Effects of a long-acting, trace mineral, reticulorumen bolus on range cow productivity and trace mineral profiles[1]

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ABSTRACT: The objectives were to determine if strategic supplementation of range cows with a long-acting (6 mo), trace mineral, reticulorumen bolus containing Cu, Se, and Co would: (1) increase cow BCS and BW, and calf birth, weaning, and postweaning weights, or weight per day of age (WDA); (2) increase liver concentrations of Cu or Zn in cows, or blood Se, Cu, or Zn concentrations in cows and calves; and (3) vary by cow breed for any of these response variables. There were 192 control and 144 bolused Composite cows (C; 25% Hereford, Angus, Gelbevieh, and Senepol or Barzona); 236 control and 158 bolused Hereford (H) cows; and 208 control and 149 bolused Brahman cross (B) cows used in a 3-yr experiment. Cows were weighed and scored for body condition in January, May, and September, and all bolused cows received boluses in January. Each year, from among the 3 breed groups a subset of 15 control and 15 bolused cows (n = 90) had samples obtained in January and May for liver Cu and Zn, blood Se, and serum Cu and Zn. As for cows, blood and serum from the calves of these cows were sampled each year in May and September for Cu, Se, and Zn. There was a significant breed × year × treatment interaction ($P = 0.001$) for cow weight loss from January to May. Calf WDA, weaning, and postweaning weights did not differ ($P > 0.40$) between bolused and control cows, but there was a significant ($P = 0.022$) breed × year × treatment interaction for birth weight. Liver Cu was deficient (<75 ppm; $P < 0.001$) in control cows and adequate (>75 to 90 ppm) for bolused cows. Liver Cu differed by year ($P < 0.001$). Blood Se was adequate (>0.1 ppm) for all cows except in January 2001 and 2002. There was no difference ($P > 0.50$) in blood Se between treatment groups in January, but bolused cows had greater ($P < 0.01$) blood Se in May. Breed differences for blood Se concentrations existed for bolused cows, with B having greater ($P < 0.05$) blood Se than either C or H cows. Breed differences also existed for control cows, with H having less blood Se ($P < 0.04$) than B or C cows. Calves from bolused cows had greater blood Se than calves from control cows ($P = 0.01$). Supplementation via a long-acting trace mineral bolus was successful in increasing liver Cu in cows and blood Se in cows and calves, but the responses varied by year. Bolus administration had variable effects on BW change in early lactation, depending on breed and year, which may indicate the need for breed- and year-specific supplementation programs.

Key words: beef cattle, breed, copper, mineral, range, selenium

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INTRODUCTION

A large area of central Arizona from Roosevelt Lake eastward to New Mexico has been reported to be deficient in Se (Kubota et al., 1967). With additional sampling, it seems that almost all of the broken Mogollon Rim country with volcanic-derived or granitic soils are Se deficient. Additionally, many of these areas appear to be Cu deficient during some time periods (our unpublished observations). Due to the rugged topography of many of these rangelands and due to posted wilderness areas allowing no vehicle access, delivery of traditional trace mineral supplements can be problematic.

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A long-acting (6 mo) reticulorumen trace mineral bolus containing Cu, Se, and Co has been developed in the United Kingdom (Cosecure; Telsol Ltd., Leeds, UK) and has shown promise for helping alleviate trace mineral deficiencies (Buckley et al., 1987; Hidiroglou et al., 1987; Givens et al., 1988), though calf growth did not differ for the 2 studies in which it was measured (Hidiroglou et al., 1987; Givens et al., 1988). A long-acting means of trace mineral delivery could be advantageous for beef production in extensively managed systems.

Gooneratne and Christensen (1989) demonstrated that the developing fetus draws extensively from maternal liver stores of Cu. Similarly, Se efficiently passes from pregnant cows to the fetus through the placenta (Koller et al., 1984; Van Saun et al., 1989), and this maternal mode of transfer has been shown to be more effective in improving Se status in calves than through the milk of cows supplemented postpartum (Enjalbert et al., 1999).

Breed effects for efficiency in metabolizing Cu are well documented (Smart and Christensen, 1985; Littledike et al., 1995; Ward et al., 1995). Breed effects for efficiency of Se metabolism have been marginally investigated (Hohenboken and McClure, 1993).

The objectives of this study were to determine if strategic supplementation of range cows during late gestation over 3 yr with a long-acting trace mineral bolus would: (1) increase cow BCS and BW, and calf birth weights, weaning weights, postweaning weights, or weight per day of age (**WDA**); (2) increase liver Cu or Zn in cows, serum Cu or Zn, or blood Se in cows and calves; and (3) vary by cow breed for any of these response variables.

MATERIALS AND METHODS

Care, handling, and sampling of the animals were approved by the University of Arizona Institutional Animal Care and Use Committee (Protocol No. 98-049).

Range Site

The study site for this experiment was at the V-V Ranch, a public lands grazing permit (Walker Basin Allotment, Coconino National Forest) administered by the US Forest Service. The permit is owned by the University of Arizona and located near Camp Verde, Arizona. The ranch comprises 31,161 ha and ranges in elevation from approximately 975 m (low desert shrub range type) to 2,195 m (Ponderosa pine montane range type). The ranch is extensive in nature, with much of the ranch only being accessed by primitive dirt roads, off-road vehicles, and horseback. Average yearly precipitation ranges from 40 cm at the lower elevations to 70 cm at the upper elevations. However, annual precipitation during the course of this trial was quite variable, with above average precipitation during the growing season in 2001, below average precipitation during the growing season in 2002, and above average precipitation during March and June and mostly below average precipitation in the summer in 2000 (Table 1). Cattle moved through 32 of the 47 upland pastures, from low elevation in winter and spring to high elevation in late summer and fall in a modified holistic management (The Savory Center, Albuquerque, NM) grazing plan.

Forage Sampling

Forage was sampled by hand clipping 4 times a year (January, April, June or August, and September) from 4 different locations on the ranch corresponding to range sites characterized by: a) desert shrub (1,228 m elevation); b) pinyon-juniper (1,829 m elevation); c) Ponderosa pine/gambel oak (2,103 m elevation); and d) the transition zone between pinyon-juniper and Ponderosa pine/gambel oak range sites (1,849 m elevation). The majority of the ranch (mid and upper elevation) contained soils derived from basalt parent material, and the lower elevation areas of the ranch contained some basaltic soils but with limestone outcroppings and with alluvial and colluvial deposits of sandstone, limestone, and basalt.

The dominant herbaceous species sampled over these sites included sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), weeping lovegrass (*Eragrostis curvula* [Schrad.) Nees), sand dropseed (*Sporobolus cryptandrus* [Torr.] A. Gray), blue grama (*Bouteloua gracilis* [Willd. Ex Kunth] Lag. Ex Griffiths), black grama (*Bouteloua eriopoda* [Torr.] Torr.), bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey subsp. Elymoides), spike muhly (*Muhlenbergia wrightii* Vasey ex Coult.), western wheatgrass (*Elymus smithii* [Rydb.] Gould), and Kentucky bluegrass (*Poa pratensis* L.); and the dominant half-shrub sampled was shrubby buckwheat (*Eriogonum wrightii*). Due to elevation differences, not all forage species were present at each site.

The grass samples were clipped to ground level by species and shrubby buckwheat had the current year's leaders clipped. Plant samples were approximately 150 g per species from plants distributed randomly over the sampling area. Clipped forage samples from each key area were analyzed separately by species within key area, but the results presented herein are pooled over all species and range sites by year. Cattle grazed in the pastures where the forage samples were obtained, though not every year, due to the rotational grazing system being used. These 10 different forage species were sampled for nutritional adequacy of Cu, Se, Co, and Zn for each year, and for the concentrations of S, Mo, and Fe to see if antagonistic interactions existed.

