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STEPWISE ADAPTATION OF SHEEP FED *AD LIBITUM* TO A HIGH CONCENTRATE DIET AND ITS EFFECT ON RUMINAL pH AND LACTIC ACID CONCENTRATION

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(Sleutelwoorde: *Aanpassing, kragvoer-ryke rantsoene, melksuur, pH, skape)*

OPSOMMING: STAPSGEWYSE AANPASSING VAN SKAPE, WAT OP 'N *AD LIBITUM* BASIS GEVOER IS, AAN KRAGVOER-RYKE RANTSOENE EN DIE EFFEK DAARVAN OP DIE pH EN MELKSUURKONSENTRASIE IN DIE RUMEN

Vyf volgroeide skape is aan 'n stapsgewyse aanpassingseksperiment onderwerp. Voermengsels wat mieliemeel en melasse in opeenvolgende konsentrasies van 10; 26,5; 43,5; 54 en 65 persent bevat het, is op 'n *ad libitum* basis aan die diere gevoer. Alle rantsoene het 'n gemengde buffer en 15% ruproteïen bevat. Monsters van rumeninhoud is met kort intervalle gedurende die eerste 14 uur van die voersiklus getrek tot met Dag 7 op die finale dieet, waartydens monsters gedurende die volle 24 uur periode geneem is. Konsentrasie van rumen NH_3-N was meesal hoër as 6 mM en dus bokant die beperkende konsentrasie van 3,4–5 mM vir die groei van rumenbakterieë. 'n Tydelike opeenhoping van melksuur in die rumen het ongeveer $\frac{1}{2}$ tot 2 ure na elk van die 2 daaglikse voerperiodes voorgekom. Die piekkonsentrasie (1–10 mM) het oor die algemeen afgeneem namate die aanpassing gevorder het. Ongewoon hoë piekwaardes het voorgekom tussen dag 22 en 71 op die finale rantsoen wat aandui dat daar 'n neiging was tot die ontwikkeling van onstabiele toestande in die rumen. Die skape het hierdie tendens teengewerk deur hul voerinname te verminder, wat 'n terugkeer na stabiele toestande tot gevolg gehad het, soos aangedui deur 'n afname in die piekwaarde van die melksuurkonsentrasie. Die gemengde bufferkomponent van die rantsoen was hoogs doeltreffend soos blyk uit die feit dat die pH van die rumeninhoud selde laer as 5,5 was, in weerwil van die hoë voerinname van tot 2,65 kg/d. Die periodes waartydens die pH laer as 5,5 was (gem. 2,1 h; perke 1–6 h) was waarskynlik te kort om die balans van die mikrobepopulasie van die rumen te versteur. Die voorkoms van urinêre stene kan toegeskryf word aan die hoë inname van P afkomstig uit die vismeelbyvoer en die bufferkomponent van die rantsoen.

SUMMARY:

A stepwise adaptation experiment was performed on 5 adult sheep fed *ad libitum* on successive diets containing 10; 26,5; 43,5; 54 to a final diet containing 65% maize meal and molasses for 119 days. All diets contained a mixed buffer and 15% CP. Samples of ruminal ingesta were taken at short intervals during the first 14 h of the feeding cycle until Day 7 on the final diet when it was continued over the entire 24 h. Concentrations of ruminal NH_3-N were mostly higher than 6 mM and therefore above the limiting concentrations (3,4–5 mM) for growth of rumen bacteria. Ruminal lactic acid accumulated transiently about $\frac{1}{2}$ – 2 h after each of the 2 daily feeds. The peak concentration (1–10 mM) showed a general tendency to decrease as the adaptation progressed. Higher than usual peak values occurred between 22–71 days on the final diet indicating a tendency towards unstable conditions in the rumen. This was counteracted by a voluntary reduction in food intake by the sheep which allowed stable conditions to return as indicated by a decrease in the peak lactic acid values. The mixed dietary buffer was most effective since, despite high food intakes of up to 2,65 kg/d, the ruminal pH rarely fell below 5,5, and this was mostly for short periods of time (av. 2,1 h, range 1–6 h) unlikely to upset the balance of the ruminal flora. The incidence of urinary calculi could be attributed to a high intake of P supplied by the fishmeal supplement and dietary buffer.

