Effects of dietary hydrochloric acid on voluntary food intake and metabolism of sheep in relation to the use of mineral acids as silage additives

By J. L. L'ESTRANGE AND T. McNAMARA*

Department of Agricultural Chemistry, University College Dublin, Glasnevin, Dublin 9, Republic of Ireland

(*Received* 28 *October* 1974 – *Accepted* 7 *January* 1975)

1. In Expt 1, a pelleted grass-meal diet was supplemented with hydrochloric acid, added to the grass pellets before feeding, at five levels from 0 to 628 mmol/kg dry matter (DM). Each diet was offered *ad lib.* for 21 d to five sheep in a 5 × 5 Latin-square design.

2. Voluntary food intake decreased rectilinearly with increasing HCl supplementation ($P < 0.001$), to 42 % of the control value for sheep on the high-HCl diet. The decrease in food intake was related both to dietary pH and to the extent of metabolic acidosis induced by the HCl treatment. Although the pH of rumen fluid decreased slightly with increasing HCl supplementation, effects of the HCl treatment on volatile fatty acid concentrations in rumen fluid were not significant ($P > 0.05$).

3. In Expt 2, palatability and metabolic effects of dietary HCl were studied by comparing its effect when mixed into the pelleted grass meal before feeding, with and without a supplement of an equivalent amount of sodium bicarbonate given intraruminally, or when HCl was given intraruminally while the sheep consumed pelleted grass meal alone. Each of the three treatments was given at two levels of HCl, 280 and 560 mmol/kg DM. At each level of dietary HCl supplementation, the three treatments and the control diet (pelleted grass meal alone) were each given to four sheep, in a Latin-square design, for 11 d.

4. At the low level of supplementation, HCl, when mixed into the pelleted grass meal, reduced food intake by 17 %, this effect was not altered by $NaHCO_3$ supplementation, but when HCl was given intraruminally food intake was not reduced. At the high level of HCl supplementation, food intake was reduced by about 40 % by each method of HCl supplementation; and $NaHCO_3$ supplementation did not appreciably alter the effect of HCl on food intake, but prevented metabolic acidosis associated with the HCl treatments. Food intakes for the low-HCl treatments were significantly higher than those for the high-HCl treatments ($P < 0.01$) and the level of dietary HCl × treatment interaction was also significant ($P < 0.01$). DM digestibility, and the pH and volatile fatty acid concentrations of rumen fluid were not significantly affected by the different treatments.

5. It is concluded that at a low level of HCl supplementation the adverse effects of dietary HCl on voluntary food intake of sheep is determined by palatability associated with low dietary pH, whereas at a high level of HCl supplementation the effect is determined by palatability and by a metabolic response.

It has been reported previously that supplementation of a pelleted grass-meal diet with the mineral acids, hydrochloric and sulphuric, and the acid salts, ammonium bisulphate and sodium bisulphate, in amounts similar to that used in the 'AIV' method of ensilage (Virtanen, 1933), caused an adverse effect on voluntary food intake of sheep (L'Estrange, Clarke & McAleese, 1969; L'Estrange & Murphy, 1972). In the experiment described here the effects of mineral acids on food intake of sheep were further studied. HCl rather than sulphates was used, as the results of earlier work had indicated that with the latter a secondary factor affecting food intake was

* Present address: The Valuation Office, Department of Finance, 6 Ely Place, Dublin 2, Republic of Ireland.

the sulphate content (L'Estrange, Upton & McAleese, 1972; Upton, L'Estrange & McAleese, 1972).

The three most likely ways by which excess HCl in the diet may affect food intake are: (*a*) reduced palatability associated with dietary pH; (*b*) a disturbance of metabolism in the rumen associated with a decrease in the pH of rumen fluid; (*c*) a disturbance of the blood acid–base balance.

In a previous experiment (L'Estrange & Murphy, 1972) it was found that food intake of sheep decreased gradually for several days after the introduction of HCl into the diet. This suggests that a metabolic disturbance was more important than palatability in affecting food intake, if it is assumed that lowered palatability would have an immediate effect on food intake, but a metabolic disturbance would have a more gradual effect.