Forage Analyses

Before mineral analysis, forage samples were dried (Thelco Model 6; Precision, Winchester, VA) at 65°C for 24 h, then ground to pass through a 2-mm screen using a Wiley mill (AOAC, 1995) by the AZ Veterinary Diagnostic Laboratory (**AZVDL**) in Tucson. For the determi-

Table 1. Precipitation totals for the V-V Ranch, cm

	Upper elevation[1]												
Year	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Average	7.93	7.63	8.05	3.98	2.11	1.36	5.69	7.21	5.50	4.94	5.41	6.53	66.32
2000	4.35[b]	3.14[c]	11.96[a]	0.42	0.12	6.72	1.54[d]	6.41[a]	0.33	15.21[a]	6.04[i]	0.21[c]	56.44
2001	6.18[a]	5.12	4.91[a]	5.34[f]	4.05[a]	0.70	9.83	11.77[b]	0.42	0.84[b]	1.12[c]	5.31	55.60
2002	1.94[f]	0.02[c]	1.83[d]	1.87[b]	0.00	0.00	4.02[a]	4.68[a]	9.10[c]	4.77[b]	5.19	6.62[c]	40.06

	Lower elevation[2]												
Year	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Average	3.02	3.23	3.35	1.64	1.01	1.01	3.63	4.96	4.02	3.14	2.55	2.60	34.14
2000	0.75	1.05	6.86	0.30	0.28	4.17	1.71	8.26	0.00	12.07	2.57	0.00	38.03
2001	4.75	2.04	2.97	2.08	1.90	1.05	3.39	5.69	0.00	0.21	0.98	2.48[a]	27.54
2002	0.00	0.00	0.84	1.45	0.00	0.00	0.63	0.94	9.85	3.00	1.80	1.61	20.12

[1] Upper elevation (2,280 m) average precipitation data (1971 to 2000) and precipitation data for 2000 to 2002 were obtained from the Happy Jack Arizona Ranger Station, available at http://www.wrcc.dri.edu/ [a] = 1 d missing, [b] = 2 d missing, [c] = 3 d missing, etc.

[2] Lower elevation (969 m) average precipitation data (1971 to 2000) and precipitation data for 2000 to 2002 were obtained from the Montezuma Castle National Monument, available at http://www.wrcc.dri.edu/ [a] = 1 d missing, [b] = 2 d missing, [c] = 3 d missing, etc.

nation of total Se, samples were first wet digested with a solution of nitric acid and magnesium nitrate followed by dry ashing at 500°C (Shimoishi, 1976). Selenium was selectively extracted from the digests by adding 2 mL of a solution of 3 g of 4-nitro,2-phenylenediamine sulfate (98%; Sigma-Aldrich Chemical Company, Inc., Milwaukee, WI) to 300 mL of 10% HCl (OmniTrace; EMD Chemicals Inc., Gibbstown, NJ). The 2-nitro,piazselenol chelate resulting from this reaction was quantified by capillary gas chromatography with electron capture detection (Shimoishi, 1976). Forage samples were analyzed for Cu, Zn, Co, Mo, Fe, and S by a commercial laboratory (Dairy One, Ithaca, NY) using inductively coupled, plasma emission spectroscopy as described by Sirois et al. (1991).

Animals

The study commenced in January 2000 and concluded in September 2002 (Figure 1). Bolused and control cows were allocated randomly by breed type, age, and weight at the onset and remained in each treatment group throughout the 3-yr trial. Over the 3-yr trial, control and bolused cows included 192 and 144 Composite (**C**) cows (25% Hereford, Angus, Gelbevieh, and Barzona or Senepol); 236 and 158 Hereford (**H**) cows; and 208 and 149 Brahman (**B**) cross (Brahman × Salers or Brahman × Hereford) cows, respectively. Due to difficulties in gathering 100% of all cattle on this large, public lands ranch at the time that the treatments were initiated, more cows were allocated to the control group than to the bolused group. Cows ranged in age from 2 to 8, 2 to 18, and 2 to 15 yr for C, H, and B, respectively.

The majority of open cows were culled each year, though there were a few exceptions with H and C cows. However, those few open cows retained were excluded from the study in the year that they were open and only included in those years in which they were pregnant and lactating. All cows that lost a calf during any of the years of the trial were excluded from data analyses for that particular year. Only H cows had replacements for cows that were culled, which is the reason that the sample size for H cows was slightly greater than for the other 2 breed types.

In January of each year (2000: Jan. 10, 11, and 22; 2001: Jan. 16, 17, 18, 19; 2002: Jan. 21, 22, and 23), cows in the bolused group were orally dosed with two 100-g Cosecure boluses consisting of 0.30% (wt/wt) Se as sodium selenate, 13.4% (wt/wt) Cu, and 0.5% (wt/wt) Co. The Cu and Co in the bolus was present in a sodium polyphosphate glass. To make this glass, copper II oxide and cobalt III oxide were melted at high temperatures along with sodium phosphate and magnesium phosphate. Copper and Co dissolved from the surface of the Cosecure bolus as polymers of a sodium magnesium copper cobalt polyphosphate. Throughout the life of the bolus, a cow receiving a standard dose would receive 26.8 g of Cu, 0.6 g of Se, and 1.0 g of Co. According to company literature, and as validated with ruminally fistulated cattle on a silage and concentrate ration, boluses dissolved in 175 d and thus released 156 mg of Cu, 5.9 mg of Co, and 3.4 mg of Se per day. The boluses measured 22 × 25 × 81 mm, and retention of the boluses was good, with less than 1% of cows losing boluses after being dosed.

Cattle were allowed a few hours after being fed before being dosed with the boluses and were held in the corral for several hours (and sometimes overnight) after receiving the boluses. During the entire study, only 6 boluses were observed on the ground in the corrals after cows left the working facility. In January 2000, we marked boluses with the cow's ear-tag number. Due to the low occurrence of bolus regurgitation, we did not repeat this procedure subsequently. Therefore, with the

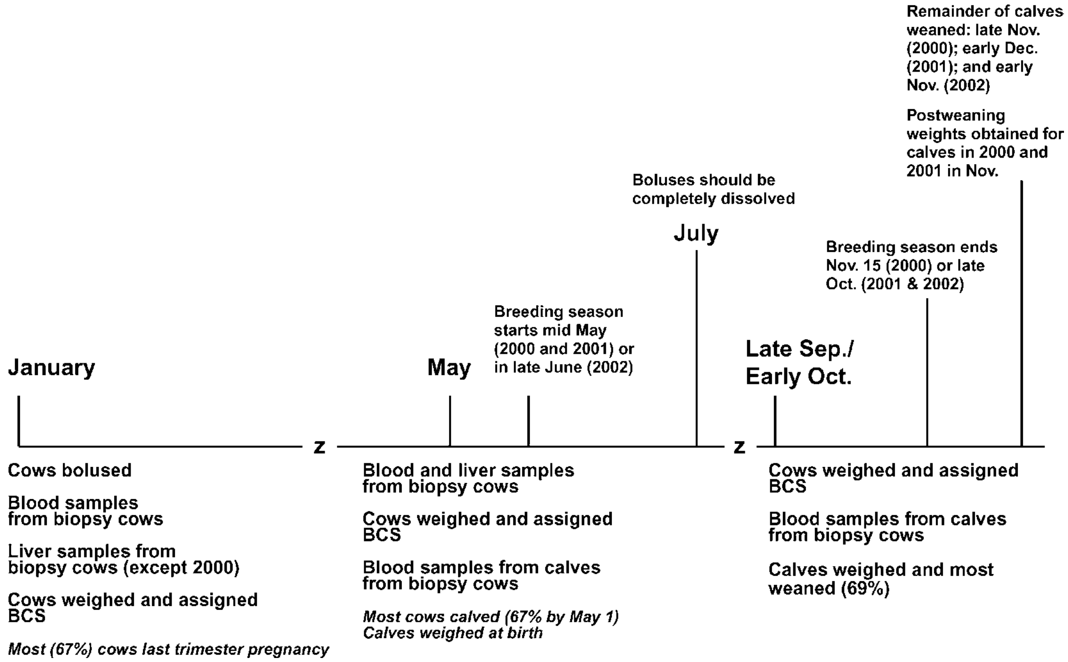

Figure 1. Sampling time line for the 3-yr trial for beef cow breeds (and their calves) administered a long-acting (6 mo) reticulorumen trace mineral bolus.

exception of 1 cow in 2000, we were not certain which 6 cows lost boluses in the 3 yr of the study.

Cows remained in a common herd without any type of oral trace mineral supplement for the 3 yr of the trial, except for having free-choice access to white, iodized salt blocks. No trace mineral supplementation, with the exception of the white, iodized salt blocks, was provided before or during the trial, except in 2002. In the winter of 2002, from early February to late April, cows were provided free access to protein blocks (27% CP; Eagle Milling Co., Inc., Casa Grande, AZ) containing 12.1 ppm of Cu, 33.5 ppm of Zn, and 0.107 ppm of Se from feed ingredients. These blocks were formulated without a trace mineral package, but due to minute amounts of trace minerals contained in the feed ingredients, the blocks contained the amounts of Cu, Zn, and Se described. At an average daily intake of 0.88 kg of protein supplement, it was estimated that the cows received 11 mg of Cu, 29 mg of Zn, and 0.094 mg of Se per day from the protein supplement.

