CASE STUDY: A comparison of 2 methionine sources for early lactation Holstein cows

J. M. DeFrain,*¹ PAS, D. H. Kleinschmit,* PAS, D. J. Tomlinson,* PAS, M. D. Edmonds,†
and E. D. Sharman,† PAS

*Zinpro Corporation, Eden Prairie, MN 55344; and †Johnson Research LLC, Parma, ID 83660

ABSTRACT

The objective was to determine whether DL-Met supplied from metal specific AA complexes (MSAAC) of zinc and manganese could maintain milk yield and composition of multiparous Holstein cows in early lactation relative to a commonly used rumen-protected DL-Met source. Forty-seven multiparous Holstein cows were ranked by previous 305 ME milk and randomly assigned to 1 of 2 treatments delivered daily as gelcap boluses and fed a common basal diet predicted by Cornell Net Carbohydrate and Protein System v6.1 to be 4.9 g/d deficient in Met. Treatments were (1) 15.1 g/d of Zinpro 120 and 9.2 g/d of Manpro 160 (Zinpro Corporation, Eden Prairie, MN), which supplied 6.58 g/d of metabolizable Met (MSAAC:Met), and (2) 6.58 g/d of metabolizable Met supplied from 11.6 g of Smartamine M (Adisseo, Antony, France) and similar levels of Zn and Mn but supplied by zinc and manganese AA complexes (Availa Zn 120 and Availa Mn 80, Zinpro Corporation; AAC+SM). All cows were fed, milked, and housed together. Milk yield was collected daily, and milk composition was analyzed weekly. Treatment × time interactions

were noted for milk yield and the yield of almost all milk components, largely due to cows treated with MSAAC:Met yielding 1.5 and 1.8 kg/d more milk at 35 and 42 DIM, respectively. The Met supplied as metal MSAAC is at least similar in availability as Met supplied from Smartamine M. Therefore, Met provided by MSAAC of zinc and manganese should be included in the summation of dietary metabolizable Met supply when balancing diets for AA in early lactation cows.

Key words: methionine, amino acid complex, zinc, manganese

INTRODUCTION

Methionine and Lys have been shown to be the 2 most limiting AA for milk protein production in lactating dairy cows in North America (NRC, 2001). Milk protein percentage has generally been the most sensitive performance parameter to alterations in intestinal supply of Lys and Met (Rulquin et al., 1993; Rulquin and Verite, 1993). A meta-analysis by Patton (2010) reported the addition of Mepron (Evonik Industries, Hanau, Germany) and Smartamine (75% DL-Met, Adisseo, Antony, France) increases yield and composition of milk true protein with only minor effects

on DMI, milk yield, and milk fat. A second meta-analysis by Zanton et al. (2014) evaluating Met hydroxyl analog in a form of 2-hydroxy-4-methylthio butanoic acid (e.g., Alimet, MFP, or MHA from Novus International, St. Charles, MO) as well as Mepron and Smartamine reported all sources of rumen-protected Met to increase milk protein yield with no change in milk yield.

Complexing trace minerals with AA has improved production and reproduction in lactating cows (Kellogg et al., 2003; Rabiee et al., 2010). Metal specific AA complexes (57.151; AAFCO, 2000) are produced by complexing a soluble metal salt with a specific AA. One example of such products is 4-Plex (Zinpro Corp., Eden Prairie, MN), where the Zn and Mn are complexed with DL-Met, and Cu is complexed with Lys. Kincaid and Cronrath (1993) demonstrated that complexes of Zn Met and Zn Lys can have a significant effect on lactation performance of early lactation cows. In the 16-wk study, feeding Zn Met and Zn Lys complex to supply 5.8 g/d of Met and 7.2 g/d of Lys, respectively, yields of both milk protein and fat increased because of the increase in the yield of 3.5% FCM (4.4 kg/d) with no change in percent fat

¹Corresponding author: jdefrain@pdscows.com

or protein in milk. All of these data suggest the AA associated with metal specific AA complexes may be used to meet the AA needs of lactating dairy cattle, especially if the complexes contain Met. The objective of this work was to determine whether the DL-Met from Zn Met and Mn Met could maintain milk yield and composition of multiparous Holstein cows in early lactation relative to a commonly used rumen-protected source of DL-Met.

