

# Genetic and Environmental Factors Affecting Serum Macrominerals and Weights in an Angus-Brahman Multibreed Herd: I. Additive and Nonadditive Group Genetic Effects of Serum Calcium, Phosphorus, and Magnesium and Weight at Weaning<sup>1</sup>

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**ABSTRACT:** Amounts of serum calcium, phosphorus, and magnesium at weaning (WCa, WP, and WMg, respectively) and weaning weights (WW) were obtained from 380 Angus (A), Brahman (B), and A × B calves of various expected A and B fractions reared at the Pine Acres Research Station of the University of Florida, Citra from 1989 to 1990. Calves were produced by mating A, .75A, .25B, .5A .5B, .25A .75B, B, and Brangus (.625A .375B) sires to dams of the same expected breed fractions, except for .25A .75B dams. Best linear unbiased estimates (BLUE) of genetic effects, expressed as regression coefficients, were 1)  $-15.07 \pm 13.65$  mg of WCa,  $-11.21 \pm 12.07$  mg of WP,  $-1.23 \pm 2.99$  mg of WMg, and  $.66 \pm 1.18$  kg of WW for the difference between A and B additive direct; 2)  $9.79 \pm 6.94$  mg of WCa,  $-5.72 \pm 6.14$  mg of WP,  $1.64 \pm 1.52$  mg of WMg, and  $.52 \pm .60$  kg of WW for the difference between A and B additive

maternal; 3)  $242.21 \pm 51.56$  mg of WCa,  $66.67 \pm 45.62$  mg of WP,  $52.16 \pm 11.27$  mg of WMg, and  $22.61 \pm 4.44$  kg of WW for A × B nonadditive direct; and 4)  $373.63 \pm 38.44$  mg of WCa,  $93.96 \pm 34.02$  mg of WP,  $69.90 \pm 8.41$  mg of WMg, and  $36.83 \pm 3.31$  kg of WW for A × B nonadditive maternal. Nonadditive (A × B) effects were the main factors affecting total (sum of additive plus nonadditive) genetic effects in this multibreed population. Total genetic effects were used to rank breed group of sire × breed group of dam combinations. The highest combination was given by the mating of B sires to F<sub>1</sub> dams ( $495.86 \pm 43.58$  mg of WCa,  $121.63 \pm 38.56$  mg of WP,  $96.49 \pm 9.53$  mg of WMg, and  $48.23 \pm 3.73$  kg of WW) and the lowest by mating A sires to A dams ( $-5.28 \pm 6.94$  mg of WCa,  $-16.92 \pm 6.14$  mg of WP,  $.41 \pm .02$  mg of WMg and  $-.14 \pm .59$  kg of WW).

Key Words: Beef Cattle, Genetic Effects, Combining Ability, Crossbreeding, Minerals, Weaning Weight

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## Introduction

The Angus (A) and Brahman (B) breeds are used extensively in crossbreeding programs in the southern region of the United States. To meet the nutritional requirements of calves for growth and

development, supplementation with macrominerals including Ca, P, and Mg is recommended. The first two macrominerals, Ca and P, participate in bone formation, and Mg is an activator of many enzymes involved in protein and carbohydrate metabolism (McDowell et al., 1983; Littledike and Goff, 1987; Arnaud and Sanchez, 1990; Shils, 1990).

Despite the major roles that Ca, P, and Mg play in growth and development of beef animals, there are no quantitative genetic studies linking amounts of macrominerals to growth traits. Mineral concentrations in serum have been widely used in nutritional studies to depict the mineral status of animals (Giduck and Fontenot, 1987;

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Table 1. Number of sires and dams by breed group composition

Breed group <sup>a</sup>	Sires				Dams			
	Total	1989	1990	1989 and 1990 <sup>b</sup>	Total	1989	1990	1989 and 1990 <sup>c</sup>
A	5	4	4	3	65	65	42	42
.75A .25B	3	2	3	2	18	18	14	14
.5A .5B	4	2	3	1	38	30	33	25
.25A .75B	4	4	3	3	0	0	0	0
B	5	3	4	2	76	52	59	35
Brangus	7	4	5	2	46	25	40	19
Total	28	19	22	13	243	190	188	135

<sup>a</sup>A = Angus; B = Brahman.