Cows were palpated rectally for pregnancy in January of each year, and a subset of cows (3 yr old and greater) expected to calve by May within each breed and treatment group was randomly allocated to obtain liver (cows only) and blood (cows and calves) samples to determine Cu, Zn, and Se status. After accounting for deleted cows (those that were late calving, lost calves, from which liver samples were not obtained, that were missing in large pastures, or that weaned their calves early), bolused and control cows used over the 3 yr for this more intensive sampling (hereafter referred to as biopsy cows) consisted of 42 and 45 C cows, 35 and 41 H cows, and 44 and 44 B cows, respectively. Biopsy cows that remained in the herd and would calve by May were retained as biopsy cows each year (n = 16 B, 13 H, and 17 C for 2 of 3 yr; n = 8 B, 5 H, and 9 C for 3 of 3 yr). The biopsy cows ranged in age from 3 to 8 yr for C, 3 to 11 yr for H, and 5 to 15 yr for B.

The majority (98.2%, n = 852) of calves used in this trial were sired by Hereford bulls via artificial insemination or natural mating. The remaining calves were sired by either Angus or Beefmaster bulls who got past the boundary fences of the ranch. The breeding season extended from May 20 to November 15 in 2000, May 16 to October 31 in 2001, and June 29 to October 26 in 2002. For a portion of the cow herd (56, 43, and 67% for C, H, and B over the 3-yr trial, respectively), the natural mating season was preceded by estrus synchronization and artificial insemination using both Ovsynch (Pursley et al., 1997a,b) and Select Synch (Geary et al., 2000; Stevenson et al., 2000) in 2000 and 2001 and Easi-Breed CIDR (Pharmacia & Upjohn Co., Kalamazoo, MI; Lucy et al., 2001) in 2002.

Data Sampling for Cattle

In September (September 25 to October 4) and January (January 10 to 23) of each year, cows were checked for pregnancy by rectal palpation. Cows were weighed and scored for BCS (1 to 9; 1 = emaciated to 9 = obese; Richards et al., 1986) in January (10 to 23), May (1 to 5), and September (September 25 to October 4) of each year. Birth and weaning weights were collected on all calves. The majority (69%) of the calves were weaned from September 25 to October 1, at approximately 184 d, and weaning weights were adjusted to 205 d of age and for age of dam according to Beef Improvement Federation (**BIF**; BIF, 2002) guidelines.

In 2000, 52% of C, 70% of H, and 60% of B were weaned on September 25th. In 2001, 41% of C, 74% of H, and 57% of B were weaned on October first. In 2002, 78% of C, 81% of H, and 86% of B were weaned on October 1, the remaining calves were weaned on July 10 (2%), September 12 (9%), or November 6 (6%), except for those that were too young. The remaining calves that were too young (<160 d of age for 2000 and 2001; <100 d in 2002) to wean in September were weaned on November 28, 2000; December 6, 2001; or November 6, 2002. Smaller calves were weaned at younger ages in 2002 due to a drought.

In 2000, all calves were shipped to the University of Arizona feedlot 3 d after weaning. In 2001 and 2002, 10 d after weaning, steers weighing 227 kg or more were shipped to the University of Arizona feedlot, whereas smaller steers and all of the heifers were shipped to the Maricopa Agricultural Center, where they were placed on Sudangrass pasture. For each calf at weaning, the WDA was calculated using the actual weaning weight and dividing by age at weaning. Postweaning weights were obtained for calves in November during 2000 and 2001.

To assess Cu and Zn levels, before administering the boluses in January, we obtained liver samples for the biopsy subgroup (n = 90; 15 from each breed and treatment group) of cows (except in January 2000) using a Schackelford-Courtney liver biopsy instrument (Sontec Instruments, Englewood, CO), as described by Rogers et al. (2001). After obtaining liver biopsies, a topical antibiotic (Aluspray, Vedco Inc., Overland Park, KS) was applied to the surgical site, and 40 mL of a long-acting penicillin (Durapen, Vedco Inc.) and an 8-way clostridial vaccine containing *Clostridial hemolytica* vaccine for Redwater (Agri Laboratories, Ltd., St. Joseph, MO) were administered. Whole blood samples for Se, and serum samples for Cu and Zn, were also obtained in January. Liver and blood samples were again collected from all biopsy cows in May. Calves from the control and bolused groups of biopsy cows had whole blood sampled in May and September for Se and blood serum sampled for Cu and Zn. For calves, whole blood samples collected for Se analysis in May 2000 were accidentally frozen and the tubes fractured, necessitating the elimination of these data from the analyses. Blood samples for cows were obtained by tail vein venipuncture using a plastic 30-mL syringe with a plastic plunger (a new syringe and needle was used for each cow; Air-Tite Products Co., Inc., Virginia Beach, VA). For whole blood Se analyses, 10 mL were transferred to vacuum tubes containing disodium EDTA (Vacutainer tube, No. 369736, Becton-Dickinson Inc., Franklin Lakes, NJ). For serum Cu and Zn, 10 mL was gently (needle removed, blood pushed out against inside of the tube) transferred to blood tubes containing no additive (Vacutainer tube, No. 369737, Becton-Dickinson). Blood samples obtained from the calves were collected by jugular venipuncture using the vacuum blood tubes described previously.

Blood Analyses

Whole blood samples were placed on ice and kept cool until transport to the AZVDL. Serum samples were collected after centrifugation at 2,400 × g for 20 min. Serum samples were transferred to 5-mL polypropylene tubes (VWR International, Brisbane, CA) and frozen at −20°C. Whole blood Se was analyzed at the AZVDL using the same methods as for the forage samples. Serum samples were analyzed for Cu and Zn at Texas A & M University by flame atomic absorption spectroscopy (Model S11, Thermal Jarrel Ash Corp., Franklin, MA). Serum samples were diluted 1:1 with double-distilled, deionized water, and standards were prepared in a 15% (vol/vol) glycerol solution.

Whole blood analysis of Se, rather than glutathione peroxidase activity in erythrocytes, was used to determine the Se status of the cows and calves because of the greater ability of whole blood Se to reflect marginal Se deficiencies (Puls, 1994) and due to the long turnover time for Se in erythrocytes. Selenium is partitioned between bovine serum and erythrocytes at about a 30:70 ratio (Scholz and Hutchinson, 1979; Puls, 1994). Selenium-dependent glutathione peroxidase activity will change with supplementation only as fast as erythrocytes turn over, which is roughly 160 d for cattle (Kaneko, 1963). Serum Se changes rapidly with dietary intake (Villar et al., 2002), and thus whole blood analysis of Se (which contains both serum and erythrocyte Se) will reflect Se status more quickly than Se-dependent glutathione peroxidase activity.

Serum Cu was measured to demonstrate its effectiveness or ineffectiveness in assessing trace mineral status to producers in Arizona. To comply with university oversight of the sampling protocol, liver biopsies for Cu analyses were not obtained from calves.

Liver Analyses

Liver biopsy samples were transferred to 1.7-mL, polypropylene microcentrifuge tubes (Intermountain Scientific Corporation, Kaysville, UT), maintained on ice for 2 to 3 h, and stored at −20°C. Liver samples (approximately 0.1 g of wet tissue) were freeze-dried (Vac-Stop Tray Drier Model 75150, LabConco, Kansas City, KS) for 24 h and then predigested with 5 mL of nitric acid for 3 d. After addition of 1 mL of hydrogen peroxide, samples were digested in an MSP 1,000 microwave sample preparation unit (CEM Corp., Matthews, NC) for 2 h at 100°C. Digested liver samples were diluted with double-distilled water before analysis of Cu and Zn by flame atomic absorption spectroscopy. Atomic absorption standards were prepared in a 2% nitric acid solution.

Missing Data

Within each sampling period, there were usually from 1 to 3 cows for which the liver could not be located during the biopsy procedure. Due to the extensive nature of the V-V Ranch (31,161 ha), we were not able to gather all cows for the May sampling period in 2002 (78 biopsy cows gathered). In May 2001, 15 cows failed to calve by the time the liver biopsy was obtained (4 B, 5 C, and 6 H), so these cows were not included in the data analyses. There were 77 calves from biopsy cows sampled in May 2000, 78 in September 2000, 69 in May 2001, 81 in September 2001, 73 in May 2002, and 67 in September 2002. There were 34 blood samples that froze before centrifugation in September 2002 and had to be eliminated from analyses due to excessive hemolysis.