MATERIALS AND METHODS

The experiment was a block design carried out by a private research organization and on an 1,800-cow commercial dairy equipped with a 40-cow carousel milking parlor. At approximately 0600 h each day, all cows that calved were ranked by previous 305 ME milk and randomly assigned to 1 of 2 treatments. Based on the meta-analysis by Zanton et al. (2014), previous trials using a similar experimental design used 3 to 38 cows per treatment. Therefore, 64 multiparous Holstein cows were enrolled within a 22-d period. It was necessary to assume cows were likely to be removed from the study because of difficulties associated with the immediate postpartum period. Prior to the start of the experiment, it was necessary to establish an exclusion criteria for cows developing mastitis and requiring therapeutic treatment. It was necessary to remove these cows because they were moved to a different pen, milked in a different parlor, and fed a different basal diet containing supplemental trace minerals. All cows enrolled in the experiment were identified with a color-coded, sequential numerical tag for treatment identification purposes. Colored leg bands were used to distinguish study cows from other nonstudy cows on the dairy. All personnel at the dairy were blinded to treatment assignment and unaware of treatment color code identification.

All cows were housed together in a single, open lot pen bedded with dried manure compost and wheat straw during inclement weather. Cows were milked 3 times per day and fed a

common basal diet devoid of supplemental trace minerals (Tables 1 and 2). Cows were individually dosed once daily with 3 gelcap boluses (Torpac Inc., Fairfield, NJ) delivered simultaneously from a single insertion of a multidose balling gun (Jorgensen Labs, Loveland, CO) in headlocks following the first milking of the day. Bolus content is shown in Table 3. The difference between boluses was limited to the source (but not level) of rumen-protected Met. The first treatment was formulated using metal specific AA (Met in this case) complexes of Zn and Mn (57.151; AAFCO, 2000; **MSAAC:Met**) and contained 15.1 g/d of Zinpro 120 (17.6% CP, 27.3% Met) and 9.2 g/d of Manpro 160 (21.4% CP, 43.4% Met). A 90% rumen bypass and 90% intestinal AA digestibility was assumed based on previously published work on ruminal solubility and breakdown of a metal specific AA complex (Heinrichs and Conrad, 1983) and duodenally infused Met (Socha et al., 2008). Therefore, MSAAC:Met supplied 6.58 g/d of metabolizable Met. The other treatment was formulated to provide 6.58 g/d of metabolizable Met using 11.6 g of Smartamine M (minimum of 70% Met, 80% Met bioavailability according to Schwab, 2007; Adisseo) and similar levels of Zn and Mn but supplied as metal AA complexes (57.150; AAFCO, 2000; **AAC+SM**) from Availa Zn 120 and Availa Mn 80 (Zinpro Corp.). The amount of metabolizable Lys and Met supplied by Availa Zn 120 and Availa Mn 80 in cows treated with AAC+SM was a total of 0.161 and 0.052 g, respectively, because these products are nonspecific AA complexes.