The future of cereals in intensive feeding for the production of meat and milk from ruminants seems to be assured at least in the Republic of South Africa which produces a surplus of maize grain (Le Roux, 1977). The present study concerns the feeding of grain in high concentrate diets which can result in lowered productivity due to reduced food intake associated with the transient accumulation of ruminal lactate, as distinct from the well documented "grain overload" or "acute lactic acidosis" syndrome where large amounts of lactate accumulate for long periods of time and are often fatal (Dunlop and Hammond, 1965; Dirksen, 1970). Previous work (Mackie, Gilchrist, Robberts, Hannah & Schwartz, 1978) showed that after a successful stepwise adaptation to a high concentrate diet there was a tendency for imbalances to occur in the ruminal flora on 2 occasions during the 54 day period on the final high concentrate diet fed to sheep. Although this did not lead to marked accumulations of lactate, since the animals were on restricted intake, the possibility remained that this could occur at *ad libitum* intake, particularly over the longer period (100–150 days) employed in intensive feeding practice. Two factors are of particular importance in regulating the growth of the ruminal flora on high concentrate diets. One is the concentration of NH_3-N which should be adequate at all times for growth of the ruminal bacteria (Satter & Slyter, 1974; Mercer & Annison, 1976); and the other is the effect on the growth rate of both ruminal bacteria and protozoa of lowered pH values for prolonged periods of time (Mackie *et al.*, 1978; Mackie & Gilchrist, 1979). In view of this, NH_3-N and ruminal pH as well as food intake, weight gain and D- and L-lactic acid were determined in the rumen of adult sheep during stepwise adaptation at *ad libitum* intake from a high roughage to a high concentrate diet, on which the animals remained for a further 119 days. All experimental diets contained a mixed buffer (McManus, Bigham & Edwards, 1972) and 15% crude protein.

Materials and methods

Animals and management

Five mature South African Mutton Merino castrated male sheep, each provided with a permanent ruminal cannula (Taljaard, 1972) were used in the experiment. They were individually housed in covered pens where water was freely available. The animals were offered half their ration twice daily at 08.00 and 16.00 h. Any food remaining was weighed back and discarded before the morning feed. The sheep were weighed at weekly intervals throughout the experiment.

Diets

Four of the sheep (A27, A35, K1 and K29) had been on a lucerne hay diet for at least 6 months before the experiment started. Sheep A85 had been on lucerne hay-teff hay (50:50) for 6 months. After this all 5 sheep followed the same experimental plan and diets given in Table 1 including a 14 day preliminary period when they were fed 1,2 kg lucerne hay.

Table 1

Experimental plan and diets fed to sheep during stepwise adaptation at ad libitum *food intake to a high concentrate diet*

Period no.:	1	2	3	4	5
Diet:	HR	HR/Int	Int	Int/HC	HC
Days on diet:	7	7	7	7	119
Composition (kg/100 kg)					
Maize stover	67,0	51,0	35,0	24,5	14,0
Maize grain	–	16,5	33,5	44,0	55,0
Molasses	10,0	10,0	10,0	10,0	10,0
Fishmeal	17,0	16,5	16,0	15,5	15,0
NaCl	0,5	0,5	0,5	0,5	0,5
Minerals*	1,5	1,5	1,5	1,5	1,5
Buffer+	4,0	4,0	4,0	4,0	4,0
Chemical analysis (g/100 g)					
CP (Nx6,25)	16,7	15,5	15,2	14,2	12,9
Mg	0,46	0,36	0,34	0,27	0,24
Ca	2,09	1,63	1,86	1,49	1,52
P	1,07	0,88	1,06	0,89	0,79
Ca/P	1,95	1,85	1,75	1,68	1,93

* Commercial mixture (Kimtrafos 25, Kynoch Feeds, South Africa) containing 24% Ca; 12% P; 0,15% Fe; 0,05% Cu; 0,1% Mg; 0,002% Co; 0,002% I; 5,0% S; 3,0% dried molasses.

