other age up to 8 yr of age. All of the changes in means, however, were within a range of 5.8 to 7.4 points for all breed groups. Hereford, Angus, and their reciprocal (HA) crosses interchanged rankings across ages, but always had greater condition scores than the other F_1 crosses. Table 9 shows estimates of breed group contrasts. The HA reciprocal cross cows exceeded the other F_1 crosses by differences (0.27 to 0.86 points) that were highly significant at all ages, except at 8 yr of age for crosses with Chianina sires ($P < 0.05$) and crosses with

Table 8. Estimates of breed-group means for body condition score (points) of cows by age[a]

Breed group[b]	Age of cow, yr 2	3	4	5	6	7	8
H	6.25	6.57	6.89	6.69	7.07	6.82	7.08
A	6.45	6.56	6.86	6.87	7.41	6.90	6.79
H-A	6.57	6.70	6.95	6.82	7.17	6.83	6.67
A-H	6.64	6.90	7.21	6.89	7.33	7.18	7.23
Rp-H	6.03	6.33	6.69	6.35	6.56	6.27	6.48
Rp-A	5.76	5.97	6.47	6.22	6.57	6.32	6.48
Bs-H	5.97	6.11	6.42	6.10	6.44	6.24	6.54
Bs-A	5.75	5.82	6.18	5.89	6.43	6.30	6.24
Gv-H	6.27	6.23	6.58	6.18	6.72	6.53	6.62
Gv-A	5.99	6.15	6.43	6.23	6.80	6.53	6.61
Ma-H	6.16	6.35	6.69	6.48	6.86	6.56	6.60
Ma-A	6.14	6.16	6.51	6.33	6.84	6.68	6.77
Ci-H	6.00	6.34	6.71	6.18	6.53	6.61	6.73
Ci-A	5.80	6.04	6.46	6.03	6.50	6.43	6.55

[a]Means were obtained by adding the unadjusted mean for H-A cows, the solution constrained to zero in the analysis, to solutions for each breed group.
[b]H = Hereford, A = Angus, Rp = Red Poll, Bs = Braunvieh, Gv = Gelbvieh, Ma = Maine Anjou, Ci = Chianina.

Gelbvieh and Maine Anjou sires (not significant). Differences from crosses with Braunvieh sires (0.56 to 0.86 points) were great at all ages. The same pattern occurred for crosses with Jersey sires in Cycle I (Arango et al., 2002b), as expected for crosses with sires of dairy breeds. Reciprocal HA cows had, on average, slightly greater condition scores (0.01 to 0.25 points) than the average of the purebred Hereford and Angus cows. That difference, in general, decreased with age, and was significant only up to 4 yr of age. Cows with Hereford dams had slightly greater condition scores (0.02 to 0.24) than cows with Angus dams. Those differences were highly significant up to 5 yr of age.

Dearborn et al. (1987) reported condition scores at 2, 3, 5, and 7 yr of age from the diallel experiment implemented at the same time as Cycle II. Breed means were similar to those reported in the present study. On average, HA cows had the greatest condition score (6.8, 7.1, 7.1, and 7.4 points) at each age, which exceeded cows with Braunvieh sires by 0.8 to 1.0 points, and cows with Red Poll sires by 0.8 to 1.3 points. In general, those differences were slightly greater than those reported here. Kropp et al. (1973), Holloway et al. (1975), and Wyatt et al. (1977) reported on an experiment with Hereford, Holstein, and Hereford-Holstein cows under range and drylot conditions. On average, in that experiment (two measurements during fall and one in spring, on range conditions and moderate level of supplementation), Hereford cows had the greatest condition scores of 5.4, 5.4, and 6.0 points (1 to 9 scale) at 2, 3, and 4 to 5 yr of age. Cows with Holstein sires had scores of 4.4, 3.8, and 4.8 points at the same ages, which agrees with the low condition scores of the cows with Braunvieh sires in this study and with Jersey sires in Cycle I (Arango et al., 2002b). In Australia, Morgan (1986) reported that 2- to 7-yr-old Herefords had the greatest condition scores of 2.6 (0 to 5 scale), whereas HA cows (2.4 points) had greater scores than Holstein-Hereford cows (1.4 points). Bowden (1980) evaluated condition by weight to height ratio and by ultrasound measurement of backfat thickness in F_1 cows with Angus dams (values from normal diets are reported here) at 2 yr of age. The HA cows had the greatest fat thickness (7.2), whereas crosses from breeds of sire with greater milk potential had the lowest values (i.e., Simmental-Angus [5.9] and Jersey-Angus [5.6]). Those results agree with the present results for Cycle II where HA cows had condition scores of 6.6 points and cows with Braunvieh sires had smallest condition scores (5.9 points).