<sup>b</sup>Number of sires present in both 1989 and 1990.

<sup>c</sup>Number of dams present in both 1989 and 1990.

Reffett-Stabel et al., 1989; Salih et al., 1989; Orr et al., 1990). However, what animals need to fulfill their growth potential are amounts of macrominerals, rather than concentrations. In addition, amounts of macrominerals in the serum will explain the growth of an animal better than concentrations because the accumulation of macrominerals in the body of animals is part of the growth and development process. Furthermore, this property of being cumulative makes amounts of macrominerals at a given age suitable for consideration as concomitant traits in multiple-trait genetic evaluation procedures used to evaluate animals for growth traits (this aspect will be discussed in the second paper of this series). Thus, the macromineral traits considered in this study are amounts of Ca, P, and Mg in serum.

The objectives of this research were 1) to estimate differences between A and B breed additive direct and maternal genetic effects for serum Ca, P, and Mg and weight at weaning; 2) to estimate A × B nonadditive direct and maternal genetic effects for serum Ca, P, and Mg and weight at weaning; and 3) to evaluate the combining ability of straightbred (A and B) and crossbred (.75A .25B, .5A .5B, and .25A .75B) sire groups for serum Ca, P, and Mg and weight at weaning, when mated across dam breed groups of the same types.

## Materials and Methods

### Animals

Macromineral and weight records were obtained in 1989 and 1990 on 380 calves from a multibreed research herd formed by A, B, and several A × B crosses. The herd was located at the Pine Acres Research Station of the University of Florida, Citra. Six sire breed groups consisting of A, .75A .25B, .5A .5B, .25A .75B, B, and Brangus (.625A .375B) were mated across five dam breed

groups of the same genetic composition as sire groups (except for .25A .75B that was unavailable). The distribution of the number of sires and dams with progeny by breed composition is shown in Table 1. A total of 28 sires was used. The number of sires per breed group per year ranged from two for .75A .25B in 1989 to five for B in 1990. Between one (for .5A .5B) and three (for A) sires per breed group were represented in both 1989 and 1990. This ensured connectedness in the data set. The number of dams was 243. There was a minimum of 14 dams (.75A .25B in 1990) and a maximum of 65 dams (A in 1989) per breed group per year. The number of calves produced in 1989 and 1990 by mating subclass (Table 2) ranged from three (.5A .5B sires mated to .75A .25B dams) to 40 (B sires mated to B dams).

### Cow Management

During most of the year cows were managed in two separate herds: A and A × B cows in one herd and B cows in the other. From June to mid-December, both herds were maintained on bahiagrass (*Paspalum notatum*) pastures without energy-protein supplementation. A free-choice mineral supplement containing 20% Ca, 9% P, and .25% Mg was provided throughout the year. In winter (mid-December to March), they were assigned to six replicated forage supplementation regimens and one control (13 herds), according to breed group of dam and breed group of sire. Supplementation consisted of bermudagrass (*Cynodon dactylon*) hay wilted to various percentages of DM, urea (32% N), and molasses. Cows were synchronized with prostaglandin F<sub>2α</sub> in March (A and A × B) and April (B), then artificially inseminated no more than twice. Subsequently, cows were assigned to six separate clean-up herds and left with a clean-up bull (one clean-up bull per breed group of sire) for 60 d.

Table 2. Number of progeny by mating type

Breed group of dam <sup>a</sup>	Breed group of sire <sup>a</sup>							Brangus	Total	
	A	.75A	.25B	.5A	.5B	.25A	.75B			B
A	26	13		7		17		20	24	107
.75A .25B	6	5		3		6		6	6	32
.5A .5B	12	9		5		9		16	12	63
B	14	18		11		15		40	13	111
Brangus	8	6		5		8		11	29	67
Total	66	51		31		55		93	84	380

<sup>a</sup>A = Angus; B = Brahman.

### Records

Weights and blood samples from all calves were taken within 3 mo of birth and at weaning. Age at first sampling ranged from 1 to 85 d (97% of calves were sampled within 70 d of birth). Age at weaning ranged from 151 to 275 d (91% of calves were weaned between 210 and 270 d of age). Approximately 10 mL of blood was withdrawn from each animal by jugular puncture using vacutainer tubes. Blood samples were then centrifuged at 700 × *g* for 30 min to separate the serum. Serum samples were deproteinized using 10% trichloroacetic acid. Flame absorption spectrophotometry (Model 306, Perkin-Elmer, Norwalk, CT) was used to determine Ca and Mg, and P was analyzed by a colorimetry method (Fick et al., 1979).