+ Containing 2% $CaCO_3$; 0,5% Na_2HPO_4; 0,5% K_2HPO_4; 0,5% $NaHCO_3$; 0,5% $KHCO_3$.

Sampling and analysis of ruminal fluid

Samples for chemical analysis were taken after 14 days on the lucerne hay diet, 1 and 7 days after each change in the experimental diets, as well as after a further 22, 42, 71, 98 and 119 days on the final high concentrate diet. The sheep were sampled before (0 h) and 0,5; 1; 1,5; 2; 3; 4,5; 6 and 8 h after the first feed, and 0,5; 1; 1,5; 2; 3; 4,5 and 6 h after the second feed until Day 7 on the final diet, whereupon sampling was continued at 2 to 3 h intervals over the remaining 10 h of the 24 h-feeding cycle. Samples of ruminal fluid were withdrawn from the rumen by applying gentle suction to a tube (15 mm i.d.) inserted into the rumen through the small hole in the cork bung of the large (83 mm i.d.) ruminal cannula. The fluid was strained through 2 layers of cheesecloth and the pH measured immediately on the strained ruminal fluid (SRF) using a portable Polymetron PM 1 meter; 10 g of the SRF was then weighed into a wide-mouth McCartney bottle containing 10 ml of 0,5 M-HCl. The acid-treated samples were centrifuged at 4 000 g for 20 min and the supernatant stored until required for analysis. L- and D-lactate were analysed using specific enzymic methods (Gawehn & Bergmeyer, 1970) and biochemicals obtained from Boehringer Mannheim (West Germany). Total lactate was calculated as the sum of the 2 isomers. NH_3-N was determined by steam distillation using the method of Schwartz, Schoeman & Färber (1964).

Results

Food intake, weight gain and incidence of urinary calculi

Food intake (Table 2) and consequently mass gain of the sheep during successive periods on diets containing increasing amounts of maize were higher for sheep A85 and K1 than for the other three sheep. These 2 sheep gained 30,2 and 22,5 kg respectively over the entire course of the experiment, of which 17,7 and 14,8 kg respectively was the mass gained on the final high concentrate diet. Sheep K29 was removed from the experiment at the beginning of period 5 when its food intake suddenly dropped to 500 g on the final diet, as did that of A27 and A35 which were removed after 71 and 98 days respectively on the same diet. Post mortem examination of sheep K29 which died and A27 and A35 which were slaughtered revealed the presence of urinary calculi. The chemical composition of the calculi from sheep A35 (Mg 16,10%; Ca 1,71%; P 16,68% ; N 5,68% ; H 2,69% ;

Table 2

Mean daily food intake (kg) of sheep during stepwise adaptation to a high concentrate diet

Period no.	Percentage grain + molasses in diet	Days on diet	Mean daily food intake+ for sheep				
			A27	A35	A85	K1	K29
Preliminary	0	14	1,23	1,23	1,23	1,23	1,23
1	10	7	1,11	1,10	1,63	1,21	0,51
2	26,5	7	1,39	1,50	1,86	1,65	1,39
3	43,5	7	1,00	1,33	2,68	2,10	1,68
4	54	7	1,38	1,13	2,31	2,25	1,91
5	65	7	1,50	1,11	2,26	2,07	‡
		22	1,67	1,39	2,45	2,06	‡
		42	1,16	1,50	2,34	2,13	‡
		71	1,23	1,46	2,10	1,90	‡
		98	‡	1,41	1,42	1,53	‡
		119	‡	‡	1,54	1,45	‡

+ Food intakes represent the mean daily intake over the 7 day period before and including the sampling day.

‡ Sheep were withdrawn from the experiment.

C 1,92%) was similar to that of calculi reported in the literature (Elam, Schneider & Ham, 1956; Packett & Coburn, 1965) for this type of high concentrate diet. The food intake and hence the intake of Ca, P and Mg of the 3 sheep with calculi was similar to that of sheep A26 and considerably less than that of A85 and K1 which survived. There was nothing in the pH, NH_3 or lactic acid concentrations in the rumen of these sheep which distinguished them from the survivors.

