J. Dairy Sci. 88:2517–2523

Dietary Manganese for Dry and Lactating Holstein Cows

W. P. Weiss[1] and M. T. Socha[2]
[1]Department of Animal Sciences, Ohio Agricultural Research and Development Center, The Ohio State University, Wooster 44691
[2]Zinpro Corp., Eden Prairie, MN 55344

ABSTRACT

Apparent digestibility and retention of Mn by dairy cows was used to compare 2 sources of Mn and to estimate Mn requirements. In experiment 1, Holstein cows at dry-off (60 d prepartum) were fed a basal diet with no supplemental Mn (43 mg of Mn/kg of dry matter) and received a daily bolus of 0 or 200 mg/d supplemental Mn from $MnSO_4$ or from Mn-Met (6 cows per treatment) until parturition. Approximately 30 d before parturition, cows were moved to metabolism stalls for total collection of feces and urine. No differences were observed between Mn sources, but apparent absorption of Mn (6.4 vs. 2.3%) tended to be greater, and apparent retention of Mn (44 vs. 12 mg/d) was greater, for cows given supplemental Mn compared with control cows. In the second experiment, apparent Mn digestibility data from 8 experiments conducted with lactating dairy cows (39 dietary treatments and 160 observations) were combined with data from experiment 1. The regression equation of intake of digestible Mn on Mn intake (i.e., Lucas test) was as follows: intake of digestible Mn (mg/d) = −151 + 0.26 × Mn intake (mg/d). Based on that equation, Mn intake had to equal 580 mg/d to meet the metabolic fecal Mn requirement. The corresponding dietary concentration, assuming dry matter intakes of 21 and 12 kg/d for lactating and dry cows, respectively, were 28 and 49 mg/kg dry matter. These concentrations are approximately 1.6 and 2.7 times higher than those needed to meet the Mn requirements for lactating and dry cows, respectively, as calculated using the 2001 National Research Council dairy requirements model. (**Key words:** manganese, digestion, dairy cow)

Abbreviation key: AC = absorption coefficient.

INTRODUCTION

Manganese is a required nutrient for dairy cows; however, clinical deficiencies are extremely rare because most feedstuffs contain at least marginally adequate concentrations of Mn. Quantifying the Mn requirement of dairy cows, especially the maintenance requirement, has been difficult. The NRC (2001) estimated the maintenance requirement (0.002 mg of available Mn/kg of BW) of dairy cows from dietary concentrations of Mn that were reported (Dyer and Rojas, 1965) to cause Mn deficiency in cattle. Based on NRC (2001) equations, the maintenance requirement for Mn represents 82% of the total Mn requirement for a nonlactating, late gestation cow and 53% for a cow producing 40 kg/d of milk. Fecal loss of endogenous Mn is assumed to comprise the entire maintenance requirement. Assuming typical DMI, a diet with approximately 14 mg of Mn/kg of DM will meet the total Mn requirement for a 600-kg cow producing 30 kg/d of milk, and a diet with approximately 17 mg of Mn/kg of DM will meet the requirement for a 700-kg nonlactating cow during the last month of gestation (NRC, 2001). Those recommended concentrations are substantially lower than recommended concentrations (40 mg/kg) in the previous report (NRC, 1989) and are below concentrations (15 to 17 mg/kg of DM) that have caused Mn deficiency in cattle (Dyer and Rojas, 1965).

The NRC (2001) model uses absorption coefficients (**AC**) to convert dietary Mn into absorbed Mn. The AC (g of absorbed Mn/g of total Mn) for Mn in feedstuffs other than Mn supplements is 0.0075 and between 0.0015 and 0.012 for Mn supplements (NRC, 2001). The NRC does not provide AC for organic sources of supplemental Mn, but, based on tissue concentrations in sheep, Mn from Mn-Met might have a higher relative bioavailability than Mn sulfate (Henry et al., 1992). Data comparing organic and inorganic sources of supplemental Mn are lacking for dairy cows.

The first objective of this experiment was to determine whether source (inorganic or organic) of Mn influenced apparent absorption and retention of Mn in late gestation cows. The second objective was to use data from digestibility studies to estimate the maintenance requirement for Mn of lactating and dry dairy cows.

