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Quantitative Prediction of Magnesium Absorption in Dairy Cows

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ABSTRACT

The objective of the current study was to predict magnesium (Mg) absorption in dairy cows based on data from our own studies and those of other investigators. Balance data from 15 independent studies with 68 different rations and 323 dairy cows or cow-periods were used. In 12 studies, grass feeds were the main source of roughage and in about one-half of the studies, MgO-supplemented rations were used. Out of the 68 rations, 14 rations contained supplemental K in the form of bicarbonate, and in 2 rations additional K was incorporated mainly in form of KCl. The K content of the rations ranged from 6.9 to 75.6 g/kg of dry matter (DM; mean 29.4 g/kg of DM). In most studies (10/15), dry, nonpregnant cows were used. For lactating animals, milk yield ranged from 4 to 22 kg/d (mean yield, 15 kg/d). All studies provided quantitative information with respect to feed intake (DM intake, Mg, and K) and total Mg excretion in feces. The mean dietary Mg content was 4.5 g/kg of DM and ranged from 0.45 to 17.3 g/kg of DM. On average, Mg absorption (% of intake) was 26.2% and ranged from 9.9 to 73.7%. The variation in Mg absorption was at least partly explained by the variation in dietary K concentrations. Magnesium absorption (% of intake) was significantly decreased by 0.31 percentage units/g of K in the DM. To counteract the depressant effect of dietary K on Mg absorption, Mg intake must be increased by 4 g/d when the dietary K concentration increases by 10 g/kg of DM so that the amount of absorbed Mg is maintained.

Key words: magnesium, absorption, potassium, model

INTRODUCTION

Magnesium plays an essential role in metabolism because it influences the activity of more than 300 cellular enzymes that are involved in energy metabolism and protein synthesis (Aikawa, 1981; Ryan, 1991). In cows, clinical hypomagnesemia (plasma Mg <0.4 mmol/L) causes grass tetany (Sjollema, 1930), and subclinical hypomagnesemia (plasma Mg values ranging from 0.4 to 0.8 mmol/L) seems to be associated with an increased incidence of milk fever (hypocalcemic paresis puerperalis; Van Leengoed, 1979; Barber et al., 1983). Thus, an adequate dietary supply of Mg is important.

The Dutch recommendation (CVB, 1996) for the requirement of Mg for dairy cows was calculated as: $(2.5 + 0.12 \times M) \times 100/A$ (g/d). In this formula, the constant of 2.5 represents an estimation of the endogenous losses on the basis of balance trials with cows (Kemp et al., 1961), M = milk production in kg/d, 0.12 = Mg content of milk, expressed in g/kg, and A represents the percentage of true Mg absorption. With respect to the percentage of Mg absorption, a value of 10% (% of Mg intake) is recommended when rations are based on grass products, whereas values of 15 to 18% are recommended when the ration contains a significant amount of corn silage (CVB, 2005a). The difference in recommended values is related to the fact that the incorporation of a significant amount of corn silage lowers the potassium concentration of the ration because corn silage is much lower in K than grass feeds such as hay, silage, and fresh grass (i.e., 12.0 vs. 24.1, 34.1, and 36.6 g/kg of DM respectively; CVB, 2005b). Indeed, it is well known that dietary K has a depressant effect on Mg absorption in ruminants (Schonewille, 1999).

For dairy cows fed corn silage-based rations, with a mean dietary K content of 16 g/kg of DM (ranging from 10.7 to 26.5 g of K/kg of DM), a quantitative relationship between the dietary K content and apparent Mg absorption was reported by Weiss (2004). However, dairy rations based on grass feeds usually contain much more K and it is not clear whether the reported quantitative relationship between dietary K and Mg absorption (Weiss, 2004) can be extrapolated to rations with greater dietary K concentrations. Therefore, an attempt was made to quantify the relationship between dietary K and Mg absorption in rations containing K in the range from 6.9 to 75.6 g/kg of DM with a mean dietary content of 29.4 g/kg of DM (SD ± 12.8). The range in dietary K concentrations in the data set used is beyond the practical range (Schonewille et al., 1997), but we anticipated that this would enhance the proper predic-

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tion of the inhibitory effect of K on Mg absorption. Because data from Mg balances obtained from sheep cannot be extrapolated quantitatively to cows (Adediji and Suttle, 1999; Schonewille, 1999), only reported data from studies with cows are used.

