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PRODUCTION AND MANAGEMENT: *Original Research*

Influence of supplemental copper, manganese, and zinc source on reproduction, mineral status, and performance in a grazing beef cow-calf herd over a 2-year period*

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ABSTRACT

Objective: This experiment evaluated the effects of Cu, Mn, and Zn source on mineral status, reproduction, and performance of grazing beef cattle in eastern Colorado.

Materials and Methods: Crossbred (Angus and Angus × Hereford; n = 261) 3-yr-old beef cows were stratified by expected calving date, BW, BCS, and liver Cu status and randomly assigned to 1 of 6 replicates. Replicates were then assigned to 1 of 2 treatments (n = 40–45 cows per replicate), resulting in 3 replicates per treatment for the 2-yr experiment. Treatments consisted of (1) inorganic–organic trace mineral combination (IOC; 75% of Cu, Mn, and Zn from sulfate forms and the remaining 25% from organic AA complexes) and (2) hydroxy trace minerals (HTM; 100% from hydroxychloride forms). Replicates were rotated among pastures approximately every 28 d to minimize pasture effects. Free-choice mineral feeders were used to provide NASEM (2000) recommended concentrations of Cu, Mn, and Zn continuously for 2 yr. Blood samples and liver biopsies were obtained from every cow before the initiation of the experiment and then from a subgroup of animals (20 random animals per replicate) at the end of yr 1 (d 335 of the experiment) and 2 (d 638 of the experiment).

Results and Discussion: Over the 2-yr experiment, mineral intake, cow BW, BCS, pregnancy rate to AI, and overall pregnancy rate did not differ across treatments. Calf weaning weights were also not affected by trace mineral source. At the end of yr 1 and yr 2, liver Cu concentrations were greater ($P \leq 0.05$) in HTM- compared with IOC-supplemented cows. Liver Zn concentrations were greater ($P < 0.05$) in cows receiving HTM at the end of yr 1 and tended ($P < 0.06$) to be greater at the end of yr 2. Liver Mn concentrations were not affected ($P > 0.05$) by trace mineral source.

Implications and Applications: Overall productivity of grazing beef cows and their calves over a 2-yr period were similar in cattle supplemented with hydroxy or a combination of sulfate and organic trace minerals. Liver Cu and Zn concentrations were greater in cows fed HTM.

Key words: cattle, free-choice mineral, pasture, intake

INTRODUCTION

Several trace minerals (**TM**) are required to optimize growth, reproduction, and health in cattle (Suttle, 2010). In beef cow-calf operations, providing a free-choice mineral is the most widely used method of supplementing macro and microminerals that may be limiting in forages (Greene, 2000). Trace mineral sources added to free-choice minerals vary in their bioavailability (Spears, 2003). Inorganic sulfate or oxide sources of TM have traditionally been used in free-choice minerals. Organic TM are generally considered to be more bioavailable than inorganic forms (Greene, 2000). Some beef cow-calf studies have indicated improved calf BW gains (Stanton et al., 2000), reproductive performance (Ahola et al., 2004; Whitehurst et al., 2014), or both when all or a portion of sulfate TM (**STM**) were replaced with organic forms.

Hydroxy TM are relatively insoluble in water or at weakly acidic pH but are solubilized under acidic condi-

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tions typical of those found in the abomasum (Spears et al., 2004). In contrast, STM are readily soluble in water as well as under acidic conditions. Copper hydroxychloride has been shown to be more bioavailable than $CuSO_4$ when supplemented to cattle diets high in the Cu antagonists, Mo, and S (Spears et al., 2004; VanValin et al., 2019). Steers supplemented with Zn hydroxychloride had greater apparent absorption and retention of Zn than steers supplemented with $ZnSO_4$ following a 14-d depletion period (Shaeffer et al., 2017). Ruminal soluble concentrations of Zn and Cu were considerably lower in steers dosed with hydroxy TM compared with those given STM (Caldera et al., 2019). The greater bioavailability of hydroxy TM compared with STM may relate to their low solubility in the rumen, resulting in less interaction with antagonists in the rumen environment. We hypothesized that long-term performance of beef cows supplemented with Cu, Mn, and Zn from hydroxy TM would be greater than that of cows supplemented with iso-concentrations of Cu, Mn, and Zn from a combination of organic and sulfate forms. The present experiment was conducted to determine whether TM source affects mineral status, reproductive performance, and gain of beef cows and their calves.

MATERIALS AND METHODS

Prior to the initiation of this experiment, all animal use, handling, and sampling techniques described herein were approved by the Colorado State University Animal Care and Use Committee (Protocol # 13-4627A).