Diurnal pattern of ruminal lactic acid concentration and pH

The diurnal pattern of the ruminal total lactic acid concentration and pH over the sampling period is shown in Figure 1 for the 2 sheep (A85 and K1) which completed the experiment and had consistently high food intakes.

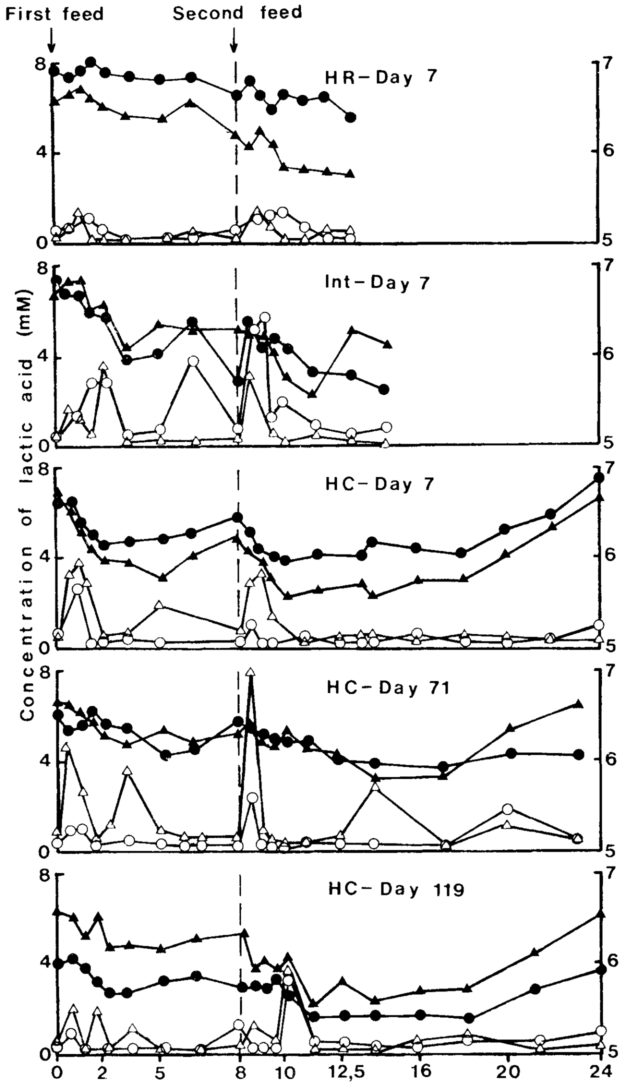

Fig. 1. *Diurnal pattern of the ruminal lactate concentration of two sheep (A85 ○—○; K1 △—△) and their ruminal pH (A85 ●—●, K1 ▲—▲) on the diets containing 10% (HR), 44% (Int) and 65% (HC) grain and molasses at* ad libitum *food intake during the course of the stepwise adaptation experiment.*

The peak lactate accumulation usually occurred within 2 h after feeding. Smaller peaks occurred whenever the animals resumed eating. Maximum values found were 7,12 mM for sheep A85 on the 26,5% grain and molasses diet, and 8,30 mM for sheep K1 after 71 days on the final diet. Sheep K29 had peak values of 9,20 and 8,02 mM after 7 days on the diet containing 54% grain and molasses and one day on that containing 65% respectively just before its food intake dropped and it was removed from the experiment. For a large part of the day the concentration of lactic acid was low (< 1 mM) on all diets. The mean peak lactate concentration (Table 3) during the adaptation period occurred after 7 days on the 26,5% grain and molasses diet and tended to decrease despite increased feed intake (Table 2). The mean values tended to increase again after 22, 42 and 71 days on the final diet indicating possible instability in the balance of the ruminal flora. However, the animals appeared to assist in maintaining the balance by subsequently reducing food intake. The percentage D-lactate in total lactate at peak accumulation (Table 3) shows that the D-isomer formed 50% of total lactate on all except 2 occasions when the final diet was fed. The percentage of D-lactate was usually greater than 60%. Similar trends in the proportions of the 2 isomers were found at times other than peak lactic acid concentration.