Cows were weighed on 2 consecutive days after the first milking on d 4 (± 1 d) and 50 (± 1 d). Milk yield was measured and recorded using calibrated meters in the parlor. Milk samples for weekly compositional analysis were collected at the first daily milking on Thursday and Saturday of each week, such that samples are within ± 3 d of 7, 14, 21, 28, 35, 42, and 49 DIM. Samples were stored at 4°C with a preservative (bronopol

tablet, Broad Spectrum Microtabs II, Advanced Instruments Inc., Norwood, MA) and analyzed by a certified DHI testing laboratory (High Desert Dairy Lab Inc., Nampa, ID) within 24 h for SCC, fat and protein content, and

Table 1. Ingredient composition of the basal diet

Ingredient	% diet DM
Corn silage	24.6
Corn grain, high moisture	15.8
Alfalfa hay	13.8
Canola meal	9.6
Dried distillers grain, corn	9.6
Alfalfa haylage	9.0
Whole cottonseed	8.8
Beet pulp	2.98
Macrominerals–vitamins ¹	2.98
Molasses–fat blend ²	1.76
Energy Booster ³	0.96
Omnigen AF ⁴	0.12

¹28.5% sodium sesquicarbonate, 25.45% calcium carbonate, 20.0% blood meal, 11.43% white salt, 6.30% magnesium oxide, 5.73% potassium carbonate, 1.78% yeast culture (XPC, Diamond V Mills Inc., Cedar Rapids, IA), 0.40% white mineral oil, 0.23% sodium monensin (Rumensin 90, Elanco Animal Health, Greenfield, IN), 0.16% vitamin E 50%, and 0.02% vitamin A and D.

²Comprised 31.3% fat as pork tallow and 31.3% sugar from a blend of cane and beet molasses all on a DM basis.

³96.1% fatty acids (46.2% C18:0, 37.0% C16:0, 3.96% C18:1 *cis*-9, 2.66% C14:0, and others <2% each); Milk Specialties Global (Eden Prairie, MN).

⁴Mixture of active dried *Saccharomyces cerevisiae*, dried *Trichoderma longibrachiatum* fermentation product, niacin, vitamin B₁₂, riboflavin-5-phosphate, D-calcium pantothenate, choline chloride, biotin, thiamine monohydrate, pyridoxine hydrochloride, menadione dimethylpyrimidinol bisulfate, folic acid, calcium aluminosilicate, sodium aluminosilicate, diatomaceous earth, calcium carbonate, rice hulls, and mineral oil; Omnigen Research LLC (Corvallis, OR).

Table 2. Analyzed chemical composition of the basal diets (excluding bolus), DM basis¹

Chemical component	Week relative to initiation of experiment		
	1	5	10
DM, %	52.78	55.29	55.68
CP, %	17.5	17.6	16.8
Fat as EE, %	5.38	6.01	6.63
ADF, %	23.9	27.3	24.4
aNDF, %	32.7	36.0	33.2
aNDFom, %	30.9	32.8	30.9
Starch, %	22.7	18.6	20.9
Ash, %	9.3	10.4	10.1
Ca, %	0.80	0.81	0.77
P, %	0.41	0.40	0.42
Mg, %	0.35	0.34	0.37
K, %	1.71	1.59	1.72
S, %	0.28	0.29	0.29
Na, %	0.44	0.57	0.55
Cl, %	0.41	0.39	0.54
Fe, mg/kg	553	595	447
Zn, mg/kg	53	48	118
Mn, mg/kg	53	47	94
Cu, mg/kg	15	9	25
Mo, mg/kg	1.2	0.9	1.1
Co, mg/kg	0.78	n.d. ²	1.16

¹Concentrations of I, Se, vitamin A, vitamin D, vitamin E, and monensin were not analyzed but calculated from the ingredient library of Cornell Net Carbohydrate and Protein System v6.1-based ration formulation software and found to be 0 mg/kg, 0.25 mg/kg, 5,468 IU/kg, 1,094 IU/kg, 24.3 IU/kg, and 2.96 mg/kg monosodium salt (monensin, Rumensin 90, Elanco Animal Health, Greenfield, IN), respectively. EE = ether extract; aNDF = amylase + sodium treated NDF; aNDFom = ash-free aNDF.