### Traits

Four traits were defined: serum Ca at weaning (WCa), serum P at weaning (WP), and serum Mg at weaning (WMg) and weaning weight (WW). All traits were adjusted to 205 d using the formula recommended by the Beef Improvement Federation (BIF, 1990). Amounts of serum Ca, P, and Mg as well as weight from the first sampling were substituted for their amounts and weight at birth in the BIF adjustment formulas. Amounts of macrominerals were computed as the product of the concentration of each macromineral in serum times the estimated serum volume for each calf. Serum volume was computed as the product of calf weight times the expected fraction of blood in cattle (blood weight/animal weight = .077; Frandson, 1975) times the expected fraction of serum in blood (serum volume/blood volume = .6; Jesse, 1979).

### Genetic Analysis

Best linear unbiased estimates (BLUE) of A additive (expressed as deviations from B) and A × B nonadditive (expressed as A × B plus B × A minus A × A plus B × B) direct and maternal genetic effects were obtained using the two-step

procedure described by Elzo et al. (1990). The model included environmental effects (year, winter management within year, clean-up herd within year, sex of calf, age of dam, calf age at first sampling, and sex of calf × age of dam subclass), group genetic effects (A sire additive, A dam additive, A × B calf nonadditive, and A × B dam nonadditive), and residual effects. There were three sexes (bulls, heifers, and steers) and six age of dam categories (3, 4, 5, 6, 7, and ≥ 8 yr of age). Calf age at first sampling in the model was defined as a discrete variable using intervals of 5 d of age (1 = 1 to 5 d, 2 = 6 to 10 d, etc.). There were 17 calf age at first sampling categories. The sex of calf × age of dam subclass contained the effects of sex of calf, age of dam, and the interaction sex of calf × age of dam. Interactions among environmental effects other than sex of calf × age of dam were nonsignificant and excluded from the final model. All effects in the model except the residual were assumed to be fixed. Residual effects were assumed to be random with mean zero, common variance and uncorrelated. Genetic effects were defined as regression coefficients. The A sire and dam additive genetic effects were defined as linear functions of the expected fraction of A alleles in the sire and the dam of a calf, respectively. Similarly, the A × B calf and dam nonadditive genetic effects were assumed to be proportional to the expected fraction of AB intralocus combinations in calves and dams. The genetic explanation of these four group genetic effects is as follows: 1) A sire genetic effect = .5 additive direct genetic effect, 2) A dam genetic effect = .5 additive direct genetic effect + additive maternal genetic effect, 3) A × B calf nonadditive genetic effect = A × B nonadditive direct genetic effect, and 4) A × B dam nonadditive genetic effect = A × B nonadditive maternal genetic effect. The importance of the effects in the model was tested using the ratio of the mean square due to each effect divided by the mean square of the residual effects (i.e., the *F*-statistic, Searle, 1971).

To study the combining ability of breed groups of sires mated across breed groups of dams, the

Table 3. *F* values and probability levels of environmental and genetic group effects for serum Ca, P, and Mg and weight at weaning

Source <sup>a</sup>	df	Trait							
		Weaning Ca		Weaning P		Weaning Mg		Weaning wt	
		<i>F</i>	<i>P</i> > <i>F</i>	<i>F</i>	<i>P</i> > <i>F</i>	<i>F</i>	<i>P</i> > <i>F</i>	<i>F</i>	<i>P</i> > <i>F</i>
Year	1	42.31	.01	13.57	.01	24.19	.01	16.24	.01
Winter management (year)	24	2.02	.01	1.27	.18	1.38	.11	2.58	.01
Clean up herd (year)	9	2.57	.01	1.68	.09	1.54	.13	1.93	.05
Calf age at first sampling	16	.83	.65	.83	.66	.90	.57	.61	.87
Sex of calf × age of dam subclass	17	3.64	.01	2.82	.01	3.86	.01	4.52	.01
Angus sire additive <sup>b</sup>	1	1.22	.27	.86	.35	.17	.68	.32	.57
Angus dam additive <sup>b</sup>	1	3.31	.07	106.84	.01	14.37	.01	3.27	.07
A × B direct nonadditive <sup>c</sup>	1	22.07	.01	2.14	.14	21.41	.01	25.90	.01
A × B maternal nonadditive <sup>c</sup>	1	94.45	.01	7.63	.01	69.14	.01	123.62	.01