Statistical Analyses

All data were analyzed using a restricted maximum likelihood-based mixed effects model appropriate for repeated measures (Littell et al., 1996, 1998). The denominator degrees of freedom for treatment *F*-statistics were approximated using the Kenward-Roger's method (Kenward and Roger, 1997). An unstructured correlation structure was used to model the relationships between repeated observations. Production data were analyzed in a model that included the fixed main effects of treatment, cow breed, year, and all 2- and 3-way interactions between those; and BIF age of dam and calf sex and their interaction as fixed main effects. The continuous fixed effect of weaning age was included in the model, and cow within breed by bolus was included as a random main effect. Blood and liver data were analyzed with a model that included the fixed main effects of treatment, cow breed, month, year, and BIF age of dam, and the random main effect of cow within breed by bolus. Interactions for blood and liver data included breed × treatment, breed × year, and treatment × year. To obtain least squares means for cow Se by treatment, month, and year, the 3-way interaction of treatment × month × year was added to the statistical model. We also added a treatment × month interaction to the base model for calf blood Se data to obtain these least squares means. Yearly mineral concentrations in forage were analyzed in a model that included the fixed main effects of plant species, year, month, and plant species × year, and the random main effect of pasture.

Unless stated, least squares means are reported for significant effects ($P < 0.05$). Comparisons between specific effect means were calculated using the PDIFF function in SAS (SAS Inst. Inc., Cary, NC).

RESULTS AND DISCUSSION

Influence of Climate

Table 1 illustrates the variation in annual and monthly precipitation for lower (969 m) and upper (2,280 m) weather stations located close to the study area. Annual precipitation at upper locations was 85, 84, and 60% of normal for 2000, 2001, and 2002, respectively. At lower elevations, annual precipitation was 111, 81, and 59% of normal for the same time period. However, precipitation in Arizona can vary greatly from month to month. In our study, precipitation in 2000 was mostly above average in both March and June and below average the rest of the summer growing season with the exception of 1 spike of moisture during August at lower elevations. In 2001, precipitation was above average during the spring and summer growing season (April to August) at greater elevations. Precipitation in 2002 was considerably below normal throughout the growing season for both lower and greater elevations until September.

Overall Forage Trace Mineral Concentrations

Table 2 presents forage mineral concentrations by year. Sulfur has been observed to reduce Cu and Se absorption when greater than 0.2 to 0.3% (Mortimer et al., 1999; Ivancic and Weiss, 2001). Copper absorption is reduced when dietary Mo concentration is over 3 ppm (Corah and Dargatz, 1996). We did not detect any problems with either Mo or S in this study. However, Fe concentrations in the forage were greater than 400 ppm each year of the study at which level it has been reported (Corah and Dargatz, 1996) that Cu absorption is reduced. It has not been determined experimentally that excess Fe in the diet reduces Se absorption, though it has been reported that iron selenide has poor availability to animals (Wichtel et al., 1994).In forage analyses conducted on native grass samples for 18 states (Corah and Dargatz, 1996), samples were observed to be deficient or marginal in Se (72.7%), Cu (67.9%), Zn (96.4%), and Co (67.9%). Granitic and volcanic-derived soils have been observed to be deficient in Se (NRC, 1983).

Concentrations of Cu in forage were nearly adequate (10 ppm; NRC, 1996) in 2000, marginally deficient (4 to 7 ppm; Corah and Dargatz, 1996) in 2002, and severely deficient (<4 ppm; Corah and Dargatz, 1996) in 2001, a year with generally more favorable precipitation during the growing season. As opposed to Cu, concentrations of Se increased with more precipitation, though the concentrations of Se were always deficient in forage (<0.1 ppm; NRC, 1996). The NRC (1996) defined adequate dietary Zn concentrations to be 30 ppm. Concentrations of Zn in forage were severely deficient (<20 ppm; Corah and Dargatz, 1996) in 2001 and 2002 and marginally deficient (20 to 40 ppm; Corah and Dargatz, 1996) in 2000. Concentrations of Co in forage exceeded requirements (0.1 ppm; NRC, 1996) throughout the trial.

Ganskopp and Bohnert (2003) observed that the concentrations of Cu in forage decreased in a wetter year (167% of normal precipitation), and they related this phenomenon to a dilution effect with increased biomass

Table 2. Mineral concentrations in forage by year

Trace mineral	n	2000	n	2001	n	2002	P-value
Copper, ppm	80	9.2 ± 0.46	80	3.9 ± 0.46	79	4.9 ± 0.45	0.001
Selenium, ppm	57	0.042 ± 0.006	75	0.079 ± 0.006	61	0.045 ± 0.006	0.001
Zinc, ppm	80	20.2 ± 1.04	80	16.0 ± 1.04	79	15.1 ± 1.03	0.001
Cobalt, ppm	80	1.16 ± 0.052	80	0.48 ± 0.052	79	0.44 ± 0.052	0.001
Iron, ppm	80	409 ± 40	80	434 ± 40	79	432 ± 39	0.833
Molybdenum, ppm	80	0.50 ± 0.17	80	0.43 ± 0.17	79	0.39 ± 0.17	0.283
Sulfur, %	80	0.12 ± 0.008	80	0.12 ± 0.008	79	0.08 ± 0.008	0.001

in favorable years. Conversely, from the data we have presented here, it seems that increased moisture on semiarid granitic or volcanic-derived rangelands may in fact increase Se levels in forage.

Cow Performance Data

Over the course of the trial, BCS of bolused cows tended ($P = 0.074$) to be greater in January than control cows, although cow BW in January was not different ($P = 0.366$; Table 3). The BCS in May and September did not differ ($P > 0.328$). The breed × treatment × year interaction was not significant ($P = 0.120$), though bolused H cows appeared to have lower BCS ($P < 0.001$) than control H in May 2000 (4.5 ± 0.13 vs. 5.0 ± 0.10).

There were no significant overall treatment differences in cow BW in May ($P = 0.129$), but the year × breed × treatment interaction was significant ($P < 0.001$) for cow BW in May. This interaction was mainly due to control H cows having greater BW in May 2000 than bolused H cows (data not shown; $P < 0.001$; 448 ± 7.2 vs. 396 ± 9.6 kg). The control C cows also tended ($P = 0.098$) to have greater BW in May 2001 than bolused C cows (data not shown; 445 ± 7.6 vs. 427 ± 8.7 kg). By September, the interaction of cow breed with year and treatment had diminished ($P = 0.107$), and the only significant difference ($P = 0.027$) occurred in September 2001, when control C cows had greater BW than bolused cows (data not shown; 465 ± 6.7 vs. 444 ± 2.7 kg).

Cattle treated with Cosecure boluses lost more weight from January to May ($P = 0.02$; Table 3). A significant ($P = 0.001$) year × breed × treatment interaction was present and is presented in Figure 2. By far, H cows were most profoundly affected ($P < 0.001$) by bolus administration in 2000, a better Cu year as indicated by the forage analysis. Control H cows gained 12 ± 11.4 kg, whereas bolused cows lost 60 ± 14.2 kg. Bolused B cows also tended ($P = 0.054$) to lose more weight than control cows in 2002 (–59 ± 9.5 vs. –37 ± 8.3 kg) from January to May.

By September, the change in cow weight was no longer different among treatment groups ($P = 0.133$; data not shown). Similarly, the 3-way interaction of year with breed and treatment was no longer significant ($P = 0.101$). However, in 2001, bolused C cows did not seem to gain as much weight from January to September as control cows (47 ± 6.7 vs. 67 ± 5.7 kg; $P = 0.013$).

There are at least 2 explanations why bolused cows lost more weight in early lactation. First, it is possible that bolused cows had greater early season milk production than control cattle. Alternately, increased supplemental Cu (especially when forage Cu levels were close to dietary requirements in 2000) could have had an antagonistic effect on cow productivity by interacting with other trace minerals in the forage (Spears, 1991) or by decreasing forage digestibility (Arthington et al., 2003).

Limited experimental research has examined the influence of added Cu and Se in the diet on milk production. Lacetera et al. (1996) reported that milk production ($P = 0.06$) and total milk solids ($P = 0.02$) were greater for dairy cows provided supplemental Se. Engle et al. (2001) failed to show any increase in milk production with added Cu in the diets of dairy cattle.

Although some research has shown a decrease in forage digestibility with added Cu (Arthington et al., 2003), other research (Lopez-Guisa and Satter, 1992) failed to demonstrate the same effect. Durand and Kawashima (1980) reviewed the effects of minerals on rumen microbial fermentation and reported that additional Co and Cu added to a diet low in these trace minerals increased cellulose degradation and fiber digestibility. They also reported that additional dietary Se increased microbial methionine synthesis. However, it would appear that more work needs to be done to more fully understand the effects of various trace minerals on ruminal fermentation.