²n.d. = not detected.

milk urea nitrogen (MUN). Milk fat, lactose, and true protein concentrations were analyzed using a B-2000 Infrared Analyzer (Bentley Instruments Inc., Chaska, MN). Milk urea nitrogen concentration was analyzed using a MUN spectrophotometer (Chemspec 150, Bentley Instruments Inc.) and somatic cells were quantified using an SCC 500 (Bentley Instruments Inc.).

Drinking water was sampled at initiation of the experiment and analyzed (Table 4) by Dairyland Laboratories Inc. (Acadia, WI) according to Eaton et al. (1995), using an inductively coupled plasma spectrometer (PerkinElmer 5300 DV OES; PerkinElmer Inc., Waltham, MA). Samples of the basal TMR were collected during wk

1, 5, and 10 and analyzed for nutrient composition by wet chemistry methods (Dairyland Laboratories Inc.). Samples were analyzed for CP via combustion method (AOAC International, 1996; method 990.03), ether extract (AOAC International, 1996; method 920.39), and lignin (AOAC, 1990; method 973.18). Starch was measured as dextrose after treating samples with glucoamylase using a YSI 2700 SELECT Biochemistry Analyzer (Application Note no. 319; YSI Inc., Yellow Springs, OH). Amylase-treated NDF concentration was determined according to AOAC method 2002.04 with a 2005 modification (includes the use of sea sand for filter aid and Whatman GF/C filter paper for residue collection), and ADF was

measured according to AOAC International (1996; method 973.18). Minerals were quantified according to AOAC International (1996; method 985.01), using an inductively coupled plasma spectrometer (PerkinElmer 5300 DV OES; PerkinElmer Inc.).

The predicted weekly means for each cow were evaluated for abnormalities (wk 1 through 7). Milk yield of one cow (treatment = MSAAC:Met) was 20.4 kg/d less during wk 7 as compared with wk 6 of lactation. Based on veterinarian examination, it appeared this was not treatment related, so all wk 7 data were deleted from this cow. Another cow (treatment = AAC+SM) had an average milk yield that was 8.6 kg/d less during wk 6 relative to wk 5 and 7 of lactation. Upon investigating the data, the first 5 d of data from this cow in wk 6 were missing, which resulted in wk 6 estimates being based on only 2 d of data. These 2 d of data were deleted for this cow. However, this cow had recovered from its ailment by the start of wk 7, so wk 7 data were retained. With the exception of data from these 2 cows, the final data set contained all data from the other cows ($n = 21$, AAC+SM; $n = 26$, MSAAC:Met). A total of 17 cows were removed from the study because of inoperable electronic ID tag (3 = AAC+SM; 3 = MSAAC:Met), mastitis (7 = AAC+SM; 0 = MSAAC:Met), displaced abomasum (1 = AAC+SM; 0 = MSAAC:Met), severe metritis (0 = AAC+SM; 1 = MSAAC:Met), injury due to daily headlock use (0 = AAC+SM; 1 = MSAAC:Met), and diarrhea and septicemia (0 = AAC+SM; 1 = MSAAC:Met).

Body weights and BW changes were analyzed as a block design with treatment as a fixed effect and block as a random effect. For milk yield and milk composition data, all data from d 1 were deleted from all cows because treatments were initiated on this day. The 3 daily milk weights were reduced to weekly means using the PROC MIXED of SAS (V9.2, SAS Institute Inc., Cary, NC). Milk SCC was transformed to somatic cell

Table 3. Bolus ingredient composition and content by treatment

Item	MSAAC:Met ¹		AAC+SM ²	
	mg/kg ³	g/d	mg/kg ³	g/d
Zn as Availa Zn 120 ⁴	—	—	80	15.113
Zn as Zinpro 120 ⁴	80	15.113	—	—
Mn as Availa Mn 80 ⁴	—	—	65	18.425
Mn as Manpro 160 ⁴	65	9.212	—	—
Cu as CuPlex 100 ⁴	10	2.267	10	2.267
Co as CoPro 25 ⁴	1.0	0.907	1.0	0.907
Iodine as EDDI ⁵ (79.5% I)	1.88	0.0536	1.88	0.0536
Se as Na selenite (4.0% Se)	0.29	0.164	0.29	0.164
Smartamine M	—	0	—	11.604
Total product	—	27.712	—	48.534
Metabolizable Met supply				
Zinpro 120	—	3.342	—	—
Manpro 160	—	3.238	—	—
Smartamine M	—	—	—	6.580
Total	—	6.580	—	6.580

¹Metal specific AA complexes of Zn and Mn bound to DL-Met.

