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A study of the effectiveness of calcined magnesite as a neutralizing agent for hydrochloric acid in the diet of sheep

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1. Five experimental diets were offered *ad lib.* for 21 d to five sheep in a 5 × 5 Latin-square design experiment as follows: pelleted grass meal alone (control); pelleted grass meal plus hydrochloric acid (470 mmol/kg dry matter (DM)); pelleted grass meal plus 470 mmol HCl/kg DM and either an equivalent amount of calcined magnesite (MgO) (235 mmol/kg DM) or twice the amount (470 mmol MgO/kg DM); pelleted grass meal plus 470 mmol MgO/kg DM.

2. MgO supplementation partly prevented the reduction in food intake caused by HCl, being more effective at the low than at the high level. When fed alone, the high level of MgO had a slight adverse effect on food intake.

3. There was no significant treatment effect on either the pH or volatile fatty acid concentrations of rumen fluid. MgO supplementation was only slightly effective in preventing the metabolic acidosis caused by HCl supplementation, as indicated by blood and urine acid–base measurements.

4. With the MgO-supplemented diets, values for the faecal and urinary excretion of magnesium were approximately 70 and 10% respectively of Mg intake and were not significantly affected by HCl supplementation. For rumen fluid, the water-soluble Mg concentration as a percentage of the total Mg concentration was similar for each treatment, approximately 90%. For faeces, the corresponding value was also similar for each treatment, approximately 30%.

5. MgO supplementation altered the effect of dietary HCl on faecal calcium excretion and on the balance of Ca, but did not alter its effect on urinary Ca excretion.

6. It is concluded that the beneficial effect of MgO supplementation on the intake of the HCl-treated diet was related more to its influence on dietary pH than on conditions in the rumen or the acid–base balance of the sheep.

The feeding of neutralizing agents with silage preserved with mineral acids has long been recommended (Lepard, Page, Maynard, Rasmussen & Savage, 1940). Calcium carbonate or limestone has been most widely used for this purpose, although in experiments with cattle it has been found to be only about half as effective as sodium bicarbonate (Brouwer, 1935; Mollgaard & Thorbek, 1938; King, 1943). These workers were concerned mainly with preventing the metabolic acidosis induced by the silage preserved with mineral acids. King (1943), however, found that after adequate neutralization of the silage its consumption increased rapidly.

Calcined magnesite (MgO) is widely used as a source of supplementary magnesium for cattle and sheep to prevent hypomagnesaemic tetany. The possibility of feeding MgO by incorporating it into silage was studied by Black (1966), who reported that at levels of 1·5 – 2·0 g/kg herbage, it was beneficial, but at higher levels it caused undesirable side effects in both the silage and the animals eating it. MgO has also been found to be as effective as $NaHCO_3$ for the maintenance of normal milk-fat

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Table 1. *Chemical composition (g/kg dry matter) of the pelleted grass meal given as the basal diet to sheep*

Proximate analysis		Mineral content	
Crude protein	184	Calcium	5·8
Diethyl ether extract	26	Magnesium	1·3
Crude fibre	188	Sodium	2·4
Ash	129	Potassium	28·2
Nitrogen-free extract	473	Chloride	18·1

content for cows given low-roughage diets (Emery, Brown & Bell, 1965; Thomas & Emery, 1966).

The widespread use of MgO in ruminant feeding, and also its much higher neutralizing value per unit weight than $CaCO_3$ suggested that a study of the potential of MgO as a neutralizing agent for silage preserved with mineral acids or their acid salts might be useful. It was therefore decided to study the effect of MgO supplementation using sheep given a pelleted grass-meal diet containing supplementary hydrochloric acid. Its effect on food intake, fermentation in the rumen, dry matter (DM) digestibility and acid–base balance was determined. In addition, its effect on Mg solubility in rumen fluid and faeces and on Mg and Ca absorption and excretion was studied.

EXPERIMENTAL

Animals. The sheep used were 2-year-old Cheviot wethers, which were housed in metabolism cages throughout the experiment.