Because we did not obtain milk production data, it is not known whether the decline in BCS for bolused cows resulted from increased milk production, antagonisms with other trace minerals in the diet, reduced fiber digestibility, or interactions of the same.

Calf Performance Data

In this study, we observed no difference in adjusted weaning weights or WDA for calves suckling cows bolused with a long-acting trace mineral bolus (Table 4). Muehlenbein et al. (2001) reported no difference in calf weaning weights for calves nursing cows supplemented pre- and postpartum with either organic or inorganic sources of Cu. Ahola et al. (2004) reported that calves nursing cows provided supplemental Cu, Zn, and Mn via free-choice mineral feeders in pastures containing

Table 3. Effects of a long-acting, trace mineral bolus on range body condition score and cow weight[1]

Item	n	No bolus	n	Bolus	*P*-value
January BCS[2]					
All cows and all years	575	4.8 ± 0.05	455	4.9 ± 0.06	0.074
C cows[3]	188	4.6 ± 0.08	143	4.7 ± 0.09	0.178
H cows[3]	183	4.8 ± 0.08	156	4.9 ± 0.08	0.069
B cows[3]	204	5.0 ± 0.09	146	5.1 ± 0.10	0.060
May BCS[2]					
All cows and all years	544	4.5 ± 0.11	394	4.4 ± 0.12	0.328
C cows[3]	171	4.6 ± 0.18	129	4.3 ± 0.20	0.156
H cows[3]	210	4.5 ± 0.21	143	4.4 ± 0.21	0.864
B cows[3]	163	4.5 ± 0.19	122	4.5 ± 0.22	0.862
September BCS[2]					
All cows and all years	542	4.6 ± 0.05	392	4.7 ± 0.06	0.516
C cows[3]	173	4.5 ± 0.08	128	4.5 ± 0.09	0.854
H cows[3]	207	4.5 ± 0.07	140	4.6 ± 0.09	0.205
B cows[3]	162	4.9 ± 0.09	124	5.0 ± 0.10	0.939
January BW, kg					
All cows and all years	580	445 ± 3.3	427	449 ± 3.8	0.366
C cows[3]	184	432 ± 5.5	137	426 ± 6.4	0.381
H cows[3]	202	435 ± 5.2	149	445 ± 5.8	0.174
B cows[3]	194	467 ± 6.0	141	475 ± 6.7	0.274
May BW, kg					
All cows and all years	543	436 ± 3.8	394	426 ± 4.4	0.129
C cows[3]	171	421 ± 6.7	129	407 ± 7.5	0.148
H cows[3]	209	442 ± 5.6	143	433 ± 6.6	0.292
B cows[3]	163	438 ± 6.9	122	437 ± 7.7	0.899
September BW, kg					
All cows and all years	538	435 ± 3.3	390	434 ± 3.7	0.882
C cows[3]	173	427 ± 5.8	128	413 ± 6.6	0.102
H cows[3]	207	431 ± 4.9	140	436 ± 5.8	0.495
B cows[3]	158	447 ± 6.0	122	453 ± 6.6	0.410
Change in BW January to May, kg					
All cows and all years	497	−10 ± 3.4	373	−21 ± 4.0	0.020
C cows[3]	164	−9 ± 5.6	122	−17 ± 6.6	0.300
H cows[3]	178	2 ± 5.6	135	−13 ± 6.4	0.071
B cows[3]	155	−23 ± 6.0	116	−32 ± 6.7	0.235

[1] Cosecure trace mineral boluses had an expected life of approximately 175 d and provided approximately 156 mg of Cu/d, 5.9 mg of Co/d, and 3.4 mg of Se/d.

[2] 1 to 9; (9 = fattest).

[3] Breeds: C = Composite (25% Hereford, Angus, Gelbevieh, and Barzona or Senepol); H = Hereford; B = Brahman cross.

13.1 ppm of Cu and 16.1 ppm of Zn had lower ($P < 0.02$) weaning weights per cow exposed than calves nursing control cows with no added Cu, Zn, or Mn in the mineral supplement. Awadeh et al. (1998) and Gunter et al. (2003) observed no difference in growth performance for calves nursing Se-supplemented cows, whereas Nelson and Miller (1987) reported that weaning weights for calves nursing Se-supplemented cows increased by 20 kg. Hidiroglou et al. (1987) and Givens et al. (1988) failed to show any increase in calf weight gains for calves nursing cows that received Cosecure boluses.

It seems that any added weight gains for calves nursing cows supplemented with either Cu or Se are dependent on several factors, chief of which are the dietary Cu or Se concentrations for cows in the study and the presence or absence of any antagonistic trace minerals in the diet such as Mo, Fe, and S for Cu (Spears, 1991) and S for Se (Ivancic and Weiss, 2001). Villar et al. (2002) reported that positive growth responses to Se supplementation appear to occur when dietary Se in the forage base is less than 0.05 ppm of DM and when plasma Se levels are less than 0.030 ppm. The pasture forage Se concentration reported by Gunter et al. (2003) was 0.11 ppm and 0.07 ppm by Awadeh et al. (1998), and they reported no difference in growth response as Villar et al. (2002) would have predicted. However, Hidiroglou et al. (1987) reported that forage concentrations in their study varied from 0.020 to 0.040 ppm, and they reported no difference in growth response through cow supplementation with Se. In our study, forage Se concentrations were less than 0.05 ppm for 2 out of 3 yr (Table 2).

Although the breed × treatment interaction for postweaning weight was not significant ($P = 0.156$) for the 2 yr it was measured (2000 and 2001), a weak trend ($P = 0.068$; Table 3) may have been present for increased postweaning weight for H calves from supplemented cows. Most of this response occurred ($P = 0.089$) in 2001

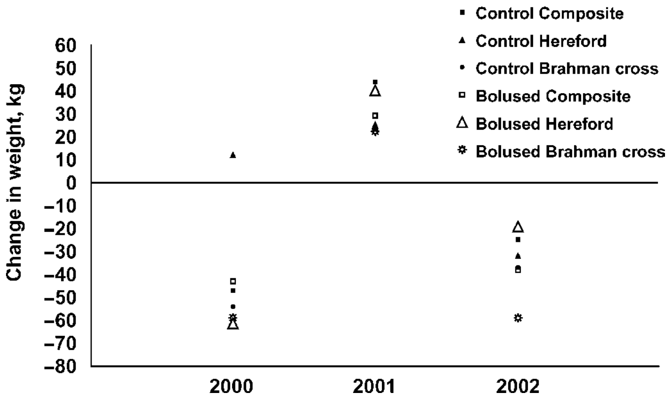

Figure 2. Change in weight from January to May over the 3-yr trial for beef cow breeds administered a long-acting (6 mo), reticulorumen trace mineral bolus. Hereford cows differed by treatment in 2000 ($P < 0.001$), and Brahman cross cows tended ($P = 0.054$) to differ in 2002. Means and SE are −47 ± 10.7, −43 ± 12.5, 12 ± 11.4, −60 ± 14.2, −54 ± 10.0, and −59 ± 11.2 kg for control and bolused Composite, Hereford, and Brahman cross cattle, respectively for 2000; 44 ± 7.7, 29 ± 8.9, 25 ± 10.1, 41 ± 9.7, 23 ± 8.3, and 22 ± 9.4 kg for control and bolused Composite, Hereford, and Brahman cross cattle, respectively for 2001; and −25 ± 7.2, −38 ± 8.5, −32 ± 6.1, −20 ± 6.4, −37 ± 8.3, and −59 ± 9.5 kg for control and bolused Composite, Hereford, and Brahman cross cattle, respectively for 2002.

(data not shown; 200 ± 9.5 vs. 179 ± 8.1 kg) when Cu concentrations in forage were severely deficient and Se concentrations slightly elevated (though still below adequate levels).

We detected a year × breed × treatment interaction ($P = 0.022$; Table 5) for birth weight, due mostly to B cows in 2001 ($P = 0.017$) and C cows ($P = 0.074$) in 2000. We were uncertain as to the nature of this effect unless it was related to forage digestibility factors discussed earlier.

