Effects of Stair-Step Nutrition and Trace Mineral Supplementation on Attainment of Puberty in Beef Heifers of Three Sire Breeds[1]

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ABSTRACT: A study was conducted to evaluate the influence of nutrition and sire breed on age at puberty and first lactation milk yield in crossbred beef heifers. After weaning, 208 heifers sired by Hereford, Limousin, or Piedmontese bulls were assigned to either a control (CG) or stair-step gain (SSG) dietary regimen plus a mineral supplement with or without Cu, Zn, and Mn top-dressed onto the feed. Heifers on the SSG regimen were fed a diet intended to supply energy to support gains at a rate of 120% of the CG diet for 55 d and then were switched to a diet formulated to produce an ADG at 70% of the rate of the CG diet for 84 d. They then switched back to the 120% diet for the last 30 d before breeding. Total weight gain and overall rate of gain did not differ among dietary treatments. Hereford- and Limousin-sired heifers gained at similar rates, and Piedmontese-sired heifers gained an average of .10 kg/d slower than the other two sire breed groups. During one period, Piedmontese-sired heifers on the CG diet gained .19 kg/d faster ($P < .01$) when supplemented with mineral than when not. During that same period, there was no influence of mineral supplementation on weight gains for Hereford- or Piedmontese-sired heifers on the high SSG diet, but Limousin-sired heifers tended ($P = .07$) to gain faster (1.00 vs .85 kg/d) when supplemented with Cu, Zn, and Mn than when not. Piedmontese-sired heifers reached puberty at the earliest age ($P = .03$), followed by Hereford- and then Limousin-sired heifers. There were no treatment effects on milk yield at an average of 70 d of lactation. However, at approximately 120 d of lactation, Piedmontese-sired heifers were producing less milk ($P < .05$) than Limousin- but not Hereford-sired heifers. Hereford-sired heifers had lower ($P < .05$) plasma Cu concentrations than Piedmontese-sired heifers. There were no treatment effects on plasma Zn concentrations. Heifers sired by bulls of breeds that differ in potential muscularity differed in growth, reproduction, milk yield, and plasma mineral concentrations, but dietary treatments resulted in little to no differences in these variables.

Key Words: Beef Cattle, Heifers, Puberty, Diet, Milk

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Introduction

The age at puberty and subsequent age at first calving influence lifetime production of beef cows (Lesmeister et al., 1973). Even though rate of gain is important for heifers to reach puberty at an early age, rapid growth during some phases of prepuberal development can decrease subsequent milk production (Sejrsen et al., 1982; Harrison et al., 1983; Sejrsen, 1994; Sejrsen and Purup, 1997). Stair-step nutritional management regimens have been used to limit growth during critical periods of mammary development and then to allow periods of rapid growth to permit heifers to reach puberty at an early age (Park et al., 1989, 1998; Barash et al., 1994; Choi et al., 1997; Lynch et al., 1997).

Trace element status has been implicated in impaired reproduction in subclinically mineral-deficient cattle (Corah and Ives, 1991). Three minerals of importance for reproduction are Cu, Mn, and Zn. Of these, dietary Cu and Zn are commonly found in levels below those recommended for breeding cattle (NRC, 1996). However, the effects of trace element supplementation on reproduction in controlled experiments have been varied (DiCostanzo et al., 1986; Phillippo et al., 1987; Vaughan et al., 1994). We previously observed no effect of a combined Cu, Zn,

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Table 1. Ingredient and chemical composition of diets fed to heifers before (all heifers) and during the treatment period for control gain (CG) and stair-step gain (SSG) treatments

Composition	All heifers	CG	SSG High	SSG Low
	% DM			
Ingredient				
Corn silage	64.1	64.9	49.1	41.9
Barley	21.4	16.3	39.7	—
Alfalfa hay	14.5	18.7	10.8	45.6
Barley straw	—	—	—	12.4
Sodium tripolyphosphate	—	.11	—	.07
Calcium carbonate	—	—	.34	—
Chemical				
DM, %	43.9	42.12	51.2	46.9
CP, %	8.6	11.3	9.5	11.9
NDF, %	42.2	47.2	41.3	50.0
ADF, %	23.4	28.2	19.1	33.0
TDN, %	69.4	64.5	73.9	59.5
Ash, %	6.8	7.7	5.4	12.5
S, %	.15	.16	.17	.17
Cu, ppm	5.5	5.9	3.6	5.6
Zn, ppm	30.5	21.2	22.3	20.6
Mn, ppm	44.0	34.5	25.8	48.6
Mo, ppm	.5	.6	.9	1.4

and Mn supplement on the number of heifers reaching puberty before the first breeding season (Grings et al., 1998). Diet and animal breed can influence mineral utilization, and we, therefore, wanted to further evaluate mineral supplementation for heifers under different management than that previously studied. Thus, the objective for this study was to determine the influence of nutritional management and trace mineral supplementation on attainment of puberty in beef heifers of three sire breeds and carryover effects on milk yield in the first lactation.