<sup>a</sup>Residual mean squares were 5.8344 mg<sup>2</sup> for weaning Ca, 4.5675 mg<sup>2</sup> for weaning P, .2790 mg<sup>2</sup> for weaning Mg, and .0433 kg<sup>2</sup> for weaning weight; df residual effects = 308.

<sup>b</sup>Angus additive group genetic effects are expressed as deviations from Brahman.

<sup>c</sup>A × B intralocus nonadditive group genetic effects are defined as deviations from those of the parental breeds; A = Angus; B = Brahman.

BLUE of the total genetic value of calves produced by each mating combination was determined. Total genetic values were computed as linear functions of the expected A sire additive, A dam additive, A × B calf nonadditive, and A × B dam nonadditive genetic effects in each mating combination. For instance, when .5A .5B sires are mated to .5A .5B (*F*<sub>1</sub>) dams, the calves produced have an estimated total genetic value of .5 (BLUE of A sire additive genetic effect) + .5 (BLUE of A dam additive genetic effect) + .5 (BLUE of A × B calf nonadditive genetic effect) + 1 BLUE of A × B dam nonadditive genetic effect).

Computations were carried out using the GLM procedure of SAS (1985).

## Results and Discussion

Amounts of macrominerals are an integral part of the growth and development process in animals (Littledike and Goff, 1987; Shils, 1990). They have a measurable contribution to increments in weight of growing individuals. Thus, there is a biological part-whole relationship between amounts of macrominerals in body tissues (e.g., bone, muscle, serum) and weights of animals. Because weights were used here to predict amounts of macrominerals in serum of calves, environmental and genetic effects for these estimated amounts of macrominerals in serum and weight at weaning would be expected to be more similar than those that would have been obtained between direct measurements of serum macrominerals and weight at weaning. This expected differential increment in the correspondence of the results of these analyses could not be quantified in this

study, because it was not feasible to measure directly the amounts of macrominerals in serum.

### Environmental Effects

Year and sex of calf × age of dam subclass were the only two environmental effects important (*P* < .01, Table 3) for all traits (WCa, WP, WMg, and WW) in the study. The effect of age of dam on calf growth has been found to be largely explained through differences in milk production related to age of dam (Neville, 1962; Rutledge et al., 1971). Thus, the effect of age of dam in this study may also have been mostly due to differences in milk production between younger and older dams. Winter management and clean-up herd were important only for WCa (*P* < .01, Table 3) and for WW (*P* < .05, Table 3). Calf age at first sampling (i.e., the sample used for the correction to 205 d of age) was not important (*P* > .5) for any trait.

Of the three macromineral traits, WCa was the one that behaved most similarly to WW. Both WCa and WW were affected by the same environmental effects (year, winter management, clean-up herd, and sex of calf × age of dam subclass). The fact that WCa and WW were affected by winter management and clean-up herd indicates that they were more sensitive to microenvironmental change than were WP and WMg, which were only affected by year and sex of calf × age of dam subclass effects. This may have been due to the larger amounts of Ca than of P and Mg needed by calves for their growth and by dams for their milk production. Thus, a change in the supply of Ca would have had a larger effect on WCa than changes in the availability of P and Mg would have had on WP and WMg.

Table 4. Best linear unbiased estimates of additive and nonadditive genetic effects for serum Ca, P, Mg, and weight at weaning

Genetic effect <sup>a</sup>	Trait			
	Weaning Ca, mg	Weaning P, mg	Weaning Mg, mg	Weaning wt, kg
Angus sire additive <sup>b</sup>	-7.53 ± 6.83	-5.60 ± 6.04	-.62 ± 1.49	-.33 ± .59
Angus dam additive <sup>b</sup>	2.25 ± 1.24	-11.32 ± 1.10**	1.03 ± .27**	.19 ± .11
A × B direct nonadditive <sup>c</sup>	242.21 ± 51.56**	66.67 ± 45.62	52.16 ± 11.27**	22.61 ± 4.44**
A × B maternal nonadditive <sup>c</sup>	373.63 ± 38.44**	93.96 ± 34.02**	69.90 ± 8.41**	36.83 ± 3.31**

<sup>a</sup>A = Angus, B = Brahman.

