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Relationships among forage aluminum levels, soil contamination on forages, and availability of elements to dairy cows

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Summary

Analyzing forage from ungrazed areas of intensively managed ryegrass pastures revealed that aluminum concentrations in the plants normally remained below 100 mg/kg of dry matter. Forage samples from grazed areas contained 100 to 400 mg Al/kg during most of the grazing season, but exceeded 1600 mg/kg during cold, wet weather as a result of increased soil contamination on the surface of the forage. Adding 1000 mg/kg Al as aluminum sulfate in the ration of cows or feeding 1 kg soil per cow per day was consistently associated with greater retention of Mg and Ca but had no measurable influence on P or K retention. Soil addition to the ration also increased Al retention values. Apparent availability of Ca and Al was consistently higher when the cows received either $Al_2(SO_4)_3$ or soil in the ration. Apparent digestibility of organic matter was uniform throughout the experiment. The studies suggest that the intake of soil or $Al_2(SO_4)_3$ did not adversely affect Mg or Ca nutrition of dairy cows.

Introduction

Experiments in the United States have shown that high Al concentrations frequently occur in rumen content samples of hypomagnesaemic animals (1000 to 3000 mg Al/kg) and in grass samples collected from tetany-producing pastures (2000 to 8000 mg/kg). Aluminum supplied at a concentration of 4000 mg/kg of dry matter as $Al_2(SO_4)_3$ reduced Ca and Mg solubility in vitro and also depressed blood serum Mg levels in steers when added directly to the rumen (Allen & Robinson, 1980; Allen et al., 1981). Valdivia (1977) reported that 1200 mg/kg Al as $AlCl_3$ had no effect on blood serum Ca or Mg levels in steers, but 2000 mg/kg Al as $AlCl_3$ depressed serum Mg in sheep after 56 days. Kappel et al. (1983) found that Na_2SO_4 was as effective as $Al_2(SO_4)_3$ in depressing serum Mg levels in cows if the sulfate levels were equal. They suggested that serum Mg depressions associated with $Al_2(SO_4)_3$ additions to the rumen were due to the sulfate anion rather than to Al. Healy (1972) previously reported that soil additions to ruminal, duodenal, and ileal liquors increased the Al concentrations in the liquors after 15 hours of contact. He suggested possible influences of Al on absorption of other elements within the animals. Grace & Healy (1974) found that soil intake of 100 g/day decreased Mg faecal loss and increased Mg retention in sheep.

It is generally accepted that Al concentrations in most agronomic crops rarely exceed 50 to 200 mg/kg in the dry matter (Hutchinson, 1945; Jones, 1961). Higher concentrations usually become toxic and suppress plant growth. Metson (1979) reported high levels of Al and Fe in forage samples as a result of soil contamination, with highest levels occurring during cold, wet periods when dry matter production by the crop was lowest. The frequent association of high Al levels in forage and rumen content samples with the incidence of hypomagnesaemia suggests that Al could be involved in the development of grass tetany, possibly as the result of plant uptake or soil contamination. This paper presents the results of two experiments conducted to determine: 1) the Al levels in forage and rumen content samples from an intensively managed ryegrass pasture in the Netherlands; 2) the source of Al in ryegrass samples; 3) the influence of soil and $Al_2(SO_4)_3$ in the ration on apparent availability of elements to non-lactating cows.

Experiments

Nine perennial ryegrass pastures on the 'Droevendaal' experimental farm at Wageningen were rotationally grazed by 60 lactating Friesian cows in 1981. The pastures, located on sandy soil, were highly fertilized and irrigated as needed to insure sufficient forage production for the herd. The pastures averaged 1.8 ha in size and could be effectively utilized in about four grazing days. One metal cage, 1.2 m × 4.2 m, was permanently located in each pasture from 24 July through 12 October. Each pasture was sampled twofold just before grazing and again on the fourth day of grazing. At the same time two forage samples (duplicates) were collected from inside each cage. The grass samples were cut by hand to a stubble height of 3 to 4 cm. In the afternoon of the fourth grazing day, rumen content samples were collected from two fistulated cows in the herd. During the last week of the study, rumen content samples were collected each afternoon. Forage remaining under the cages was removed after each pasture was grazed.