Materials and Methods

Heifers were sired by Hereford (n = 15), Limousin (n = 18), or Piedmontese (n = 22) bulls bred to crossbred dams. The choice of sire breeds was based on the production of cattle that differ in their degree of muscle and fat deposition but have similar size and growth rates. Dams included primarily Hereford Simmental, Charolais, Tarentaise, Red Angus, and Angus crosses with varying degrees of crossbreeding. Dams ranged in age from 2 to 11 yr of age. Average birth date of heifers was April 10, and heifers were weaned at an average of 171 d of age. After weaning, 208 heifers were blocked by sire breed and randomly assigned to either a control gain (**CG**) or stair-step gain (**SSG**) dietary regimen plus a mineral supplement with or without Cu, Zn, and Mn top-dressed onto the feed.

Heifers were housed in eight pens with two pens per diet-mineral combination. While in pens, heifers were fed corn silage-based diets (Table 1). Heifers assigned to CG or SSG diets were all fed the same diet for 2 mo. Heifers on the SSG regimen were then switched to a diet intended to supply energy to produce weight gains at 120% of the rate of the CG diet. After 55 d, stair-step heifers were switched to a diet formulated to produce gains at 70% of the rate of the CG diet for 84 d, at which time they switched back to the 120% diet for the last 30 d. Heifers were weighed at each diet change. The timing of diet changes and pen average DMI during each period are presented in Table 2.

Beginning on d 29 after all heifers were placed on the common diet, trace mineral was top-dressed onto the feed in the bunks at a rate of 84 $g \cdot heifer^{-1} \cdot d^{-1}$. The mineral supplement supplied Ca, P, Na, Cl, Mg, Co, and I. For heifers receiving Cu, Zn, and Mn, those minerals were supplied in the mineral supplement in the sulfate forms at a concentration of 600, 1,400, and 2,000 ppm, respectively.

Androgenized steers fitted with marking harnesses were used to aid in estrus detection. Heifers were observed twice daily for evidence of estrual behavior, and dates of observed behavior were recorded. Within 6 to 10 d after an observed estrus, heifers were examined by rectal ultrasonography for the presence of a corpus luteum. A blood sample was collected from the tail vein for determination of serum progesterone using the procedure of Bellows et al. (1991). Heifers were determined to have reached puberty if, following

Table 2. Average DM intakes ($kg \cdot heifer^{-1} \cdot d^{-1}$) of control gain (CG) and stair-step gain (SSG) diets with and without trace mineral supplementation (TM) fed to heifers. Feed was measured on a pen basis

Dates of feeding: Start	Dates of feeding: Stop	SSG period	Control –TM	Control +TM	Stair-step –TM	Stair-step +TM
Oct 19	Dec 13		5.6	5.6	5.0	5.3
Dec 14	Feb 7	High	6.0	5.8	6.5	6.9
Feb 8	May 3	Low	7.2	7.3	6.5	6.9
May 4	June 3	High	8.1	8.2	9.7	9.7

an observed estrus, they had a corpus luteum and a serum progesterone concentration of greater than 1 ng/mL.

Blood for mineral analyses was collected by jugular venipuncture into acid-washed syringes and placed into acid-washed tubes containing heparin on the day before the start of mineral supplementation and after 172 d of supplementation. Blood was placed on ice until it was returned to the laboratory. Blood was centrifuged, and plasma was extracted and frozen until it was analyzed for Cu and Zn content. Plasma Cu and Zn were analyzed using atomic absorption spectrophotometry (Perkin Elmer Model 5000, Norwalk, CT).

After the study, heifers were allotted to pens based on sire breeds. Crossbred bulls of the same sire breed were housed with the heifers for a 48-d breeding season. Pregnancy was confirmed by ultrasonography 63 d after the end of the breeding season.

