Effects of methionine hydroxy copper supplementation on lactation performance, nutrient digestibility, and blood biochemical parameters in lactating cows

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ABSTRACT

The objective of this study was to investigate the effects of methionine hydroxy Cu [(HMTBA)₂-Cu] supplementation on lactation performance, nutrient digestibility, and blood biochemical parameters in lactating cows. Thirty lactating Holstein cows were assigned to 1 of 3 treatments in a randomized block design: (1) Cu sulfate only (S): 12 mg of Cu provided by CuSO₄ per kilogram of concentrate; (2) Cu sulfate and (HMTBA)₂-Cu (SM): 6 mg of Cu provided by CuSO₄ and 6 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate; or (3) (HMTBA)₂-Cu only (M): 12 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate. The level of dietary Cu was determined according to the NRC (2001) requirement. This experiment lasted for 120 d, with the first 20 d for adaptation and with sample and data collection beginning on d 21. The milk yield and 4% fat-corrected milk yield of cows in the SM treatment tended to increase compared with those in the S and M treatments. Cows fed SM also tended to have higher NDF and ADF apparent digestibility values than did cows fed S or M. Plasma Cu concentration significantly increased for the SM treatment compared with the S and M treatments. Cows fed S had higher plasma K concentration than did cows in the other 2 treatments. In conclusion, replacing one-half of the dietary Cu sulfate with (HMTBA)₂-Cu increased plasma Cu concentration and tended to improve the neutral and acid detergent fiber apparent digestibility values and the lactation performance of lactating dairy cattle. **Key words:** dairy cow, lactation performance, methionine hydroxy copper, organic trace mineral

INTRODUCTION

Previous studies have shown that Cu plays an important role in lactation performance (Engle and Spears, 2000; Loeffler et al., 2007), reproduction (Georgjevskii and Samokin, 1982), immune function (Stabel and Spears, 1993; Arthington et al., 1996), and rumen function (Ivan, 1988, 1989) in dairy cows. Copper deficiency always relates to a series of physiological and metabolic disorders (NRC, 2001). Copper deficiency in dairy cows is traditionally prevented by supplying a higher level of dietary inorganic Cu supplementation, in an attempt to guarantee digestion and absorption of the required amount from the gastrointestinal tract. A growing awareness of environmental problems caused by undigested Cu compounds has led to numerous research studies addressing the low absorption rate of inorganic Cu (Benke et al., 2008). Three major reasons for the low absorption rate of inorganic Cu are the animal species, diet composition, and source of Cu. First, the fact that the Cu absorption in ruminant animals is far less than that in monogastric animals (Georgjevskii and Samokin, 1982; Suttle, 1991; NRC, 2001) is widely accepted. The extent of Cu absorption in dairy calves can be as high as 60% in their first 4 wk after birth; however, adult dairy cattle absorb only 1 to 5% of their Cu intake (Bremner et al., 1987). This is largely due to their rumen development and the rumen environment, where it may lead to the formation of a Cu complex with other elements in the absorption process (Dick, 1953; Gengelbach and Spears, 1998; Spears, 2003). Second, it is well documented that the Cu requirement varies greatly in ruminants, depending on concentrations of dietary S and Mo (Allen and Gawthorne, 1987; Gooneratne et al., 1989; Suttle, 1991). Third, several research studies have been carried out to address the absorption rate of different Cu sources, but the results have not been consistent for organic and inorganic forms of Cu (Nockels et al., 1993; Ward et al., 1993). In cattle fed diets that were high in Mo, Cu proteinate was more

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bioavailable than Cu sulfate in some studies (Kincaid et al., 1986; Ward et al., 1996) but not in others (Wittenberg, et al., 1990). The relative bioavailability of Cu lysine was generally similar to that of cupric sulfate (Ward et al., 1993; Kegley and Spears, 1994).

Copper sulfate is a readily available and widely used inorganic Cu source (Chapman and Bell, 1963; McDowell, 1992), but the efficiency of absorption is very low for inorganic sources (NRC, 2001). The source of organic Cu used in the current study, methionine hydroxy Cu [(HMTBA)₂-Cu; Novus International Inc., St. Charles, MO], is a new chelating product composed of 2 molecules of 2-hydroxy-4-methylthio butanoic acid (HMTBA) chelated with 1 molecule of Cu. This experiment was conducted to determine whether replacing dietary Cu sulfate with (HMTBA)₂-Cu would improve the performance of dairy cows.