A nutrient balance experiment initiated on 23 October was conducted for 40 days in the digestion stable at Droevendaal experiment farm with 6 dry, non-pregnant Friesian cows with initial body weights of 520 to 650 kg. Each animal received a basic ration of approximately 4.4 kg of concentrates and 5.8 kg of hay, on dry matter basis. To avoid the risk of Mg definciency, 26.0 g of MgO was supplied to the concentrates. Individual meals were carefully weighed and packaged before the study began. All cows received the basic ration during the entire 40 days. During the last 20 days, 3 cows received 500 g of soil and 3 cows received 62 g of $Al_2(SO_4)_3 \cdot 18H_2O$ per meal in addition to the basic ration. Soil was uniformily mixed with the concentrates and the mixture was moistened with about 4 l of water. The $Al_2(SO_4)_3$ was dissolved in 0.5 l of water and mixed with the concentrates, resulting in the addition of 1000 mg Al/kg of dry ration.

The 40-day study was divided into four periods of ten days each. Days 1 to 10 and 21 to 30 were adjustment periods in which no samples were collected. During days 11 to 20 and 31 to 40, all urine and faeces were collected daily, weighed, and proportionately sampled. At the end of each sampling period two subsamples of urine and four subsamples of faeces from each cow were taken for analyses. All ration components and the drinking water were also analyzed. All feed, faeces, ryegrass, rumen content, and soil samples were oven-dried at 105 °C and ground to pass a 1-mm sieve. Samples were digested in 1:1 nitric and sulfuric acids before colorimetrically measuring Al by a modified method of Hill (1966) and P by the molybdate-blue method. Calcium, Mg and K were measured by atomic adsorption spectroscopy after extraction with trichloroacetic acid. Organic matter in the feed and faeces was determined by dry-ashing in a muffle furnace.

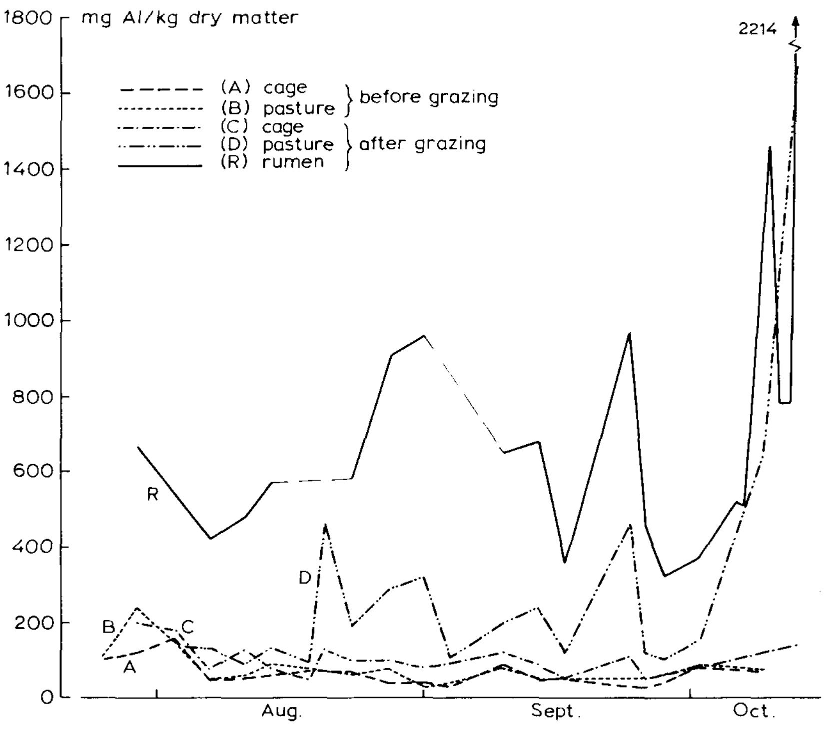

Fig. 1. Concentrations of Al (mg/kg dry matter) in ryegrass and rumen samples of cows during the second half of the grazing period.

Results and discussion

Fig. 1 shows the trends in Al concentrations in ryegrass and rumen content samples collected during the grazing study. It is apparent that Al levels in the ryegrass before grazing (lines A and B) were consistently low throughout the season, usually below 100 mg/kg of dry forage. After grazing, ryegrass protected by cages was still low in Al (line C). However, grazed ryegrass samples (line D) generally contained 100 to 400 mg/kg Al until early October when values reached over 1600 mg/kg. Aluminum concentrations in rumen content samples (line R) were even higher, ranging between 400 and 1000 mg/kg until October, when values exceeded 2200 mg/kg of dry matter.