The pattern of ruminal pH shown in Figure 1 revealed that immediately after feeding the pH values tended to increase slightly or remain at prefeeding levels for *ca.* 2 h before starting to decrease. Minimum values were recorded 4–10 h after the second feed especially on the final diet containing 65% grain and molasses. However, despite intakes of up to 2,65 kg of food per day the pH of the rumen rarely fell below 5,5 and this was usually only for a few hours even on the diet containing the highest level of grain. Table 4 shows that the minimum pH values decreased as the adaptation progressed. Values of 5,20 on day 42, 5,30 on day 119 and 5,30 on day 22 of the final diet were found for sheep A35, A85 and K1 respectively. The lowest value found for sheep K29 was pH 5,4 just before it was removed from the experiment. The pH values for sheep A85 were below 6,00 for the entire 24 h period on the 98th and 119th day of the final high concentrate diet except for a period of half an hour on day 98.

Ruminal ammonia concentrations

The pattern of ruminal ammonia concentration was similar to that reported by Mackie *et al.* (1978) with peak values occurring *ca.* 1–2 h after feeding. These values did not exceed 23 mM NH_3-N until after Day 7 on the final diet when both peak and minimum concentrations started to increase to values of 32,4–39,4 and 8,2–12,1 mM respectively. The minimum concentrations were often recorded between the 2 daily feeds and usually 3–5 h after feeding. They were mostly greater than 6 mM (Table 5), although on several occasions on

Table 3

Percentage D-lactate at peak lactate concentration (mM) in the rumen of sheep adapted stepwise to a high concentrate diet

Period no.	Percentage grain + molasses in diet	Days on diet	Peak lactate conc. (mM) Mean ± SD	D-lactate at peak (%) Mean ± SD
Preliminary	0	14	1,73 ± 0,70	54 ± 6
1	10	1	1,66 ± 0,28	64 ± 24
		7	1,40 ± 0,27	66 ± 7
2	26,5	1	2,76 ± 2,45	65 ± 19
		7	5,15 ± 1,82	63 ± 14
3	43,5	1	3,29 ± 2,20	67 ± 13
		7	3,37 ± 1,53	57 ± 14
4	54	1	2,58 ± 1,33	67 ± 5
		7	3,41 ± 3,52	52 ± 16
5	65	1	3,56 ± 2,80	48 ± 22
		7	3,27 ± 1,58	44 ± 18
		22	4,20 ± 2,08	63 ± 14
		42	4,15 ± 2,61	54 ± 17
		71	4,10 ± 2,89	62 ± 7
		98	1,83	61
		119	3,76	86

Table 4

Minimum pH values in the rumen of sheep adapted stepwise to a high concentrate diet

Period no.	Percentage grain + molasses in diet	Days on diet	Minimum ruminal pH of sheep A27	A35	A85	K1	K29	Mean ± SD
Preliminary	0	14	5,95	6,35	6,35	5,85	5,90	6,08 ± 0,25
1	10	1	6,40	6,50	6,75	6,80	7,00	6,69 ± 0,24
		7	5,95	5,75	6,40	5,75	5,80	5,93 ± 0,28
2	26,5	1	5,75	6,10	6,55	5,90	6,10	6,08 ± 0,30
		7	5,75	NS+	6,20	5,70	5,50	5,70 ± 0,30
3	43,5	1	6,00	NS	5,85	5,75	5,60	5,80 ± 0,17
		7	5,70	5,70	5,65	5,60	5,50	5,63 ± 0,08
4	54	1	5,60	5,45	5,60	5,50	5,55	5,54 ± 0,07
		7	5,55	5,70	6,10	5,50	5,45	5,66 ± 0,26
5	65	1	5,70	5,70	5,90	5,60	5,45	5,67 ± 0,16
		7	5,80	5,40	5,95	5,55	6,50*	5,68 ± 0,25
		22	5,40	5,30	5,75	5,30	‡	5,44 ± 0,21
		42	5,50	5,20	5,80	5,40	‡	5,48 ± 0,25
		71	5,80	5,50	5,90	5,80	‡	5,75 ± 0,17
		98	‡	5,40	5,65	5,65	‡	5,57
		119	‡	‡	5,30	5,50	‡	5,40