Liver and Blood Mineral Concentrations in Biopsy Cattle

Tables 6 and 7 present the least squares means for biopsy cows. Liver Cu for control cows was deficient (less than 75 to 90 ppm; Corah and Dargatz, 1996), whereas liver Cu was adequate (>75 to 90 ppm) for cows receiving the Cosecure boluses. There were no significant ($P = 0.168$) breed effects detected for liver Cu, but concentrations varied by both month and year ($P < 0.001$); concentrations were 116 ± 9.1 ppm in 2000, 84 ± 6.6 ppm in 2001, and 88 ± 10.8 ppm in 2002 when pooled over all cows. There was a treatment × year interaction ($P < 0.001$) detected for cow liver Cu (Table 6). In 2001, a poor forage Cu year, liver Cu only increased from 79 ± 8.4 ppm to 90 ± 8.3 ppm for control vs. bolused cows. In 2002, a slightly better year for forage Cu, liver Cu increased from 68 ± 12.6 ppm to 108 ± 15.0 ppm for control vs. bolused cows. The levels of liver Cu corresponded to forage concentrations of Cu

Table 4. Birth weight, adjusted weaning weight, weight per day of age, and postweaning weight for calves nursing cows administered a long-acting trace mineral bolus[1]

Item	n	No bolus	n	Bolus	*P*-value
Birth wt, kg					
From all calves and all years	465	35.4 ± 0.27	366	34.9 ± 0.27	0.517
C calves[2]	171	35.4 ± 0.41	123	35.4 ± 0.45	0.522
H calves[2]	137	34.9 ± 0.41	119	34.9 ± 0.45	0.697
B calves	157	35.8 ± 0.45	124	34.9 ± 0.50	0.370
Adjusted weaning wt, kg[3]					
From all calves and all years	467	201 ± 1.9	347	199 ± 2.1	0.520
C calves[2]	158	210 ± 3.1	116	211 ± 3.6	0.815
H calves[2]	154	177 ± 2.8	109	177 ± 3.3	0.974
B calves[2]	155	215 ± 3.4	122	210 ± 3.7	0.187
Wt/d of age at weaning, kg					
From all calves and all years	477	0.95 ± 0.01	355	0.94 ± 0.01	0.596
C calves[2]	141	0.99 ± 0.01	98	1.00 ± 0.02	0.787
H calves[2]	137	0.84 ± 0.01	100	0.84 ± 0.02	0.960
B calves[2]	122	1.01 ± 0.02	94	0.99 ± 0.02	0.215
November postweaning wt,[4] kg					
From all calves and all years	115	181 ± 3.4	95	184 ± 3.5	0.402
C calves[2]	40	193 ± 5.4	35	194 ± 5.3	0.937
H calves[2]	29	155 ± 5.2	23	169 ± 6.3	0.068
B calves[2]	46	194 ± 5.3	37	190 ± 5.4	0.442

[1] Cosecure trace mineral boluses had an expected life of approximately 175 d and provided approximately 156 mg of Cu/d, 5.9 mg of Co/d, and 3.4 mg of Se/d.

[2] Breed of dams: C = Composite (25% Hereford, Angus, Gelbevieh, and Barzona or Senepol); H = Hereford; B = Brahman cross; sires were predominantly Hereford bulls.

[3] Weaning weights adjusted according to Beef Improvement Federation guidelines (BIF, 1990).

[4] Postweaning weights obtained only for 2000 and 2001.

Table 5. Birth weight (kg) by year and breed for calves nursing cows administered a long-acting trace mineral bolus[1]

	Year											
	2000				2001				2002			
Breed	n	No bolus	n	Bolus	n	No bolus	n	Bolus	n	No bolus	n	Bolus
C calves[2]	63	37.2 ± 0.54	49	35.8 ± 0.63	56	36.3 ± 0.59	40	37.2 ± 0.68	52	33.6 ± 0.63	34	33.1 ± 0.77
H calves[2]	48	35.4 ± 0.63	37	34.5 ± 0.73	33	36.3 ± 0.77	32	36.7 ± 0.73	56	32.7 ± 0.59	50	33.6 ± 0.59
B calves[2]	78	36.3 ± 0.50	63	36.7 ± 0.59	46	37.2 ± 0.63[c]	38	35.4 ± 0.68[d]	33	33.1 ± 0.77	23	33.1 ± 0.86

[c,d]Within year and breed, means without a common superscript letter differ ($P < 0.05$).

[1] Cosecure trace mineral boluses had an expected life of approximately 175 d and provided approximately 156 mg of Cu/d, 5.9 mg of Co/d, and 3.4 mg of Se/d.

[2] Breed of dams: C = Composite (25% Hereford, Angus, Gelbvieh, and Barzona or Senepol); H = Hereford; B = Brahman cross; sires were predominantly Hereford bulls.

but did not correlate well to cow serum Cu levels with a Pearson correlation of 0.07 ($P = 0.336$) There was no difference between bolused and control cows ($P = 0.619$) for serum Cu (Table 6), and these data confirm widely reported findings (Clark et al., 1993; Radostits et al., 1994; Swenson, 1998) that serum Cu is not a good indication of trace mineral status until levels approach deficient levels (for serum Cu, < 0.60 ppm; Puls, 1994), which Claypool et al. (1975) reported occurred (for plasma Cu) when DM liver Cu concentrations declined to 40 ppm or lower.

Due to interrelationships which have been reported to exist between Cu and Zn metabolism (Oestreicher and Cousins, 1985), we desired to see if providing additional dietary Cu would affect liver Zn. In this study, forage Zn concentrations were always deficient, yet levels of Zn in the liver were always adequate. Concentrations of liver Zn never fell below adequate levels (80 to 90 ppm; Corah and Dargatz, 1996), though it declined ($P < 0.001$) from January (133 ± 3.0 ppm) to May (116 ± 2.1 ppm). These data suggest that dietary levels recommended for grazing beef cattle by NRC (1996) may not be well understood for range cattle in central AZ or at least sampling liver for Zn adequacy may not reflect true metabolic status. Because there were no differences observed ($P = 0.931$) between control and bolused cows in liver Zn (Table 6), we can probably dismiss the possibility of competitive binding of Zn transporters by added dietary Cu. Another possibility is that the range cows in this study were obtaining additional dietary Zn from other browse plants than the one half shrub (shrubby buckwheat) measured. Meen (2001) reported that browse species on the Arizona strip (approximately 400 km northwest of the study site) contained about twice as much Zn as grasses, though they were still severely deficient. Liver Zn and serum Zn did not differ ($P > 0.72$; Table 6) between treatment groups, an expected result because the cows in this study did not receive supplemental Zn. The Pearson correlation between liver Zn and serum Zn was low (0.15; $P = 0.024$).

Serum Zn concentrations for cows differed by month and year ($P < 0.001$). Serum Zn levels are defined as adequate at 0.80 ppm by Radostits et al. (1994). Serum Zn for cows declined during the drought year 2002 being 0.73 ± 0.035 ppm vs. 1.02 ± 0.017 ppm in 2000 and 1.01 ± 0.020 ppm in 2001. There was a breed × treatment interaction ($P = 0.048$) for serum Zn, primarily due to

Table 6. Effects of a long-acting trace mineral bolus on cow liver Cu, liver Zn, serum Cu, serum Zn, and whole blood Se[1]

Item	n	No bolus	n	Bolus	*P*-value
Liver Cu,[2] ppm	67	71 ± 6.6	75	120 ± 7.5	0.001
2000, May only	38	68 ± 11.8	41	163 ± 11.9	0.001
2001, over all months	19	79 ± 8.4	22	90 ± 8.3	0.296
2002, over all months	10	68 ± 12.6	12	108 ± 15.0	0.021
Liver Zn,[2] ppm	66	126 ± 3.4	75	127 ± 3.9	0.931
Serum Cu,[2] ppm	69	0.77 ± 0.021	75	0.79 ± 0.024	0.619
Serum Zn,[2] ppm	68	0.91 ± 0.020	74	0.92 ± 0.023	0.718
C cows[3]	25	0.96 ± 0.033	22	0.97 ± 0.047	0.781
H cows[3]	18	0.81 ± 0.032	27	0.89 ± 0.027	0.074
B cows[3]	25	0.97 ± 0.033	25	0.91 ± 0.031	0.107
Whole blood Se,[2] ppm	68	0.123 ± 0.004	75	0.132 ± 0.004	0.057

[1] Cosecure trace mineral boluses had an expected life of approximately 175 d and provided approximately 156 mg of Cu/d, 5.9 mg of Co/d, and 3.4 mg of Se/d.

[2] Samples pooled over all months and all years.

[3] Breeds: C = Composite (25% Hereford, Angus, Gelbvieh, and Barzona or Senepol); H = Hereford; B = Brahman cross.