MATERIALS AND METHODS

Protocol and Diets (Experiment 1)

At dry-off (60 d before anticipated calving), 18 Holstein cows (second or greater lactation) were assigned

Received November 15, 2004.
Accepted March 10, 2005.
Corresponding author: W. P. Weiss; e-mail: weiss.6@osu.edu.

Table 1. Ingredient composition of diet.[1]

Ingredient	% of DM
Corn silage	32.5
Alfalfa silage	13.0
Grass hay	7.0
Ground corn and cob meal	10.3
Soybean hulls	25.0
Soybean meal, 44% CP	2.5
Oat hulls	8.0
Animal/vegetable fat	1.0
Iodized salt	0.30
Magnesium oxide	0.14
Trace mineral premix[2]	0.13
Vitamin premix[3]	0.13

[1]Cows also received a bolus of 2.5 g of corn meal (control) or 200 mg Mn from $MnSO_4$ or Mn-Met daily.

[2]Premix contained sodium selenate, zinc oxide, and copper sulfate and contained 195 mg Se/kg, 8450 mg Zn/kg, and 2900 mg Cu/kg.

[3]Premix contained 4600 kIU vitamin A/kg, 1100 kIU vitamin D/kg, and 32,600 IU vitamin E/kg.

randomly to 1 of 3 treatments. Cows were moved to a single freestall pen and fed a common diet (Tables 1 and 2). Starting at dry-off, cows were given a gelatin bolus each day containing 2.5 g of corn meal (Control), 0.62 g of reagent-grade $MnSO_4$, or 2.50 g of Mn-Met (Manpro; Zinpro Corp., Eden Prairie, MN). The $MnSO_4$ and Mn-Met boluses provided 200 mg of Mn/d. At approximately 30 d before anticipated calving, cows (in groups of 6; 2 cows per treatment) were moved to tie stalls and individually fed the same diet they received in the group pen for 3 to 5 d to measure ad libitum DMI. Cows were then moved to metabolism stalls for 4 d and then returned to the group pen. When cows were in the metabolism stalls, daily intake and fecal and urinary output were measured for each cow (Weiss and Wyatt, 2000). Urine was kept separate from feces by using externally attached urine collection cups (Fellner et al., 1988). During urination, a portion of the urine (approximately 5%) was diverted into vessels containing adequate HCl to maintain pH <5, and the remaining urine flowed into containers without acid. The amount of feed offered to each cow during the total collection trial was restricted to 98% of that consumed during the preceding 3 d (while cows were in tie stalls). At approximately 3 d before cows were expected to calve, they were moved to individual box stalls and continued to receive the same diets and treatments until parturition.

Cows were weighed at dry-off, when moved to the tie stalls (approximately 30 d before parturition), when moved to the box stalls (approximately 3 d before parturition), and 24 h after parturition. Calves were weighed within 24 h of birth.

Sampling and Analyses

Blood samples were taken via the tail vein from all cows at dry-off, the day cows left the metabolism stalls (approximately 25 d before anticipated calving), and within 15 h after parturition. Blood from calves (jugular vein) was sampled within 15 h of birth. A sample of first milking colostrum was taken from each cow. Blood samples were collected into heparinized, trace metal-free vacutainers, and colostrum samples were placed in acid-washed containers.

Over the experiment (approximately 4 mo were required for all cows to finish the experiment), forages and concentrates were sampled weekly and composited into monthly samples. Weekly forage samples were analyzed for DM to adjust TMR for changes in forage moisture. During the metabolism study, feeds, orts (if any), urine, and feces were sampled daily (samples of orts, urine, and feces represented 10, 2, and 1%, respec-

Table 2. Nutrient composition of diet and ingredients.

	Diet	Corn silage	Alfalfa silage	Grass hay	Concentrate
DM, %	64.9	33.5	46.9	87.3	88.0
OM, %	94.3	94.9	90.2	93.7	95.1
NDF, %	53.2	47.1	54.4	75.6	53.7
CP, %	11.3	9.0	18.3	9.2	11.3
LCFA,[1] %	3.0	2.5	2.0	1.2	4.0
Ca, %	0.47	0.21	0.94	0.27	0.55
P, %	0.21	0.22	0.32	0.22	0.17
Mg, %	0.26	0.15	0.20	0.15	0.36
K,%	1.60	1.77	2.93	2.11	1.04
Cu, mg/kg	11	4	7	4	18
Zn, mg/kg	49	30	29	16	72
Mn,[2] mg/kg	43	52	78	80	22

[1]LCFA = Long-chain fatty acids.