Heifers were managed together until the last trimester of pregnancy, when they were used in another research project (Lammoglia et al., 1997). After calving, heifers were again managed as a single group. Only 142 heifers remained in the herd at the time of milk yield estimation. Milk yield was estimated by the weigh-suckle-weigh technique twice, at approximately 70 and 120 d of lactation. Calves were removed from the presence of dams for 6 h, allowed to suckle, and again separated from their dams for 12 to 13 h. Calves were weighed, allowed to suckle, and immediately reweighed. Change in weight was assumed to be milk intake. Twenty-four-hour milk yield was determined by projecting the 12- to 13-h milk yield to a 24-h basis.

Data were analyzed using GLM procedures of SAS (1990). An analysis was conducted initially that included assignment of cows to one of four dam breed groups (Hereford-cross, Simmental-cross, composite [Charolais, Red Angus, and Tarentaise], and unknown and other crosses). Dam breed group had no significant effects on any variables tested and was then omitted from the analyses. All models included the effects of dam age, sire breed, diet, mineral supplementation, and their interactions, pen within nutritional management strategy, and sire within breed. Diet, mineral, and the interaction were tested using replicate within nutritional management strategy as the error term. Sire breed was tested using sire within breed as the error term. Four heifers had not reached puberty by the end of the study and were treated as missing values in the analysis for age at puberty. The model for plasma mineral concentrations included initial plasma mineral concentrations as a covariate, and the model for milk yield included day of lactation as a covariate. Assignment to precalving nutrition group (Lammoglia et al., 1997) was also included in the model for milk yield, although it was not a significant factor. Where dam age was significant, orthogonal polynomials were used to test for linear or quadratic effects of dam age. Where F-tests were significant, treatment mean separation was by least significant difference.

Results and Discussion

Trace mineral requirements for gestating cows are listed by the NRC (1996) to be 10 ppm Cu, 30 ppm Zn, and 40 ppm Mn. In addition, a Cu:Mo ratio of less than 4.5:1 is suggested as being preferable for improved Cu utilization (Corah and Arthington, 1994). Dietary Cu was below 10 ppm in all diets and was only 3.6 ppm for the high SSG diet (Table 1). Dietary Zn was below recommended levels for all periods except the first 54 d, when all heifers received the same diet. Dietary Mn was below recommended levels for the CG and high SSG diets. With these low dietary levels, some potential for animal response to supplementation exists.

Initial weights and rates of gain of heifers are presented in Table 3. Overall rate of gain did not differ ($P > .10$) among dietary treatments but did differ among sire breeds ($P < .01$). Rates of gain during specific periods were affected by diet. During the first high SSG phase, SSG heifers gained .13 kg/d, or 117% faster than CG heifers. In the following low growth phase, SSG heifers gained .25 kg/d, at 72% of the rate of the CG heifers ($P < .01$).

The first period of more rapid gain corresponded to an average age of 246 ± 16 d of age. Only one heifer had reached puberty by the beginning of this period. This was a Hereford-sired heifer on the CG + trace mineral treatment.

Sire breed affected weight gain throughout the study. Gains of Hereford- and Limousin-sired heifers did not differ, and Piedmontese-sired heifers gained an average of .11 kg/d slower than heifers of the other sire breeds.

The effect of mineral supplementation on weight gains was dependent on the sire breed and nutritional management (Table 3) during the first period of high growth for the SSG heifers. On the high SSG diet, there was no influence of mineral supplementation on weight gains for Hereford- or Piedmontese-sired heifers, but Limousin-sired heifers tended ($P = .07$) to gain faster when supplemented with Cu, Zn, and Mn than when not. The high SSG diet was lower in Cu than either the CG or low SSG diet. During this same period, Hereford- and Limousin-sired heifers fed the CG diet did not differ ($P > .10$) from heifers of those sire breeds not receiving mineral supplementation. However, Piedmontese-sired heifers on the CG diet gained .18 kg/d faster ($P < .01$) when supplemented with mineral than when not. The rate of gain for the unsupplemented Piedmontese-sired heifers in the CG group was less than for any other group of heifers during this period.