Experimental Design

Body weights, BCS, and liver biopsies were obtained over a 2-d period (January 16 and 17, 2014), before the initiation of the experiment, from 261 crossbred (Angus and Angus × Hereford; 535.0 ± 5.9 kg of initial BW) 3-yr-old cows at the Eastern Colorado Research Center (Akron, CO). On January 30 (beginning of the experiment) all cows were stratified based on expected calving date, BW, BCS, and liver Cu concentration and randomly assigned to 1 of 6 replicates (n = 42, 44, 45, 41, 44, and 45 for replicates 1, 2, 3, 4, 5, and 6, respectively). Replicates were then assigned to 1 of 2 treatments, resulting in 3 replicates per treatment for each year of the 2-yr experiment. Treatments were as follows: (1) inorganic–organic TM combination (**IOC**) providing 75% of Cu, Mn, and Zn from sulfate forms and 25% of Cu, Mn, and Zn from organic AA complexes (Availa-Cu, Availa-Zn, and Availa-Mn; Zinpro Corp., Eden Prairie, MN) and (2) hydroxy TM (**HTM**; 100% IntelliBond C, M, and Z, Micronutrients USA LLC, Indianapolis, IN). Ingredient composition of the free-choice mineral supplements is presented in Table 1, and chemical analysis of each supplement is shown in Table 2. With the exception of Cu, Mn, and Zn, all macro- and microminerals and vitamins A, D, and E were added to the free-choice mineral supplements from the same sources for both treatments in concentrations to meet or exceed the NASEM (2000) recommended concentrations. Mineral treatments were provided at a single location in each pasture, free choice, in covered mineral feeders beginning in February of yr 1 through the end of the 2-yr experiment. Mineral treatments remained available for ad libitum consumption for all animals throughout the 2-yr experiment, with a target intake of 114 $g \cdot cow^{-1} \cdot calf^{-1} \cdot d^{-1}$. Mineral feeders were monitored 3 times a week to ensure all animals had ad libitum access to free-choice mineral throughout the experiment.

All procedures described below were repeated over 2 consecutive years, except where noted. Cows remained on their respective treatments and within their respective replicates for both years. Cows calved between March 30 and May 31 in yr 1 (d 60–121 of the experiment) and between

Table 1. Ingredient composition of free-choice mineral supplements on a DM basis

	Free-choice mineral treatment	
Item,[1] %	IOC[2]	HTM[3]
Ca_2PO_4	38.05	38.23
NaCl	32.97	32.98
$CaCO_3$	13.97	16.53
BioMos	3.75	3.75
MgO	2.22	2.20
Se (0.16% Se as $NaSeO_3$)	1.69	1.69
Soybean oil	1.10	1.00
KCl	0.85	0.85
Vitamin A	0.53	0.53
EDDI	0.25	0.25
Vitamin E	0.13	0.13
Vitamin D_3	0.05	0.05
$CoCO_3$	0.03	0.03
Availa-Mn 80	1.10	0
$MnSO_4$	0.73	0
Availa-Zn 120	0.94	0
$ZnSO_4$	0.91	0
Availa-Cu 100	0.38	0
$CuSO_4$	0.44	0
IntelliBond C	0	0.26
IntelliBond M	0	0.74
IntelliBond Z	0	0.79

[1]Biomoss = *Saccharomyces cerevisiae* yeast, Alltech (Nicholasville, KY); EDDI = ethylenediamine dihydroiodide (79.6% I); Availa-Mn, Availa-Zn, and Availa-Cu, Zinpro Corp. (Eden Prairie, MN); IntelliBond C, M, Z, Micronutrients USA LLC (Indianapolis, IN).

[2]IOC = 75% of Cu, Mn, and Zn from inorganic sulfate forms and 25% from organic AA complexes; Zinpro Corp.

[3]HTM = 100% of Cu, Mn, and Zn from hydroxychloride forms; Micronutrients USA LLC.

April 20 and June 10 in yr 2 (d 444–486 of the experiment). Calves were weaned on November 6 in yr 1 (d 280 of the experiment) and October 23 in yr 2 (d 631 for the experiment). Basal forage (Table 3) and water TM concentrations were determined using monthly samples collected from pasture (n = 10 samples·pasture replicate^{-1}·mo^{-1} and analyzed separately; Holden et al., 1994), supplemental winter feeds (n = 1 sample per bale fed), and water source (n = 1 sample·water source^{-1}·pasture replicate^{-1}·mo^{-1}).