[2]Cows also received a bolus of 2.5 g of corn meal (control) or 200 mg of Mn from $MnSO_4$ or Mn-Met daily. Dietary concentration of Mn, including Mn provided by the boluses, was approximately 60 mg/kg for supplemented groups.

tively, of daily amounts) and were composited within cow. Feeds, orts, and fecal samples were lyophilized and ground (1-mm screen; Wiley mill; Arthur Thomas, Philadelphia, PA). Water samples were taken on approximately d 30 and 60 of the experiment during the second and third collection period (samples were taken from the water stream immediately before water entered the drinking cups).

Organic nutrients, energy, and N in feed, orts, and fecal samples were analyzed as described by Weiss and Wyatt (2004). For calculating N digestibility and retention, samples of undried feces and acidified urine were assayed for N. Samples of dried, ground feed; orts; feces; non-acidified urine; whole blood; and colostrum were digested in nitric and perchloric acids (Timmons et al., 2001), and Mn was assayed using flame atomic absorption spectroscopy (Varian Spectra AA 200; Varian Inc., Palo Alto, CA). Urine, whole blood, and colostrum were concentrated before analysis using the method described for milk by Timmons et al. (2001). The starting mass of whole blood and milk was 20 g and was 30 g for urine.

Calculations and Statistical Analyses

Apparent digestibility or absorption was calculated as follows: (intake – fecal excretion)/intake. Apparent retention was calculated as follows: intake – fecal excretion – urinary excretion. The Mn consumed via the bolus was included in the Mn intake. Because water intake was not measured, consumption of Mn via water was not included. The water consumed by these cows contained 0.03 mg of Mn/L and, based on an estimated (Holter and Urban, 1992) water intake of 35 L/d, consumption of water would have increased intake of Mn by about 1 mg/d.

Data were analyzed using PROC MIXED (SAS, 1999). The model included block (cows were blocked by anticipated calving date) as a random effect (5 df), treatment as a fixed effect (2 df), and error (10 df). The treatment effect was partitioned into 2 contrasts: effect of Mn supplementation (control vs. $MnSO_4$ + Mn-Met) and the effect of type of supplement ($MnSO_4$ vs. Mn-Met). Retention of Mn was compared to 0 using least squares means and a *t*-test (SAS, 1999). One calf was born dead ($MnSO_4$ group); therefore, error degrees of freedom for calf blood data was 9. A second analysis was conducted to compare the concentration of Mn in whole blood collected from the cow and calf at parturition using PROC MIXED. The model included treatment (fixed, 2 df), animal type (cow or calf, fixed, 1 df), treatment × animal type interaction (2 df), block (random, 5 df), and error (23 df).

Estimating Mn Requirements (Experiment 2)

Apparent Mn digestibility data from experiment 1 were combined with data collected from lactating dairy cows from experiments conducted at the Ohio Agricultural Research and Development Center. The protocol for total collection was the same as described previously, except that cows were milked twice daily in the stalls, and milk was measured and sampled daily. Data from lactating cows (160 cows or cow-periods, if the experiment was a Latin square) came from 8 different experiments with 39 dietary treatments. Details concerning the lactating cow data set can be found in Weiss and Wyatt (2004). The combined data set had 178 observations. Dietary Mn was not a treatment in any experiment, except for the dry cow study (experiment 1). All diets exceeded the 1989 NRC recommendation for Mn (40 mg/kg), but diets differed in Mn concentration. With the exception of the dry cow experiment (experiment 1), MnO was the only form of supplemental Mn fed. Excretion of Mn via milk and urine are trivial in comparison with fecal losses. The concentration of Mn in urine and milk was measured in 2 experiments (43 observations), and urinary and milk losses of Mn averaged 0.4 and 0.6 mg/d, respectively. The sum of urine and milk Mn was <0.1% of average Mn intake. The relationship between intake of Mn and intake of apparently digestible Mn was quantified using PROC MIXED (SAS, 1999) with experiment (trial) included as a random class effect (St-Pierre, 2001). Analyses were conducted using individual observations (n = 178). Trial-adjusted data were calculated as described by St-Pierre (2001). The intercept and slope obtained when intake of digestible Mn was regressed on Mn intake (i.e., Lucas test) are estimates of metabolic fecal Mn and true digestibility of Mn, respectively (Van Soest, 1982).