+ NS = not sampled
‡ Sheep were withdrawn from the experiment
* Value for sheep K29 omitted from calculation of Mean ± SD

Table 5

Minimum ruminal NH_3-N concentrations (mM) during stepwise adaptation to a high concentrate diet

Period no.	Percentage grain + molasses in diet	Days on diet	Minimum ruminal NH_3-N of sheep					Mean ± SD
			A27	A35	A85	K1	K29	
Preliminary	0	14	10,3	17,5	8,1	19,4	12,3	13,5 ±4,8
1	10	1	3,2	6,3	5,3	10,2	12,2	7,4 ± 3,7
		7	6,4	13,1	5,6	9,8	9,3	8,8 ± 3,0
2	26,5	1	8,1	15,0	5,5	12,4	13,5	10,9 ±4,0
		7	14,6	NS+	7,1	15,4	16,6	13,4 ± 4,3
3	43,5	1	10,5	NS	9,0	11,1	10,2	10,2 ± 0,9
		7	7,9	13,0	10,2	10,0	13,9	11,0 ± 2,4
4	54	1	5,8	15,9	7,8	14,6	6,9	10,2 ±4,7
		7	6,3	14,0	14,6	15,4	7,7	11,6 ±4,3
5	65	1	4,3	6,0	11,2	12,0	6,5	8,0 ±3,4
		7	12,7	13,1	21,6	11,6	34,6*	14,8 ±4,6
		22	NS	9,3	6,2	14,6	‡	10,0
		42	10,4	17,2	12,1	11,8	‡	12,9 ± 3,0
		71	15,2	20,3	20,3	16,4	‡	18,1 ± 2,6
		98	‡	12,5	12,5	8,2	‡	11,1
		119	‡	‡	23,1	15,6	‡	19,4

+ NS = not sampled
‡ Sheep were withdrawn from the experiment
* Value for sheep K29 omitted from calculation of Mean ± SD

the high roughage (10% molasses) and the 26,5% grain and molasses diets values were between 3–5 mM for short periods of time (*ca.* 2–3 h).

Discussion

The present stepwise adaptation experiment demonstrates that provided the growth of the ruminal flora is regulated by controlling pH and availability of NH_3-N in the rumen, adult sheep fed *ad libitum* adapt readily to a diet containing 65% maize meal and molasses with food intakes and rapid weight gains.

Accumulations of lactic acid found in the rumen were low and transient. Peak concentrations occurred *ca.* ½-2 h after each of the 2 daily feeds and never exceeded 10 mM regardless of diet. There was a general tendency for the peak values to decrease as the adaptation progressed from diets containing 26,5% to 65% grain and molasses. Higher than usual peak concentrations of lactic acid were found in the rumen of different sheep between 22–71 days on the final diet containing 65% grain and molasses. Such increases in peak values of ruminal lactate had been shown by Mackie *et al.* (1978) to be associated with a 50–80% decrease in the number of ciliate protozoa, and a simultaneous sharp increase in the number of total culturable bacteria which resulted in unstable conditions in the rumen of sheep adapted stepwise to a diet containing 71% maize meal and molasses. At the same time one of the animals refused all food for one day and this allowed the ruminal flora to regain balance. In the present experiment all animals voluntarily reduced food intake on the final high concentrate diet which not only assisted in controlling the accumulation of lactic acid, but would also have allowed the ruminal flora to recover balance. Thus, the fact that lactic acid accumulated only transiently and in low concentrations showed that the balance of the ruminal flora was in general successfully maintained throughout the course of the experiment lasting 150 days.