After replicates and treatments were assigned, animals were housed by replicate in 6 separate pastures. Cows were maintained on native pastures that consisted primarily of blue grama (*Bouteloua gracilis*), prairie sandreed (*Calamovilfa longifolia*), and needle-and-thread grass (*Stipa comata*). During both years of the experiment, a supplemental alfalfa–grass hay mix was provided at 9.5 kg of DM·animal^{-1}·d^{-1} to compensate for poor winter forage quality. Hay feeding began on February 28 in yr 1 (d 29 of the experiment) and March 2 (d 396 of the experiment) in yr 2 of the experiment. In addition to hay, a mixture of corn stalks, corn silage, and wet distillers grain was fed at a rate of 0.6 kg of DM·animal^{-1}·d^{-1} beginning in early April. Supplemental feed was discontinued as range quality increased in May.

Replicates were rotated among pastures approximately every 28 d, and mineral weigh-backs were performed at each rotation to determine mineral disappearance. Replicates were grouped within treatment for approximately 30 d before and during calving (approximately 50 d) for management purposes. Mineral treatments continued to be available at these times, although mineral disappearance within replicates could not be monitored.

Mineral Status

Liver and plasma Cu, Mn, and Zn concentrations were used to determined mineral status of animals used in this experiment. A liver biopsy sample was collected from every cow before the start of the experiment and then from a subgroup of animals (20 random animals per replicate) at the end of yr 1 (d 335 of the experiment) and the same 20 animals at the end of yr 2 (d 638 of the experiment) using the true-cut technique described by Pearson and Craig (1980), as modified by Engle and Spears (2000). Liver samples were immediately rinsed with 0.01 *M* PBS (pH 7.4), placed in an acid-washed polypropylene tube, capped, and placed on ice before storage at –20°C (approximate time from collection to storage was 5 h). Blood samples were collected, at the time of liver biopsy, via jugular venipuncture in TM-free heparinized Vacutainer tubes (Becton Dickinson Co., Franklin, NJ). Once collected, samples were placed on ice for 5 h before being centrifuged at 2,000 × *g* for 20 min at room temperature. Plasma was then transferred to acid-washed storage vials and stored at –20°C. All metals were quantified via inductively coupled plasma-atomic emission spectroscopy methods (Braselton et al., 1997).

Table 2. Chemical analysis of free-choice mineral supplements

Chemical analysis	IOC[1]	HTM[2]	SEM
DM, %	96.6	95.9	1.28
CP, %	0.07	0.06	0.035
Crude fat, %	1.2	1.1	0.179
Ca, %	12.5	12.9	0.256
P, %	8.1	8.3	0.181
Co, mg/kg of DM	16.9	15.2	0.288
Cu, mg/kg of DM	1,587.8	1,593.3	30.82
Mn, mg/kg of DM	3,630.3	3,586.5	140.74
Se, mg/kg of DM	25.0	25.1	0.337
Zn, mg/kg of DM	4,678.0	4,708.0	110.34

[1]IOC = 75% of Cu, Mn, and Zn from sulfate forms and 25% from organic AA complexes.

[2]HTM = 100% of Cu, Mn, and Zn from hydroxychloride forms.

Cow and Calf Performance

Every cow was inseminated once following a 7-d CO-Synch + controlled internal drug-release insert estrus synchronization protocol, as described by Ahola et al. (2004; d 174 of the experiment). Briefly, 8 d before breeding all cows within the same TM treatment were commingled into 1 pasture with access to their respective free-choice TM supplement. Seven days before breeding, all cows received a GnRH injection and a vaginal controlled internal drug-release insert. Seven day later all controlled internal drug-release inserts were removed, lutalyze was administered, and each cow received a heat-detection patch. Calves were removed at this time for 48 h. The following day all cows with deployed heat-detection patches were artificially inseminated. All remaining cows were artificially inseminated on d 2 after lutalyze administration, and all

Table 3. Macromineral and micromineral concentrations in pasture samples by year[1]

Mineral	Yr 1	Yr 2	SEM	*P* <
Ca, % DM	0.52	0.48	0.048	0.082
P, % DM	0.12	0.13	0.005	0.688
Mg, % DM	0.34	0.32	0.016	0.034
K, % DM	1.06	0.98	0.055	0.042
Na, % DM	0.07	0.06	0.003	0.061
S, % DM	0.15	0.14	0.008	0.083
Fe, mg/kg of DM	136.78	132.10	6.05	0.592
Mo, mg/kg of DM	1.88	1.78	0.084	0.321

[1]Monthy pasture samples were obtained from all pasture replicates; n = 10 forage samples·pasture^{-1}·mo^{-1}.

cows were sorted back into their appropriate pastures with their calves.