RESULTS AND DISCUSSION

The average BW at dry-off, approximately 3 d before parturition, and at 3 d postpartum were 716 (SEM = 30), 759 (SEM = 28), and 692 kg (SEM = 20), respectively, and not affected by treatment. Change in BW during the dry period averaged about 1 kg/d (not affected by treatment). The average birth weight of the calves was 45.3 kg (SEM = 2.4) and was not affected by treatment. Dry matter intake when cows were in the digestion stalls (mid dry period) did not differ among treatments and averaged 11.8 kg/d (Table 3) or approximately 1.6% of BW. Intake of digestible energy averaged 31.7 Mcal/d. Apparent digestibility of organic nutrients was not affected by treatment (Table 3).

Table 3. Daily intakes during the digestion trials and apparent digestibility of organic nutrients.[1]

	Control	$MnSO_4$	Mn-Met	SEM
Intake				
DM, kg	11.6	12.4	11.4	0.5
DE, Mcal	31.1	33.5	30.6	1.3
CP, kg	1.27	1.36	1.24	0.06
Digestibility coefficient, %				
DM	61.4	62.4	62.2	0.9
Energy	60.9	61.3	61.1	0.8
CP	46.7	47.6	46.7	2.9
NDF	54.5	53.9	53.8	2.0
Starch	92.1	92.4	92.5	0.7

[1]Control diet contained no supplemental Mn; $MnSO_4$ and Mn-Met treatments included a daily bolus that provided 200 mg/d of Mn from $MnSO_4$ or Mn-Met, respectively.

Mn Metabolism

As expected, intake of Mn was higher ($P < 0.01$) for cows given supplemental Mn (Table 4). Intake of absorbable Mn from the basal diet averaged 3.8 mg/d using an AC of 0.0075 (NRC, 2001), which was well in excess of the estimated (NRC, 2001) requirement for absorbed Mn for these cows (1.8 mg/d). Intake of absorbed Mn by cows on the $MnSO_4$ and Mn-Met treatments was 6.5 and 6.0 mg/d, respectively, assuming the 2 sources had the same AC (i.e., 0.012). Cows given supplemental Mn had greater ($P < 0.05$) fecal excretion of Mn than control cows, but source of Mn had no effect. Apparent absorption tended ($P < 0.09$) to be greater for cows given supplemental Mn, but source of supplemental Mn did not affect Mn absorption. Apparent absorption measured in this experiment (2.3 to 6.7%) was similar to values reported in other experiments. In sheep fed a basal diet with 32 mg/kg Mn (no supplemental Mn), apparent absorption of Mn was –3% (Watson et al., 1973). In another experiment, in which wethers were fed either a 60 or 90% concentrate diet with 63 or 70 mg/kg Mn (approximately 50% of the Mn was from Mn sulfate), apparent absorption of Mn averaged about 20% for the 60% concentrate diets and 8% for the 90% concentrate diets (Defoor et al., 2001).

Table 4. Effect of Mn supplementation on Mn absorption and excretion by late gestation dairy cows and on concentrations of Mn in whole blood and colostrum.[1]

	Control	$MnSO_4$	Mn-Met	SEM
Mn intake,[a] mg/d	505	744	679	26
Fecal Mn,[a] mg/d	493	699	634	29
Urinary Mn, mg/d	0.2	0.2	0.3	0.1
Apparent absorption,[b] %	2.3	6.1	6.7	1.9
Apparent retention,[a] mg/d	12	44*	44*	12
Whole blood Mn,[2] μg/L				
Dry-off	15.9	14.5	14.9	0.9
30 d prepartum	15.3	16.6	15.3	1.3
Parturition	16.6	14.8	15.8	0.9
Calf	23.0	27.7	26.8	2.8
Colostrum Mn, μg/L	34.7	33.1	35.8	4.1

[1]Control diet contained no supplemental Mn; $MnSO_4$ and Mn-Met treatments included a daily bolus that provided 200 mg/d of Mn from $MnSO_4$ or Mn-Met, respectively. Intake of Mn includes that provided by the boluses.