Implications

Large and significant differences were found among Angus, Hereford, their reciprocal crosses, and crosses with Red Poll, Braunvieh, Gelbvieh, Maine Anjou, and Chianina sires for cow weight, height, and condition score at different ages. These traits are related to efficiency of beef production. Such differences can be exploited to match breeding systems with specific production systems and market requirements to optimize beef production. Such decisions can be made with more confidence because 1) breed of sire differences generally

Table 9. Contrasts between breed-groups (± standard errors) and variance component estimates (VCE) for body condition score (points) of cows

Breed group[a]	Age of cow, yr						
	2	3	4	5	6	7	8
HA-x[b]	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bs-x	−0.74 ± 0.12**	−0.83 ± 0.13**	−0.78 ± 0.12**	−0.86 ± 0.15**	−0.82 ± 0.13**	−0.74 ± 0.14**	−0.56 ± 0.15**
Gv-x	−0.48 ± 0.13**	−0.61 ± 0.14**	−0.58 ± 0.14**	−0.65 ± 0.16**	−0.49 ± 0.15**	−0.48 ± 0.15**	−0.34 ± 0.17
Ci-x	−0.71 ± 0.12**	−0.61 ± 0.13**	−0.49 ± 0.12**	−0.75 ± 0.14**	−0.74 ± 0.13**	−0.49 ± 0.14**	−0.31 ± 0.15*
Ma-x	−0.46 ± 0.12**	−0.54 ± 0.13**	−0.49 ± 0.12**	−0.45 ± 0.14**	−0.40 ± 0.13**	−0.39 ± 0.14**	−0.27 ± 0.15
Rp-x	−0.71 ± 0.12**	−0.65 ± 0.13**	−0.50 ± 0.12**	−0.57 ± 0.14**	−0.69 ± 0.13**	−0.71 ± 0.14**	−0.47 ± 0.15**
(H,A)-p[c]	0.25 ± 0.10*	0.23 ± 0.10*	0.21 ± 0.10*	0.07 ± 0.11	0.01 ± 0.11	0.14 ± 0.11	0.02 ± 0.14
Hx-Ax[d]	0.17 ± 0.06**	0.24 ± 0.06**	0.21 ± 0.06**	0.11 ± 0.07	0.02 ± 0.07	0.05 ± 0.07	0.15 ± 0.07
VCE[e]							
σ_p	0.931	0.915	0.857	0.906	0.900	0.843	0.753
σ_g	0.426	0.461	0.453	0.622	0.480	0.501	0.539
σ_c	0.308	0.423	0.396	0.239	0.437	0.447	0.220
h^2	0.21	0.25	0.28	0.47	0.28	0.35	0.51
$2R/\sigma_g$[f]	3.47	3.60	3.44	2.76	3.42	2.95	2.08

*$P < 0.05$.
**$P < 0.01$.
[a]x = crosses, p = pure breeds, H = Hereford, A = Angus, HA = mean of reciprocal crosses of HA and AH, Bs = Braunvieh, Gv = Gelbvieh, Ci = Chianina, Ma = Maine Anjou, Rp = Red Poll.
[b]Contrasts: respective breed of sire group vs Hereford-Angus crosses (HA-x).
[c]Contrast: H-A pure breeds vs HA-x.
[d]Contrast: crosses with Hereford dams vs crosses with Angus dams.
[e]σ_p = phenotypic standard deviation, σ_g = genetic standard deviation and σ_c = permanent environmental standard deviation, h^2 = heritability.
[f]Twice the range (R) in sire breed differences divided by genetic standard deviation.

were maintained across postyearling ages through maturity, 2) differences in weight due to differences in condition (fatness and, indirectly, milk production) were of small magnitude, 3) ranking of breed groups was generally the same for actual weight and for weight adjusted for condition score, 4) differences among breed groups for height closely followed differences for weight, and 5) differences for condition score were small across ages and breed groups.

Literature Cited

Arango, J. A., L. V. Cundiff, and L. D. Van Vleck. 2002a. Genetic parameters for weight, weight adjusted for body condition score, height, and body condition score in beef cows. J. Anim. Sci. 80:3112–3122.