Table 3. Average daily gain and initial and final weights of heifers of three sire breeds (SB) fed on a control gain (CG) or stair-step gain (SSG) plane of nutrition[a] (D) with or without supplementation of Cu, Zn, and Mn (± TM)

	Hereford				Limousin				Piedmontese					P-values[b]			
	CG		SS		CG		SS		CG		SS						
Item	−TM	+TM	−TM	+TM	−TM	+TM	−TM	+TM	−TM	+TM	−TM	+TM	SEM	SB	D	TM	SB × D × TM
n	16	15	13	14	16	15	16	16	21	21	23	22					
Avg daily gain, kg/d																	
10/19–12/13	.79	.75	.83	.81	.83	.80	.84	.74	.83	.71	.77	.78	.012	.56	.89	.54	.30
12/14–2/7	.83	.81	.92	1.00	.74	.83	.85	1.00	.57	.76	.78	.78	.012	.01	.06	.20	.04
2/8–5/3	.92	.99	.70	.65	.89	.97	.62	.75	.76	.88	.57	.60	.011	.01	.01	.31	.44
5/4–6/3	.99	.83	.90	1.02	1.00	.81	1.12	1.16	.81	.75	.86	1.00	.019	.02	.34	.90	.92
Overall	.88	.87	.81	.82	.85	.87	.80	.86	.74	.80	.71	.74	.007	.01	.29	.46	.70
Heifer wt, kg																	
Initial	202	209	195	208	211	208	205	209	192	198	198	195	2.8	.05	.49	.12	.63
Final	395	400	373	389	398	400	380	397	354	373	354	358	1.8	.01	.28	.31	.54

[a]Predicted rate of gain: 10/19 to 12/13 CG = SS; 12/14 to 2/7 SS = 120% of CG; 2/8 to 5/3 SS = 70% of CG; 5/4 to 6/3 SS = 120% of CG.
[b]There were no significant two-way interactions ($P > .10$).

Breed differences in mineral requirements or utilization have been reported by other researchers. Littledike et al. (1995) evaluated the effect of breed on mineral concentrations in tissues of beef cattle and found Limousin cattle to have higher concentrations of liver Cu than other breeds measured, which included Hereford- but not Piedmontese-sired cows. These researchers concluded that Limousin cattle may be more suited to environments where Cu is limiting. In the present study, Limousin-sired cattle tended to gain faster with mineral supplementation in the most Cu-limited environment than cattle of other sire breeds. This could imply either a greater need for minerals or a more efficient use of dietary mineral by Limousin-sired cattle, as suggested by Littledike et al. (1995).

Age at puberty was affected by sire breed of heifer. Piedmontese heifers reached puberty at the earliest age, followed by Hereford and then Limousin (Table 4). There were no interactions of postweaning management and sire breed on age at puberty. Ferrell (1982) found that even though rate of postweaning gain and breed influenced mean age at puberty, these factors did not interact.

Freetly and Cundiff (1997) reported that heifers sired by Hereford bulls had a higher rate of gain in the drylot than did Piedmontese-sired heifers regardless of the level of nutrition. Age at puberty did not differ between heifers of these two sire breeds in their study. Even though Piedmontese-sired heifers in our study reached puberty at an age similar (352 d of age) to those in the study of Freetly and Cundiff (1997) (344 d of age), Hereford-sired heifers reached puberty 20 d later in our study than in the study of Freetly and Cundiff (1997). This occurred even though overall ADG was greater in our study.

There were no treatment effects on pregnancy rates (Table 4). Milk yield was determined at two times during the first lactation. There were no treatment effects on milk yield at an average of 70 d of lactation (Table 4). However, at approximately 120 d of lactation, Piedmontese-sired heifers were producing less milk ($P < .05$) than Limousin-, but not Hereford-sired, heifers. Milk yield averaged across the two dates was greater for Limousin- than for Piedmontese-sired heifers, and milk yield of Hereford-sired heifers did not differ from that of the other sire breeds. This had some relevance to calf preweaning ADG, because calves produced through breeding Piedmontese-sired heifers to Piedmontese-sired bulls gained more slowly (.67 kg/d; $P < .01$) than either Hereford- or Limousin-sired calves (.72 and .75 kg/d, respectively), which did not differ from one another.

Neither feeding regimen nor trace mineral supplementation during the yearling growth period had carryover effects on milk yield during first lactation. Marston et al. (1995) reported that feeding a high-concentrate diet to beef heifers for 60 d before their first breeding season had no subsequent effect on milk yield early in lactation. Buskirk et al. (1995), however, reported an increase in milk yield during the first lactation of beef heifers fed a higher level of grain supplement between weaning and breeding compared with heifers fed a lower level of grain supplement during this period.