[2]Blood sample at dry-off was collected before treatments started, and blood from dam and calf and colostrum samples were taken within 12 h postpartum.

[a]Supplemented ($MnSO_4$ and Mn-Met) greater than control ($P < 0.05$).

[b]Supplemented ($MnSO_4$ and Mn-Met) greater than control ($P < 0.09$).

*Retention greater than zero ($P < 0.05$).

An explanation for the higher apparent digestibility of Mn for cows fed supplemental Mn is that true absorption of Mn from the Mn supplements was higher than that for the basal ingredients. Another possible explanation is dilution of endogenous fecal Mn. Ruminants excrete substantial amounts of endogenous Mn via feces. Lactating dairy cows excreted approximately 95% of an intravenous dose of ^{54}Mn via feces within 5 d (Van Bruwaene et al., 1984). The amount excreted (percentage of dose) was essentially the same when ^{54}Mn was dosed orally. The dietary concentration of Mn fed to those cows was not provided. Loss of endogenous fecal Mn does not necessarily represent a true requirement because fecal excretion of endogenous Mn is used by ruminants to maintain Mn homeostasis (Miller, 1975). Ruminants also appear to regulate gut absorption of Mn in response to Mn supply. Fecal excretion (within 7 d of dose) of intravenously dosed ^{54}Mn was 70 and 88% of the dose in wethers fed diets with 30 or 4000 mg/kg of Mn, respectively, showing increased endogenous fecal Mn with higher Mn intake (Watson et al., 1973). In the same experiment, fecal excretion of an oral dose of ^{54}Mn was 84 and 90% of the dose for wethers fed the low and high Mn diets, showing reduced absorption when Mn supply is high.

The marginal digestibilities of Mn from the supplements were calculated by first determining intake of Mn provided by basal diets (i.e., Mn intake – 200 mg Mn provided by bolus). Then, fecal Mn that originated from basal ingredients was estimated by multiplying intake of Mn from basal ingredients by 0.977 (i.e., the mean indigestibility coefficient for the control treatment). That value was subtracted from total fecal Mn to estimate fecal Mn provided by the supplement. Marginal digestibility = [intake of supplemental Mn (i.e., 200 mg) – fecal Mn provided by supplement] ÷ 200. This calculation assumes that digestibility of basal Mn was not influenced by Mn supplementation. The resulting marginal digestibilities were 16 and 17% for $MnSO_4$ and Mn-Met, respectively.

Urinary excretion of Mn was not affected by treatment and represented <0.1% of Mn intake, which is

consistent with other data (Watson et al., 1973; Gustafson and Olsson, 2004). Apparent retention of Mn was 12 mg/d for control cows and was increased ($P < 0.01$) to 44 mg/d for cows fed supplemental Mn (no effect of source). Sheep fed diets with Mn-Met had greater Mn concentrations in bone, but not liver or kidney, than sheep fed $MnSO_4$ (Henry et al., 1992). Averaged across all 3 tissues (but not weighted by relative mass of tissues), Mn-Met resulted in 21% higher Mn concentrations than $MnSO_4$. Diets in that experiment contained 900 to 2700 mg/kg of supplemental Mn.

Apparent retention of Mn was not different from zero for the control treatment ($P > 0.33$), but was greater than zero ($P < 0.05$) for cows fed $MnSO_4$ and for cows fed Mn-Met. Apparent retention of Mn by cows fed supplemental Mn was higher than what would likely be needed for growth of fetal and associated maternal tissues. The accretion of Mn by the conceptus of late gestation dairy cows averaged about 1 mg/d when cows were fed diets with 50 to 60 mg/kg Mn (House and Bell, 1993). Howes and Dyer (1971) reported that the concentration of liver Mn in newborn calves increased when gestating cows were fed diets with higher concentrations of Mn (20 vs. 44 mg/kg), suggesting that feeding supplemental Mn might have caused increased fetal retention of Mn. The concentration of Mn in whole blood of newborn calves from cows fed supplemental Mn was numerically higher ($P = 0.20$) than that from calves from control cows, but variation among calves was extremely high (Table 3). Concentrations of Mn in colostrum and whole blood from cows were not affected by treatment. The concentration of Mn in whole blood from newborn calves was higher ($P < 0.01$) than the concentration in whole blood from cows at parturition, but no treatment × animal type interaction ($P > 0.38$) was observed.