MATERIALS AND METHODS

The dairy cows selected were cared for in accordance with the practices outlined in the *Guide for the Care and Use of Agricultural Animals in Research and Teaching* (FASS, 2010).

Treatments, Experimental Design, and Cow Management

The study was conducted from July 20, 2008, to April 12, 2009, at the Hutubi Dairy Farm in Xinjiang (northwest China). Ten days before the start of the experiment, 30 Holstein dairy cows (DIM = 45 ± 26 ; milk yield = 31.8 ± 2.4 kg; parities = 1 to 5, and BW = 592 ± 22 kg) were assigned into 1 of 3 treatments using a randomized block design. Three treatments were (1) Cu sulfate only (**S**): 12 mg of Cu provided by CuSO₄ per kilogram of concentrate; (2) Cu sulfate and (HMTBA)₂-Cu (**SM**): 6 mg of Cu provided by CuSO₄ and another 6 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate; or (3) (HMTBA)₂-Cu only (**M**): 12 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate. The supplementation level of Cu was determined according to the NRC (2001) requirement, and the Cu concentration in the basal diet was calculated separately (9.78 mg/kg). The trial was 120 d in duration, with the first 20 d for adaptation and with sample collection beginning on d 21.

Cows in the experiment were component fed, and the Cu supplement was included in the compound premixes (1% of concentrate). Six feeders (5 cows/feeder) were responsible for daily feeding of the premix. The 5 cows the feeder was responsible for was randomly arranged daily. The compound premix was preweighed for each

cow 3 times/d, and the keepers delivered it to the cows. The premix was added on top and stirred into the concentrate at every feeding. During the adaptation period, the experimental premixes S, SM, or M were gradually supplemented to their corresponding treatments and replaced the control premix by 10% more every day as a transition. The full replacement was achieved on d 10 and was maintained thereafter to the end of this experiment. Ingredients and nutrient composition of the experimental diets are listed in Table 1; the concentrate and forage were fed separately 3 times/d (0400, 1100, and 1700 h). In the current experiment, approximately 1.90 kg of corn silage, 0.54 kg of alfalfa hay, 0.40 kg of brewers grain, 3.65 kg of concentrate, and 1.80 kg of alfalfa hay were delivered to each cow in the morning feeding, and approximately 1.42 kg of corn silage, 0.18 kg of alfalfa hay, 0.30 kg of brewers grain, 2.74 kg of concentrate, and 1.50 kg of alfalfa hay were supplied to each cow in the noon and afternoon feedings. Water was available for ad libitum consumption. A mineral supplement block was not provided in the open lot. The (HMTBA)₂-Cu was supplied by the Novus International Trade Company (St. Charles, MO). Ingredients and nutrient levels of the diets are shown in Table 1.

Data and Samples Collection

Milk Yield and Milk Components. All cows on the farm were milked 3 times daily while feeding at 0430, 1130, and 1730 h using a pipeline milking machine. Milk yields of the experimental cows were recorded daily for the first 3 d of the experiment and then every 10 d for the remainder of the experiment. Milk samples were taken for the first 3 d of the experiment and then every 30 d at all milkings until the end of the experiment, and samples were analyzed for milk components at the DHI milk testing laboratory at Xinjiang Agricultural University (Urumqi, Xinjiang, China).

DMI and Digestibility. To calculate the DMI of individual cows, the amount of every ingredient offered was measured from d 1 to 3, d 31 to 33, d 61 to 63, d 91 to 93, and d 115 to 120 of the experiment, and theorts of individual cows during these days were collected and weighed after every feeding. Ingredient and orts samples were oven-dried at 65°C for 48 h, ground to pass through a 1-mm screen using a Wiley mill (standard model 4, Arthur H. Thomas Co., Philadelphia, PA), and stored at -20°C for DM, OM, NDF, and ADF analysis. During the period from d 115 to 120, 3 cows from each treatment with similar DMI were selected for a 5-d digestibility test, and the floor was cushioned with rubber mats during the test. Six fecal holders were arranged in shift, and were responsible for collecting

Table 1. Ingredient composition and nutritional level of the experimental diets (% DM basis)