To minimize variation in breeding measurements, 2 AI technicians performed the inseminations. Each technician bred every other cow within each replicate, and 1 technician thawed semen. Cows were not exposed to bulls until 14 d after mass insemination to allow for accurate differentiation between pregnancy to AI and pregnancy to natural service. Twelve Angus bulls that had previously passed a breeding soundness evaluation were exposed to the cows for 46 d (2 bulls·treatment^{-1}·pasture^{-1}).

To determine pregnancy rate to AI, cattle were examined via rectal ultrasonography (Aloka 500V equipped with 5.0-MHz linear array transducer, Corometrics Medical Systems, Wallingford, CT) by a state-licensed veterinarian 45 d after mass mating (d 233 of the experiment), as described by Ahola et al. (2004). Cows with fetuses that were approximately 45 d old were classified as pregnant to AI, whereas all other cattle were classified as not pregnant to AI. Final pregnancy rates were determined via palpation per rectum with the aid of ultrasonography approximately 45 d after bull removal by a state-licensed veterinarian.

Cow BW and BCS (1 = emaciated, 9 = obese; Richards et al., 1986; assigned by 2 technicians and averaged for analysis) were collected from all cows when liver biopsies and blood were collected. Weaning weights were collected on each calf on the day of weaning and adjusted to 205 d of age using Beef Improvement Federation (BIF, 2010) adjustments for age of dam and sex of calf.

Statistical Analysis

Cow performance, mineral status, mineral intake, forage mineral concentrations, and calf performance data were assessed using a restricted maximum likelihood-based, mixed-effects model, repeated-measures analysis (PROC MIXED; SAS Institute Inc., Cary, NC). Initial cow performance and mineral status models contained fixed effects of treatment, time, and the treatment × time interaction. Initial calf performance models included fixed effects of treatment, year, age of calf, sex of calf, and all relevant 2- and 3-way interactions. A spatial power covariance structure was used in the analysis, and the containment approximation was used to calculate denominator degrees of freedom. Replicate was used as the experimental unit. Reproductive data (pregnancy to a synchronized AI, and final pregnancy throughout the breeding season) were analyzed using logistic regression (PROC GENMOD of SAS). Individual animal was used as the experimental unit. Initial models for reproductive response contained fixed effects of treatment, postpartum interval, BCS, BW, year, and AI technician, in addition to all relevant 2- and 3-way interactions. When an interaction was not significant, it was removed from the model. If the interaction of year × treatment was not significant, data were pooled across years; otherwise, data were reported for each year separately. Significance was determined at $P \leq 0.05$, and tendencies were determined if $P > 0.05$ and ≤ 0.10

RESULTS AND DISCUSSION

Mineral and CP Content of Diets

Average mineral concentrations of pasture samples by year are presented in Table 3. Based on NASEM (2000) recommendations, pastures were adequate in Ca, Mg, K, S, Fe, and Mn, below the maximum tolerable concentrations for Mo, marginal in P and Na, and deficient in Cu and Zn. Pasture Cu, Mn, and Zn concentrations by month are shown in Figure 1. Copper concentrations in pasture samples ranged from 3.3 to 5.0 mg/kg of DM. Pasture Zn concentrations ranged from 17.4 to 30.8 and Mn concentrations ranged from 45.8 to 69.0 mg/kg of DM. There was a month-by-year interaction for Cu ($P < 0.02$) and Mn ($P < 0.02$) concentrations in grazed forages. Forage Cu concentrations were relatively consistent across both years but appeared to gradually increase in yr 2 between the months of March and June. Forage Mn concentrations decreased from February through September and then increased from October to December in yr 1. However, in yr 2, forage Mn concentrations increased from January through May and then gradually decreased from June to December. Monthly CP concentrations of pastures are presented in Figure 2. Over both years CP content of grazed forage increased from April through June and then decreased from July through March. Hay was fed during the winter months, and the nutrient composition was as follows: 87% DM, 12.3% CP, 0.93% Ca, 0.22% P, 0.20% S, 6.8 mg of Cu/kg, 55.1 mg of Mn/kg, 1.6 mg of Mo/kg of DM, and 22.7 mg of Zn/kg of DM. Water samples analyzed had <0.01 mg of Cu/L, < 0.01 mg of Zn/L, and 0.05 mg of Mn/L.

Free-Choice Mineral Intake

Free-choice mineral intake was not affected ($P < 0.93$) by treatment and averaged 196.6 g·cow-calf pair^{-1}·d^{-1} for the IOC and HTM treatments (Figure 3). Average mineral intake exceeded targeted intake of 114 g·cow-calf pair^{-1}·d^{-1}. Consistent with previous studies (Karn, 1992; Patterson et al., 2013), mineral intake by month varied greatly throughout both years of the experiment. Mineral intake was greater ($P < 0.04$) during the winter months when forage quality was low, based on CP concentrations. The greater mineral intake also coincided with cows being in late gestation and exceeded NASEM (2000) requirements by approximately 3 times during the late fall and winter months and met the NASEM (2000) requirements for gestating cows during the early spring and fall months over both years. These data indicate that free-choice mineral consumption is highly variable and may be influenced by factors such as forage quality and environmental conditions (Karn, 1992; Patterson et al., 2013).

