DIETARY SILICA EFFECTS ON MINERAL METABOLISM IN LAMBS[1]

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Summary

Eighteen wether lambs averaging 32 kg were used to determine the effects of dietary silica, added as silicic acid, on mineral metabolism. Lambs were fed 1200 g daily of a coastal bermuda grass based diet supplemented with either 0, .5 or 1.5% silicic acid. A 7-d total collection of urine and feces was conducted after lambs had adjusted to the dietary treatments for 19 days. Urinary excretion of silica was higher ($p < .01$) in lambs fed added silicic acid. Ruminal soluble concentrations of manganese tended to be lower ($p < .10$) and apparent absorption and retention of manganese were lower ($p < .05$) in lambs supplemented with silicic acid compared to control lambs. Apparent absorption and retention of calcium were slightly lower ($p < .10$) in silicic acid fed lambs. No differences in urinary silica excretion or in apparent absorption and retention of manganese and calcium were observed between lambs fed .5 and those given 1.5% silicic acid. Phosphorus, magnesium, iron, zinc and copper absorption and retention were not affected by treatment.

(Key Words : Silica, Manganese, Calcium, Minerals, Lambs)

Introduction

Grazing ruminants ingest appreciable quantities of silica as a constituent of forages. The silica content of forages varies greatly depending on such factors as plant species, stage of growth and soil type (Jones and Handreck, 1967). A large proportion of ingested silica would be in a relatively insoluble form as polymerized silicic acid (solid silica) but a considerable amount of soluble silica as monosilicic acid may occur in immature forages (Jones and Handreck, 1967).

Silica in forages has been related to incidence of siliceous urinary calculi in ruminants (Bailey, 1981). Other studies have found that silica depresses digestibility of cell-wall constituents (Van Soest and Jones, 1968) and organic matter (Smith et al., 1971) of forages. Studies evaluating the effect of silica on mineral utilization by ruminants are limiting. The addition of sodium silicate in drinking water at a level of 500 mg silicate/l increased fecal excretion of cadmium, copper, manganese and nickel in lambs fed a diet containing sewage solids (Bruce et al., 1978). However, the addition of 1.0% silicic acid to a diet supplemented with 150 mg cadmium/kg decreased fecal cadmium excretion in sheep (Bruce and Smith, 1979). The present study was conducted to determine the effect of dietary silica on mineral metabolism in lambs.

Materials and Methods

Eighteen Suffolk and Dorset wether lambs weighing 32 kg initially were blocked according to weight and breed and randomly assigned within a block to treatments. Treatments were supplemental silicic acid at 0, .5 and 1.5% of the diet. Lambs were fed 1200 g/d in two equal feedings and deionized water was provided *ad libitum*. The ingredient and mineral composition of the basal diet is shown in table 1. The basal diet contained .72% silica (SiO_2).

Lambs were housed individually in 1.52 × 1.52 m pens and adjusted to the diets for 14 days, then placed in stainless steel metabolism crates. A 5-d adjustment to the crate preceded

[1]Use of trade names in this publication does not imply endorsement by the North Carolina Agricultural Research Service nc criticism of similar products not mentioned.

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TABLE 1. INGREDIENT AND MINERAL COMPOSITION OF THE BASAL DIET

Item	Amount
Ingredient composition	(%)
Coastal bermudagrass pellets	90.00
Corn, ground	9.45
Sodium chloride[a]	.50
Vitamin A, D, E[b]	.05
Mineral composition	
Calcium	.84
Phosphorus	.38
Magnesium	.23
	(mg/kg)
Iron	169.0
Zinc	33.4
Copper	5.5
Manganese	40.9

[a] Sodium selenite added to sodium chloride to provide .1 mg selenium/kg diet.
[b] Contained per kg vitamin mix: vitamin A, 9,903,000 IU; vitamin D, 3,301,000 IU and vitamin E, 3,301 IU.

a 7-d total collection of feces and urine. Urine, preserved with 20 ml of 50% HCl and total fecal output were measured daily. A 1% aliquot of urine and 10% aliquot of feces were taken daily and then frozen and composite for each animal. At the completion of the study, composite fecal samples were dried at 55°C in a forced-air oven. Blood samples were obtained by jugular puncture into heparinized vacutainers and ruminal fluid samples were obtained via stomach tube at the end of the collection period. Blood and ruminal samples were collected 2 hours post-feeding and immediately placed on ice. Ruminal fluid was centrifuged at 20,000 × g for 30 min and the supernatant fraction was used for determination of soluble mineral concentrations. Blood samples were centrifuged and the plasma obtained was used for mineral analysis.

Feed, fecal and urine samples were prepared for mineral analysis by wet ashing with nitric acid followed by hydrogen peroxide. Calcium, magnesium, iron, copper, zinc and manganese were determined by atomic absorption spectrophotometry (Perkin Elmer, Model 5000, Norwalk, CT). Phosphorus was determined by the procedure of Fiske and Subbarow (1925). Urinary silica was measured by the colorimetric method of King et al. (1955). Silica in feed was determined as described by Goering and Van Soest (1970).