Item, ¹ %	Treatment ²		
	S	SM	M
Ingredient			
Corn silage	24.60	24.60	24.60
Brewers grain	4.90	4.90	4.90
Alfalfa hay	17.70	17.70	17.70
Concentrate without premix ³	52.80	52.80	52.80
Total	100.00	100.00	100.00
Nutritional level			
CP	15.90	15.90	15.90
NDF	40.20	40.20	40.20
ADF	23.60	23.60	23.60
OM	91.60	91.60	91.60
Ether extract	6.40	6.40	6.40
Ca	0.79	0.79	0.79
P	0.44	0.44	0.44
K	1.20	1.20	1.20
Na	0.37	0.37	0.37
Cl	0.41	0.41	0.41
Sulfur, ⁴ mg/kg	2,306.00	2,309.00	2,312.00
Cu from CuSO ₄ ·5H ₂ O, mg/kg	12.00	6.00	—
Cu from (HMTBA) ₂ -Cu, ⁵ mg/kg	—	6.00	12.00
Basal Cu level, ⁶ mg/kg	9.78	9.78	9.78
Fe, mg/kg	214.44	214.44	214.44
Zn, mg/kg	87.18	87.18	87.18
Mn, mg/kg	46.11	46.11	46.11
Mo, mg/kg	2.38	2.38	2.38
NE _L , ⁷ MJ/kg	6.78	6.78	6.78

¹Defined based on the consecutive 3-d intake of all cows determined in the adaptation period.

²Treatments: S = Cu sulfate only: 12 mg of Cu provided by CuSO₄ per kilogram of concentrate; SM = Cu sulfate and methionine hydroxy Cu [(HMTBA)₂-Cu]: 6 mg of Cu provided by CuSO₄, and 6 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate; M = (HMTBA)₂-Cu only: 12 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate.

³Contained the following per kilogram of concentrate without premix: 48% corn grain, 16% wheat bran, 12% cottonseed meal, 6% cottonseed protein, 4% beet meal, 1% sunflower meal (extruded), 3.4% sunflower meal (solute), 3% rapeseed meal, 2% plastered starch urea, 1.5% limestone, 1.2% Ca phosphate, 1% premix, 0.1% detoxifier, 0.8% salt.

⁴Note that the difference for total S content brought about by replacing CuSO₄ with (HMTBA)₂-Cu was not all dissolvable. The change in methionine content was undetectable in this experiment.

⁵(HMTBA)₂-Cu (Novus International Inc., St. Charles, MO) is composed of 2 molecules of 2-hydroxy-4-methylthio butanoic acid (HMTBA) chelated with 1 molecule of Cu.

⁶From corn silage, brewers dried grain, alfalfa hay, and concentrate.

⁷NRC (2001) was used to calculate nutrient composition.

fecal samples of individual cows. Urine bags were adhered to the vulva of cows, and all urine was collected into plastic buckets. All feces were weighed and pooled for individual cows per day, and 2% intensively mixed feces were sampled and oven-dried at 65°C for 48 h, ground to pass through a 1-mm screen, and then stored at -20°C in labeled valve bags for DM, OM, NDF, and ADF analyses.

Blood Collection and Serum Preparation. Ten milliliters of jugular blood was taken from each cow before (at 0 h) and at 1, 2, and 4 h after the morning feeding on d 4, 24, 64, 94, and 114 into blood collection tubes (Vacutainer; Becton Dickinson, Franklin Lakes, NJ). Before sampling, the skin was washed with Milli-Q water (Millipore Corp., Billerica, MA). The tubes with blood samples were centrifuged at 3,500 × *g* for 15 min to obtain serum, which was separated into several aliquots and stored at -80°C in an ultra-low-temperature freezer (DW-86L286; Haier, Qingdao, China) until further analysis of serum biochemical parameters. Another set of 3-mL blood samples from each cow was anticoagulated with EDTA at the same time for the regular blood test.

Analytical Procedures

Nutritional Evaluation. Feed and feces samples were determined for DM at 65°C for 48 h in a forced-air oven (model 2000; Experimental Mill, Beijing, China) and were tested for OM (method 942.05; AOAC, 1990). Crude protein was determined using an automated N analyzer (Rapid NIII, Elementar, Hanau, Germany). Neutral detergent fiber was measured by the method of Van Soest et al. (1991) using heat-stable α-amylase (No. A-3306; Sigma Chemical Co., St. Louis, MO) and Na sulfite, and ash concentration was corrected for the Ankom 200 fiber analyzer (Ankom Technology, Fairport, NY). The feed samples were also analyzed for ADF (method 973.18c; AOAC, 1990), ether extract (method 920.39; AOAC, 1990), Ca, and P by atomic absorption spectrometry (method 945.46; AOAC, 1990).