Arango, J. A., L. V. Cundiff, and L. D. Van Vleck. 2002b. Breed comparisons of Angus, Charolais, Hereford, Jersey, Limousin, Simmental, and South Devon for weight, weight adjusted for body condition score, height, and body condition score of cows. J. Anim. Sci. 80:3123–3132.

Boldman, K. G., L. A. Kriese, L. D. Van Vleck, C. P. Van Tassell, and S. D. Kachman. 1995. A Manual for Use of MTDFREML. A Set of Programs to Obtain Estimates of Variances and Covariances [DRAFT]. ARS-USDA, Washington, DC.

Bowden, D. M. 1980. Feed utilization for calf production in the first lactation by 2-yr-old F_1 crossbred cows. J. Anim. Sci. 51:304–315.

Cundiff, L. V., K. E. Gregory, R. M. Koch, and G. E. Dickerson. 1986. Genetic diversity among cattle breeds and its use to increase beef production in a temperate environment. Proc. 3rd World Cong. Genet. Appl. Livest. Prod., Lincoln, Nebraska IX:271–282.

Cundiff, L. V., K. E. Gregory, and R. M. Koch. 1988. Productivity of large sized cattle breeds in beef cow herds in the temperate zones of northern America. Proc. 3rd. World Cong. Sheep and Beef Cattle Breeding, Paris, France 2:3–23. INRA Publications, Paris, France.

Dearborn, D. D., K. E. Gregory, D. D. Lunstra, and L. V. Cundiff. 1987. Heterosis and breed maternal and transmitted effects in beef cattle. V. Weight, height, and condition score of females. J. Anim. Sci. 64:706–713.

Dickerson, G. E. 1993. Evaluation of Breeds and Crosses of Domestic Animals. FAO Animal Production and Health Paper No. 108. Rome, Italy.

Frahm, R. R., and D. M. Marshall. 1985. Comparisons among two-breed cross cow groups. I. Cow productivity and calf performance to weaning. J. Anim. Sci. 61:844–855.

Gregory, K. E., L. V. Cundiff, G. M. Smith, D. B. Laster, and H. A. Fitzhugh, Jr. 1978. Characterization of biological types of cattle—Cycle II. I. Birth and weaning traits. J. Anim. Sci. 47:1022–1030.

Gregory, K. E., and R. R. Maurer. 1991. Prenatal and postnatal maternal contributions to reproductive, maternal, and size-related traits of beef cattle. J. Anim. Sci. 69:961–976.

Holloway, J. W., D. F. Stephens, J. V. Whiteman, and R. Totusek. 1975. Performance of 3-yr-old Hereford, Hereford × Holstein and Holstein cows on range and drylot. J. Anim. Sci. 40:114–125.

Jenkins, T. G., M. Kaps, L. V. Cundiff, and C. L. Ferrell. 1991. Evaluation of between and within-breed variation in measures of weight-age relationships. J. Anim. Sci. 69:3118–3128.

Kropp, J. R., D. F. Stephens, J. W. Holloway, J. V. Whiteman, L. Knori, and R. Totusek. 1973. Performance on range and drylot of 2-year-old Hereford, Hereford × Holstein and Holstein females as influenced by level of winter supplementation. J. Anim. Sci. 37:1222–1232.

Laster, D. B., G. M. Smith, L. V. Cundiff, and K. E. Gregory. 1979. Characterization of biological types of cattle: II. Postweaning growth and puberty of heifers. J. Anim. Sci. 48:500–508.

Montaño-Bermudez, M. 1987. Components of performance and biological efficiency of crossbred beef cattle with different genetic potential for milk. Ph.D. Diss., Univ. of Nebraska, Lincoln.

Morgan, J. H. L. 1986. The use of crossbred cows to increase beef production per hectare. Proc. 3rd. World Cong. Genet. Appl. Livest. Prod. Lincoln, Nebraska IX:319–324.

Morrison, D. G., P. E. Humes, and K. L. Koonce. 1989. Comparison of Brahman and continental European crossbred cows for calving ease in a subtropical environment. J. Anim. Sci. 67:1722–1731.

Setshwaelo, L. L., L. V. Cundiff, and G. E. Dickerson. 1990. Breed effects on crossbred cow-calf performance. J. Anim. Sci. 68:1577–1587.

Wyatt, R. D., K. S. Lusby, J. V. Whiteman, M. B. Gould, and R. Totusek. 1977. Performance of 4- and 5-year-old Hereford, Hereford × Holstein and Holstein cows on range and in drylot. J. Anim. Sci. 45:1120–1130.