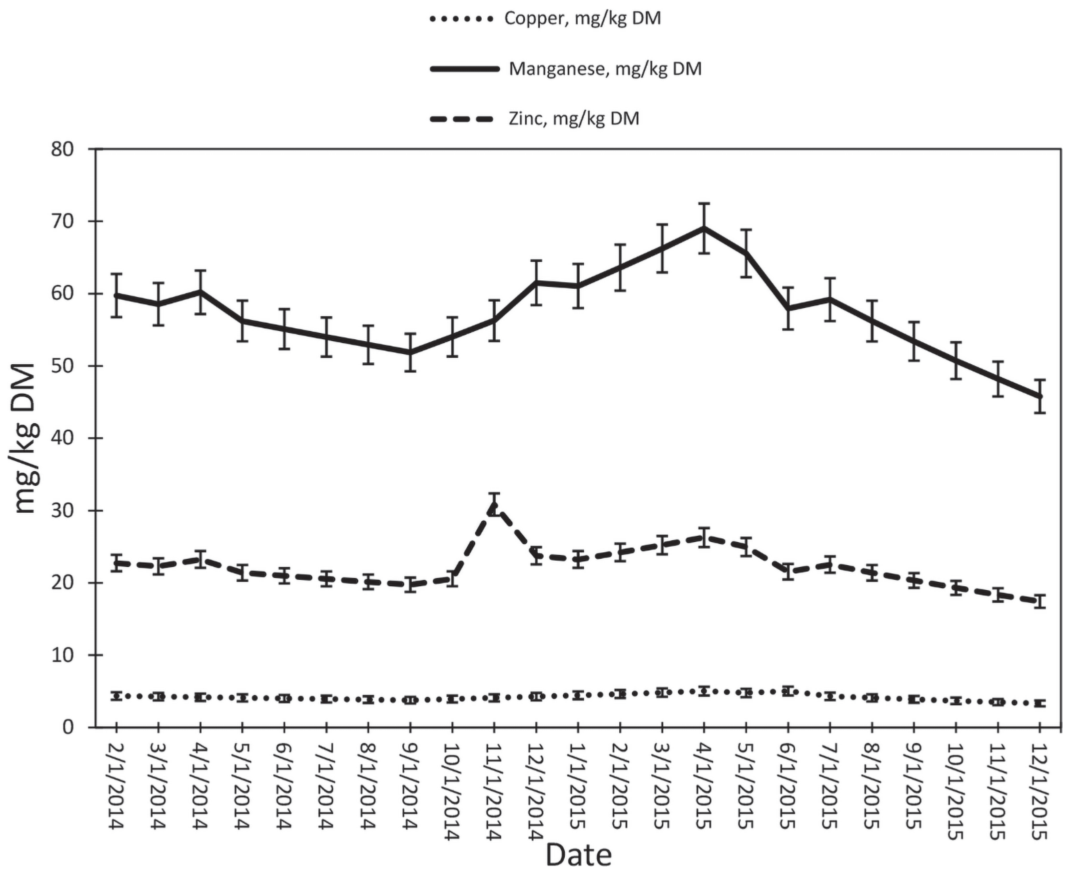

Figure 1. Monthly copper, manganese, and zinc concentrations of grazed forage throughout the experiment. Monthly pasture samples were obtained from all pasture replicates; n = 10 forage samples·pasture^{-1}·mo^{-1}, analyzed individually. Error bars represent SE. Copper—month: $P < 0.02$, year: $P < 0.39$, month × year: $P < 0.02$. Manganese—month: $P < 0.007$, year: $P < 0.75$, month × year: $P < 0.02$. Zinc—month: $P < 0.32$, year: $P < 0.87$, month × year: $P < 0.10$. Date = month/day/year.