<sup>b</sup>Angus sire additive genetic effects are expressed as deviations from Brahman.

<sup>c</sup>A × B intralocus nonadditive genetic effects are defined as deviations from those of the parental breeds.

\*\**P* < .01.

### Genetic Effects

Angus sire additive genetic effects were small (Table 4) and nonsignificant (*P* > .25, Table 3). Angus dam additive genetic effects were also small and nonsignificant for WCa and WW (Table 4) but were important (*P* < .01) for WP (-11.32 ± 1.10 mg, Table 4) and WMg (1.03 ± .27 mg, Table 4). On the other hand, none of the A (minus B) additive direct or maternal genetic effects were significant. Thus, A and B had approximately the same direct and maternal genetic abilities of WCa, WP, WMg, and WW, and maternal genetic effects were somewhat larger than direct genetic effects in this multibreed herd.

Nonadditive A × B direct genetic effects were between approximately 6 (WP) and 42.7 (WMg) times larger than A additive direct genetic effects. Except for WP (66.67 ± 45.62 mg, Table 4), the BLUE of all A × B nonadditive direct genetic effects (242.21 ± 51.56 mg WCa, 52.16 ± 11.27 mg WMg, and 22.61 ± 4.44 kg WW, Table 4) were significant (*P* < .01).

Nonadditive A × B maternal genetic effects were even larger than their direct counterparts (Table 4). Their BLUE were between 1.3 (WMg) and 1.6 (WW) times larger than the BLUE of A × B nonadditive direct genetic effects, and between 16.4 (WP) and 70.8 (WW) times larger than the BLUE of A maternal direct genetic effects. In fact, the sum of direct and maternal nonadditive genetic effects (615.84 ± 60.46 mg of WCa, *P* < .01; 160.63 ± 53.49 mg of WP, *P* < .01; 122.06 ± 13.22 mg of WMg, *P* < .01; and 59.43 ± 5.21 kg of WW, *P* < .01) accounted for 99.2, 90.5, 99.7, and 99.8% of the total (additive plus nonadditive direct and maternal) genetic effects for WCa, WP, WMg, and WW, respectively. The large A × B nonadditive direct and maternal genetic effects suggest that A and B have substantially different sets of alleles affecting WCa, WP, WMg, and WW and that these alleles, on the average, interact positively resulting in larger genetic values for these traits in crossbred calves.

The BLUE of the A × B nonadditive direct genetic effect for WW (22.61 ± 4.44 kg, *P* < .01) was between the 20.7 ± 2.6 kg (*P* < .01) computed by Peacock et al. (1981) and the 24.2 ± 1.04 kg (*P* < .01) reported by Wyatt and Franke (1986) and was larger than the 9.47 ± 8.96 kg obtained by Elzo et al. (1990). On the other hand, the BLUE of the A × B nonadditive maternal genetic effect for WW (36.83 ± 3.31 kg, *P* < .01) was larger than the estimates of Peacock et al. (1981): 24.3 ± 2.0 kg (*P* < .01), Wyatt and Franke (1986): 13.0 ± 1.06 kg (*P* < .01), and Elzo et al. (1990): 20.95 ± 3.56 kg (*P* < .01). Estimates of A × B nonadditive direct and maternal genetic effects for WCa, WP, and WMg were not found in the literature.

The overall ranking of the BLUE of all genetic effects, from largest to smallest, was A × B nonadditive maternal, A × B nonadditive direct, A additive maternal, and A additive direct. The same pattern existed for WCa, WP, WMg, and WW, which adds genetic support to the known biochemical and physiological ties that exist between Ca, P, Mg, and growth (Littledike and Goff, 1987; Arnaud and Sanchez, 1990; Shils, 1990). Thus, A × B crossbred calves and calves from A × B crossbred dams had larger amounts of serum Ca, P, and Mg and heavier weights at weaning than A and B straightbred calves. Crossbred (A × B) dams may have achieved their advantage over straightbred dams through greater milk production, larger fraction of solids in milk, or both. Crossbred (A × B) calves may have grown faster than straightbreds because of a larger capacity to consume milk, more milk available from crossbred dams, and/or a better efficiency of utilization of the ingested Ca, P, Mg, and other nutrients. These aspects need to be documented in this multibreed herd. In addition, more detailed studies need to be conducted to understand the biological basis of the differences in amounts of macrominerals in serum found in these calves and their relationship with growth and development.