The higher Al levels in grazed than in ungrazed forage indicate that the Al increased as a result of grazing, presumably due to soil contamination on the surface of the forage. It should be noted, however, that grazed samples (line D) were collected from forage stubble that was approximately 6 to 8 cm in height while ungrazed forage (lines A, B & C) was 20 to 30 cm in height. It is possible that this morphological difference in the plants could have resulted in some differences in Al concentrations. However, Cherney et al. (1983a) conducted similar studies in which caged areas were clipped periodically to simulate grazing, and forage in those areas remained low in Al concentration. The dramatic increase in Al concentrations in grazed forage and rumen content samples during October is attributed largely to climatic differences. During that period temperatures were lower and rainfall was higher than during any other part of the grazing season. These conditions presumably resulted in relatively more soil contamination on the forage during grazing because of higher soil moisture levels and slower growth rates of the grass. This conclusion is consistent with results of Metson et al. (1979) and Cherney et al. (1983a).

Data showing average intake, excretion, and retention of five elements by six cows during the feeding study are reported in Table 1. Additions of $Al_2(SO_4)_3$ or soil to the ration significantly increased retention of Mg and Ca. The results were consistent in each of the six cows. Increases in Ca retention were greater than those for Mg retention. For both elements, retention increased more when soil was supplied than when $Al_2(SO_4)_3$ was supplied to the ration. The increased Mg retention was accompanied by significantly lower urinary Mg levels in cows receiving $Al_2(SO_4)_3$. Each cow receiving $Al_2(SO_4)_3$ and 2 of the 3 cows receiving soil in the ration excreted less urinary Mg. Increased Ca retention was accompanied by significantly lower urinary Ca in cows fed soil, but urinary Ca increased slightly in cows fed $Al_2(SO_4)_3$ in the ration. The additional intake of Mg and Ca provided by the addition of soil to the ration resulted in greater faecal Mg and Ca in all cows. However, most of the Ca provided in the soil was retained by the cows, while most of the Mg provided in the soil occurred in the faeces.

Effects of $Al_2(SO_4)_3$ or soil in the ration on P and K balance in the cows was less apparent and less consistent than for the other elements. Although average P and K retention increased in cows receiving $Al_2(SO_4)_3$ or soil, the results were not consistent among cows within treatments and effects were not significant.

Table 1. Influences of aluminum sulfate and soil in the ration on balance of elements (in g per cow per day) in six dry cows during 10 days[1].

Ration additive[2]	Intake	Excreted faeces	Excreted urine	Retained	Intake	Excreted faeces	Excreted urine	Retained
		Mg					Ca	
None	46.7	38.9	7.7	0.1	73.7	68.1	1.7	4.0
$Al_2(SO_4)_3$	46.2*	39.4	5.7*	1.1**	74.7*	66.1	2.1*	6.6*
None	46.7	40.4	5.9	0.3	73.7	68.8	2.5	2.4
Soil	52.6**	44.6**	5.5	2.5**	80.5**	71.5*	1.7**	7.4**
C.V.%	0.2	1.8	10.1	23.3	0.4	1.6	7.0	19.9
		K					P	
None	225.1	17.4	193.5	14.2	40.1	37.7	0.18	2.2
$Al_2(SO_4)_3$	228.8*	18.0	194.4	16.4	39.8*	36.8	0.15	2.9
None	224.5	20.2	186.5	17.9	40.0	37.6	0.21	2.2
Soil	233.1**	25.3	183.8	23.9	40.5*	36.8	0.20	3.5
C.V.%	0.6	16.4	4.8	39.9	0.3	1.9	8.9	21.8
		Al						
None	4.3	8.4	0.008	−4.1				
$Al_2(SO_4)_3$	14.9**	17.8**	0.011	−3.0				
None	4.3	7.1	0.008	−2.9				
Soil	58.5**	51.5**	0.039*	7.0**				
C.V.%	0.1	3.6	67	99				

[1] Each number is the average for 3 cows during a 10-day period.
[2] $Al_2(SO_4)_3$ supplied 1000 mg Al/kg of dry ration. Soil intake equalled 1 kg per cow per day.
* $P < 0.05$; ** $P < 0.01$.

Cows receiving only the basic ration showed negative Al retention values and very low urinary Al excretion. Faecal Al excretion exceeded Al intake. Addition of $Al_2(SO_4)_3$ to the ration significantly increased faecal Al, but had no significant influence on urinary Al or Al retention, although retention increased somewhat in each cow. Addition of soil to the ration also increased faecel Al, however, urinary Al was increased nearly 5-fold and Al retention increased over 3-fold, although the values increased from a very small base and the coefficients of variation were quite large. These significant relationships were consistent in each of the 3 cows given soil in the ration. The increased urinary Al values suggest that Al in the soil had some activity in the animals.