Cow-Calf Performance

Cow BW ($P \geq 0.71$) and BCS ($P \geq 0.61$) were similar across treatments at the end of yr 1 and yr 2 of the experiment (Table 4). Pregnancy rate following AI ($P \geq 0.28$) and overall pregnancy rate ($P \geq 0.39$) for the 60-d breeding season were not affected by treatment. Overall pregnancy rate was greater than 95% for both treatments

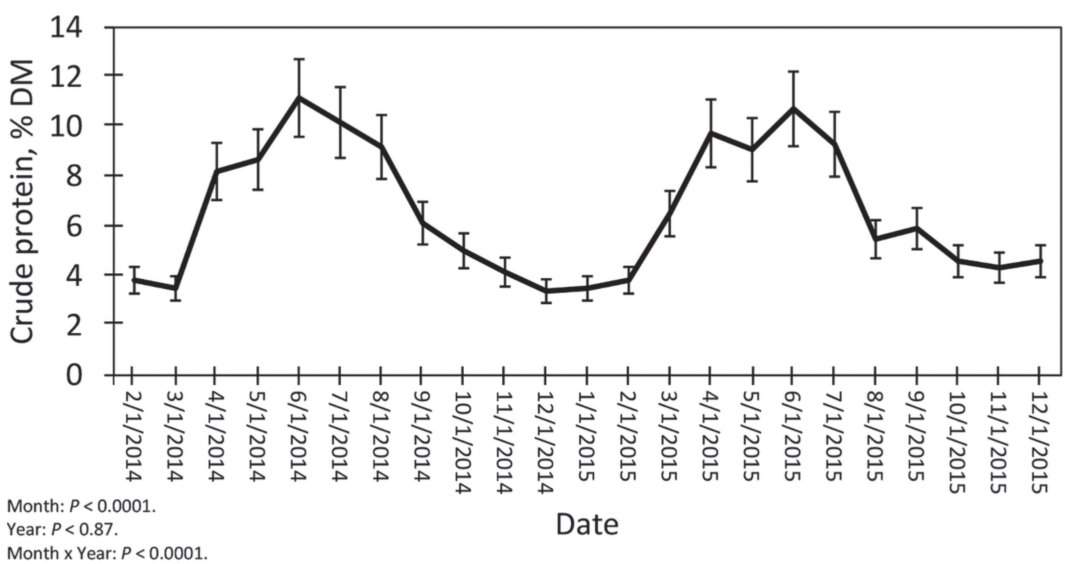

Figure 2. Monthly CP concentrations of grazed forage throughout the experiment. Monthly pasture samples were obtained from all pasture replicates; n = 10 forage samples·pasture^{-1}·mo^{-1}, analyzed individually. Error bars represent SE. Date = month/day/year.