*Combining Ability of Sire Breed Groups and Dam Breed Groups*

The combining abilities of five breed groups of sires (A, .75A .25B, .5A .5B, .25A .75B B) mated across six breed groups of dams (A, .75A .25B, F<sub>1</sub>, F<sub>2</sub>, .25A .75B, B) are presented in Table 5. Combining ability was expressed as the weighted sum total of additive and nonadditive direct and maternal genetic effects present in each breed group of sire × breed group of dam combination. Because additive genetic effects were expressed as deviations from B and nonadditive genetic effects as deviations from intrabreed interactions, B calves had zeros for the total genetic values in all traits.

The best combination was given by the mating of B sires to F<sub>1</sub> dams: 495.86 ± 43.58 mg of WCa (*P* < .01), 121.63 ± 38.56 mg of WP (*P* < .01), 96.49 ±

9.53 mg of WMg (*P* < .01) and 48.23 ± 3.73 kg of WW (*P* < .01). However, these values differ little from those of the mating of F<sub>1</sub> dams to the other breed groups of sires, giving the F<sub>1</sub> dams the best overall combining ability for all breed groups of dams. This was because 1) F<sub>1</sub> dams express 100% of the A × B nonadditive maternal genetic effects, and these were the largest of all group genetic effects, 2) calves from F<sub>1</sub> dams and sires of any AB expected breed composition show 50% of the A × B nonadditive direct genetic effects, and these were the second-largest group genetic effects, and 3) A additive direct and maternal genetic effects were very small, rendering them almost immaterial to the BLUE of total genetic values.

The second-best overall combining ability corresponded to F<sub>2</sub> dams for the same reasons indicated for F<sub>1</sub> dams, except that they were expected to express only 50% of the A × B nonadditive maternal genetic effects.

Table 5. Combining ability of sire breed groups across dam breed groups

Breed group of dam <sup>a</sup> and trait <sup>b</sup>	Breed group of sire <sup>a</sup>				
	Angus	.75A .25B	.5A .5B	.25A .75B	Brahman
Angus					
WCa	-5.28 ± 6.94	57.15 ± 13.98**	119.59 ± 26.04**	182.03 ± 38.68**	244.46 ± 51.48**
WP	-16.92 ± 6.14**	1.15 ± 12.37	19.22 ± 23.04	37.29 ± 34.23	55.35 ± 45.55
WMg	.41 ± 1.52	13.60 ± 3.06**	26.80 ± 5.70**	39.99 ± 8.46**	53.18 ± 11.26**
WW	-.14 ± .59	5.65 ± 1.20**	11.45 ± 2.25**	17.24 ± 3.31**	23.03 ± 4.41**
.75A .25B					
WCa	194.82 ± 19.26**	226.98 ± 23.18**	259.14 ± 28.13**	291.30 ± 33.66**	323.46 ± 39.53**
WP	37.81 ± 17.04	47.54 ± 20.51	57.28 ± 24.89	67.01 ± 29.79	76.75 ± 34.98
WMg	39.41 ± 4.21**	46.08 ± 5.07**	52.75 ± 6.15**	59.43 ± 7.36**	66.10 ± 8.64**
WW	19.29 ± 1.65**	22.22 ± 1.98**	25.16 ± 2.41**	28.10 ± 2.88**	31.04 ± 3.38**
.5A .5B(F <sub>1</sub> )					
WCa	488.33 ± 32.97**	490.21 ± 43.77**	492.09 ± 43.64**	493.98 ± 43.57**	495.86 ± 43.58**
WP	116.03 ± 38.91**	117.43 ± 38.73**	118.83 ± 38.61**	120.23 ± 38.55**	121.63 ± 38.56**
WMg	95.88 ± 9.62**	96.03 ± 9.57**	96.19 ± 9.54**	96.34 ± 9.53**	96.49 ± 9.53**
WW	47.89 ± 3.76**	47.97 ± 3.75**	48.06 ± 3.73**	48.15 ± 3.73**	48.23 ± 3.73**
.5A .5B(F <sub>2</sub> )					
WCa	301.51 ± 30.94**	303.40 ± 30.61**	305.28 ± 30.37**	307.16 ± 30.23**	309.05 ± 30.19**
WP	69.05 ± 27.37**	70.45 ± 27.08**	71.85 ± 26.87**	73.25 ± 26.75**	74.55 ± 26.71**
WMg	60.93 ± 6.76**	61.08 ± 6.69**	61.24 ± 6.64**	61.39 ± 6.61**	61.54 ± 6.60**
WW	29.53 ± 2.65**	29.62 ± 2.62**	29.70 ± 2.60**	29.79 ± 2.59**	29.87 ± 2.58**
.25A .75B					
WCa	314.80 ± 40.24**	286.41 ± 34.08**	258.01 ± 28.17**	229.61 ± 22.71**	201.23 ± 18.12**
WP	76.81 ± 35.61	69.87 ± 30.15	62.94 ± 24.92**	56.01 ± 20.09**	49.07 ± 16.03**
WMg	64.97 ± 8.80**	58.61 ± 7.45**	52.24 ± 6.16**	45.88 ± 4.97**	39.51 ± 3.96**
WW	30.59 ± 3.44**	27.83 ± 2.92**	25.06 ± 2.41**	22.29 ± 1.94**	19.53 ± 1.55**
Brahman					
WCa	234.68 ± 52.50**	176.01 ± 39.15**	117.34 ± 26.10	58.67 ± 13.05**	0
WP	61.07 ± 46.19	45.80 ± 34.64	30.54 ± 23.09	15.27 ± 11.55	0
WMg	51.54 ± 11.41**	38.66 ± 8.56**	25.77 ± 5.71**	12.89 ± 2.85**	0
WW	22.48 ± 4.47**	16.86 ± 3.35**	11.24 ± 2.23**	5.62 ± 1.12**	0