MATERIALS AND METHODS

Data Set

Balance data from 15 independent studies with 68 different rations and 323 dairy cows or cow-periods (when experiment was designed as a Latin square) were used (Table 1). A general description with respect to the rations and animals used is provided in Table 2. Briefly, in 12 studies, grass feeds were the main source of roughage; and in about half of the studies, MgO-supplemented rations were used (Table 2). Out of the 68 rations, 14 rations contained supplemental K in the form of bicarbonate, and in 2 rations additional K was incorporated mainly in form of KCl (Table 2). In most studies (10 of 15), dry, nonpregnant cows were used. For lactating animals, milk yield ranged from 4 to 22 kg/d and mean milk yield was about 15 kg/d. All studies provided quantitative information with respect to feed intake (DMI, Mg, and K) and total Mg excretion in feces. Magnesium absorption was a main objective in each study.

Clearly, absorption data obtained from balance trials only provide information on apparent Mg absorption; that is, Mg intake (g/d) – fecal Mg excretion (g/d). Because it is preferred to derive Mg allowances based on a factorial approach (CVB, 2005b) including the net maintenance requirement of Mg, apparent Mg absorption has to be converted into true Mg absorption. The endogenous fecal Mg losses in cattle are estimated to be 4 mg/kg of BW (Schonewille and Beynen, 2005) and are assumed to be inevitable and constant; that is, independent of Mg intake. Thus, absolute true Mg absorption (g/d) was estimated by using the calculated endogenous fecal Mg losses and the observed apparent Mg absorption (g/d): true Mg absorption = Mg intake – fecal Mg + endogenous fecal Mg, where endogenous fecal Mg = 4 mg/kg of BW. The values for true Mg absorption are given in Table 1.

Statistical Analyses

Data were analyzed with the SAS statistical package (SAS Institute, 2003). The MIXED procedure was used to evaluate the relationships between true Mg absorption, expressed either in absolute terms (g/d) or relative to Mg intake (% of intake) and the dependent variables K intake (g/d), Mg intake (g/d), DMI (kg/d), the K content of the ration (g/kg of DM), and the Mg content of the ration (g/kg of DM). It turned out that DMI and both Mg intake and K intake were significantly ($P <$ 0.016) correlated. Thus, DMI was not used as a dependent variable when either Mg or K intake was incorporated into the model. Trial was included as a random class variable (St-Pierre, 2001) and the dependent variables were included as continuous variables.

RESULTS AND DISCUSSION

It is well known that both dietary Mg and K are important determinants of Mg absorption in ruminants (Brown et al., 1978; Martens, 1979; Care et al., 1984; Martens et al., 1987; Leonhard et al., 1989; Leonhard-Marek and Martens, 1996). However, Kemp (1960) suggested that dietary CP might interfere with Mg absorption because signs of tetany were observed when cows were fed herbage heavily fertilized with N. However, under controlled feeding conditions, dietary CP did not affect Mg absorption (Grace and MacRae, 1972; Moore et al., 1972; Fontenot et al., 1973; Gäbel and Martens, 1986). Furthermore, a wide array of dietary compounds in relation to Mg absorption, including CP, was recently evaluated by Weiss (2004) and it was found that only Mg intake and dietary K concentration were significantly related to Mg absorption. Furthermore, in all studies mentioned in Table 1, dietary CP was not variable at constant K intakes, which makes it difficult to demonstrate a specific effect, if any, of CP on Mg absorption. Therefore, the data set used in the current study only contains variables related to Mg and K intake.

When true Mg absorption is regressed on Mg intake (adjusted for trial effects) the following equation was estimated:

$$\text{True Mg absorption (g/d)} = 1.3\ (\pm 0.67) + 0.20\ (\pm 0.01) \times \text{Mg intake (g/d)}. \quad [1]$$

The values in parentheses represent the standard errors of the coefficients. The residual standard error (**SE$_{\mathbf{RES}}$**) was found to be 0.38 and the standard error associated with trial (**SE$_{\mathbf{TRIAL}}$**) was 1.48. The slope of equation [1] was significantly different from zero ($P <$ 0.001) whereas the intercept tended to be significantly different from zero ($P = 0.065$), which is unwanted because an estimate of absolute true Mg absorption (g/d) was used as an independent variable. Our estimation of the endogenous fecal Mg losses may be overestimated. Indeed, on the basis of an isotope dilution method, Simesen et al. (1962) reported a value of 1.5 mg/kg of BW. On the other hand, on the basis of feeding artificial rations low in Mg, Rook et al. (1964) estimated an endogenous fecal Mg loss of 6 mg/kg of BW. It can be