Milk Components. Milk components (protein, fat, lactose, and SNF) in the fresh milk of all cows were determined with a near-infrared milk ingredient analyzer (Miris Dairy Milk Analyser; Miris AB, Uppsala, Sweden) in the DHI laboratory at Xinjiang Agricultural University. Milk was deproteinized (Ekinci and Broderick, 1997) and analyzed for MUN by colorimetric assay and methods as described by Huang et al. (2009).

Blood Biomarkers. Blood metabolites and parameters, such as total protein, albumin, serum urea N, total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, triglycerides, and K of serum were analyzed using a clinical autoanalyzer (c8000; Abbott Laboratories, Abbott Park, IL). The contents or activities of ceruloplasmin, malondialdehyde, total superoxide dismutase, Cu-Zn-superoxide dismutase, Mn-superoxide dismutase, and glutathione peroxidase in serum were detected using standard pro-

Table 2. Effects of methionine hydroxy Cu [(HMTBA)₂-Cu] on the milk composition of cows

Item	Treatment ¹			SEM	P-value
	S	SM	M		
DMI, kg/d	19.2	20.3	19.8	0.35	0.23
Milk yield, kg/d	28.8	33.8	31.3	1.06	0.08
Fat, %	3.81	3.74	3.75	0.06	0.81
Protein, %	3.34	3.28	3.28	0.04	0.19
Lactose, %	4.48	4.35	4.43	0.05	0.08
SNF, %	8.63	8.84	8.63	0.05	0.33
Fat yield, kg/d	1.04	1.22	1.10	0.04	0.09
Protein yield, kg/d	0.92	0.92	0.90	0.03	0.72
Lactose yield, kg/d	1.23	1.23	1.21	0.04	0.45
Urea N, mg/dL	18.39	17.70	18.83	0.45	0.19
4% FCM, kg/d	26.1	30.1	27.5	0.91	0.06

¹Treatments: S = Cu sulfate only: 12 mg of Cu provided by CuSO₄ per kilogram of concentrate; SM = Cu sulfate and (HMTBA)₂-Cu: 6 mg of Cu provided by CuSO₄, and another 6 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate; M = (HMTBA)₂-Cu only: 12 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate.

cedures and commercial kits (Nanjing Jiancheng Biology Research Institute, Nanjing, China).

Serum Cu Concentrations. The concentrations of Cu in feed, fecal, and serum samples were determined using a SpectorAA-30 atomic absorption spectrophotometer (Varian Techtron Pty. Ltd., Mulgrave, Victoria, Australia) equipped with a programmable sample changer (Model PSC-56) and data acquisition system (Model DS-15). Measurements were performed at 324.7 nm for Cu by using hollow cathode lamps operated at 3 mA and bandwidths of 0.2 nm. Acetylene was used as the assist gas, and the gas pressure and flow rate were 0.05 MPa and 1,600 mL/min, respectively.

Statistical Analysis

Data were analyzed using repeated measures analysis models in the PROC MIXED procedure of SAS (SAS Institute, 2004). Cow was used as the experimental unit. The model used to analyze the data was

$$Y_{ijk} = \mu + \text{trt}_i + \text{cow}_j(\text{trt}_i) + \text{time}_k + \text{trt}_i \times \text{time}_k + E_{ijk},$$

where Y_{ijk} is the dependent variable, μ is the overall mean, trt_i is the fixed effect of the i th treatment ($i = 1, 2, 3$), $\text{cow}_j(\text{trt}_i)$ is the random effect of the j th cow within the i th treatment ($j = 1, \dots, 10$), time_k is the fixed effect of sample collection/measurement time ($k = 1, \dots, 12$ for milk yield measurements, $k = 1, \dots, 4$ for milk composition and blood analyses), $\text{trt}_i \times \text{time}_k$ is the fixed effect of the interaction between the i th treatment and the k th time, and E_{ijk} is the random residual, $\sim N(0, \delta_e^2)$. Significant differences were declared

at $P \leq 0.05$, and trends were reported at $0.05 < P \leq 0.10$.

