EFFECTS OF DIETARY SILICIC ACID AND CADMIUM ON SHORT-TERM MINERAL BALANCES IN SHEEP[1]

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Summary

Previous experiments have shown that aqueous sodium silicate ingested in drinking water may *modify the gastrointestinal uptake and(or) tissue retention of certain trace elements*, including heavy metals. The present experiment tested, with a mineral balance trial using sheep, the hypothesis that dietary silicic acid could modify uptake, retention and(or) biological effects of dietary Cd. Twenty-four wethers were fed a fibrous diet of ground alfalfa hay and cottonseed hulls to which either 0 or 150 ppm Cd was added as $CdCl_2$ and 0, .5 or 1% silicic acid (as dry matter of the diet). Body weight, feed intake, excretion of urine (volume) and feces (weight), digestibility of dry and organic matter, retention of nitrogen, and packed cell volumes of blood were not affected by either Cd or silicic acid ($p < .10$). Cadmium decreased ($p < .05$) Ca retention and increased ($p < .01$) Mg retention. Silicic acid decreased ($p < .05$) K retention. Silicic acid failed ($p < .10$) to modify the retention of added dietary Cd. Body retention of K, Mn, and Ni in response to silicic acid varied with Cd levels. If Cd is interfering with mineral retention, silicic acid may be effective in preventing this interference
(Key Words: Cadium, Silicic Acid, Mineral Retention, Sheep)

Introduction

There is concern about trace elements and organo-metallic compounds contamination in the agricultural ecosystem (Munro and Charbonneau, 1978). Cadmium is of primary focus (Anonymous, 1971) and is of concern to livestock production, as sewages containing Cd are commonly used as pasture fertilizers. Studies on polluted grasslands show that grasses accumulate Cd and cattle grazing these grasses deposit Cd into body tissues (Munshower, 1977). Other studies have shown that rats and cattle fed diets containing Cd, retain Cd in their tissues (Johnson et al., 1981; Combs et al., 1983). Excess cadmium will cause disorders such as renal dysfunction, growth inhibition and tumors (Flick et al., 1971). Methods that ameliorate Cd concentrations in the food chain are needed.

Siliceous substances form salts of silicate ions under certain conditions (Iler, 1955) and have been used in sewage treatment to complex heavy metals into insoluble forms (Conner and Gowman, 1974). The possibility of such precipitation occurring in sheep with the ingestion of aqueous sodium silicate in sheep was investigated by Bruce (1978). Sodium silicate in drinking water gave variable results due to inconsistent water intake. In this study silicic acid powder added directly to the diet was used in a mineral balance trial with sheep to examine the hypothesis that dietary silicic acid could modify uptake, retention, and(or) biological effects of dietary Cd.

Materials and Methods

A mineral balance trial in metabolism crates was conducted, with 24 wether sheep. All sheep were placed on a roughage diet of 50% alfalfa and 50% cottonseed hulls (table 1). Cadmium at 0 or 150 ppm and 0, .5, or 1% silicic acid was added to the diet and used in a 2 x 3 factorial arrangement of treatments in a randomized complete block, each block consisting of four animals. Cadmium concentration was based on published levels of chronic toxicity (Underwood, 1977), and silicic acid concentrations were based on rumen culture experiments (Bruce, 1979).

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TABLE 1. CHEMICAL COMPOSITION OF SHEEP DIET USED IN THE BALANCE TRIAL (PERCENT OF DRY MATTER)

Component	Content
Dry matter (%)	95.5
Ash (%)	15.2
N (%)	2.10[a]
Ca (%)	1.29
PS(%)	.23
Mg (%)	.30
Na (%)	.30
K (%)	2.23
Cd (ppm)	.01[b]
Cu (ppm)	9.0
Fe (ppm)	1020
Mn (ppm)	50
Ni (ppm)	6.6
Zn (ppm)	26

[a]13.13% crude protein.
[b]Cd content of diets with added $CdCl_2$ was 146.7ppm.

Wethers were selected at random from a group available for experimental work and placed in individual stalls that made collection of urine and feces and measurement of feed intake possible. Feed was mixed daily with Cd and silicic acid mixed in small fixed amounts of water and then incorporated into the diet. The sheep were weighed, blood samples were collected by jugular venipuncture and treatments imposed for an 8 d dietary adjustment period. Urine and fecal collections were started at the end of the adjustment period and continued for 7-d. Feed was provided ad libitum, and intake was measured. Drinking water was provided ad libitum with automatic waterers. At the end of the collection period the animals were weighed and blood samples taken.