With reference to conditions in the rumen, it has been reported by Baile & Mayer (1968) that the appetite satiety mechanism of ruminants involves a receptor on the lumen side in the reticulo-rumen. An effect of rumen fluid pH on voluntary food intake has been shown by Bhattacharya & Warner (1967), who reported that for steers, intraruminal infusions of lactic, citric or phosphoric acids, sufficient to maintain the pH of rumen fluid at 0·6 units below control values, caused a 50–70% reduction in food intake. It has been reported also by several workers (e.g. Montgomery, Schultz & Baumgardt, 1963) that the adverse effect of volatile fatty acids (VFA) infused intraruminally is much greater when these are given as the free acids than when they are given as the neutral salts. There has not been an adequate explanation of this difference, but the absence of any effect of the free acids on the blood acid–base balance (Montgomery *et al.* 1963) suggests that it is probably associated with changing conditions in the rumen.

In the previous study with mineral acid-treated diets fed to sheep (L'Estrange & Murphy, 1972), it was found that HCl caused only a very small change in the pH of rumen fluid and did not alter the concentrations of VFA in the rumen fluid. A more noticeable metabolic change caused by the acid treatment of the diet was its induction of a chronic form of metabolic acidosis in the sheep, which developed gradually for several days after the introduction of the acid-treated diet and which quickly disappeared when this diet was withdrawn. It was concluded, therefore, that the metabolic acidosis, rather than a disturbance of rumen conditions was more likely to be the cause of the reduction in food intake.

It seemed desirable, therefore, to study more fully the effect of HCl on food intake of sheep in relation to palatability, changes in rumen conditions and metabolic disturbance. It was hoped that the results would give further information about the mechanism by which mineral acids affect food intake of ruminants, and also help to clarify the general problem of low voluntary consumption of silage by ruminants.

In the first experiment the relationship between the level of HCl added to a pelleted grass-meal diet, and food intake and metabolic changes was studied. In the second experiment, palatability and metabolic effects of dietary HCl were studied separately, by comparing the effects of the acid when it was fed mixed into the pelleted grass

Table 1. *Chemical composition (g/kg dry matter) of the pelleted grass meal given as the basal diet to sheep in Expts 1 and 2*

	Batch*	
	a	b
Proximate analysis		
Crude protein	184	147
Diethyl ether extract	26	26
Crude fibre	188	240
Ash	129	86
Nitrogen-free extract	473	401
Mineral content		
Calcium	5·8	5·6
Magnesium	1·3	1·4
Sodium	2·4	2·1
Potassium	28·2	38·1
Chloride	18·1	15·1

* Batch a was used for Expt 1 and the first half of Expt 2 and batch b was used for the second half of Expt 2.

meal or when it was given in solution intraruminally, and by studying also the effects of intraruminal administration of sodium bicarbonate on the intake of pelleted grass meal containing added HCl. Preliminary reports of these studies have already been presented (L'Estrange, 1972; L'Estrange & McNamara, 1973).

MATERIALS AND METHODS

Expt 1

Animals. Five 2-year-old Cheviot wethers weighing about 50 kg were used and were housed in metabolism cages throughout the experiment. They were fitted with permanent rumen cannulas.

Treatments. A basal diet of pelleted grass meal, the composition of which is shown in Table 1, was supplemented with HCl at five different levels: 0, 157, 314, 470 and 628 mmol/kg dry matter (DM). Batches of the experimental diets were prepared by pouring 300 ml of a solution containing the appropriate amount of HCl onto 2 kg pelleted grass meal in a plastic container and mixing thoroughly. The control diet was prepared by diluting the pelleted grass meal to the same extent using distilled water.