Treatments. Pelleted dried-grass meal, the composition of which is shown in Table 1, was used as the basal diet. The pelleted grass meal was offered alone or supplemented with HCl and MgO as follows: basal only (control); basal plus 470 mmol HCl/kg DM; basal plus 470 mmol HCl/kg DM and equivalent amount of MgO (235 mmol/kg DM); basal plus 470 mmol HCl plus 470 mmol MgO/kg DM; basal plus 470 mmol MgO/kg DM. The HCl was added by pouring 300 ml 1·4 M-HCl onto 2 kg pelleted grass meal in a plastic container which was shaken thoroughly to ensure an even mixture. In treatments without HCl, distilled water (150 ml/kg) was added to the pelleted grass meal using the same procedure. The MgO, which was a fine powder containing 800 g magnesium oxide/kg, was added to each 2 kg batch of diet after addition of the HCl or distilled water and was mixed by shaking the plastic container.

Procedure. The five treatments were given to five sheep in a 5×5 Latin-square design experiment. The diets were offered *ad lib.* for 21 d, followed by a 7 d recovery period when they were offered the control diet *ad lib.*, before the next dietary treatment. Food intake was recorded daily and food residues were removed twice weekly. Distilled water was provided throughout the experiment and its intake recorded. Urine and faeces were collected and sampled using the procedures previously described (L'Estrange & Murphy, 1972). Blood samples from each animal were taken from the jugular vein at regular intervals during the experiment. The sampling and storage procedures were those previously described by L'Estrange & Murphy (1972). Rumen fluid samples were taken from each sheep at 14.00 hours on days 5 and 19 of each treatment period. The pH of whole rumen contents was measured immediately after sampling. The sample was then filtered through muslin cloth and stored at 2° and mercuric chloride was added as a preservative.

Analytical methods. The procedures used for the analysis of DM content of food, pH of blood, urine and rumen fluid, total carbon dioxide concentration for plasma, base excess (BE) status of blood, volatile fatty acid (VFA) content of rumen fluid, Ca and Mg contents of serum and of ashed food, faeces and urine samples, were those previously described by L'Estrange & Murphy (1972). Chloride contents of serum and urine and of 1·6 M-nitric acid extracts of food and faeces were determined using the method previously described by L'Estrange & McNamara (1975). Water-soluble Mg concentration for the rumen fluid was determined by adding 8 ml water to 2 ml rumen fluid, which was then centrifuged at 2000 rev./min for 10 min and the Mg content of the supernatant fraction was estimated. Water-soluble Mg concentration for the faeces was determined by adding 1 g fresh faeces to 10 ml water, boiling for 5 min and after centrifugation estimating the Mg content of the supernatant fraction. Acid-soluble Mg concentration for the rumen fluid and faeces was determined by substituting 1 M-HCl for water in the method described for the estimation of water-soluble Mg.

RESULTS

Dietary pH. The pH of the pelleted grass meal (diluted 1:5 (v/v) with distilled water) was lowered from 5·81 to 3·15 by HCl supplementation. MgO supplementation of the diet containing HCl increased the pH of the diet to 4·38 and 4·78 at the low and high levels of MgO respectively. MgO supplementation of the basal diet (equivalent to the high level of MgO supplementation of the HCl-containing diet) increased the pH to 6·52.

DM intake. From day 7 to day 21 of the treatment period, voluntary DM intake was decreased by HCl supplementation without added MgO to approximately 66% of the value for the basal diet (control) (Table 2). MgO supplementation of the HCl-containing diet increased DM intake to 84 and 75% of control value at the low and high MgO levels respectively; the increase was significant ($P < 0·05$) for the low level of MgO only. For the diet containing MgO at the high level, without supplementary HCl, DM intake was reduced to 87% of the control value, this reduction was not significant ($P > 0·05$). For each treatment DM intake during the first 7 d of treatment (Table 2) was similar to that during the subsequent 14 d, although the effect of HCl was not so great. During the 7 d recovery period DM intake increased rapidly to control values with no significant carry-over effects of treatment (Table 2).

Water intake and excretion. Daily water intake was not significantly affected by treatment ($P > 0·05$). Water intake/unit DM eaten (Table 2) was significantly higher for the diet containing HCl without added MgO than for the control diet ($P < 0·05$), and was intermediate between those for the other treatments. Urine volume (Table 2) was significantly higher for the diet containing HCl and the low level of supplementary MgO than for the other treatments ($P < 0·05$).