Data were analyzed statistically by analysis of variance for a randomized block designed (Steel and Torrie, 1980). Differences between treatment means were determined by single degree of freedom comparisons using the General Linear Model procedure (SAS, 1982). Comparisons made were control vs supplemental silica and .5% vs 1.5% supplemental silica.

Results and Discussion

Concentration of silica (mg/dl) in urine was not affected by dietary silica (table 2). However, total urinary excretion of silica (mg/day) was higher ($p < .01$) in lambs fed added silica because of higher ($p < .07$) urinary outputs in these animals. The increased urinary silica excretion due to silicic acid supplementation was relatively small considering the quantities of silicic acid added to the basal diet. This would suggest that most of the added siliced acid was not solubilized and absorbed from the gastrointestinal tract since most absorbed silica is excreted in the urine (Jones and Handreck, 1965; Bailey, 1976). Urinary excretion of silica was similar in lambs fed .5% and those fed 1.5% silicic acid.

Soluble mineral concentrations in rumen fluid

TABLE 2. URINARY SILICA EXCRETION IN LAMBS FED SUPPLEMENTAL SILICA

Item	Supplemental silicic acid (%)			
	0	.5	1.5	SE[a]
Urine output (g/d)[b]	1785	2474	2447	263
Urinary silica (mg/dl)	2.2	2.3	2.3	.2
Urinary silica (mg/d)[c]	38.9	53.8	51.6	2.2

[a] Pooled standard error, N=6.
[b] Control vs silicic acid treatments ($p < .10$).
[c] Control vs silicic acid treatments ($p < .05$).

of lambs are shown in table 3. Supplemental silicic acid slightly reduced ($p < .10$) soluble manganese concentrations, but no difference was observed between soluble manganese concentrations in lambs fed .5% and those fed 1.5% silicic acid. Soluble concentrations of other minerals measured in rumen fluid were not affected by silicic acid.

Apparent absorption, urinary excretion and retention of minerals are shown in table 4. Mineral intake was similar across treatments. Apparent absorption and retention of calcium was slightly lower ($p < .10$) in lambs fed silicic acid. The higher fecal calcium excretion in lambs fed silicic acid may have been due to formation of insoluble calcium complexes postruminal in the digestive tract, since no effect of supplemental silica was noted for soluble calcium concentrations in rumen fluid. No differences in calcium absorption or retention were observed between lambs fed .5% and those given 1.5% silicic acid.

Apparent absorption and retention of manganese were reduced ($p < .05$) by silicic acid addition to the basal bermuda grass diet (table 4). The depression in manganese absorption tended to be greater in lambs supplemented with 1.5% silicic acid, but no significant differences in manganese apparent absorption and retention were detected between .5 and 1.5% added silicic acid. The reduced soluble manganese concentrations in rumen fluid may explain the higher fecal manganese excretion in lambs fed silicic acid. The addition of aqueous sodium silicate to drinking water to provide 500 mg silicate/l also increased fecal manganese excretion in lambs (Bruce et al., 1978). One type of antagonistic mechanism involving mineral elements is the formation of insoluble complexes between dissimilar elements (Suttle, 1975). Manganese silicate has been shown to be relatively unavailable in poultry (Carlisle, 1986). Silica also has been used to alleviate manganese toxicity in plants (Jones and Handreck, 1967).

Phosphorus, magnesium, iron, zinc and copper apparent absorption and retention were not affected by silicic acid addition (table 4). Urinary excretion of minerals was not significantly affected by treatment. However, urinary excretion of phosphorus tended to be higher in lambs fed supplemental silicic acid.

Plasma mineral concentrations are shown in table 5. Dietary silica treatment did not significantly affect the plasma minerals measured. There was a tendency for decreased plasma calcium with increasing dietary silica. Administration of organic silicon resulted in decreased blood calcium in rats (Charnot and Peres, 1978).

In summary, the addition of .5 or 1.5% silicic acid to a bermudagrass based diet decreased apparent absorption and retention of manganese and calcium. Metabolism of phosphorus, magnesium, iron, zinc and copper were not affected by silicic acid addition to the basal diet. The relatively small increases in urinary silica excretion with silicic acid addition suggest that most of the added silicic acid was never solubilized in the gastrointestinal tract. It also is possible that much of the silicic acid was solubilized then converted to insoluble forms in the gastrointestinal tract.

TABLE 3. SOLUBLE MINERAL CONCENTRATIONS IN RUMEN FLUID OF LAMBS FED SUPPLEMENTAL SILICA

Mineral	Supplemental silicic acid (%)			SE[a]
	0	.5	1.5	
	········ μg/ml ········			
Calcium	270	271	270	20
Phosphorus	265	257	272	13
Magnesium	243	243	247	20
Iron	1.36	1.38	1.37	.16
Zinc	.67	.66	.68	.06
Copper	.08	.08	.08	.01
Manganese[b]	.36	.29	.25	.04

[a] Pooled standard error, N=6.
[b] Control vs silicic acid treatments ($p < .10$).