Table 7. Effects of a long-acting trace mineral bolus on cow whole blood selenium (ppm) by month[1]

	No bolus				Bolus			
Item	n	January	n	May	n	January	n	May
2000, month within year	36	0.130 ± 0.004^b	38	0.157 ± 0.005^c	37	0.127 ± 0.004^b	41	0.194 ± 0.005^d
2001, month within year	24	0.088 ± 0.004^b	20	0.158 ± 0.008^c	28	0.091 ± 0.004^b	22	0.178 ± 0.008^d
2002, month within year	11	0.066 ± 0.004^b	10	0.146 ± 0.005^c	12	0.069 ± 0.003^b	12	0.189 ± 0.005^d

[b–d]Within a row, means without a common superscript letter differ ($P < 0.05$).

[1]Cosecure trace mineral boluses had an expected life of approximately 175 d and provided approximately 156 mg of Cu/d, 5.9 mg of Co/d, and 3.4 mg of Se/d.

a weak trend ($P = 0.107$; Table 6) for bolused B cows to have less Zn than control B cows and for bolused H cows to have more ($P = 0.074$) serum Zn. A breed effect ($P = 0.008$) for serum Zn is presented in Figure 3. Hereford cows appeared to have less ($P < 0.05$) serum Zn than B and C cattle. We did not detect a breed effect ($P = 0.149$) for liver Zn, being 129 ± 5.6, 132 ± 3.8, and 120 ± 4.7 ppm for C, H and B cattle, respectively. Given the dichotomy we observed in this study between liver and serum Zn, it seems that more research is needed to understand the relationship between liver and serum Zn and the possible Zn transport mechanisms regulating these fractions. Littledike et al. (1995) reported a significant ($P < 0.05$) negative correlation (–0.22) between liver and serum Zn, whereas we observed a significant ($P = 0.024$) positive correlation (0.15) between the 2 levels.

Serum Cu and Zn did not differ ($P > 0.31$) by treatment for calves from biopsy cows (Table 8), though serum Cu concentrations for both bolused and control calves fell below what is considered adequate (0.60 ppm; Puls, 1994; data not shown) in 2000. There was a significant month and year effect for serum Cu ($P < 0.001$) and Zn ($P < 0.01$). Serum Cu levels for calves were less ($P < 0.001$) in 2000 (0.42 ± 0.012 ppm) than in 2001 (0.79 ± 0.015 ppm) and 2002 (0.76 ± 0.032 ppm). However, liver Cu concentrations for biopsy cows in May 2000 were at their greatest levels and forage concentrations of Cu were also at their greatest levels in the year 2000. As noted for serum Cu data for cows, serum Cu data for calves in this study are questionable.

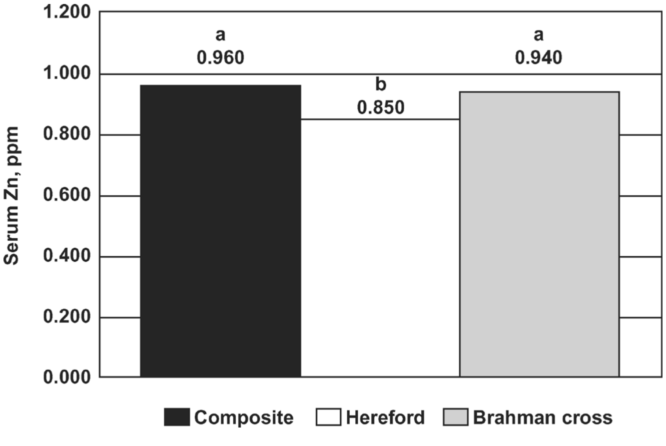

Figure 3. Effect of cow breed on serum Zn concentrations. Means were pooled over all years, months, and treatments for cows administered a long-acting (6 mo), reticulorumen trace mineral bolus. The SE was 0.034 ppm for Composite, 0.022 ppm for Hereford, and 0.027 ppm for Brahman cross cattle. The breed effect P-value was = 0.008. [a,b]Means without a common superscript differ ($P < 0.05$).

Calf serum Zn × year did not follow the same pattern observed for cow serum Zn, though it should be considered that calf serum Zn was measured in May and September instead of in January and May. Calf serum Zn was greatest ($P < 0.01$; data not shown) in 2001, being 1.19 ± 0.029 ppm vs. 0.97 ± 0.024 ppm in 2000 and 0.99 ± 0.061 ppm in 2002.

For biopsy cows, whole blood Se differed by month, year, and by age of dam ($P < 0.001$), as well as by breed ($P = 0.004$) and breed × year ($P = 0.018$). There was a tendency ($P = 0.057$) for blood Se concentrations to be greater for bolused cows (Table 6). In spite of the low concentrations of Se in forage, cow blood Se levels were adequate for both treatment groups (> 0.1 ppm; Radostits et al., 1994) for all time periods except in January 2001 and 2002 when they were marginally deficient (0.05 to 0.1 ppm; Radostits et al., 1994; Table 7). There were no differences in blood Se for control vs. bolused cows in January ($P > 0.05$; Table 7), but bolused cows had greater Se in May ($P < 0.01$; treatment × month × year interaction, $P < 0.001$). Hidiroglou et al. (1987) reported that Shorthorn × Charolais cows supplemented with 2 Cosecure boluses (120 g each for their experiment vs. 100 g each for this experiment) had greater glutathione peroxidase activity than control cows and that activity peaked at 5 mo posttreatment.

Breed ($P < 0.001$) and breed × year ($P = 0.018$) effects for cow Se concentrations are presented in Figures 4 and 5, respectively. It seems that B cows were more efficient in metabolizing Se, having greater ($P < 0.05$) whole blood Se than either C or H cows (Figure 4). Langlands et al. (1980) reported that Brahman cattle in Australia had greater ($P < 0.001$) blood Se than Brahman cross, Africander, Africander cross, Brahman-Africander × Hereford-Shorthorn cross, or Hereford × Shorthorn cross cattle. In evaluating specific sire breeds, they also reported that Brahman × Hereford crosses had greater ($P < 0.05$) Se than Hereford × Hereford, Friesan

Table 8. Serum copper, serum zinc, and whole blood selenium for calves nursing cows administered a long-acting trace mineral bolus[1]

Item		No bolus		Bolus	*P*-value
Serum Cu,[2] ppm	129	0.67 ± 0.016	140	0.65 ± 0.019	0.308
Serum Zn,[2] ppm	129	1.05 ± 0.030	139	1.05 ± 0.036	0.930
Whole blood Se,[2,3] ppm	96	0.118 ± 0.005	105	0.135 ± 0.006	0.010

[1] Cosecure trace mineral boluses had an expected life of approximately 175 d and provided approximately 156 mg/d Cu, 5.9 mg/d Co, and 3.4 mg/d Se.

[2] Samples pooled over all months and all years.

[3] Selenium concentrations not determined for May 2000 due to accidental freezing of samples.

× Hereford, and Simmental × Hereford genotypes. Our data support their findings, though the effect varied by year ($P = 0.018$; Figure 5), with the breed effect being more pronounced in 2001, a better year for forage Se. Bolused B cows had greater ($P < 0.02$; 0.146 ± 0.005 ppm; data not shown) Se whole blood concentrations than C (0.123 ± 0.008 ppm) and H cows (0.126 ± 0.005 ppm), which did not differ ($P = 0.72$). Control H cows had less ($P < 0.04$; 0.108 ± 0.006 ppm; data not shown) Se concentrations than B (0.137 ± 0.006 ppm) and C cows (0.125 ± 0.006 ppm), which did not differ ($P = 0.103$). These data imply that B cattle may be better able to opportunistically exploit increased availability of Se in environments in which trace minerals are ordinarily limiting.