Total urine was collected daily from each sheep into glass jugs containing 10 ml of reagent grade concentrated HCl. Ten percent aliquots were sampled and composited over the 7-d trial. The samples were stored at 4°C. Feces were collected using fecal bags fitted individually to each sheep. Bags were emptied, contents weighed and sampled twice daily. Ten percent of daily collections were composited, oven dried for 48 h at 55°C, ground in a Wiley mill through a 1 mm screen, and thoroughly mixed. Dry matter (DM) was determined by oven drying to constant weight at 105°C. All chemical data were adjusted to DM basis. Feed samples were treated in the same manner.

Samples of urine, feed and feces were analyzed for total Kjeldahl nitrogen (N) (AOAC, 1970). Samples of feed and feces were ashed at 600°C for 6 h for determination of organic matter and ash. In preparation for mineral analysis, small samples of feed and feces were wet ashed with reagent grade concentrated HNO_3 and subsequently with 72% reagent grade $HClO_4$. Urine was brought to room temperature, agitated, and filtered to remove coarse particles. An atomic absorption spectrophotometer[2] was used to measure Cd, Ca, Fe, K, Mg, Mn, Ni, Na and Zn in urine and solutions from wet ashed samples of feed and feces. Phosphorus was measured spectrophotometrically by the molybdovanadate method (AOAC, 1970).

DM digestibility, organic matter digestibility, body weight changes, nitrogen balance and mineral balances (mg retained over period of the trial) for Ca, P, Mg, Na, K, Cd, Cu, Fe, Mn, Ni and Zn were calculated. Differences among means between treatment groups were tested using factorial analysis of variance as outlined by Steel and Torrie (1960).

Results

Feed intakes during the 7-d balance trial averaged 8.4 kg/sheep for all groups with no effects ($p < .10$) due to Cd or silicic acid treatments. The dietary nutritive value was not high enough to preclude body weight losses at the dietary intake maintained by the sheep (table 2). Volume of urine and weight of fecal excretions, DM digestibilities, organic matter digestibilities and g of N-retained were not affected ($p < .10$) by treatment (table 2).

Each of the six diets were measured for Cd content after mixing. Cadmium balance data were calculated for the three groups given Cd at 150 ppm Cd. The Cd in the 0 ppm Cd diets was below practical detection limits. The Cd balance data (table 3) do not support the hypothesis that silicic acid in the digestive tract would complex with Cd and reduce its absorption. Sheep fed 1%

[2]Perkin-Elmer model 403, Perkin-Elmer Corp., Norwalk, CT.

TABLE 2. WEIGHT CHANGES, DIETARY INTAKE, AMOUNT OF FECAL AND URINARY EXCRETION, DRY MATTER AND ORGANIC MATTER DIGESTIBILITIES OF THE DIET, AND NITROGEN RETENTION BY SHEEP FED VARIED LEVELS OF SILICIC ACID WITH AND WITHOUT CADMIUM[a]

	Treatment					
Cd (ppm)	0	0	0	150	150	150
Silicic acid (%)	0	.5	1	0	.5	1
Observation	Values, total per head for 7 days					
Weight change (kg)	-.7(1.1)	-.8(2.4)	-1.7(2.7)	-1.6(2.8)	-.8(2.6)	-.4(1.8)
Intake (kg)	8.3(2.1)	8.8(.9)	7.1(3.5)	7.9(1.5)	8.7(.5)	9.6(1.2)
Feces (kg)	4.6(1.4)	4.7(.5)	3.8(2.2)	4.1(.7)	4.7(.2)	4.8(.7)
Urine (l)	6.7(1.4)	7.4(1.8)	7.6(3.0)	7.5(2.2)	9.8(1.9)	8.4(1.5)
DMD[b] (%)	45(8)	47(2)	47(4)	48(2)	46(4)	51(4)
OMD[c] (%)	51(7)	54(2)	55(3)	55(4)	53(5)	56(5)
N retained, (g)	67(31)	66(8)	29(40)	61(20	55(17)	71(20)

[a]Values are means and (standard errors) from 4 sheep. There were no differences for any observation between treatments: ($p < .1$).
[b]Dry matter digestibility of diet.
[c]Organic matter digestibility of diet.