Estimated Mn Requirement (Experiment 2)

Mean intake of Mn was 1005 mg/d (SD = 308), mean apparent digestibility of Mn was 10.3% (SD = 12.6), and average Mn retention was 109 mg/d (SD = 123) for the lactating cows in the data set. With trial included as a random effect, the relationship (Figure 1) between intake of digestible Mn (mg/d) and Mn intake (mg/d) was

$$\text{Digestible Mn intake} = -151\ (\pm 41) + 0.26\ (\pm 0.035) \times \text{Mn intake}. \quad [1]$$

The intercept and slope in that equation were different from zero ($P < 0.01$). The estimates of metabolic fecal Mn and true digestibility from equation [1] are 125 and 43 times greater than the corresponding maintenance requirement and AC from NRC (2001). However, comparing the individual components is not appropriate because, within a system (NRC or equation [1]), the components are dependent upon each other. The NRC (2001) estimated the maintenance requirement by assuming that an intake of approximately 0.3 mg of dietary Mn/kg of BW was adequate to prevent deficiency signs. That value was multiplied by an assumed AC (0.0075) to yield the estimated requirement of 0.002 mg of available Mn/kg of BW. Therefore, the estimated maintenance requirement is a function of the AC that was used. Similarly, the intercept and slope in equation [1] are not statistically independent; therefore, the maintenance requirement for Mn (i.e., metabolic fecal Mn) estimated using equation [1] is a function of the estimated true digestibility of Mn. The amount of dietary Mn needed to meet the maintenance requirement (NRC, 2001) and the amount of dietary Mn needed for metabolic fecal Mn (equation [1]) can be compared.

Based on NRC (2001) equations, the mean maintenance requirement (mean BW of lactating cows was 605 kg) for available Mn was 1.21, the lactation requirement (mean milk production was 30.5 kg/d) was 0.92, and the mean total requirement was 2.13 mg/d for lactating cows in our data set. The average AC for diets fed to lactating cows in this data set was 0.006 (approximately 25% of dietary Mn was from MnO) based on values in NRC (2001). Therefore, the maintenance and total requirement for dietary Mn was 201 and 355 mg/d. For the dry cows in the data set (experiment 1), the available Mn requirement (NRC, 2001) for maintenance and the total requirement averaged 1.5 and 1.8 mg/d. The average AC for the dry cow diets (assuming Mn-Met and $MnSO_4$ were equal) was 0.0083. Therefore, the maintenance and total dietary requirement for Mn of dry cows (NRC, 2001) were 181 and 217 mg/d.

Based on equation [1], metabolic fecal Mn (i.e., an estimate of the maintenance requirement) is 151 mg/d. Using the true digestibility (0.26) in equation [1], 580 mg/d of dietary Mn is needed to meet the maintenance requirement of dairy cows and an additional 1 to 3 mg of dietary Mn were needed to meet the lactation or gestation requirement. Therefore, the total dietary requirement for Mn of dry and lactating dairy cows based on equation [1] was approximately 582 mg/d. The requirements for dietary Mn based on equation [1] were approximately 1.6 and 2.7 times higher than NRC (2001) requirements for lactating and dry cows, respectively. Average DMI for lactating and dry cows in this data set were 20.9 and 11.8 kg/d; therefore, dietary concentrations of 28 and 49 mg of Mn/kg of DMI would be needed to meet the requirements calculated with equation [1] compared with 17 and 18 mg/kg calculated from NRC (2001) equations.