Table 2. *Dry matter* (DM) *intake, organic matter (OM) digestibility, water intake, urine volume and moisture content of faeces for sheep given pelleted grass meal alone*† *(control) or supplemented with hydrochloric acid or calcined magnesite (MgO) or both*

(Mean values for five sheep/treatment. The five diets were given to five sheep in a 5 × 5 Latin-square design experiment, in which each of the diets was offered *ad lib.* for 21 d, followed by a 7 d recovery period when they were offered the control diet *ad lib.*, before the next dietary treatment)

	Control	+470 mmol HCl/kg DM	+470 mmol HCl and 235 mmol MgO/kg DM	+470 mmol HCl and 470 mmol MgO/kg DM	+470 mmol MgO/kg DM	SE of treatment mean	*F* test
pH of diets‡	5·81	3·15	4·38	4·78	6·52	—	—
DM intake (g/kg live wt$^{0.75}$ per d)							
Days 0–7	84·0	60·6	69·7	69·1	74·4	4·7	*
Days 7–21	84·0	51·1	71·3	62·7	74·4	3·7	**
7 d recovery period	90·9	82·4	88·3	106·9	88·3	5·8	NS
OM digestibility (days 7–21)	0·60	0·68	0·60	0·61	0·60	0·02	*
Water intake (days 7–21)							
l/d	5·6	4·7	5·7	5·1	5·7	0·38	NS
l/kg DM eaten	3·5	4·8	4·3	4·3	4·1	0·30	*
Urine volume (l/d) (days 7–21)	2·22	2·58	2·91	2·14	2·27	0·17	*
Moisture content of faeces (g/kg) (days 7–21)	690	603	712	733	748	23	**

NS, not significant ($P > 0{\cdot}05$); * $0{\cdot}05 > P > 0{\cdot}01$; ** $0{\cdot}01 > P > 0{\cdot}001$.

† Prepared as for HCl-supplemented diets, using distilled water instead of HCl. For details, see p. 234.

‡ Diluted 1:5 (v/v) with distilled water.

The moisture content of faeces (Table 2) was significantly lower for the diet containing HCl without added MgO than for the other treatments ($P < 0{\cdot}01$). MgO supplementation, particularly at the higher level (both with and without HCl), increased the moisture content of faeces above the control value but the difference was not significant ($P > 0{\cdot}05$). It may be noted that scouring was not observed in the sheep when they were given MgO-supplemented diets.

Organic matter digestibility. Organic matter digestibility was significantly higher ($P < 0{\cdot}05$) for the diet containing HCl without added MgO than for the other treatments, which had very similar values (Table 2).

pH and VFA in rumen fluid. The pH of rumen fluid was lower, by about 0·2 units, for the diet containing HCl without added MgO than for the other treatments, but this difference was not significant ($P > 0{\cdot}05$); the average value for all treatments was 6·72. There was no significant treatment effect on total VFA concentration, which averaged 86·3 mmol/l for all treatments. The molar proportions of individual VFA for rumen fluid were also not significantly affected by treatment; average values for acetic, propionic, isobutyric, butyric, isovaleric and valeric were 688, 144, 24·2, 107, 27·8 and 10·8 mmol/mol respectively.

Acid–base balance. The diet containing HCl without added MgO significantly lowered plasma total CO_2 concentration ($P < 0{\cdot}001$) and blood BE status ($P < 0{\cdot}01$) but did not significantly affect blood pH ($P > 0{\cdot}05$) (Table 3). MgO supplementation of the diet containing HCl did not significantly affect blood pH, plasma total CO_2 concentration or blood BE status ($P > 0{\cdot}05$) and, therefore, was not effective in preventing the metabolic acidosis caused by HCl in the diet.

For the urine, the diet containing HCl without added MgO significantly lowered pH and bicarbonate excretion and increased the excretion of ammonia-nitrogen and Ca (Table 3). When the HCl-containing diet was supplemented with MgO there was no significant change in the effect of the HCl on urine pH or urinary Ca excretion but, at the high level of MgO supplementation, ammonia-N excretion was reduced and at both levels of MgO, bicarbonate excretion was increased. The urine, which was alkaline when the sheep were given the pelleted grass meal alone, was not made more alkaline by MgO supplementation.