Table 1. Data used for regression analysis

Reference	BW (kg)	DMI (kg/d)	K (g/kg of DM)	Mg (g/kg of DM)	Mg intake (g/d)	K intake (g/d)	True Mg absorption[1]		n[2]
							(g/d)	(% of intake)	
Kemp et al. (1961)[2]	500	10.9	26.0	1.08	11.8	284	3.60	30.5	2
		12.3	31.0	1.12	13.8	381	4.75	34.6	2
		11.8	32.0	1.22	14.5	379	5.80	40.1	2
		11.7	18.0	1.23	14.4	211	4.45	30.1	2
		12.3	33.0	1.36	16.7	405	4.20	25.2	4
		11.9	34.0	1.24	14.8	406	4.30	29.1	2
		12.0	21.0	1.63	19.6	253	5.60	28.6	4
		11.8	20.0	1.35	15.9	236	3.95	24.8	2
		11.5	37.0	1.37	15.7	425	4.35	27.7	4
		12.7	41.0	1.47	18.6	519	4.10	22.0	1
		10.5	30.0	1.52	15.9	314	3.65	23.0	2
		9.2	17.0	1.88	17.3	156	5.90	29.4	4
		10.0	16.0	2.01	20.1	160	5.90	34.2	2
Rogers and van't Klooster (1969)[3]	440	10.7	37.5	1.20	12.8	400	3.71	29.0	2
		9.0	6.9	1.55	14.0	62	4.36	31.3	2
		9.3	11.1	1.90	17.6	103	5.31	30.2	2
		11.8	31.5	2.00	23.6	371	5.31	22.6	2
		11.7	15.8	2.04	23.9	185	7.41	31.1	2
Field and Suttle (1979)	350	5.1	12.8	0.45	2.3	65	1.68	73.7	6
		5.0	12.8	1.00	5.0	64	2.67	53.2	6
		4.4	12.8	1.80	7.8	55	3.00	38.3	6
		4.5	38.0	1.00	4.5	170	1.69	37.6	6
		4.4	38.0	1.80	7.9	167	2.07	26.2	6
Rahnema et al. (1994)	615	17.1	18.9	3.16	54.1	323	18.5	34.1	5
		17.5	18.4	3.15	55.2	323	16.2	29.3	5
		16.9	19.1	3.16	53.4	322	13.1	24.5	5
		18.1	18.7	3.04	55.1	339	15.6	28.2	5
		17.4	18.2	3.07	53.5	316	16.4	30.1	5
Schonewille et al. (1994a)	540	7.5	11.6	5.47	41.0	87	14.5	35.3	6
		7.4	11.2	5.32	39.4	83	11.7	29.9	6
Schonewille et al. (1994b)	630	8.8	17.6	4.57	40.2	155	8.42	21.0	5
		8.9	17.8	4.53	40.3	159	7.92	19.7	5
Schonewille et al. (1994c)	620	7.9	22.2	5.27	41.6	175	9.28	22.3	6
		8.0	21.9	4.64	37.1	175	7.18	19.4	6
Schonewille et al. (1997)	700	6.7	40.6	6.07	40.7	272	7.70	18.9	6
		6.7	46.7	6.15	41.2	313	7.70	18.7	6
		6.0	34.0	7.97	47.8	204	11.90	24.9	6
		6.7	34.0	6.34	42.5	228	7.40	17.4	6
		6.9	30.7	6.19	42.7	212	5.90	13.8	6
		6.9	43.6	6.20	42.8	301	7.80	18.2	6
Schonewille et al. (1999)	670	6.5	26.0	2.34	15.1	168	4.30	28.5	6
		6.4	42.6	2.16	13.9	274	2.97	21.4	6
		6.7	43.1	2.18	14.7	291	2.96	20.2	6
Schonewille et al. (2000)	750	6.4	33.1	1.97	12.6	212	3.70	29.4	5
		6.3	33.3	1.95	12.3	210	3.50	28.5	5
		6.3	33.5	1.92	12.1	211	3.60	29.8	5
		6.4	33.3	1.95	12.4	212	3.90	31.5	5
		6.3	33.5	1.93	12.2	212	3.80	31.2	5
Schonewille and Beynen (2002)	600	13.4	34.9	2.72	36.3	468	6.80	18.7	6
		12.0	25.2	2.97	35.6	302	9.40	26.4	6
Schonewille et al. (2002)	660	6.8	39.0	2.61	17.7	265	4.84	27.3	4
		6.4	34.9	2.72	17.5	225	5.04	28.8	4
		6.1	30.3	2.84	17.3	185	5.64	32.6	4
		5.8	25.2	2.97	17.2	146	6.34	36.9	4
Jittakhot et al. (2004a)	600	18.6	30.7	3.66	68.1	571	11.40	16.7	6
		18.6	30.8	6.25	116	573	20.90	18.0	6
Jittakhot et al. (2004b)	706	7.0	30.3	3.87	27.1	212	6.24	23.0	6
		7.0	30.8	6.36	44.6	216	9.78	22.0	6
		7.1	30.8	9.14	64.6	218	14.68	22.7	6
		7.1	31.2	11.77	8.35	221	19.93	23.9	6
		7.1	30.4	14.08	100.4	217	22.98	22.9	6
		7.2	30.8	17.34	124.3	221	24.78	19.9	6