Procedure. The five diets were fed to five sheep in a 5×5 Latin-square design experiment. Each of the experimental diets was offered *ad lib.* for 21 d, followed by a 7 d recovery period when the control diet was offered *ad lib.*, before the next dietary treatment. Food intake was recorded daily, and food residues were withdrawn and dried twice weekly for the measurement of DM intake. Distilled water was provided throughout the experiment and its intake was recorded.

Blood samples were taken from the jugular vein of each sheep at 14.00 hours on days 4, 8, 12, 16 and 20 of each treatment period for acid–base and mineral analysis. Rumen fluid samples were taken through the rumen cannulas at 10.00, 12.00, 14.00

and 16.00 hours on days 3 and 17 of each period, for pH and VFA analysis, using the methods previously described by L'Estrange & Murphy (1972).

Expt 2

Animals. Eight 2–3-year-old Cheviot wethers were used, including four animals which were fitted with permanent rumen cannulas and which had taken part in Expt 1, and were housed in metabolism cages throughout the experiment.

Treatments. A basal diet of pelleted grass meal, the composition of which is shown in Table 1, was supplemented with dietary HCl at two levels: 280 and 560 mmol/kg DM. At each level of dietary HCl there were four treatments, as follows: (A) HCl mixed into the pelleted grass meal before feeding by pouring 250 ml 2 M- or 4 M-HCl onto 2 kg pellets as in Expt 1; (B) HCl given intraruminally through a stomach tube in four equal portions during the day while the sheep were offered the pelleted grass meal to which water had been added (250 ml/2 kg). The amount of HCl infused was based on the DM intake for the previous day; (C) HCl added to the pelleted grass meal as for treatment A but with $NaHCO_3$ given intraruminally through a stomach pump in four equal portions during the day. The amount of $NaHCO_3$ infused was equivalent to the amount of HCl intake for the previous day, calculated from DM intake; (D) control, i.e. the basal diet of pelleted grass meal to which water had been added (250 ml/2 kg).

Procedure. The four treatments at each level of dietary HCl were given to four sheep in a 4×4 Latin-square change-over design experiment. Two of the sheep in each 'Latin-square' were fitted with permanent rumen cannulas. Each of the experimental diets was given for 11 d, followed by a 3 d recovery period when they were given the control diet, before the next set of treatments. For each treatment the pelleted grass meal, with added HCl or water, was offered *ad lib.* from 09.30 to 17.00 hours. Food intake was recorded daily throughout the experiment. In addition, on day 4 food intake was recorded at intervals during the day to study the treatment effect on the pattern of eating during the day. Urine and faeces were collected and sampled from the two non-fistulated animals in each 'Latin-square' as previously described (L'Estrange & Murphy, 1972). The pH of urine was recorded daily and the composite samples of urine and faeces were kept for subsequent analysis. Rumen fluid samples were taken from the two fistulated animals in each 'Latin-square' at 10.00, 11.30 and 15.00 hours on day 11, and blood samples from the jugular vein were taken from the four sheep in each 'Latin-square' at 10.00, 11.30 and 15.00 hours on day 9 or 10 as previously described (L'Estrange & Murphy, 1972).

Analytical methods

The procedures used for the analysis of the DM content of food and faeces; pH of blood, urine and rumen fluid; total carbon dioxide concentration for plasma and urine; base excess (BE) status of blood; calcium, magnesium and sodium contents of the food and serum, and Ca concentration for the urine, were those previously described (L'Estrange & Murphy, 1972). The chloride concentration for serum was determined by titration with silver nitrate using a Radiometer system (Radiometer

A/S, 72 Emdrupvej, Copenhagen NV, Denmark) incorporating an automatic titration unit (type SBR 2) connected to a pH meter (type pH M26) with an Ag electrode (type P 401) and a mercuric sulphate electrode (type K 601) coupled to an automatic burette (type ABU-12). The Cl^- content of the food was determined by the same method, using an extract obtained by mixing 0·3 g oven-dried food with 25 ml 1·6 M-nitric acid.

RESULTS

Expt 1

The five sheep remained apparently healthy throughout the experiment.