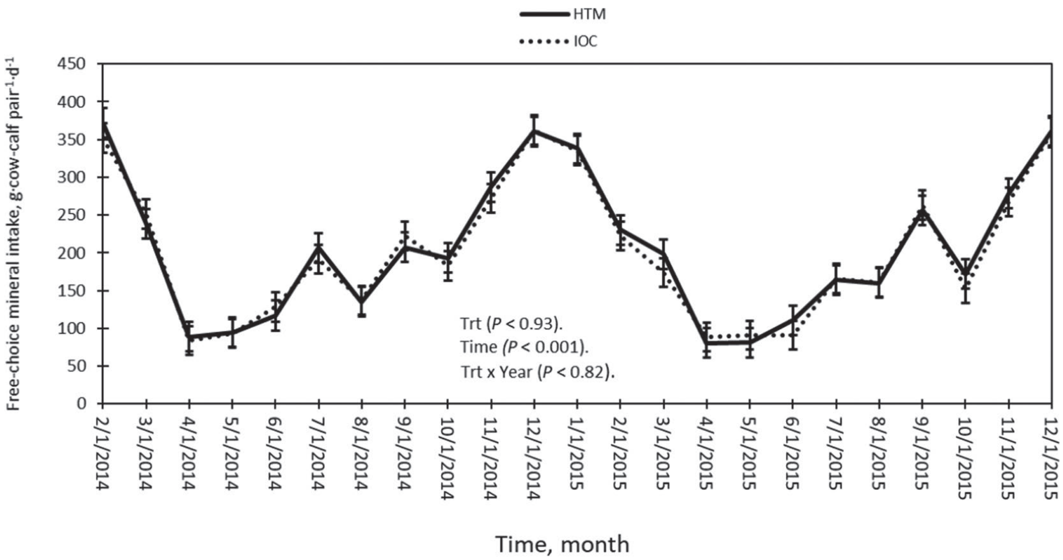

Figure 3. Influence of trace mineral source on free-choice mineral intake in cows and calves over a 2-yr period. Monthly samples (n = 10 forage samples per pasture replicate) were obtained throughout the experiment. Free-choice mineral treatments (Trt) were as follows: (1) inorganic–organic trace mineral combination (IOC) providing 75% of Cu, Mn, and Zn from sulfate forms and 25% of Cu, Mn, and Zn from organic AA complexes (Availa-Cu, Availa-Zn, and Availa-Mn; Zinpro Corp., Eden Prairie, MN) and (2) hydroxy trace minerals (HTM; 100% IntelliBond C, M, and Z, Micronutrients USA LLC, Indianapolis, IN). With the exception of Cu, Mn, and Zn, all macro- and microminerals and vitamins A, D, and E were added to the free-choice mineral supplements from the same sources for both treatments in concentrations to meet or exceed the NASEM (2000) recommended concentrations. Mineral treatments were provided at a single location in each pasture, free choice, in covered mineral feeders beginning in February of yr 1 through the end of the 2-yr experiment. Cows and calves had access to the same mineral feeders within a pasture, with a target intake of 114 $g \cdot cow^{-1} \cdot d^{-1}$. Error bars represent SE.

and is comparable to those reported by Ahola et al. (2004) for cows supplemented with Cu, Mn, and Zn. Actual calf weaning weights (yr 1: $P \geq 0.76$; yr 2: $P \geq 0.85$) and adjusted calf BW at weaning (yr 1: $P \geq 0.65$; yr 2: $P \geq 0.71$) were not affected by treatment (Table 5).

Results of the present experiment indicate that overall productivity of beef cows and their calves supplemented with HTM does not differ from those receiving a combination of 75% STM and 25% organic TM. Several studies have evaluated the effect of replacing all or a portion of STM with organic forms on performance of cows and their calves; however, the results obtained in these studies have been variable. Stanton et al. (2000) reported that replacing STM with TM complexes improved calf gains and cow pregnancy rate to AI. In a 3-yr experiment, young cows (3 and 4 yr old) supplemented with TM complexes had a greater pregnancy rate and shorter calving interval than those receiving inorganic TM in 2 of the 3 yr (Arthington and Swensont, 2004).

Trace mineral source did not affect reproductive performance of mature cows or weaning weights of calves in this experiment. Cows receiving a 50% STM and 50% TM proteinate mixture tended to have a greater pregnancy rate following AI than those supplemented with 100% STM (Ahola et al., 2004). However, these authors also indicated that overall pregnancy was not affected by TM source. Yearling beef heifers supplemented with methionine hydroxy analog chelates of Cu, Mn, and Zn had a greater pregnancy rate than those receiving STM (Whitehurst et

Table 4. Effect of trace mineral source, supplied in free-choice mineral feeders, on cow BW, BCS, and reproductive performance

	Trace mineral source			
Item	IOC[1]	HTM[2]	SEM	*P* <
n	131	130	—	—
BW, kg				
Initial	535	535	5.9	0.89
End of yr 1	568	570	6.1	0.82
End of yr 2	580	587	5.1	0.71
BCS[3]				
Initial	5.46	5.47	0.04	0.54
End of yr 1	5.53	5.54	0.05	0.61
End of yr 2	5.29	5.27	0.05	0.68
Pregnancy rate to AI,[4] %	44.7	50.6	—	0.28
Overall pregnancy rate,[5] %	96.1	96.4	—	0.39

[1]IOC = 75% of Cu, Mn, and Zn from sulfate forms and 25% from organic AA complexes.

[2]HTM = 100% of Cu, Mn, and Zn from hydroxychloride forms.

[3]Body condition score: 1 = emaciated, 9 = obese.

[4]Includes data from yr 1 and 2.

[5]Overall pregnancy rate for 60-d breeding season. Includes data from yr 1 and 2.

al., 2014). In other studies (Olson et al., 1999; Ahola et al., 2005) no benefit was observed in reproductive performance or calf weaning weights in cows supplemented with organic TM compared with STM.

Mineral Status

Initial liver concentrations of Cu ($P \geq 0.91$), Mn ($P \geq 0.94$), and Zn ($P \geq 0.79$) were similar across treatments (Table 6). Liver Cu concentrations were greater ($P \leq 0.05$) in cows receiving HTM compared with those supplemented with IOC at the end of yr 1 and yr 2. Zinc concentrations in liver were also greater ($P \leq 0.05$) for the HTM treatment in yr 1 and tended ($P < 0.06$) to be greater in yr 2. Liver Mn concentrations were not affected by treatment at the end of yr 1 ($P \geq 0.64$) or 2 ($P \geq 0.72$).