TABLE 4. APPARENT ABSORPTION, URINARY EXCRETION AND RETENTION OF MINERALS IN LAMBS FED SUPPLEMENTAL SILICA

Item	Supplemental silicic acid (%)			SE[a]
	0	.5	1.5	
Aparent absorption (%)				
Calcium[b]	34.2	29.6	30.1	1.6
Phosphorus	72.7	72.6	72.4	.9
Magnesium	13.4	17.0	13.5	2.7
Iron	19.9	19.2	16.7	1.8
Zinc	9.8	12.5	11.5	1.4
Copper	21.5	18.4	16.4	4.5
Manganese[c]	12.6	11.1	9.2	.9
Urinary excretion (mg/d)				
Calcium	1.4	1.4	1.5	.1
Phosphorus	1367	1437	1497	61
Magnesium	28.5	28.5	28.3	2.3
Iron	.51	.54	.56	.05
Zinc	.16	.16	.17	.01
Copper	.05	.06	.06	.004
Manganese	.03	.03	.03	.004
Retention (mg/d)				
Calcium[b]	3446	2982	3033	165
Phosphorus	1963	1900	1864	77
Magnesium	330	428	334	70
Iron	39.9	38.5	33.4	3.6
Zinc	3.8	4.8	4.4	5.6
Copper	1.4	1.2	1.0	.3
Manganese[c]	6.2	5.4	4.5	.5

[a] Pooled standard error, N=6
[b] Control vs silicic acid treatments ($p < .10$).
[c] Control vs silicic acid treatments ($p < .05$).

TABLE 5. PLASMA MINERAL CONCENTRATIONS IN LAMBS FED SUPPLEMENTAL SILICA

Mineral	Supplemental silicic acid (%)			SE[a]
	0	.5	1.5	
Calcium (mg/dl)	11.0	10.8	10.6	.2
Phosphorus (mg/dl)	7.6	7.6	7.6	.1
Magnesium (mg/dl)	1.8	1.9	2.0	.1
Iron (μg/dl)	189	182	179	6
Zinc (μg/dl)	66	68	69	4
Copper (μg/dl)	73	74	77	3

[a] Pooled standard error, N=6.

Literature Cited

Bailey, C. B. 1976. Fate of the silica in prairie hay and alfalfa hay consumed by cattle. Can. J. Anim Sci. 56:213.

Bailey, C. B. 1981. Silica metabolism and silica urolithiasis in ruminants: A review. Can. J. Anim. Sci. 61:219.

Bruce, L. B. and G. S. Smith. 1979. Cadmium retention by sheep fed silicic acid. J. Anim. Sci. 49:184 (Abstr.).

Bruce, L. B., G. S. Smith and C. Staples. 1978. Effects of sodium silicate in drinking water on fecal excretion of heavy metals by lambs. Proc. West. Sec. Am. Soc. Anim. Sci. 29:335.

Carlisle, E. M. 1986. Silicon. In: W. Mertz (Ed.). Trace Elements in Human and Animal Nutrition. Vol. 2, pp. 373-390. Academic Press Inc., New York.

Charnot, Y. and G. Peres. 1978. Silicon, endocrine balance and mineral metabolism. In: G. Bendz and I. Lindqvist (Eds.). Biochemistry of Silicon and Related Problems. pp. 269-280. Plenum Press, New York.

Fiske, C. H. and Y. Subbarow. 1925. The colorimetric determination of phosphorus. J. Biol. Chem. 66: 375.

Goering, H. K. and P. J. Van Soest. 1970. Forage fiber analysis. USDA Agric. Handbook 379. Washington, DC.

Jones, L. H. P. and K. A. Handreck. 1965. The relation between the silica content of the diet and the excretion of silica by sheep. J. Agric. Sci. 65:129.

Jones, L. H. P. and K. A. Handreck. 1967. Silica in soils, plants and animals. Adv. Agron. 19:107.

King, E. J., B. D. Stacy, P. F. Holt, D. M. Yates and D. Pickles. 1955. The colorimetric determination of silicon in the micro-analysis of biological material and mineral dusts. Analyst 80:441.

Smith, G. S., A. B. Nelson and E. J. A. Boggino. 1971. Digestibility of forages *in vitro* as affected by content of "silica". J. Anim. Sci. 33:466.

SAS. 1982. SAS User's Guide: Statistics. Statistical Analysis System Institute, Inc., Cary, NC.

Steel, R. G. D. and J. H. Torrie. 1980. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York.

Suttle, N. F. 1975. Trace element interactions in animals. In: D. J. D. Nicholas and A. R. Egan (Eds.). Trace Elements in Soil-Plant-Animal Systems. pp. 271-289. Academic Press, New York.

Van Soest, P. J. and L. H. P. Jones. 1968. Effect of silica in forages upon digestibility. J. Dairy Sci. 51:1644.