RESULTS

Feed Intake and Lactation Performance

No significant difference was observed in DMI among the treatments. The average milk yield ($P = 0.08$) and 4% FCM yield ($P = 0.06$) tended to increase for the SM treatment compared with the S and M treatments. Milk fat yield ($P = 0.09$) tended to be higher, whereas milk lactose content ($P = 0.08$) tended to be lower in the SM treatment than in the S and M treatments, as shown in Table 2.

Nutrient Digestibility

Methionine hydroxy Cu replacement had no influence on the digestibility of OM, CP, and ether extract ($P > 0.1$; Table 3). Replacing 50% Cu sulfate with (HMTBA)₂-Cu (SM diet) tended to improve the apparent digestibility values of NDF ($P = 0.09$) and ADF ($P = 0.08$), and the apparent digestibility values of NDF and ADF for cows in the SM treatment (57.1 and 55.1%) were higher than those for cows in the S (49.1 and 44.0%) and M (49.0 and 46.4%) treatments, as shown in Table 3.

Blood Analysis

A significant increase was observed for average serum Cu concentration in the SM treatment compared with the S treatment ($P < 0.01$), whereas a significant increase was observed for serum K concentration in the

Table 3. Effects of methionine hydroxy Cu [(HMTBA)₂-Cu] on nutrient apparent digestibility

Item, %	Treatment ¹			SEM	P-value
	S	SM	M		
OM	62.2	68.3	65.4	1.54	0.29
CP	63.7	69.1	68.4	1.23	0.54
Ether extract	50.4	59.1	51.9	1.83	0.21
NDF	49.1	57.1	49.0	1.98	0.09
ADF	44.0	55.1	46.4	1.54	0.08

¹Treatments: S = Cu sulfate only: 12 mg of Cu provided by CuSO₄ per kilogram of concentrate; SM = Cu sulfate and (HMTBA)₂-Cu: 6 mg of Cu provided by CuSO₄, and another 6 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate; M = (HMTBA)₂-Cu only: 12 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate.

S treatment compared with the SM and M treatments ($0.01 < P < 0.05$); the trends are shown in Figure 1. Other blood and serum parameters, such as the levels of serum total protein, total cholesterol, and total superoxide dismutase, are not presented in the tables because none of the parameters was significantly affected by treatment ($P > 0.1$).

DISCUSSION

Experimental Design

Many previous studies on trace elements involved a combination of more than 2 elements (Nocek et al., 2006; Sharman et al., 2008; Siciliano-Jones et al., 2008) or several supplemental levels of different sources

Figure 1. Concentrations and trends of serum Cu and K⁺. Treatments: S = Cu sulfate only: 12 mg of Cu provided by CuSO₄ per kilogram of concentrate; SM = Cu sulfate and methionine hydroxy Cu [(HMTBA)₂-Cu]: 6 mg of Cu provided by CuSO₄, and another 6 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate; M = (HMTBA)₂-Cu only: 12 mg of Cu provided by (HMTBA)₂-Cu per kilogram of concentrate. ** indicates an increase ($P < 0.01$) in serum Cu concentration in the SM treatment compared with the S treatment; * indicates an increase ($P = 0.03$) in serum K concentration in the S treatment compared with the SM and M treatments.

(Virden et al., 2004; Nocek et al., 2006; Zhang et al., 2008). However, only the source effect of Cu was considered in the current study. Cows in all treatments received 9.78 mg/kg of Cu from the basal diet and 12 mg/kg of Cu from premixes, which in total exceeded the dietary Cu recommendations of NRC (1989; 10 mg/kg) and NRC (2001; 16 mg/kg) for lactating dairy cows with 650 kg of BW and producing 40 kg of milk/d. In this way, we avoided the possible system errors introduced by varying the Cu level in the diet.

Lactation Performance

Milk Production. The average milk yield of cows in the SM treatment tended to be consistently higher than yields in the other treatments. The higher milk production of cows in the SM treatment was observed from d 40 to 80 of the trial, which was immediately after a 2-d shortage of brewers grain at d 33 and 34 and during vaccination at d 62. The authors inferred that supplementation of (HMTBA)₂-Cu during these challenges might have helped the cows cope with the stress and might explain the observed improvement in milk yield. In the literature, supplementation of organic forms of Cu to cattle under a variety of stresses resulted in improved Cu status (Nockels et al., 1993) and milk production (Olkowski et al., 1990).