Figure 6 presents the effect of cow age on cow Se concentrations. Mature cows 5- to 10-yr-old had greater ($P < 0.001$) blood Se than 3-yr-old and 11- to 15-yr-old cows. Mature cows presumably would have a larger rumen than younger cows and thus would be able to consume a greater total amount of forage than younger cows on the same diet (Varel and Kreikemeier, 1999; Sowell et al., 2003). Though it may improve economic and biological efficiency by increasing the age of culling for mature beef cows (Kress et al., 1988), conceivably there could come a time when the physiological efficiency of older cows to harvest and process forage in extensive range environments is compromised. Thus, we would anticipate that nutrient absorption would decline as it becomes more difficult for older cows to traverse and harvest forage in limiting environments. Though it may seem intuitive that this would be the case, we could not find extensive research in the literature to support this hypothesis. In the one study we could find (Suverly et al., 2000), forage intake of stockpiled winter pastures was greater ($P < 0.10$) for 10-yr-old cows than for 8- and 4-yr-old cows, with no difference ($P > 0.10$) observed among 10-, 12-, and 6-yr-old cows. It seems that more research is needed to identify optimal culling ages for beef cows with respect to economic, biological, and physiological efficiency, though this may

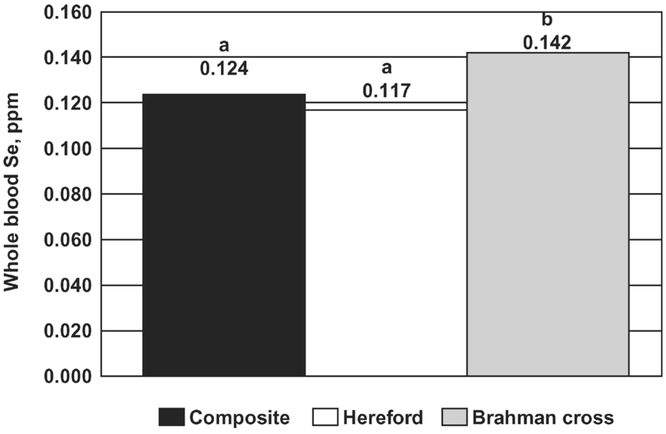

Figure 4. Effect of cow breed on whole blood Se concentrations. Means were pooled over all years, months, and treatments for cows administered a long-acting (6 mo), reticulorumen trace mineral bolus. The SE was 0.006 ppm for Composite, 0.004 ppm for Hereford, and 0.005 ppm for Brahman cross cattle. The breed effect *P*-value was <0.001 [a,b]Means without a common superscript differ ($P < 0.05$).

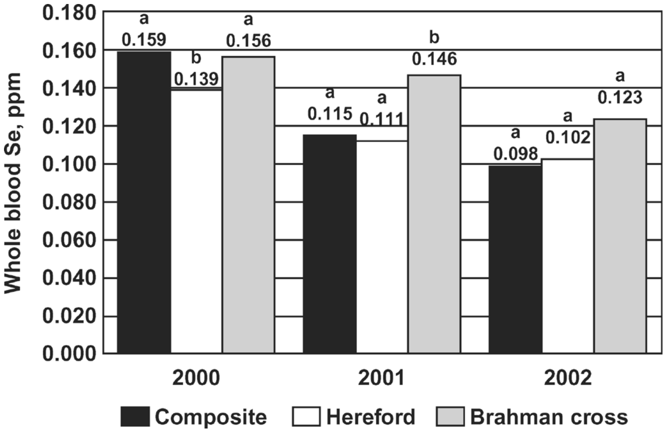

Figure 5. Effects of cow breed × year on whole blood Se concentrations. Means were pooled over all months and treatments for cows administered a long-acting (6 mo), reticulorumen trace mineral bolus. The SE was 0.005 ppm for Composite and Brahman cross and 0.006 ppm for Hereford cows in 2000; 0.006 ppm for Composite, 0.005 ppm for Hereford, and 0.007 ppm for Brahman cross cows in 2001; and 0.014 ppm for Composite, 0.008 ppm for Hereford, and 0.007 ppm for Brahman cross cows in 2002. The breed × year effect *P*-value was = 0.018. [a,b]Means without a common superscript differ ($P < 0.05$).

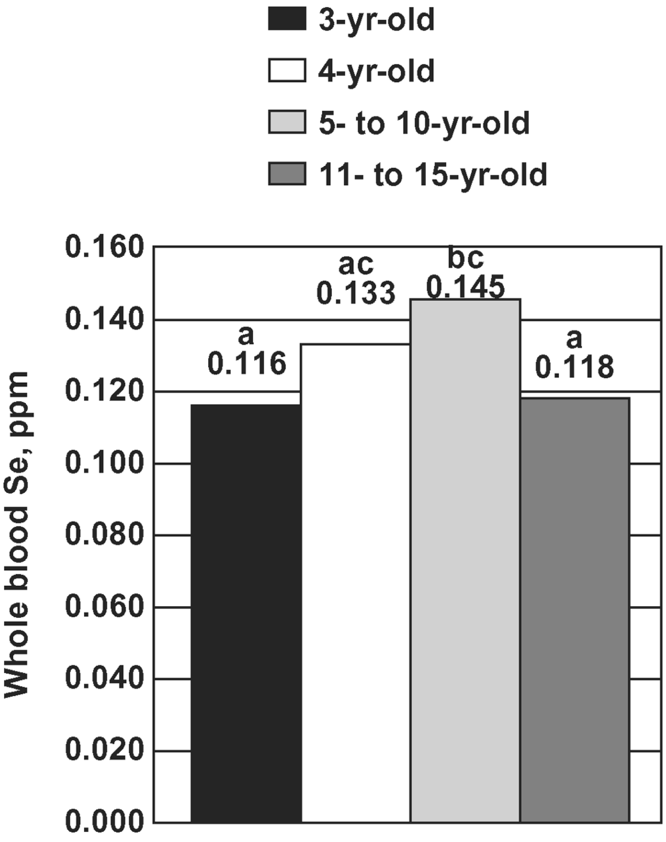

Figure 6. Effect of cow age on whole blood Se concentrations. Means were pooled over all years, months, and treatments for cows administered a long-acting (6 mo), reticulorumen trace mineral bolus. The SE was 0.006 ppm for 3-yr-old, 0.008 ppm for 4-yr-old, 0.003 ppm for 5- to 10-yr-old, and 0.005 ppm for 11- to 15-yr-old cattle. The age effect P-value was <0.001. $^{a–c}$Means without a common superscript differ ($P < 0.05$).

be very difficult to accomplish given the wide variation that exists among different range cow environments.

Calves nursing bolused biopsy cows had greater (P = 0.01) whole blood Se than calves nursing control biopsy cows (Table 8). The concentration of Se for calves dropped ($P < 0.001$; data not shown) from May (0.152 ± 0.006 ppm) to September (0.101 ± 0.005 ppm) and was to be expected as stores of Se acquired prenatally declined.

Hidiroglou et al. (1987) reported that glutathione peroxidase activity for calves nursing cows administered Cosecure boluses was greater ($P < 0.01$) than for calves nursing control cows, declining after peaking at 1 mo of age. However, calves from their study for the treatment group of cows still had greater ($P < 0.01$) glutathione peroxidase activity 6 mo after birth. Similarly, when we added the treatment × month interaction ($P = 0.904$) to the statistical model to obtain least squares means by month and treatment, it appeared that calf Se levels in September were greater ($P = 0.036$; data not shown) for calves nursing bolused cows (0.109 ± 0.007 vs. 0.093 ± 0.006 ppm).

Calf Se differed by month and year ($P < 0.001$; data not shown) and was greatest in 2001, a better year for forage Se. The calf Se concentration in 2001 was 0.143 ± 0.005 ppm vs. 0.103 ± 0.006 ppm in 2000 and 0.134 ± 0.009 ppm in 2002.

We failed to detect any significant breed effects (P = 0.334) for calf Se. Hohenboken and McClure (1993) failed to demonstrate any breed effects for blood Se for Angus calves sired by New Zealand vs. United States sires, but they did not impose any type of nutritional treatments on these calves. Most of the calves in this study were 50% Hereford, diluting the B influence we observed for cows for Se. It is possible that if the nutritional treatments imposed on the cow herd had been applied directly to the calves instead of by indirect application via fetal transfer of Se and through the milk of the dam, then we might have seen some breed effects among the calves. However, because we did not impose any type of nutritional treatment directly to calves in this study, it is not known if the breed effects we observed for the dams would have been exhibited in their Hereford cross calves.

IMPLICATIONS

Strategic supplementation of copper and selenium via a long-acting trace mineral bolus in late gestation was successful in increasing liver copper in cows and blood selenium in cows and calves but varied by year for copper and selenium, and for cow selenium, by breed. When favorable growing season moisture occurs, it is critical to evaluate copper status in forage and supplement accordingly. Breeds of cattle and different age classes of cattle differ in their ability to metabolize supplemental selenium. Suggested dietary requirements for zinc for range cows or the method of assessing adequacy may need to be reevaluated. Cow and calf responses to added copper and selenium varied by year, necessitating careful monitoring of levels of these trace minerals in the forage during different growing conditions, and altering trace mineral supplementation programs accordingly.

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