Continued

Table 1 (Continued). Data used for regression analysis

Reference	BW (kg)	DMI (kg/d)	K (g/kg of DM)	Mg (g/kg of DM)	Mg intake (g/d)	K intake (g/d)	True Mg absorption[1]		n[2]
							(g/d)	(% of intake)	
Jittakhot et al. (2004c)	790	7.1	20.5	5.80	41.1	145	8.36	20.3	6
		7.5	48.2	5.47	41.0	361	8.46	20.6	6
		8.0	75.6	5.02	40.0	602	3.96	9.9	6
		7.1	20.9	9.69	68.9	149	15.96	23.2	6
		7.5	47.8	9.25	69.6	360	12.06	17.3	6
		8.0	75.5	8.55	68.7	607	7.96	11.6	6

[1] True Mg absorption (g/d) was calculated as Mg intake (g/d) – fecal Mg excretion (g/d) + 0.004 × BW.

[2] Number of cows on each ration.

[3] Data from individual cows fed similar diets were pooled.

suggested that BW is not the sole determinant of endogenous fecal Mg loss, but that DMI might also be important. However, as far as we know, there are insufficient data to quantify a reliable relationship between endogenous fecal Mg losses and DMI. Clearly, this issue is not yet settled.

In our data set, mean Mg intake (37.7 g/d, Table 3) was associated with a mean estimated Mg absorption of 23.0% of Mg intake (equation [1]); a value resembling the number reported by Weiss (2004; 18.5% of Mg intake). The discrepancy between our estimate of efficiency of Mg absorption and the value reported by Weiss (2004) may be explained by the fact that an estimate of true Mg absorption is used in the current study, whereas Weiss (2004) used apparent Mg absorption. Furthermore, compared with the current data set (Table 1), the mean dietary K content in the data set used by Weiss (2004) was considerably lower (30.3 vs. 16.0 g/kg of DM, respectively). Alternatively, we cannot exclude the possibility that the difference in Mg absorption (% of intake) calculated from equation [1] and the value reported by Weiss (2004) is related to a difference in DMI. Indeed, the equation provided by Weiss (2004) is based on studies with lactating cows, whereas equation [1] was primarily based on studies with dry, nonpregnant cows with corresponding lower DMI (Table 2). However, there is evidence that Mg absorption might not be sensitive to DMI. It has been shown that dry and lactating cows are equally efficient in Mg absorption (% of intake) when DMI (Mg content of the ration was either 3.8 or 6.4 g/kg of DM) increased from 7 to 18.6 kg/d (Jittakhot et al., 2004a).