It is highly possible that the increased Al retention due to the addition of soil to the ration resulted from a slow rate of soil passage through the digestive tract, for example, by soil settling to the bottom of the rumen. This effect would result in a gradual accumulation of soil in the digestive tract during periods of high soil intake and a gradual depletion of soil from the tract during periods of low soil intake. These two periods, respectively, would then have very high and very low Al retention values. Because the cows in this experiment grazed ryegrass pasture until mid-

October, their soil intake would have been high prior to the feeding study, as indicated by Fig. 1. During the first 20 days of the experiment no soil intake occurred, soil was perhaps excreted from the digestive tract, and resulting Al retention values were very negative. Later, when soil was added to the ration, it probably accumulated in the animals again, and the Al retention values became positive. This effect of slow rate of soil passage through the animals might have similarly influenced the cows that received $Al_2(SO_4)_3$, resulting in somewhat higher Al retention values (less negative) during days 31 to 40 than during days 11 to 20. Therefore, the higher Al retention values in $Al_2(SO_4)_3$ treated cows may be partially due to less soil excretion during the $Al_2(SO_4)_3$ feeding period than during the first 20 days when only the basic ration was fed. However, it should be emphasized that rate of soil passage through the cows was not measured in this study and, if such an effect did indeed occur, the duration and magnatude of the effect are unknown.

The general increase in retention of all measured elements that accompanied soil or $Al_2(SO_4)_3$ additions to the ration suggests there was no adverse affect on nutritional balance in the animals. The data are consistent with results of Grace & Healy (1974), showing that soil intake was associated with increased apparent availibility of Ca and Mg, and that soil intake provided supplemental Ca and Mg to diets low in these elements. Kappel et al. (1983) recently reported that increased Al levels in 20 cows during the grass tetany season did not significantly change plasma Mg levels, even though ruminal Al increased from 1600 to 4374 mg/kg. Cherney et al. (1983b) found that soil additions to ryegrass in an in vitro digestion system increased Ca and Mg concentrations in solution after 24 hours.

The data in Table 2 indicate that apparent availability of Mg and K was not significantly affected by either treatment. Apparent availability of P increased in each of the 3 cows that received soil and in 2 of the 3 cows receiving $Al_2(SO_4)_3$ in the ration but effects were not significant. Availability of Ca consistently increased in

Table 2. Influences of aluminum sulfate and soil in the ration on apparent availability of elements and apparent digestibility of organic matter (O.M.) in dry cows[1] (%).

Ration additive[2]	Elements					O.M.
	Mg	Ca	K	P	Al	
None	17	7.5	92	6.0	96	70.3
$Al_2(SO_4)_3$	14	11.7*	92	7.6	20**	70.3
None	13	6.6	91	6.0	67	69.3
Soil	15	11.2*	89	9.2	12*	70.0
C.V.%	13	15	1.4	21	34	0.5

[1] Each number is the average for 3 cows during a 10-day period.
[2] $Al_2(SO_4)_3$ supplied 1000 mg Al/kg of dry ration. Soil intake equalled 1 kg per cow per day.
* $P < 0.05$; ** $P < 0.01$.

each of the 6 cows when soil or $Al_2(SO_4)_3$ was added to the ration, resulting in significant treatment effects. The availability values obtained for Mg and K are within the ranges previously reported for lacating cows by Kemp & Geurink (1978), but are somewhat lower than they obtained for Ca and P. This difference is understandable because the cows in this experiment were non-lactating. Both soil and $Al_2(SO_4)_3$ additions resulted in significantly lower Al availability values. The high values for apparent availability of Al associated with the basic ration, plus the very low values obtained when $Al_2(SO_4)_3$ or soil was added to the basic ration, support the possibility that soil passage rate through the animals was slower than passage rate of the basic ration. Neither soil nor $Al_2(SO_4)_3$ influenced the apparent digestibility of organic matter in the ration. Cherney et al. (1983b) also showed no affect of soil on organic matter digestibility of ryegrass in vitro.

Investigations in Louisiana have consistently shown high Al levels in forage samples from tetany-producing pastures and in rumen content samples of hypomagnesaemia animals. The data presented here also show that high Al levels can occur in forage and rumen content samples from intensively grazed pastures in the Netherlands. The results agree with those of Cherney et al. (1983a) indicating that the Al source was soil contamination on the surface of the forage rather than Al uptake by the grass. Both studies also indicate that soil contamination on the forage, thus soil ingestion by grazing animals, occurred to the greatest extent under the same climatic conditions associated with the occurrence of hypomagnesaemia. Cherney et al. (1983a) showed that soil ingestion averaged about 95 g/kg of dry forage during periods of greatest contamination. That value is very similar to the 1 kg soil/10 kg dry ration supplied daily in the nutrient balance experiment reported here. However the soil ingested had no apparent adverse affects on Mg or Ca nutrition in the animals. The results suggest that soil ingestion would not adversely influence the development of hypomagnesaemia.

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