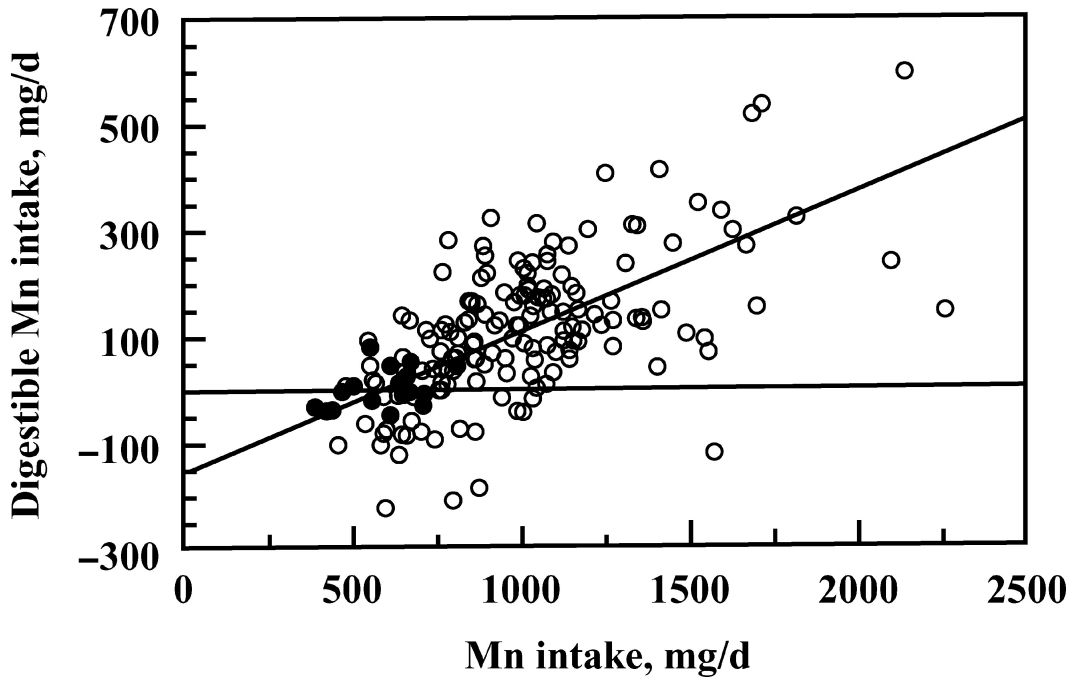

Figure 1. Relationship between intake of Mn and intake of apparently digested Mn in dry (●) and lactating (○) dairy cows (Y = –151 (±41) + 0.26 (±0.035) X). Each point represents a cow or cow-period and is adjusted for random trial effects (St-Pierre, 2001).

Both the NRC (2001) method and equation [1] have limitations. The maintenance requirement for Mn of dairy cows has not been quantified directly (NRC, 2001), and the value used by NRC is dependent on the AC that was used. The AC values in NRC are based on very limited data. Because of substantial fecal excretion of endogenous Mn (Van Bruwaene et al., 1984), measuring true absorption of Mn is extremely difficult. Perhaps the most direct measurements were obtained by Sansom et al. (1978). They calculated that 0.5 to 0.75% of dietary Mn (mostly from $MnCl_2$) was absorbed from the gut based on differences in blood Mn concentrations between the portal vein and systemic circulation, but those data were collected from only 2 cows. The coefficients in equation [1], although statistically significant ($P < 0.01$), have high standard errors. Based on those standard errors, estimates of dietary Mn requirements could easily vary by 30%. The 580 mg/d dietary Mn calculated from equation [1] assumes absorption efficiency is constant; however, in ruminants, absorption of Mn appears to become more efficient when dietary supply is low (Watson et al., 1973). Therefore, the amount of dietary Mn needed to meet the maintenance requirement as estimated using equation [1] may be <582 mg/d.

The final criticism of equation [1] is that retention data in general are not appropriate for determining requirements for trace minerals (Mertz, 1987). The basis of this criticism is that excretion of a trace mineral is proportional to the current pool size, whereas uptake of the mineral depends on supply of available mineral (among other factors). Therefore, assuming intake of available mineral is greater than obligatory losses and less than toxic levels, a balance study does not determine the requirement for a mineral element, but rather the intake required to maintain the existing pool size (Mertz, 1987). Because fecal loss of Mn represents >99% of the total loss of Mn from the cow, the data in Figure 1 are quantitatively the same as if Mn intake was plotted against Mn retention (Y-axis). Conceptually, however, Figure 1 differs from a plot of Mn intake and Mn retention. The Y-intercept in Figure 1 is the extrapolated estimate of fecal excretion when no Mn is consumed and is an estimate of obligatory losses of Mn. In theory, the Y-intercept does not include endogenous fecal Mn that is excreted in an attempt to maintain Mn homeostasis.