Live-weight changes. There was a significant treatment effect ($P < 0·01$) on live-weight gain during the experimental period (Table 2). Animals given the control diet and the diet with the low level of HCl supplementation gained weight, but those given the treatments with the higher intake of HCl lost weight; the amount increased progressively as the level of HCl supplementation increased.

DM intake. DM intake was significantly affected by treatment ($P < 0·01$); intake decreased progressively as the level of supplementary HCl increased, reaching only 42% of the control value at the high level of HCl supplementation (Table 2). Intake, where affected, decreased progressively during the first 7 d of treatment and then was fairly constant. During the recovery period, food intake increased immediately after withdrawal of the HCl-supplemented diets, although a slight and non-significant ($P > 0·05$) carry-over effect was found following the high levels of HCl supplementation (Table 2). The results shown in Table 2 also suggest that the rectilinear decrease in food intake as the level of dietary HCl increased, which was significant ($P < 0·001$), was closely paralleled to a corresponding decrease in dietary pH.

Water intake. Daily water intake progressively decreased as the level of HCl supplementation increased; however, water intake/unit weight of food eaten was not significantly affected by HCl treatment (Table 2).

pH and VFA content of rumen fluid. The mean pH of rumen fluid decreased as the level of dietary HCl increased from 6·55 for animals given the control diet to 6·27 for animals given the diet with the high level of HCl supplementation; however, the treatment effect was not significant ($P > 0·05$). There was no significant treatment effect ($P > 0·05$) on total VFA concentration, which averaged 94·6 mmol/l for the five treatments, or on the molar proportion of individual VFA which averaged for acetic, propionic, isobutyric, butyric, isovaleric, and valeric; 675, 159, 21, 113, 20 and 13 mmol/mol total VFA respectively. Although pH, total VFA concentrations and molar proportions of propionic, isobutyric and isovaleric acids were each significantly affected by time of sampling during the day ($P < 0·01$), the time of sampling × treatment interaction for each was not significant ($P > 0·05$).

Blood acid–base status. As the level of dietary HCl increased there was a gradual decrease in mean blood pH, plasma CO_2 concentration and blood BE status (Table 2). The treatment effect on blood pH was not significant ($P > 0·05$). Plasma CO_2 concentration was significantly affected by treatment ($P < 0·05$), decreasing from a mean value of 28·0 (control) to 24·8 mmol/l for animals given the high-HCl treatment.

Table 2. *Expt* 1. *Live-wt change, dry matter* (DM) *intake, water intake and blood acid–base and mineral concentrations for sheep given pelleted grass meal alone*† *(control) or supplemented with hydrochloric acid at different levels*

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

	Level of HCl added (mmol/kg DM)					SE of treatment mean	*F* test
	0	157	314	470	628		
pH of diets‡	5·76	4·72	3·71	2·87	2·60	—	—
Live-wt change (g/d) (days 0–21)	177	221	−48	−113	−143	44·3	**
DM intake (g/kg $^{0.75}$ per d)							
Days 0–7	92·0	75·5	74·5	57·4	52·6	5·3	**
Days 7–21	93·1	83·0	60·0	47·3	38·3	6·9	**
7 d recovery period	88·9	91·5	82·4	76·6	77·1	6·3	NS
Water intake (days 7–21)							
l/d	6·1	5·2	5·2	3·4	3·1	0·40	**
l/kg DM eaten	3·6	3·2	4·9	3·8	5·0	0·65	NS
Blood measurements§							
Blood pH	7·43	7·43	7·41	7·41	7·39	0·01	NS
Plasma carbon dioxide (mmol/l)	28·0	27·3	26·3	26·0	24·8	0·52	*
Blood base excess (mmol/l)	2·16	1·70	0·36	0·26	−1·20	0·73	**
Serum: Calcium (mmol/l)	2·08	2·10	2·08	2·05	2·08	0·04	NS
Magnesium (mmol/l)	0·77	0·77	0·72	0·70	0·78	0·11	**
Chloride (mmol/l)	112	111	108	112	110	1·58	NS

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

† Prepared as for the HCl-supplemented diets, using distilled water instead of HCl. For details, see p. 223.