Minerals in serum. The serum Mg concentration was increased by MgO supplementation by about 0·08 mmol/l, both with and without HCl supplementation, while the serum Ca concentration was not affected by treatment (Table 3).

Intake, excretion and balance of Mg. While MgO supplementation resulted in a very large increase in Mg intake, the amount consumed was about 20% less than it would have been if the supplement had been eaten uniformly with the rest of the DM. This was due to a tendency for the supplement to fall to the bottom of the food container and accumulate in the food residue.

The metabolism of Mg was similar for both the control diet and the diet containing HCl without added MgO; faecal Mg excretion was approximately the same as the intake, resulting in a small negative balance due to Mg excretion in the urine (Table 4). The metabolism of Mg for MgO-supplemented diets was considerably different from that for the control diet. Over all, excretion in the faeces accounted for about 70% of

Table 3. *Effects of treatment on blood acid–base balance, serum calcium and magnesium concentrations and urinary acid–base excretion for sheep given pelleted grass meal alone*† *(control) or supplemented with hydrochloric acid or calcined magnesite (MgO) or both*

(The five diets were given to five sheep in a 5 × 5 Latin-square design experiment, in which each of the five diets was offered *ad lib.* for 21 d, followed by a 7 d recovery period when they were offered the control diet *ad lib.*, before the next dietary treatment)

	Control	+470 mmol HCl/kg DM	+470 mmol HCl and 235 mmol MgO/kg DM	+470 mmol HCl and 470 mmol MgO/ kg DM	+470 mmol MgO/kg DM	SE of treatment mean	*F* test
Blood measurements‡							
Blood pH	7·41	7·40	7·40	7·40	7·42	0·03	NS
Plasma carbon dioxide (mmol/l)	24·9	22·4	22·8	23·6	25·4	0·37	***
Blood base excess (mmol/l)	−0·48	−2·67	−2·38	−2·18	−0·08	0·39	**
Serum: Mg (mmol/l)	0·72	0·74	0·79	0·80	0·78	0·02	*
Ca (mmol/l)	1·89	1·95	1·98	1·97	1·94	0·05	NS
Urine measurements§							
pH	8·83	5·94	6·16	6·43	8·00	0·07	***
Bicarbonate (mmol/d)	938	90	411	478	701	151	*
Ammonia-nitrogen (mmol/d)	37	65	68	36	26	9·3	*
Ca (mmol/d)	6·9	33·2	52·8	39·4	5·6	7·0	*

NS, not significant ($P > 0·05$); * $0·05 > P > 0·01$; ** $0·01 > P > 0·001$; *** $P < 0·001$.

† Prepared as for HCl-supplemented diets, using distilled water instead of HCl. For details see p. 234.

‡ Mean values for samples taken on days 4, 8, 14 and 20 from the five sheep for each treatment.

§ Mean values from results for days 7–21 for five sheep/treatment.

Table 4. *Intake, and faecal and urinary excretion of magnesium, calcium and chloride for days 7–21 of each treatment period for sheep given pelleted grass meal alone† (control) or supplemented with hydrochloric acid or calcined magnesite (MgO) or both*

(Mean values for five sheep/treatment. The five diets were given to five sheep in a 5 × 5 Latin-square design experiment, in which each of the diets was offered *ad lib.* for 21 d, followed by a 7 d recovery period when they were offered the control diet *ad lib.*, before the next dietary treatment)