Apparent discrepancies in the literature concerning the effect of rate of gain on subsequent milk production seem to be related to both the timing and level of

Table 4. Age at puberty, percentage pregnant, milk yield, and plasma minerals of heifers sired by Hereford (H), Limousin (L), or Piedmontese (P) bulls fed at a control gain (CG) or stair-step gain (SSG) plane of nutrition with or without supplementation of Cu, Zn, and Mn (± TM)

	Sire breed (SB)			Diet (D)		Mineral (TM)			*P*-values[a]		
Item	H	L	P	CG	SS	−TM	+TM	SEM	SB	D	TM
Age at puberty, d	373	392	352	377	368	372	373	2.7	.01	.92	.44
Percentage pregnant	75.4	89.5	86.7	81.8	86.0	80.8	87.0	.03	.17	.42	.28
Plasma											
Cu, ppm	.95	.99	1.03	.98	.99	.97	1.00	.01	.04	.50	.76
Zn, ppm	.77	.82	.78	.77	.81	.79	.78	.01	.38	.83	.43
24-h milk yield, kg											
n	39	50	53	71	71	69	73	—	—	—	—
6/18	5.8	6.0	5.2	5.5	5.8	5.8	5.6	.12	.12	.62	.44
8/6	4.2	4.7	3.9	4.1	4.5	4.4	4.2	.11	.05	.50	.34

[a]There were no significant two- or three-way interactions ($P > .10$).

gain. Laflamme (1993) concluded from a review of the literature that subsequent milk production potential may be depressed when beef heifers are exposed to moderate to high planes of nutrition during the first few months of life but that high growth rates after weaning have little effect. Sejrsen et al. (1982) suggested that the period in which mammary growth in Holstein heifers is most negatively affected by high rates of BW gain is between 90 and 300 kg. Preweaning growth rates of the heifers used in this study averaged 1.04 kg/d and did not differ due to sire breed.

Park et al. (1998) were able to manipulate milk yield of beef heifers during their first lactation by altering the dietary regimen between weaning and breeding. They used a high-low-high stair-step strategy and found increased milk yields in heifers reared with the stair-step regimen compared with controlled-gain heifers. Weight gain for the stair-step heifers during the restricted period was only .14 kg/d, compared with .63 kg/d in our study.

Park et al. (1998) limited energy intake by restricting feed intake, but heifers in our study were fed for ad libitum consumption. Dry matter intakes measured on a pen basis differed for CG and SSG periods (*t*-test; $P < .01$) (Table 2). Therefore, energy intake differences among treatments in our study were a combination of differences in energy density and DM intake.

Dam age did affect some weight variables and age at puberty (Table 5). Increasing dam age resulted in linear increases ($P < .01$) in heifer weight both initially and at the end of the study. Age at puberty was greater for heifers from younger dams.

Plasma Cu levels were influenced by sire breed; Hereford-sired heifers had lower plasma Cu concentrations than Piedmontese-sired heifers (Table 4). There were no treatment effects on plasma Zn concentrations. Previously, we observed no effect of trace mineral supplement on plasma Cu or Zn with similar corn silage-based diets. However, heifers at this location did have decreased plasma Cu when fed oatlage-based diets (Grings et al., 1998).

Implications

The period between weaning and puberty is critical in the management of replacement heifers, and rates of growth are influenced by breed and nutrition. Sire breed of heifer seems to affect growth, reproduction, milk yield, and plasma mineral concentrations, but

Table 5. Effects of dam age on weights, average daily gains, and age at puberty of heifers

	Cow age (years at calving)				Polynomial *P*-value	
Item	2	3	4	5+	Linear	Quadratic
Initial wt, kg	186	195	210	219	.01	.90
Final wt, kg	366	373	397	388	.01	.27
ADG, 2/8 to 5/3, kg/d	.81	.77	.80	.72	.03	.41
ADG, 5/4 to 6/3, kg/d	1.00	.95	.97	.83	.02	.38
Overall ADG kg/d	.82	.81	.85	.77	.16	.09
Age at puberty, d	397	366	358	369	.01	.01

there seems to be little direct effect of either trace mineral supplementation or altering rates of gain from weaning through the beginning of the breeding season on reproductive performance and subsequent milk yield for beef heifers gaining over .6 kg/d. This may allow for some flexibility in gain strategy and diet formulation and subsequent alterations in feed costs.

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