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

§ Mean value for samples taken at 14.00 hours on days 4, 8, 12, 16 and 20 from the five sheep on each treatment.

Blood BE status was also significantly affected by treatment ($P < 0.01$), decreasing from a mean value of 2·16 (control) to −1·2 mmol/l for animals given the high-HCl treatment. The day of sampling × treatment interaction was not significant for blood pH, plasma CO_2 concentration or blood BE status ($P > 0.05$). During the recovery period the values for these measurements returned to those for the control animals within 3 d.

Mineral content of serum. There was no significant treatment effect on the concentration of Ca or Cl^- for serum (Table 2). The concentration of Mg for serum was, however, significantly affected by HCl treatment ($P < 0.01$), values generally decreasing as dietary HCl increased, except for animals given the high-HCl treatment (Table 2).

Expt 2

The eight sheep remained apparently healthy throughout this experiment.

DM intake. At the low level of supplementation HCl, when mixed into the pelleted grass meal, caused a decrease in DM intake of 17% of the control value, an effect which was not appreciably altered by $NaHCO_3$ supplementation (Table 3). However, at this level, HCl given intraruminally did not significantly affect DM intake. At the high level of supplementation, HCl mixed into the pelleted grass meal caused a decrease in intake of 48% of the control value, an effect which was not significantly altered by $NaHCO_3$ supplementation. At this level of supplementation, HCl given intraruminally caused a decrease in DM intake of 42% of the control value. Over all the level of HCl supplementation, and the level of HCl supplementation × treatment interaction, each significantly affected food intake ($P < 0.01$).

Variation in daily food intake during the 11 d on the control diet and on treatments where HCl was added to the pelleted grass meal was very similar to that for the same treatments in Expt 1. However, the intake of animals given intraruminal HCl at the high level fluctuated more widely, as the HCl intake for each day was based on DM intake on the previous day and consequently could be too high or too low in relation to the DM eaten on the same day. The pattern of eating during the day was similar for all treatments; approximately two-thirds of the food was eaten during the first 2·5 h of feeding, and the effect of treatment was fairly constant throughout the 7·5 h feeding period.

DM digestibility. DM digestibility values for all treatments were higher than the control value, although the differences were not significant ($P > 0.05$) (Table 3).

pH and VFA contents of rumen fluid. The pH of rumen fluid (Table 3), which averaged 6·45 for all treatments, was not significantly affected by treatment, although the mean pH value obtained when HCl was given intraruminally at the high level was lower than that for the other treatments. Treatment effect on the total VFA concentration for rumen fluid was not significant ($P > 0.05$); the mean value for all treatments was 73·1 mmol/l. The molar proportions of individual VFA also were not significantly affected by treatment ($P > 0.05$), average values for all treatments for acetic, propionic and butyric acids were: 677, 180 and 126 mmol/mol respectively. It should be noted, however, that as rumen fluid samples were taken from two animals only for

Table 3. *Expt 2. Mean dry matter (DM) intake, blood acid–base status, mineral concentrations for serum, and pH and calcium concentration for urine, for sheep given pelleted grass meal alone† (control) or supplemented with hydrochloric acid at a level of 280 (L) or 560 (H) mmol/kg DM eaten, either mixed in the diet or administered intraruminally, with or without intraruminal administration of sodium bicarbonate*

(The four treatments at each level of dietary HCl were given to four sheep in a 4 × 4 Latin-square change-over design experiment. Two of the sheep in each 'Latin-square' were fitted with permanent rumen cannulas. The experimental diets were given for 11 d, followed by a 3 d recovery period when they were given the control diet, before the next set of treatments)