<sup>a</sup>A = Angus; B = Brahman.

<sup>b</sup>Total genetic values for weaning calcium (WCa), weaning phosphorus (WP), and weaning magnesium (WMg) are expressed in milligrams and for weaning weight (WW) in kilograms.

\*\**P* < .01.

The worst combination was given by the mating of A sires and A dams:  $-5.28 \pm 6.94$  mg of WCa,  $-16.92 \pm 6.14$  mg of WP ( $P < .01$ ),  $.41 \pm .02$  mg of WMg, and  $-.14 \pm .59$  kg of WW. Only additive direct and maternal genetic effects were responsible for these differences.

Contrary to dam breed groups, there was no sire breed group that was uniformly better than the rest when mated across dam breed groups. Large differences in A  $\times$  B nonadditive maternal genetic effects among specific sire group  $\times$  dam group combinations were the main reason for this, followed closely by differences in A  $\times$  B nonadditive direct genetic effects.

The ranking of the sire breed group  $\times$  dam breed group combinations based on total group genetic effects was the same for WCa, WP, WMg, and WW. This resulted as a consequence of the equal ranking of the additive and nonadditive direct and maternal genetic effects for all these traits.

Nonadditive genetic effects (especially maternal) were the factors that most influenced the rankings of the sire breed group  $\times$  dam breed group combinations. Thus, as indicated by Elzo (1983), nonadditive genetic effects will need to be included in mixed models used to predict genetic values of the progeny of animals involved in specific interbreed matings for amounts of macrominerals in serum and(or) WW. The regression approach used here for additive and nonadditive genetic effects could be one of the criteria used to construct genetic groups in such genetic evaluation procedures.

## Implications

The correspondence of the ranking of the genetic effects for serum calcium, serum phosphorus, serum magnesium, and weight at weaning together with the known physiological links among these traits indicate that some of the same alleles are contributing to their genotypes. The large interbreed nonadditive genetic effects for serum calcium, phosphorus and magnesium and weight at weaning suggest either that Angus and Brahman have different sets of alleles affecting these traits, or that alleles in these sets have vastly different frequencies. Serum calcium, phosphorus, and magnesium could be useful 1) to better understand the process of growth and development 2) to aid in the genetic evaluation of animals and breed groups, and 3) to optimize multibreed production systems.

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