²Amino acid complexes of Zn and Mn plus Smartamine M (Adisseo, Antony, France).

³Using a 22.7-kg DMI.

⁴Zinpro Corporation (Eden Prairie, MN).

⁵EDDI = ethylenediamine dihydroiodide.

score according to Shook (1993). Cow $\times$ week was included as a fixed effect, and [time of milking $\times$ day(week)] was used as the random term. This random term was included to help account for any large differences that might have occurred because of

weather, variations in milking times, and so on, because cows started the experiment on different days. Using the weekly means, data were analyzed as a block design with repeated measures. Cows had not been used for research in the previous lactation.

Previous 305 ME was included as a covariate, which significantly influenced ($P = 0.01$) milk production during the experiment. Fixed effects in the model included 305 ME as a covariate, treatment, week, and treatment $\times$ week. Lactation number was considered as an additional factor to include in the analysis, but it was not significant for milk production and, thus, was removed from the model. Block was included as a random effect. Week was the repeated term, with cow as the subject. Various covariance structures were evaluated [CS, AR(1), UN, and ANTE(1)], and for milk production and milk fat percentage, the AR(1) structure showed the best fit. Based on those analyses, as well as the belief that AR(1) would match the biology well, the AR(1) covariance structure was used for all analyses. Least squares means and SEM are reported, and differences were considered significant when $P < 0.05$ and a trend when $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

Ingredient and nutrient composition of the basal TMR are shown in Tables 1 and 2. Diets were formulated to meet or exceed NRC (2001) requirements using the Cornell Net Carbohydrate and Protein System v 6.1. The animal inputs used for the model included lactating Holstein cow, 44 mo of age, 635 kg current BW, 680 kg mature BW, 3.0 BCS, 24 mo of age at first calving, 13-mo calving interval, 20°C previous temperature, 20°C current temperature, 43 kg of milk, 3.70% milk fat, 3.07% milk true protein, 25 DIM, 0 d pregnant, and 0 g/d of target gain. The model predicted DMI was 20.6 kg/d, whereas the formulated DMI was 25.4 kg/d, resulting in a 42.6 kg/d ME and 45.6 kg/d MP allowable milk. Therefore, the basal diet (25.4 kg/d) supplied 3,011 g/d of MP that was 5.88% Lys and 1.67% Met (3.52:1 Lys:Met ratio) and was predicted to be 4.90 and 13.52 g/d deficient in Met and Lys, respectively. Considering all metabolizable Met and Lys supplied by the basal diet

Table 4. Analyzed nutrient content of drinking water

Item	Value	Possible problems ¹
pH	7.64	<5.1 or >9.0
Nitrate-N, mg/kg	2.82	>100
Ca, mg/kg	44	>500
Mg, mg/kg	10.6	>125
P, mg/kg	0.199	
K, mg/kg	2.79	
Cu, mg/kg	0.013	>0.6 to 1.0
Fe, mg/kg	0.038	>0.3 (taste, veal)
Zn, mg/kg	0.134	>25
Na, mg/kg	47	>20 for veal calves
Mn, mg/kg	0.007	>0.05 (taste)
Sulfates, mg/kg	62	>2,000
Total dissolved solids, mg/kg	390	>3,000
Hardness, mg/kg	153	

¹Dairyland Laboratories Inc. (Acadia, WI; <https://www.dairylandlabs.net/water/understanding-your-results>).

and boluses, all cows received 3,019 g/d of MP that was 5.90% Lys and 1.89% Met (3.09:1 Lys:Met ratio). Because all cows were supplied similar source and level of all trace minerals, any differences among treatments are due to differences in the source of the daily bolus of 6.58 g of metabolizable Met. It should be noted that Patton (2010) found the status of dietary Met, Lys, or other AA deficiencies not to affect true milk protein percentage in response to rumen-protected Met supplementation.