TABLE 3. SEVEN-DAY BALANCE DATA FOR CALCIUM, CADMIUM, COPPER, IRON, MAGNESIUM, MANGANESE, NICKEL, PHOSPHORUS, POTASSIUM, SODIUM, AND ZINC BY SHEEP FED VARIED LEVELS OF SILICIC ACID WITH AND WITHOUT CADMIUM[a]

	Treatment					
Cd (ppm)	0	0	0	150	150	150
Silicic acid (%)	0	.5	1	0	.5	1
Element	Body retention of elements (7-d, mg)					
Calcium[b]	8(13)	6(8)	−4(15)	−1(5)	−17(11)	−8(8)
Cadmium	< .01	< .01	< .01	94(51)	86(100)	197(164)
Copper	8(10)	15(14)	−1(8)	3(6)	2(6)	9(5)
Iron	1(1)	0(3)	−1(2)	0(1)	1(1)	2(1)
Magnesium[c]	2(3)	2(1)	3(4)	5(2)	4(2)	11(5)
Manganese[d]	30(46)	31(16)	47(89)	−16(17)	14(24)	38(39)
Nickel[e]	29(8)	21(7)	14(6)	13(5)	18(4)	26(6)
Phosphorus	0(2)	4(6)	−2(5)	0(3)	−1(2)	3(2)
Potassium[f]	3(4)	−2(3)	−7(7)	2(2)	−11(4)	−6(3)
Sodium	14(4)	14(3)	9(4)	12(2)	11(2)	15(3)
Zinc	13(34)	14(11)	−8(26)	4(22)	−7(20)	23(13)

[a]Values are means and (standard errors) from 4 sheep.
[b]Means of 0 and 150 ppm Cd (3 and −9) differ ($p < .05$).
[c]Means of 0 and 150 ppm Cd (2 and 7) differ ($p < .01$).
[d]Cd vs silicic acid interaction ($p < .05$).
[e]Cd vs silicic acid interaction ($p < .01$).
[f]Means of 0, .5 and 1% silicic acid (1, 7 and −7) differ ($p < .05$); Cd vs silicic acid interaction ($p < .05$)

silicic acid with 150 ppm Cd retained the most Cd, but this group was also the most variable. About 90% of added dietary Cd was excreted in feces.

Other elements measured were affected by the treatments. Calcium retention (table 3) was decreased by the 150 ppm Cd treatment ($P < .05$) and unaffected by silicic acid. Body retention of Mg was increased ($p < .01$) with the addition of Cd (table 3). Silicic acid treatments decreased retention of K ($p < .05$), with an interaction ($p < .05$) occurring between Cd and silicic acid on K retention (table 3). Manganese retention was affected by an interaction ($p < .05$) of Cd and silicic acid (table 3). The 0 ppm Cd diet group at 0% silicic acid retained more Mn than the respective 150 ppm group. Opposite effects were noted at .5 and 1% levels of silicic acid. Nickel retention was affected by an interaction ($p < .01$) of Cd and silicic acid, but not influenced by either individually (table 3). Nickel retention in 0 ppm Cd diet at 0 and .5% silicic acid levels was higher ($p < .01$) than 150 ppm diet group. The silicic acid and the 150 ppm Cd diet group had higher ($p < .01$) Ni retention than did the 0 ppm Cd diet with 1% silicic acid. Sheep mineral retention responses to the silicic acid levels varied with the Cd levels for P, Na, Fe, Cu and Zn (table 3). The general trend in these cases was for 0% silicic acid and 0 ppm Cd to retain greater amounts of mineral than 0% silicic acid and 150 ppm Cd. With the addition of 1% silicic acid, the group with Cd added tended to retain greater amounts of these minerals.

Discussion

Dietary silicic acid did not affect the retention of dietary Cd. The addition of silicic acid to the diet decreased K retention by sheep in this study. Smith and Nelson (1975) previously reported that sodium silicate depressed in virtro digestibility of forage DM, but this was relieved by a mixture of minerals containing Mg, Mn, Zn, Co and Cu. The sheep balance data show that retention of Mn and Ni varied with the level of Cd and silicic acid. When Cd was present and silicic acid levels increased, retention of Mn and Ni increased. This is direct evidence that dietary silicic acid and Cd are able to modify retention of certain minerals. Cadmium affects metabolism of essential minerals (Fox, 1974) and from the data presented here also affects absorption. However, based on this study, it is not possible to determine whether solubility, absorption characteristics or some other factor mediates the effects. If Cd is interfering with mineral absorption, the present study indicates some degree of effectiveness by silicic acid in preventing this interference. These effects are important observations and need continued investigation.

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