	Control		+HCl		With intraruminal HCl		+HCl with intraruminal $NaHCO_3$††		SE of treatment mean	*F* test		
	L	H	L	H	L	H	L	H		Treatment	HCl level	HCl level × treatment
pH of diets‡	5·6	5·6	4·4	3·2	5·6	5·6	4·4	3·2	—	—	—	—
DM intake§ (g/kg $^{0.75}$ per d)	81·9	84·0	68·1	43·6	79·8	48·4	71·3	52·0	3·08	***	**	**
DM digestibility‖ (days 5–11)	0·58	0·62	0·61	0·64	0·63	0·68	0·65	0·66	0·02	NS	NS	NS
Blood measurements¶												
Blood pH	7·40	7·41	7·34	7·35	7·36	7·28	7·41	7·44	0·02	**	NS	NS
Plasma carbon dioxide (mmol/l)	25·4	28·9	24·1	25·2	22·9	20·8	29·1	29·2	1·39	***	NS	*
Blood base excess (mmol/l)	−0·7	2·2	−3·5	−1·8	−3·2	−7·0	2·5	3·5	0·60	***	NS	NS
Serum: Na (mmol/l)	170	174	167	173	164	168	164	169	2·67	NS	NS	NS
Ca (mmol/l)	2·18	2·08	2·13	2·08	2·13	2·10	2·08	2·13	0·28	NS	NS	NS
Magnesium (mmol/l)	0·74	0·84	0·71	0·72	0·71	0·76	0·70	0·74	0·02	*	NS	NS
Chloride (mmol/l)	117	118	119	120	122	124	117	121	0·89	**	NS	NS
Urine measurements‖ (days 0–11)												
pH	8·4	8·6	8·4	7·2	7·2	7·9	8·7	8·7	0·58	NS	NS	NS
Ca (mmol/d)	5·3	3·8	10·3	23·8	16·9	28·9	6·3	3·2	3·17	***	NS	*

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

† Prepared as for the HCl-supplemented diets, using distilled water instead of HCl. For details, see p. 223.

‡ Diluted 1:5 (v/v) with distilled water. § Mean intake for 11 d for four sheep/treatment. ‖ Mean values for two sheep for each treatment.

¶ Mean values for samples taken at 10.00, 11.30 and 15.00 hours on day 9 or 10, for four sheep/treatment.

†† The amount of $NaHCO_3$ infused was equivalent to the amount of HCl consumed on the previous day, calculated from DM intake.

each treatment, the tests of significance for pH and VFA were not very sensitive. There was a significant 'time of sampling' effect on rumen fluid pH ($P < 0.01$), average values for all treatments were 6·86, 6·26 and 6·31 at 10.00, 11.30 and 15.00 hours respectively, but the time of sampling × treatment interaction was not significant ($P > 0.05$).

Blood acid–base status. With the low-HCl treatments metabolic acidosis developed in animals given HCl either mixed into the pelleted grass meal or intraruminally, although the effect of these treatments was significant ($P < 0.01$) only for plasma CO_2 concentration and not for blood pH or blood BE status (Table 3). $NaHCO_3$ supplementation prevented the development of acidosis. With the high-HCl treatments the extent of metabolic acidosis for animals given the HCl treatments was greater, particularly when HCl was given intraruminally; blood pH, plasma CO_2 concentration and blood BE status were all significantly affected by HCl treatment ($P < 0.01$). $NaHCO_3$ supplementation again prevented the development of the acidosis. Over all, the level of HCl supplementation did not significantly affect blood pH, plasma CO_2 concentration or blood BE status ($P > 0.05$), while the level of HCl supplementation × treatment interaction was significant only for plasma CO_2 concentration ($P < 0.05$). At each level of HCl supplementation the effect of time of sampling on blood pH, plasma CO_2 concentration and blood BE status was significant ($P < 0.01$); average values for all treatments at 10.00, 11.30 and 15.00 hours were respectively: pH 7·40, 7·37 and 7·36; plasma CO_2 concentration 28·0, 25·3 and 24·8 mmol/l; blood BE status +1·43, −1·78 and −1·88 mmol/l. Treatment differences were fairly consistent at each sampling time; a significant time of sampling × treatment interaction ($P < 0.05$) was obtained only for blood pH on the high-HCl treatments, where the treatment effect was greater at 15.00 hours.