All supplemental trace minerals were excluded from the basal TMR fed to all cows and supplied via daily bolus. Analysis of drinking water

revealed little to no trace mineral antagonists present in high concentrations (Table 4). Trace mineral analysis of the TMR (Table 2) indicated higher levels of Zn, Mn, Cu, and Co in the sample collected at wk 10 of the experiment. This indicates cows were likely supplemented with the nonstudy herd mineral-vitamin premix between wk 5 and 10 of the experiment. However, considering all cows were housed in the same pen and fed the same basal TMR, both MSAAC:Met and AAC+SM treated cows received the additional trace minerals during this time.

Effects of treatments on BW, milk yield, and milk composition are

shown in Table 5. No significant differences were observed for the main effect of treatment for all variables measured. It should be noted that average milk yield (51.9 kg/d) was 8.5 and 5.6 kg/d greater than maximum milk yields used in the meta-analyses on Smartamine M by Zanton et al. (2014) and Patton (2010), respectively. There was a tendency for MSAAC:Met treated cows to produce milk with higher lactose (4.81 vs. 4.89%, $P = 0.06$) and other solids content (5.73 vs. 5.81%, $P = 0.06$). Treatment $\times$ time interactions were noted for milk yield and the yield of almost all milk components (Figures 1–5). Cows treated with MSAAC:Met

Table 5. Effect of treatments on BW, milk yield, milk composition, and somatic cell score (SCS)

Item	MSAAC:Met ¹	AAC+SM ²	SEM ³	P-value	
				Trt ⁴	Trt $\times$ Wk
Initial BW, kg	713	721	14	0.65	—
Final BW, kg	652	652	11	0.99	—
BW change, kg	-60	-70	10	0.24	—
Milk, kg/d	51.9	51.8	1.5	0.95	0.05
ECM, ⁵ kg/d	53.8	54.4	1.8	0.70	0.31
3.5% FCM, ⁶ kg/d	54.1	54.9	1.7	0.65	0.23
Composition, %					
Fat	3.79	3.91	0.086	0.14	0.07
True protein	3.05	3.11	0.110	0.51	0.94
Lactose	4.89	4.81	0.048	0.06	0.95
Other solids	5.81	5.73	0.053	0.06	0.94
Solids-not-fat	8.91	8.89	0.061	0.89	0.77
Total solids	12.69	12.79	0.100	0.47	0.12
Yield, kg/d					
Fat	1.93	1.98	0.077	0.49	0.28
True protein	1.58	1.61	0.040	0.43	0.01
Lactose	2.54	2.49	0.068	0.51	0.10
Other solids	3.02	2.97	0.082	0.54	0.09
Solids-not-fat	4.60	4.58	0.118	0.89	0.03
Total solids	6.53	6.56	0.190	0.89	0.13
SCS ⁷	0.99	0.99	0.22	0.99	0.31
MUN, ⁸ mg/dL	14.41	13.84	0.48	0.11	0.01

¹Metal specific AA complexes of Zn and Mn bound to DL-Met dosed to supply 80 mg/kg Zn, 65 mg/kg Mn, and 6.58 g/d of metabolizable Met.

²Amino acid complexes of Zn and Mn plus Smartamine M (Adisseo, Antony, France) dosed to supply 80 mg/kg Zn, 65 mg/kg Mn, and 6.58 g/d metabolizable Met.