Milk Components. Similar to other reports in the literature (Uchida et al., 2001; Ballantine et al., 2002), Cu supplementation did not affect milk fat or protein yield and content. Other studies have reported an increase in milk protein content when feeding organic Cu (Kincaid and Socha, 2004). It is interesting that in this trial, a trend was observed for changes in lactose content with treatments. The average lactose content in milk ranges from 4.5 to 4.8% and is rarely affected by treatments. In this trial, lactose levels were slightly lower than normal and might be associated with the wide range of changes in ambient temperature (−32 to 43°C) during the trial.

Nutrient Digestibility

In this study, cows fed SM showed a trend toward higher NDF and ADF digestibility values. The effect of Cu on fiber digestibility has been widely studied, with some studies reporting improvements in fiber digestibility (Lopez-Guisa and Satter, 1992; Zhang et al., 2008) and others concluding the opposite (Martinez and Church, 1970; Ward et al., 1993). Fiber-degrading microorganisms are sensitive to rumen pH. Ji et al. (2001) reported that at pH lower than 6.2, the cellulolytic activity of bacteria is reduced. It is interesting that Cu sulfate supplementation has been shown to

reduce rumen pH (Saxena and Srivastava, 1980) and to be deleterious to rumen microorganisms (Ward et al., 1993). However, when Cu was bound to an AA (Heinrichs and Conrad, 1983), it was not found to be toxic to rumen microorganisms. In light of these observations, a reduction of rumen pH and a deleterious effect on rumen microorganisms might be avoided by replacing inorganic Cu with an organic Cu source and might partially explain the improvements in fiber digestibility in cows fed SM. However, the reason the same effect was not observed in cows fed M is not clear. It is possible that rumen microorganisms need some Cu in the ionic (salt) form for optimal growth (Hubbert et al., 1958). A lack or excess of ionic Cu, as in groups M and S, respectively, might hinder microbial metabolism and fiber digestion (Ward et al., 1993).

Blood Analysis: Serum Cu and K

In the serum, Cu exists in 3 major forms: ceruloplasmin, albumin-bound, or AA-bound forms. They are in 2 pools, between which Cu does not appear to be exchangeable: ceruloplasmin is the main pool corresponding to Cu exported from the liver to tissues, whereas the albumin- and AA-bound forms work as the second pool mainly corresponding to Cu transported from the intestine to the liver in the portal circulation (Cousins, 1985). Serum Cu, commonly used for diagnosis of Cu deficiency, is a poor indicator of Cu status and storage in the liver (Vermunt and West, 1994). In fact, dairy cows that are considered deficient, based on the evaluation of serum Cu concentration, have been found to be at or near a toxic state after examination of the liver Cu concentration (Blakley and Hamilton, 1985). Different from previous experiments, serum Cu was evaluated at 0, 1, 2, and 4 h after the first feeding, with no significant diurnal changes. However, cows fed SM showed the highest average serum Cu followed by cows fed M, and cows fed S showed the lowest average serum Cu. Unlike in previous experiments, we sampled not only at fasting but also at 1, 2, and 4 h after the first feeding, and serum Cu concentration of the same individual in a short continuous time was detected. Absorption of Cu mainly occurs in the rumen and small intestine of dairy cows, and absorbed Cu is transported through the blood. The primary route of Cu excretion is in the feces (approximately 280 mg/d), and less than 1 and 0.5% of total Cu is excreted in the urine and milk, respectively. Because of the presence of Cu in endogenous excretion and hair loss, it becomes very difficult to measure Cu absorption. However, the average serum Cu across all time points could provide an indication of relative absorption when compared across treatments. The SM group showed the highest serum Cu, which

might suggest the highest absorption rate. The benefits of combining the 2 sources might be related to their sites of absorption. The Cu from sulfates might be absorbed across the rumen wall, whereas the Cu from HMTBA-Cu (rumen bypass) might be absorbed at the small intestine.

CONCLUSIONS

The results from this study indicated that replacing one-half of sulfate Cu with HMTBA-Cu increased plasma Cu concentration and tended to improve NDF and ADF apparent digestibility values and lactation performance of dairy cattle.

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