	Control	+470 mmol HCl/kg DM	+470 mmol HCl and 235 mmol MgO/kg DM	+470 mmol HCl and 470 mmol MgO/kg DM	+470 mmol MgO/kg DM	SE of treatment mean	*F* test
Mg							
Intake (g/d)	2·66	1·51	7·56	9·71	11·3	—	—
Faecal: g/d	2·74	1·45	5·33	6·13	7·25	0·74	***
% of intake	102	97·2	73·2	70·6	67·0	5·1	***
Urinary: g/d	0·39	0·39	0·93	0·82	0·83	0·07	***
% of intake	14·4	26·4	12·8	10·7	7·7	2·65	**
Balance (g/d)	−0·46	−0·33	1·30	2·77	3·19	0·64	**
Ca							
Intake (g/d)	9·30	5·51	7·87	7·00	8·22	—	—
Faecal (% of intake)	97·6	85·2	95·6	94·2	98·6	1·42	***
Urinary (% of intake)	1·57	13·0	12·9	10·9	1·46	1·60	***
Balance (g/d)	0·09	0·07	−0·67	−0·42	−0·01	0·23	NS
Cl^-							
Intake (g/d)	34·9	32·8	43·7	43·1	27·6	—	—
Faecal (% of intake)	2·7	1·2	3·8	2·6	6·0	0·48	***
Urinary (% of intake)	94	92	91	83	101	3·8	NS
Balance (g/d)	1·7	2·2	0·4	4·2	−1·4	0·62	NS

DM, dry matter; NS, not significant ($P > 0·05$); ** $0·01 > P > 0·001$; *** $P < 0·001$.

† Prepared as for HCl-supplemented diets, using distilled water instead of HCl. For details, see p. 234.

the intake, while excretion in the urine accounted for about 10% of the intake, resulting in a positive balance. HCl supplementation had no apparent effect on the metabolism of the supplementary Mg.

The excretion of Mg during the first 7 d of each treatment period and during the 7 d recovery period was also studied. For the MgO-supplemented diets the increase in both faecal and urinary excretion of Mg occurred within about 4 d of the introduction of the supplement. During the recovery period following the MgO-supplemented diets, Mg excretion in urine and faeces decreased to the control level within about 2 and 4 d respectively. In the absence of supplementary MgO the excretion of Mg in the urine and faeces was fairly uniform throughout the period studied.

Solubility of Mg in rumen fluid and faeces. The solubility of Mg in rumen fluid was measured in samples taken at 14.00 hours from two sheep for each treatment. The mean concentration of Mg was approximately similar for the control and HCl-supplemented diets (62 mg/l). The concentration was increased up to 3-fold by MgO supplementation; the treatment effect was significant ($P < 0{\cdot}01$). However, the proportion which was either water-soluble or acid-soluble was not significantly affected by treatment, and was about 90 and 100% respectively. In faeces collected on days 7–21 from five sheep/treatment, the mean Mg concentration was increased significantly ($P < 0{\cdot}01$) by MgO supplementation, values were 2- to 3-fold those for the diet containing no supplementary MgO. However, as for rumen fluid, the proportion of water-soluble and acid-soluble Mg was not significantly affected by treatment, averaging 30 and 86% respectively.

Intake, excretion and balance of Ca. With the control diet, approximately 98% of dietary Ca was excreted in faeces and 1·5% in urine (Table 4). The diet containing MgO alone did not affect this pattern. The HCl-supplemented diet (without MgO) increased the urinary Ca level to 13% of intake and reduced the faecal Ca level to 85% of intake. MgO supplementation of diets containing HCl did not result in a decrease in the high output of urinary Ca but caused, however, an increase in faecal excretion of Ca to approximately 95% of the control value and, therefore, resulted in a negative balance of Ca.

Intake, excretion and balance of Cl^-. As the Cl^- content of the basal pelleted grass meal was high, intake of Cl^- was not very substantially increased by HCl supplementation (Table 4). The excretion in urine and the balance of Cl^- were not significantly affected by treatment ($P > 0{\cdot}05$). Cl^- excretion in faeces as a percentage of intake was decreased by HCl supplementation alone but was increased by MgO supplementation.

DISCUSSION

The effect of HCl supplementation on voluntary food intake of the sheep in this experiment was of the same order as that caused by the same level of HCl supplementation in a previous experiment (L'Estrange & McNamara, 1975). MgO added to the HCl-supplemented diet was more effective in preventing the decrease in food intake when it was added at a level equivalent to that of HCl than when it was added at twice that level. The finding that when given alone the high level of MgO supplementation reduced the intake of the pelleted grass meal probably explains this effect.