³Standard error of means that was the highest between the treatments.

⁴Trt = treatment.

⁵ECM (energy-corrected milk) = (0.327 $\times$ milk yield) + (12.95 $\times$ fat yield) + (7.65 $\times$ true protein yield).

⁶FCM = (0.432 $\times$ milk yield) + (16.216 $\times$ fat yield).

⁷SCS = $\log^2(\text{SCC}/100) + 3$ (Shook, 1993).

⁸MUN = milk urea nitrogen.

Figure 1. Milk yield by treatment and time [metal specific AA of Zn and Mn bound to Met = dashed line, AA complexes of Zn and Mn + Smartamine M (Adisseo, Antony, France) = solid line; treatment $\times$ time effect, $P = 0.05$, SEM = 1.5].

averaged 1.5 and 1.8 kg/d more milk at 35 and 42 DIM, respectively, relative to cows fed AAC+SM ($P = 0.05$; Figure 1). However, milk yields between treatments were similar at 49 DIM. Similarly, cows treated with MSAAC:Met also yielded greater solids-not-fat at 35 and 42 DIM, resulting in a significant effect of treatment $\times$ time ($P = 0.03$; Figure 2). The treatment $\times$ time interaction for milk

Figure 2. Milk solids-not-fat yield by treatment and time [metal specific AA of Zn and Mn bound to Met = dashed line, AA complexes of Zn and Mn + Smartamine M (Adisseo, Antony, France) = solid line; treatment $\times$ time effect, $P = 0.03$, SEM = 0.118].

Figure 3. Milk true protein yield by treatment and time [metal specific AA of Zn and Mn bound to Met = dashed line, AA complexes of Zn and Mn + Smartamine M (Adisseo, Antony, France) = solid line; treatment $\times$ time effect, $P = 0.01$, SEM = 0.040].

yield at 35 and 42 DIM likely drove the treatment $\times$ time interaction noted for yield of milk true protein ($P = 0.01$; Figure 3). In a longer-term experiment (sulfates vs. metal specific AA complexes of Zn, Cu, Mn, and Co glucoheptonate; *iso*-levels of Zn, Mn, Cu, and Co fed from 21 d pre- through 150 d postpartum), Kincaid and Socha (2004) also observed treatment $\times$ time effects. They

Figure 4. Milk urea nitrogen (MUN) by treatment and time [metal specific AA of Zn and Mn bound to Met = dashed line, AA complexes of Zn and Mn + Smartamine M (Adisseo, Antony, France) = solid line; treatment $\times$ time effect, $P = 0.01$, SEM = 0.48].

Figure 5. Milk fat percentage by treatment and time [metal specific AA of Zn and Mn bound to Met = dashed line, AA complexes of Zn and Mn + Smartamine M (Adisseo, Antony, France) = solid line; Treatment $\times$ time effect, $P = 0.01$].

reported cows fed metal specific AA complexes and Co glucoheptonate produced more milk and milk components at peak production and less milk and milk components in mid-lactation. A treatment $\times$ time effect was also noted for MUN ($P = 0.01$; Figure 4); cows fed MSAAC:Met steadily increased from approximately 12.8 to 15.6 dL during the first 50 DIM, whereas MUN appeared more erratic in AAC+SM treated cows, increasing almost 2 mg/dL from 21 to 35 DIM and then decreasing again at 42 and 49 DIM. Supplementation of diets with metal specific AA complexes has not affected MUN in other studies (Kincaid and Cronrath, 1993), although diet Zn content was almost 9 times greater than the control treatment.

IMPLICATIONS

These data indicate Met supplied as metal specific AA complexes is at least similar in availability as Met supplied from Smartamine M. Therefore, metal specific AA (Met) complexes of zinc and manganese should be included in the summation of dietary metabolizable Met supply when balancing diets for AA in early lactation cows.