The greater liver Cu (end of yr 1 and 2) and Zn (end of yr 1) concentrations in cows supplemented with HTM suggest that hydroxy forms of Cu and Zn were more bioavailable than the IOC. In the presence of greater concentrations of Mo (6.8–6.9 mg of Mo/kg of DM) and S (0.25–3.0% S), Cu from Cu hydroxychloride was more bioavailable than $CuSO_4$ based on plasma ceruloplasmin activity and plasma and liver Cu concentrations (Spears et al., 2004; VanValin et al., 2019). Sulfur and Mo are Cu antagonists in ruminants (Suttle, 2010). Pasture S concentrations in the present experiment (S = 0.14%) were not in excess of NASEM (2000) S requirements of 0.15%. However, pasture Mo concentrations ranged from 1.49 to 2.37 mg/kg (average of 1.83 mg of Mo/kg of DM), and the Cu:Mo ratio in forage samples (Cu:Mo 3.9) was similar to those recommended by Suttle (2010) of a Cu:Mo >4.0. Studies have indicated that bioavailability of Cu from Cu hydroxychloride is similar to Cu AA complexes (Arthington et al., 2003; Cheng et al., 2011). Steers supplemented for 72 d with 10 mg of Cu/kg of DM from Cu hydroxychloride or a Cu AA complex had similar liver Cu concentrations (Arthington et al., 2003). Plasma and liver Cu concentrations also did not differ in lambs supplemented with 10 or 20 mg of Cu/kg of DM from either Cu hydroxychloride or Cu lysine for 60 d (Cheng et al., 2011). Apparent absorption of Zn by steers was greater from Zn hydroxychloride than from $ZnSO_4$ (Shaeffer et al., 2017). In broilers fed a Zn deficient diet, bioavailability of Zn from Zn hydroxychloride was greater than $ZnSO_4$ and equal to a Zn AA complex (Rochell et al., 2013).

Plasma Cu, Mn, and Zn concentrations were not affected by treatment (data not shown). Plasma Cu, Mn, and Zn concentrations were well within the normal range (Suttle, 2010) at the end of both years of the experiment.

Table 5. Effect of trace mineral source, supplied in free-choice mineral feeders, on calf weaning weights

Item	Trace mineral source			
	IOC[1]	HTM[2]	SEM	*P* <
Yr 1				
n	126	127	—	—
Actual weaning weight,[3] kg	229	226	6.2	0.76
205-d adjusted weight,[4] kg	250	249	5.5	0.65
Yr 2				
n	128	127	—	—
Actual weaning weight,[3] kg	225.5	226.5	8.2	0.85
205-d adjusted weight,[4] kg	266.1	266.0	6.5	0.71

[1]IOC = 75% of Cu, Mn, and Zn from sulfate forms and 25% from organic AA complexes.

[2]HTM = 100% of Cu, Mn, and Zn from hydroxychloride forms.

[3]Actual weaning weight with sex and age of calf included in the model statement.

[4]Weaning weight adjusted to 205 d of age using age of cow and calf sex to adjust weights.

Table 6. Effect of trace mineral source, supplied in free-choice mineral feeders, on liver Cu, Mn, and Zn concentrations in cows

Item[1]	Trace mineral source			
	IOC[2]	HTM[3]	SEM	*P* <
n				
Initial	131	130	—	—
End of yr 1	60	60	—	—
End of yr 2	60	60	—	—
Cu, mg/kg of DM				
Initial	202.9	209.1	9.3	0.91
End of yr 1	265.7	385.9	15.9	0.05
End of yr 2	276.5	380.0	21.3	0.05
Mn, mg/kg of DM				
Initial	7.5	7.1	0.4	0.79
End of yr 1	9.0	9.0	0.4	0.64
End of yr 2	9.3	9.4	0.2	0.72
Zn, mg/kg of DM				
Initial	89.8	89.4	6.8	0.94
End of yr 1	116.8	136.8	5.9	0.05
End of yr 2	123.8	144.7	5.2	0.06

[1]Initial = d 0 of the experiment; end of yr 1 = d 335 of the experiment; and end of yr 2 = d 638 of the experiment.

[2]IOC = 75% of Cu, Mn, and Zn from sulfate forms and 25% from organic AA complexes.

[3]HTM = 100% of Cu, Mn, and Zn from hydroxychloride forms.

APPLICATIONS

This 2-yr experiment compared the performance and mineral status of beef cows provided free-choice mineral supplements supplying Cu, Mn, and Zn from IOC or HTM. Reproductive performance and calf BW at weaning were similar for cows supplemented with IOC and HTM. Liver Cu (yr 1 and 2) and Zn (yr 1 only) concentrations were greater in cows supplemented with HTM than in those receiving the IOC. Results indicate that overall productivity of beef cows and their calves receiving hydroxy forms of Cu, Mn, and Zn did not differ from that of those provided a sulfate–organic TM combination. In areas where free-choice mineral intake is limited, mineral sources that provide greater mineral availability may be warranted.

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