The extent of metabolic acidosis caused by HCl supplementation alone was also of the same order as that obtained in a previous experiment, using a similar level of supplementation (L'Estrange & McNamara, 1975). MgO supplementation, surprisingly, was not effective in restoring blood acid–base status and urine acid–base excretion of the animals, and it proved much less efficient in counteracting acidosis in this study, than either $NaHCO_3$ or limestone when these were used as neutralizing agents for silage which was preserved with mineral acids and fed to cattle (King, 1943).

The low efficiency of MgO in countering acidosis may be accounted for by its low availability. Supplementation with HCl alone caused only a slight decrease in rumen fluid pH, as previously reported by L'Estrange & Murphy (1972) and L'Estrange & McNamara (1975), and MgO supplementation also had very little effect on the pH of rumen fluid, in agreement with results obtained by Emery *et al.* (1965) for the dairy cow. It may be concluded, therefore, that the increase in food intake obtained with the HCl-treated diet when these were supplemented with MgO resulted mainly from the effect of MgO on the pH of the HCl-treated diet. This is further evidence that the adverse effect of dietary HCl on food intake of sheep can be accounted for mainly by reduced palatability of the diet associated with low dietary pH, rather than by a disturbance of acid–base metabolism (L'Estrange & McNamara, 1975).

The increase in organic matter digestibility associated with HCl supplementation of the pelleted grass meal is in agreement with previous results (L'Estrange & Murphy, 1972). It was probably a result of the lower DM intake for this treatment as MgO supplementation of the HCl-treated diet, while increasing DM intake, resulted in a decrease in organic matter digestibility. It has previously been reported that MgO supplementation of the diet does not adversely affect DM digestibility in cattle (Moore, Fontenot & Tucker, 1971).

The effects of the high level of MgO supplementation used in this experiment are of interest also in relation to the widespread feeding of this material to cattle and sheep to prevent hypomagnesaemic tetany. The amount provided at the high level of supplementation used in our study was somewhat higher than that generally recommended for sheep, which is approximately 4·5–9·0 g Mg/sheep per d. In a previous study (Black, 1966), it was found that the addition of 5·3 kg MgO/ton fresh herbage before ensilage, which raised the Mg content of the DM to 13·1 g/kg, caused severe scouring in sheep. In this experiment, the level of Mg in the DM for the high-MgO treatments was 10·9 g/kg, which, although it increased the moisture content of faeces, did not cause scouring problems, probably because dried-grass meal rather than silage was the basal diet. The proportion of the supplementary Mg that was excreted in urine was similar to that obtained by Black (1966) for MgO supplementation of silage at similar levels. In this experiment, the availability of Mg from the basal diet as well as from the supplementary MgO was low, although there was a very high proportion of water-soluble Mg in the rumen. In view of the recent reports that the reticulo-rumen is the most important site for the absorption of Mg in the ruminant (Rogers & Van'T Klooster, 1969; Strachan & Rook, 1974), these results indicate that the low availability of Mg to ruminants given grass-based diets is due to factors affecting its transport across the rumen wall rather than its solubility in rumen fluid.

The increase in urinary Ca excretion caused by HCl supplementation alone was similar to that previously reported for sheep given diets supplemented with mineral acids or their acid salts (L'Estrange, 1970; L'Estrange & Murphy, 1972). In this experiment, the increase in urinary Ca excretion was accompanied by a decrease in faecal Ca excretion and no change in the balance of Ca, whereas in the previous experiment (L'Estrange & Murphy, 1972) faecal Ca was not reduced and its balance was accordingly changed. In this experiment, when MgO was added to the diet together with HCl, urinary Ca remained high but the percentage excreted in faeces was not reduced, and the balance of Ca in this instance was changed. In the literature there is general agreement that mineral acid-loading of animals leads to increased Ca excretion in urine, but whether this results from increased absorption of Ca from the intestine or from an increase in resorption of Ca from bone is not clear (Braithwaite, 1972). The results here indicate that dietary factors such as the level of Mg in the diet may influence whether acid-loading leads to increased absorption from the intestine or to increased resorption from bone.

Over all, it may be concluded from this experiment that MgO could only be used effectively as a neutralizing agent for silage preserved with mineral acids if it was thoroughly mixed into the silage before feeding, at a level approximately equivalent to that of the mineral acid added.

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