Concentrations of NH_3-N were mostly higher than 6 mM and therefore above the limiting concentrations (3,4–5 mM) for growth of rumen bacteria (Satter &

Slyter, 1974; Mercer & Annison, 1976). On a few occasions on diets containing 10 and 26,5% grain and molasses they were growth limiting (3,2 mM) or marginal (5,3–5,6 mM) for short periods of time (2–3 h) which were unlikely to have any marked effect on bacterial growth. However, on the final diet containing 65% grain and molasses, the NH_3-N concentration rose to 7–12 mM thus providing a more than adequate supply of NH_3-N for bacterial growth at a time when this was critical owing to the fact that the starch and sugar fermenters would, as a result of their rapid growth, be in a position to utilize the available NH_3-N at the expense of the slower growing organisms like the lactate-utilizing bacteria essential for a balanced ruminal flora (Mackie *et al.*, 1978; Mackie & Gilchrist, 1979). On the other hand, despite a dietary CP content of 15% , the maximum values of NH_3-N ($<$ 40 mM) would have little inhibitory effect ($>$ 30 mM) on growth of the ciliate protozoa (Hino, Kametaka & Kandatsu, 1973). These results suggest that relatively little of the fishmeal, used as N supplement in all the experimental diets, was degraded in the rumen, possibly because of a high rate of passage of digesta out of the rumen as a result of the high food intake (Sutton, 1971).

The mixed dietary buffer (McManus *et al.*, 1972) was most effective since, despite high food intakes of up to 2,65 kg/day, the values of ruminal pH rarely fell below 5,5, and this was mostly for short periods of time (av. 2,1 h, range 1–6 h) even on the final diet containing 65% grain and molasses. Previous microbiological studies (Mackie *et al.*, 1978) showed that the balance of the ruminal flora could be successfully maintained under these conditions of pH. McManus & Bigham (1978) found that inclusion of the mixed buffer in an all-wheat diet fed to growing lambs promoted increased numbers of bacteria. These were predominantly Gram-negative staining compared to the bacterial flora of animals fed the same diet with $CaCO_3$ alone as buffer which gave rise to a greater proprotion of Gram-positive bacteria, including cocci likely to be *Streptococcus bovis* which have been associated with lactic acidosis (Slyter, 1976).

The incidence of calculi in the present experiment can be ascribed to a high level of P in the diet (0,73–1,07%) and a low Ca/P ratio (1,68–1,95), while the additional K in the buffer could have aggravated the problem (Elam Schneider & Ham, 1956; Hoar, Emerick & Embry, 1970). It was estimated that *ca.* 43–50% of the P was supplied by the fishmeal in the diet. Scott (1972) showed that when fishmeal was added to a diet containing 80% barley, the urinary P excretion, which is strongly correlated with the formation of calculi, was higher than when the barley was supplemented with soybean meal. This was not due to a higher P content of the fishmeal diet but was attributed to differences in absorption of P from the gut. An explanation for these results and also the high incidence of calculi in the present experiment is possibly related to differences in NH_3 concentrations in the rumen, since soybean meal tends to be more readily degraded than fishmeal. A higher NH_3 concentration could result in precipitation of $MgNH_4PO_4$ in the forestomach which is one of the main sites of Mg absorption (Ben-Ghedalia, Tagari, Zamwel & Bondi, 1975). The presence of Mg in the digesta could then interfere with P absorption. Alternatively, the inclusion of buffer salts in high concentrate, cereal based diets would give rise to an alkaline urine high in $HPO_4^{=}$ which would easily precipitate in the form of crystals containing magnesium, ammonium and phosphate (see composition of urinary calculi in Results). Since the intake of Ca, P and Mg of the non-calculi wethers was equal to or greater than that of the calculi wethers, and there was nothing to distinguish these 2 groups of sheep, it is possible that the calculi wethers tended to absorb more P and Mg thus excreting more via the urine and less via the faeces (Packett, Lineberger & Jackson, 1968) and were, as a result, more prone to urolithiasis. In view of the unsuitability of the mixed buffer for adult wethers on a diet high in fishmeal, one of the sheep which completed the present experiment (A85) and a second wether (A52) were kept successfully for an additional 214 and 224 days respectively on a diet similar to that containing 65% grain and molasses, except that the mixed buffer was replaced with 3% $CaCO_3$ alone.

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