The observed reduction in Mg absorption in ruminants at high K intakes (Ram et al., 1998; Schonewille et al., 1999; Jittakhot et al., 2004c) can be explained by the depolarizing action of high luminal K concentrations on the apical membrane potential of rumen epithelium cells, which reduces the driving force for Mg uptake by these cells (Martens et al., 1987; Leonhard-Marek and Martens, 1996). Consequently, the negative effect of K intake on Mg absorption should be taken into account when predicting Mg absorption. In the practice of feed formulation it is preferred to calculate the required amount of dietary Mg on the basis of net Mg requirement and the efficiency of true Mg absorption. Thus, prediction of Mg absorption expressed as a percentage of Mg intake, would be of practical relevance. Various regression models were evaluated (Table 4) to assess true Mg absorption (% of intake); the model (adjusted for trial effects) showing the lowest residual standard error (5.99) appeared to be (SE_{TRIAL} 17.8; $P_{INTERCEPT,\ SLOPE} < 0.001$):

$$\text{Mg absorption (\% of intake)} = 34.9\ (\pm 2.62) - 0.31\ (\pm 0.068) \times \text{dietary K (g/kg of DM)}. \quad [2]$$

A similar equation was reported by Weiss (2004): Mg digestibility = 31.6 (±6.3) – 0.75 (±0.35) × dietary K (g/kg of DM); dimensions are adjusted to common units. The current estimate of the intercept (equation [2]) seems to be statistically equal to the value reported by Weiss (2004). However, in contrast to Weiss (2004), true Mg absorption was used as an independent variable in the current study (equation [2]). Probably, estimated endogenous fecal Mg losses were too small compared with the total fecal Mg excretion to influence mean Mg absorption expressed as a percentage of intake.

With respect to the estimated coefficient of dietary K there seems to be a discrepancy between the value reported by Weiss (2004) and the value estimated in the current study (i.e., 0.75 (±0.35) and –0.31 (±0.068), respectively). However, on the basis of 95% confidence intervals (Student's *t* distribution, critical *t*-value = 2), the values are not statistically different, primarily because of the large SE of the slope estimated by Weiss (2004). Indeed, in the present equation [2], both the intercept and the slope are accompanied by a relatively small standard error that is probably due to the much larger range in dietary K contents in the current data set (Table 1). Furthermore, it is difficult to see why a

Table 2. General description of the rations and the status of the animals used to compose the current data set

Reference	Description
Kemp et al. (1961)	Rations: fresh grass, no supplemental K or Mg. Variation in the K and Mg contents of grass were due to different fertilization regimens. Cows: midlactation, mean milk hield of about 15 kg/d (range: 8 to 20 kg/d).
Rogers and van't Klooster (1969)	Rations: 4 hay-based rations supplemented with various amounts of by-product based concentrates and 1 ration with grass as the sole source of nutrition. One hay-based ration was supplemented with 100 g of K/cow per d (mixture containing 85% KCl and 15% K_2CO_3). Cows: lactating, mean milk yield of about 11 kg/d (range: 9 to 13 kg/d).
Field and Suttle (1979)	Rations: 1 kg of oat straw and about 4.5 kg of semipurified pellets with appropriate amount of calcinated magnesite (solubility not given) and KCl. Cows: monozygotic twins, nonlactating.
Rahnema et al. (1994)	Rations: TMR containing chopped alfalfa hay, alfalfa haylage, corn silage and concentrate at 1:1:1:2 (DM). Rations were supplemented (maximum 5% of total DM) with either Ca-salts of fatty acids or a mixture of animal-vegetable fat. Cows: midlactation, milk yield was 20 ± 0.9 kg/d.
Schonewille et al. (1994a)[1]	Rations: corn silage 75% of total DMI. About 85% of Mg intake was derived from supplemental MgO.[1] Rations were not supplemented K. Heifers: 4.5 to 7 mo in gestation.
Schonewille et al. (1994b)	Rations: grass silage, corn silage and by-product based concentrate at 5.6:1.4:1 (DM). Treatments: Low and high Ca. About 75% of total Mg intake was derived from a mixture of MgO[1] and hydrated Mg-chloride at 1.5:1 (g). Rations were not supplemented with K. Cows: nonpregnant, dry.
Schonewille et al. (1994c)	Rations: grass silage (63%, DM), corn silage (24%, DM) and by-product based concentrate (13%, DM). Treatments: DCAD +276 or −170 mEq/kg hydrated Mg-sulfate at 1:5.7:1.5 (anion-rich). Rations were not supplemented with K. Cows: nonpregnant, dry.
Schonewille et al. (1997)	Rations: grass silages of various origin and 0.5 kg of a beet pulp-based concentrate containing supplemental MgO[1] which accounted for about 65% of total Mg intake. Cows: nonpregnant, dry.
Schonewille et al. (1999)	Rations: artificially dried grass and about 1 kg of a beet pulp-based concentrate. Treatments: Low intrinsic K (LK), high intrinsic K (HK) and LK + $KHCO_3$ (supplemental K is about 38% of total K intake). Rations did not contain supplemental Mg. Cows: nonpregnant, dry.
Schonewille et al. (2000)	Rations: artificially dried grass and 2 kg of experimental concentrate containing either a mix of cellulose and corn gluten feed or native or popped cornmeal each at 2 levels equivalent to 11 or 20% starch (DM). Almost all Mg was intrinsically present in the feedstuffs, K was not supplemented. Cows: nonpregnant, dry.
Schonewille and Beynen (2002)	Rations: artificially dried grass and by-product based concentrate fed at either a 4:1 or a 1.5:1 ratio (energy basis). Rations were supplemented with MgO.[1] Supplemental Mg was either 46 (40% concentrate) or 23% (20% concentrate) of total Mg intake. Rations did not contain supplemental K. Cows: midlactation, initial milk yield was 12 kg/d, but dropped to 4 kg/d in the course of the experiment.
Schonewille et al. (2002)	Rations: artificially dried grass and by-product based concentrate fed at the following roughage/concentrate ratios 100:0, 80:20, 60:40 and 40:60 (energy basis). All rations were supplemented with a small amount of a MgO[1] rich concentrate (maximum amount; 120 g/d). Supplemental Mg intake ranged from 22 (60% concentrate) or 63% (no concentrate) of total Mg intake. Rations did not contain supplemental K. Cows: nonpregnant, dry.
Jittakhot et al. (2004a)	Rations: artificially dried grass (39%, DM), hay (4%, DM) and by-product based concentrate (57%, DM). Supplemental Mg (from MgO[1]) was either 32 (low Mg) or 63% (high Mg) of total Mg intake. Supplemental K ($KHCO_3$) was about 30% of total K intake. Cows: midlactation, milk yield 22 kg/d.
Jittakhot et al. (2004b)	Rations: ingredient composition was exactly the same as used by Jittakhot et al. (2004a). Supplemental Mg (from MgO[1]) ranged from 31 (lowest Mg intake) to 86% (highest Mg intake) of total Mg intake. Supplemental K ($KHCO_3$) is about 30% of total K intake. Cows: nonpregnant, dry.
Jittakhot et al. (2004c)	Rations: artificially dried grass (40%, DM), hay (4%, DM) and by-product based concentrate (56%, DM). Supplemental Mg (from MgO[1]) ranged from 68 (low Mg intake) to 83% (high Mg intake) of total Mg intake. Supplemental K ($KHCO_3$) ranged from 0 to 76% of total K intake. Cows: nonpregnant, dry.