Mineral content of serum. The Cl^- concentration for serum was increased by HCl when given intraruminally; the effect was significant ($P < 0.01$) for the low-HCl treatments (Table 3). Serum levels for the other minerals studied, i.e. Na, Ca and Mg, were not significantly affected by treatment (Table 3).

Urine pH and Ca excretion. There was considerable variation between the two sheep in the effect of treatment on pH and excretion of Ca in urine (Table 3). The pH of urine was not significantly affected by treatment. Urinary Ca excretion was increased by HCl given in the diet or intraruminally ($P < 0.001$) while $NaHCO_3$ supplementation restored values for Ca excretion to the control values. Over all the effect of the level of HCl supplementation on urinary Ca excretion was not significant ($P > 0.05$) but the level of HCl supplementation × treatment interaction was significant ($P < 0.05$). As urine samples were taken from only two animals for each treatment, these tests of significance were not very sensitive.

DISCUSSION

The results of Expt 1 confirm the previous finding (L'Estrange & Murphy, 1972) that HCl when added to a pelleted grass-meal diet adversely affects voluntary food intake of sheep. The relationship between the level of dietary HCl and food intake was found to be almost rectilinear over the range studied. As in the previous study,

food intake gradually decreased for about 7 d after the introduction of the mineral acid and then remained constant for the rest of the 21 d experimental period, increasing again to the control intake within a few days of withdrawal of the supplement.

HCl supplementation, even at the high level of 560 mmol/kg dietary DM, caused only a small and non-significant effect on the pH of rumen fluid and did not affect its total VFA concentration or the proportions of individual VFA, a result also in agreement with that of the previous experiment (L'Estrange & Murphy, 1972). It appears therefore that the adverse effect of dietary HCl on food intake was not the result of a reduction in rumen pH, as suggested for other acids by Bhattacharya & Warner (1967). The most striking metabolic effect caused by HCl supplementation in Expt 1 was that it induced a chronic form of metabolic acidosis in the sheep, the extent of which, although related to the level of HCl supplementation, was not severe even at the highest level. The results were of the same order as previous results obtained for mineral acid supplementation for sheep (L'Estrange & Murphy, 1972) and cattle (Lebeda, Bouda & Kučěra (1970). Although the results for Expt 1 suggested a close relationship between the extent of metabolic acidosis and the reduction in food intake of the sheep, it was not possible to deduce from the results whether or not the acidosis was the direct cause of the reduction in food intake. A close relationship found between dietary pH and DM intake suggested that food intake was possibly determined by palatability associated with low dietary pH.

In Expt 2 the attempt to separate palatability and metabolic effects of dietary HCl by comparing the effects of the HCl when mixed into the pelleted grass meal or given intraruminally proved quite successful. The reduction in food intake caused by each level of HCl when mixed into the pelleted grass meal without intraruminal administration of $NaHCO_3$ was very similar to that found using similar amounts of HCl in Expt 1. However, when given intraruminally, the low level of HCl supplementation had no effect on food intake, indicating that the effect of HCl when added to the pelleted grass meal was determined by palatability rather than by a metabolic disturbance. This was further substantiated by the results obtained for $NaHCO_3$ administration when the HCl-treated diet was fed, which, although preventing the development of metabolic acidosis, did not increase food intake to control levels.

The results obtained for the high level of HCl supplementation suggest that food intake was determined both by palatability and by a metabolic disturbance. The reduction in food intake caused by HCl was similar whether it was mixed into the pelleted grass meal or given intraruminally. The finding that the administration of $NaHCO_3$ when feeding the HCl-treated diet (which prevented the development of metabolic acidosis and decrease in pH of rumen fluid) caused only a small and non-significant increase in food intake, confirmed the importance of palatability in determining food intake at the high level of HCl supplementation also. From previous studies of the effect of NaCl supplementation on food intake of sheep (L'Estrange *et al.* 1972), the palatability effect of HCl was probably caused by the low pH of the diets rather than by the increase in Cl^- content per se. It is, however, somewhat surprising to find that a reduction in dietary pH to a value of 4·4 may have this effect on food intake. From this result it may be speculated that, with silages made