ACKNOWLEDGMENTS

Appreciation is extended to personnel at Teunissen Dairy (New Plymouth, ID) for their assistance in carrying out the trial protocol and to Evan Titgemeyer of Kansas State University (Manhattan, KS) for his assistance in analysis of trial data. This project was supported by Zinpro Corporation (Eden Prairie, MN).

LITERATURE CITED

- AAFCO. 2000. Official Publication. Assoc. Am. Feed Control Offic., Atlanta, GA.
- AOAC. 1990. Fiber (Acid Detergent) and Lignin in Animal Feed. 15th ed. Assoc. Offic. Anal. Chem., Washington, DC.
- AOAC International. 1996. Official Methods of Analysis. 16th ed. AOAC Int., Arlington, VA.
- Eaton, A. D., L. S. Clesceri, and A. E. Greenberg, ed. 1995. Standard Methods for Examination of Water and Wastewater. 19th ed. Am. Public Health Assoc., Washington, DC.
- Heinrichs, A. J., and H. R. Conrad. 1983. Rumen solubility and breakdown of metal proteinate compounds. *J. Dairy Sci.* 66(Suppl. 1):147. (Abstr.)
- Kellogg, D. W., M. T. Socha, D. J. Tomlinson, and A. B. Johnson. 2003. Effects of feeding cobalt glucoheptonate and metal specific amino acid complexes of zinc, manganese, and copper on lactation and reproductive performance of dairy cows. *Prof. Anim. Sci.* 19:1–9.
- Kincaid, R. L., and J. D. Cronrath. 1993. Effects of added dietary fat and amino acids on performance of lactating cows. *J. Dairy Sci.* 76:1601–1606.
- Kincaid, R. L., and M. T. Socha. 2004. Inorganic versus complexed trace mineral supplements on performance of dairy cows. *Prof. Anim. Sci.* 20:66–73.
- NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.
- Patton, R. A. 2010. Effect of rumen-protected methionine on feed intake, milk production, true milk protein concentration, and true milk protein yield, and the factors that influence these effects: A meta-analysis. *J. Dairy Sci.* 93:2105–2118.
- Rabiee, A. R., I. J. Lean, M. A. Stevenson, and M. T. Socha. 2010. Effects of feeding organic trace minerals on milk production and reproductive performance in lactating dairy cows: A meta-analysis. *J. Dairy Sci.* 93:4239–4251.
- Rulquin, H., P. M. Pisulewski, R. Verite, and J. Guinard. 1993. Milk production and composition as a function of postruminal lysine and methionine supply: A nutrient-response approach. *Livest. Prod. Sci.* 37:69–90.
- Rulquin, H., and R. Verite. 1993. Amino acid nutrition of dairy cows: Production effects and animal requirements. Page 55 in *Recent Advances in Animal Production*, Proc. 27th Univ. Nottingham Feed Manuf. Conf. P. C. Gainsworthy, ed. Nottingham Univ. Press, Nottingham, UK.
- Schwab, C. G. 2007. Protected proteins and amino acids for ruminants. Pages 115–141 in *Biotechnology in Animal Feeds and Feeding*. Wiley-VCH Verlag GmbH, Weinheim, Germany.
- Shook, G. E. 1993. Genetic improvement of mastitis through selection on somatic cell count. *Vet. Clin. North Am. Food Anim. Pract.* 9:563–581.
- Socha, M. T., C. G. Schwab, D. E. Putnam, N. L. Whitehouse, B. D. Garthwaite, and G. A. Ducharme. 2008. Extent of methionine limitation in peak-, early-, and mid-lactation dairy cows. *J. Dairy Sci.* 91:1996–2010.
- Zanton, G. I., G. R. Bowman, M. Vazquez-Anon, and L. M. Rode. 2014. Meta-analysis of lactation performance in dairy cows receiving supplemental dietary methionine sources or postruminal infusion of methionine. *J. Dairy Sci.* 97:7085–7101.