[1] Mg was supplemented in the form of powdered MgO with an in vitro solubility of 95% (Schonewille et al., 1992).

Table 3. Descriptive statistics for the data set (n = 68 treatment means from 15 studies) used to generate the equations[1]

Item	Mean	SD	Minimum	Maximum
BW, kg	624	275.9	350	790
DMI, kg/d	8.8	8.39	4.4	18.6
Mg content, g/kg of DM	4.48	7.450	0.45	17.3
K content, g/kg of DM	30.3	29.19	6.9	75.6
Mg intake, g/d	37.7	59.59	2.3	124.3
K intake, g/d	258	288.6	55	607
Apparent Mg absorption[2]				
g/d	6.1	12.11	0.3	22.0
% of intake	14.7	14.73	1.9	30.0
True Mg absorption				
g/d	8.6	12.40	1.7	24.8
% of intake	26.2	21.83	9.9	73.7

[1] Means and standard deviations (SD) are corrected for the number of animals per treatment.

[2] Data not shown in Table 1.

smaller range in dietary K concentrations should result in a higher estimate of the coefficient associated with K. It could be speculated that the somewhat greater mean K intake (g/d) in the data set used by Weiss (2004) is responsible for the numerical difference in calculated K associated coefficients. However, as far as we know, there are no studies reporting a depressant effect of K intake (g/d) on Mg absorption independent of the dietary K concentration (g/kg of DM). This issue remains a matter of dispute.

The current estimate (equation [2]) of the inhibitory effect of dietary K on Mg absorption is derived from a data set in which grass feeds were the main source of roughage, whereas in the data set used by Weiss (2004), corn silage was the predominant form of roughage. Thus, it can be suggested that next to the dietary K content, the type of roughage is also relevant in relation to Mg absorption. However, as far as we know, there are no controlled studies reporting a K × type of roughage interaction on Mg absorption.