without added mineral acids, the positive correlation found between pH and voluntary intake of the silage by sheep (Wilkins, Hutchinson, Wilson & Harris, 1971; Brown & Radcliffe, 1972) is a palatability response to dietary pH. In addition, for cattle and sheep, the increase in consumption brought about by neutralization with $NaHCO_3$ of silage made without added inorganic acid (Orth & Kaufmann, 1966; McLeod, Wilkins & Raymond, 1970) may be due to improved palatability associated with the increase in pH.

The results from Expt 2 for DM digestibility and for pH and VFA concentrations of rumen fluid were inconclusive as only two animals were sampled for each treatment. However, there appeared to be no adverse effect on DM digestibility or on VFA production in the rumen by any of the treatments relative to the control, a result in agreement with that of previous studies when HCl was given mixed with the diet (L'Estrange & Murphy, 1972).

In Expt 2, urine samples were also taken from two sheep per treatment only. Unexpectedly, in view of previous results (L'Estrange & Murphy, 1972), urinary pH was not consistently reduced by dietary HCl at each level of supplementation. However, urinary Ca excretion, particularly at the high level of supplementation, was substantially increased by HCl, in agreement with previous results. This effect was largely overcome by $NaHCO_3$ administration, which also restored the blood acid–base balance. An explanation of the results for urinary pH for this experiment is not readily apparent. Possibly the restriction of food consumption to 7·5 h/d may have caused diurnal variation in urinary acid–base excretion which could mask treatment differences measured over the 24 h period.

The authors are indebted to Mr D. B. R. Poole and Dr P. A. M. Rogers, An Foras Taluntais, Dunsinea, Republic of Ireland, for rumen cannulation of experimental animals, and thank also Mr M. Caffrey, Mr S. Dillon and Miss K. McCormack for skilled technical assistance.

REFERENCES

Baile, C. A. & Mayer, J. (1968). *J. Dairy Sci.* **51**, 1490.
Bhattacharya, A. N. & Warner, R. G. (1967). *J. Dairy Sci.* **50**, 1116.
Brown, D. C. & Radcliffe, J. C. (1972). *Aust. J. agric. Res.* **23**, 25.
Lebeda, M., Bouda, J. & Kucěra, A. (1970). *Acta vet., Brno* **39**, 415.
L'Estrange, J. L. (1972). *Proc. Br. Soc. Anim. Prod.* p. 148.
L'Estrange, J. L., Clarke, J. J. & McAleese, D. M. (1969). *Ir. J. agric. Res.* **8**, 133.
L'Estrange, J. L. & McNamara, T. (1973). *Ir. Grassld Anim. Prod. J.* **7**, 152.
L'Estrange, J. L. & Murphy, F. (1972). *Br. J. Nutr.* **28**, 1.
L'Estrange, J. L., Upton, P. K. & McAleese, D. M. (1972). *Ir. J. agric. Res.* **11**, 127.
McLeod, D. S., Wilkins, R. J. & Raymond, W. F. (1970). *J. agric. Sci., Camb.* **75**, 311.
Montgomery, M. J., Schultz, L. H. & Baumgardt, B. R. (1963). *J. Dairy Sci.* **46**, 1380.
Orth, A. & Kaufmann, W. (1966). *Z. Tierphysiol. Tierernähr. Futtermittelk.* **21**, 350.
Upton, P. K., L'Estrange, J. L. & McAleese, D. M. (1972). *Ir. J. agric. Res.* **11**, 145.
Virtanen, A. J. (1933). *Emp. J. exp. Agric.* **1**, 143.
Wilkins, R. J., Hutchinson, K. J., Wilson, R. F. & Harris, C. E. (1971). *J. agric. Sci., Camb.* **77**, 531.

Printed in Great Britain