CONCLUSIONS

In late gestation, nonlactating Holstein cows, Mn from $MnSO_4$ and Mn-Met had the same relative bioavailability, which was higher than that for Mn supplied by basal feedstuffs. When a Lucas test was performed on a large data set that included both dry and lactating Holstein cows, an intake of approximately 580

mg/d of Mn was needed to meet estimated inevitable fecal losses of Mn (i.e., maintenance requirement). That value is approximately 1.6 and 2.7 times higher than NRC (2001) estimated Mn requirements for lactating and dry cows, respectively.

REFERENCES

Defoor, P. J., N. A. Cole, M. L. Galyean, and O. R. Jones. 2001. Effects of grain sorghum planting density and processing method on nutrient digestibility and retention by ruminants. J. Anim. Sci. 79:19–25.

Dyer, I. A., and M. A. Rojas. 1965. Manganese requirements and functions in cattle. JAVMA 147:1393–1396.

Fellner, V., M. F. Weiss, A. T. Belo, R. L. Belyea, F. A. Martz, and A. H. Orma. 1988. Urine cup for collection of urine from cows. J. Dairy Sci. 71:2250–2255.

Gustafson, G. M., and I. Olsson. 2004. Partitioning of nutrient and trace elements in feed between body retention, faeces, and urine by growing dairy-breed steers. Acta Agric. Scand. Sect. A Anim. Sci. 54:10–19.

Henry, P. R., C. B. Ammerman, and R. C. Littell. 1992. Relative bioavailability of manganese from a manganese-methionine complex and inorganic sources for ruminants. J. Dairy Sci. 75:3473–3478.

Holter, J. B., and J. W. E. Urban. 1992. Water partitioning and intake prediction in dry and lactating Holstein cows. J. Dairy Sci. 75:1472–1479.

House, W. A., and A. W. Bell. 1993. Mineral accretion in the fetus and adnexa during late gestation in Holstein cows. J. Dairy Sci. 76:2999–3010.

Howes, A. D., and I. A. Dyer. 1971. Diet and supplemental mineral effects on manganese metabolism in newborn calves. J. Anim. Sci. 32:141–145.

Mertz, W. 1987. Use and misuse of balance studies. J. Nutr. 117:1811–1813.

Miller, W. J. 1975. New concepts and developments in metabolism and homeostasis of inorganic elements in dairy cattle: A review. J. Dairy Sci. 58:1549–1560.

National Research Council. 1989. Nutrient Requirements for Dairy Cattle. 6th rev. ed. Natl. Acad. Press, Washington, DC.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.

Sansom, B. F., H. W. Symonds, and M. J. Vagg. 1978. The absorption of dietary manganese by dairy cows. Res. Vet. Sci. 24:366–369.

SAS. 1999. SAS/STAT User's Guide, Version 8. SAS Inst., Inc., Cary, NC.

St-Pierre, N. R. 2001. Invited review: Integrating quantitative findings from multiple studies using mixed model methodology. J. Dairy Sci. 84:741–755.

Timmons, J. S., W. P. Weiss, D. L. Palmquist, and W. J. Harper. 2001. Relationships among dietary roasted soybeans, milk components, and spontaneous oxidized flavor of milk. J. Dairy Sci. 84:2440–2449.

Van Bruwaene, R., G. B. Gerber, R. Kirchmann, J. Colard, and J. Van Kerkom. 1984. Metabolism of ^{51}Cr, ^{54}Mn, ^{59}Fe and ^{60}Co in lactating dairy cows. Health Phys. 46:1069–1082.

Van Soest, P. J. 1982. Pages 43–50 in Nutritional Ecology of the Ruminant. O & B Books, Inc., Corvallis, OR.

Watson, L. T., C. B. Ammerman, J. P. Feaster, and C. E. Roessler. 1973. Influence of manganese intake on metabolism of manganese and other minerals in sheep. J. Anim. Sci. 36:131–136.

Weiss, W. P., and D. J. Wyatt. 2000. Effect of oil content and kernel processing of corn silage on digestibility and milk production by dairy cows. J. Dairy Sci. 83:351–358.

Weiss, W. P., and D. J. Wyatt. 2004. Macromineral digestion by lactating dairy cows: Estimating phosphorus excretion via manure. J. Dairy Sci. 87:2158–2166.