It has been shown that the intake of extra Mg can counteract the inhibitory effect of dietary K on Mg absorption (Ram et al., 1998; Jittakhot et al., 2004c). However, when either Mg intake (g/d) or DMI and dietary Mg content (g/kg of DM) were introduced as extra independent variables into equation [2], the residual standard error of the regression model was increased (Table 4). Apparently, Mg absorption expressed as a percentage of intake cannot be accurately predicted on the basis of the current data set. To account for the negative effect of dietary K on Mg absorption, the dietary K concentration (g/kg of DM) was added as an independent variable into equation [1], which resulted in the following equation (adjusted for trial effects):

$$\begin{aligned}\text{Mg absorption (g/d)} &= 3.6\ (\pm 0.67) + 0.20\ (\pm 0.01)\\ &\times \text{Mg intake (g/d)} - 0.08\ (\pm 0.014) \qquad [3]\\ &\times \text{dietary K (g/kg of DM)}.\end{aligned}$$

The SE_{TRIAL} and SE_{RES} were found to be 0.96 and 0.26, respectively. The intercept and both the positive coefficient for Mg intake and the negative coefficient for dietary K are significantly different from zero ($P < 0.001$). In the light of the low residual standard error, equation [3] seems to be suitable to predict absolute Mg absorption.

A similar equation was reported by Weiss (2004): Mg absorption = 4.5 (±4.0) + 0.24 (±0.07) × Mg intake – 0.44 (±0.22) × dietary K (dimension of K is adjusted to g/kg of DM). The current estimates of both the intercept and the coefficients (equation [3]) seem to be statistically equal to the values reported by Weiss (2004). The issue of numerical difference between the coefficients associated with dietary K reported by Weiss (2004) and the current study is already discussed in relation to equation [2].

Table 4. Outcome of 4 different regression models (PROC MIXED) to predict true Mg absorption expressed as a percentage of intake[1]

Predictor set	Predictor variables	SE_{TRIAL}	SE_{RES}	Coefficients	SE	*P*
1	Intercept	17.8	5.99	34.9	2.62	<0.001
	Dietary K (g/kg of DM)			–0.31	0.068	<0.001
2	Intercept	17.1	6.10	39.0	4.47	<0.001
	DMI (kg/d)			–0.46	0.406	0.276
	Dietary K (g/kg of DM)			–0.30	0.068	<0.001
3	Intercept	13.0	6.46	43.8	4.27	<0.001
	DMI (kg/d)			–0.58	0.345	0.115
	Dietary Mg (g/kg of DM)			–0.81	0.349	0.025
	Dietary K (g/kg of DM)			–0.31	0.067	<0.001
4	Intercept	12.8	6.37	39.0	2.81	<0.001
	Mg intake (g/d)			–0.11	0.042	0.015
	Dietary K (g/kg of DM)			–0.31	0.067	<0.001

[1] Trial was included as a random class variable (St-Pierre, 2001).

In Europe, grass feeds instead of corn silage are more commonly used as a main source of roughage. Therefore, grass feeds were the main source of roughage in the rations used to compile the current data set (Table 2). Thus, the current equation [3] is probably more suitable in grass-based rations. Indeed, when the equation reported by Weiss (2004) is applied to the current data set (mean Mg intake and dietary K are 37.7 g/d and 30.3 g/kg of DM respectively, Table 3), an amount of 0.2 g/d apparent Mg absorption is predicted, whereas a mean of 6.1 g/d was observed (Table 3). Thus, it seems that the coefficient associated with dietary K as reported by Weiss (2004) overestimates the inhibitory effect of K on Mg absorption, at least when grass-based rations are fed. On the basis of equation [3], it can be calculated that an increase in the dietary K content of 10 g/kg of DM can be counteracted by an additional intake of 4 g of Mg/d (coefficient of dietary K/coefficient of Mg intake multiplied by 10).

CONCLUSIONS

For predominantly grass-based rations associated with wide ranges in dietary Mg and K concentrations, a mean true Mg absorption of around 20% of intake was found. The inhibitory effect of dietary K on Mg absorption was accurately estimated, probably due to a wide range in dietary K concentrations, and was found to be 0.31 percentage units/g of K in the DM. To maintain the amount of absorbed Mg when the dietary K content increases by 10 g/kg of DM, Mg intake must be increased by 4 g/d.

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