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THE EFFECT OF HIGH LEVELS OF SODIUM BICARBONATE IN THE DRINKING WATER OF SHEEP ON RUMEN FUNCTION

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INTRODUCTION

In some of the arid regions of the world the only available drinking water has a high salt content and consequently it is essential to know the maximum tolerance of animals towards the different ingredients of such water. According to Adelaar (1965) the following permissible levels of ions in the drinking water of livestock were determined by the responsible authorities in South Africa:—

Total solids	5000 ppm
Sodium (as Na)	2000 ppm
Calcium (as Ca)	1000 ppm
Magnesium (as Mg)	500 ppm
Nitrates (as NO_3)	400 ppm
Chlorides (as Cl)	3000 ppm
Sulphates (as SO_4)	1000 ppm
Fluorine (as F)	6 ppm

As bicarbonate is one of the least harmless ions to the animal body and as levels of bicarbonate exceeding the above-mentioned figure are not regarded with concern in water for human use, it is questionable whether such a low limit of bicarbonate in the drinking water of livestock is justifiable. In ruminant animals, however, the motility of the rumen is particularly susceptible to alkalinity (Clark & Lombard, 1950) and it was therefore necessary to establish the effect of high levels of bicarbonate on the functions of the rumen.

MATERIALS AND METHODS

Experiment No. 1

Four adult Merino wethers with permanent rumen fistulae were divided at random into two groups of two each. They were placed in individual pens where each sheep received its own feed and water. One pair was given lucerne hay and the other teff hay *ad lib.* The lucerne hay ration was regarded as a fairly good diet while experience had shown that teff hay alone was insufficient as a maintenance diet for Merino sheep. Every morning 1,500 gm of hay was given to the sheep between 8 and 9 a.m. and the remainder weighed the following morning. The intake of water was determined similarly and corrected for evaporation losses. No period of adaptation to the rations was necessary as all the sheep had been on similar rations for months except that the teff hay group had also received a non-protein nitrogen supplement until some weeks before the start of this experiment.

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The ruminal contractions of all sheep were recorded twice a week in the morning before feeding according to the method described by Quin, Van der Wath & Myburgh (1938). The number of mixing movements per 5 minute period was then determined from the recordings and expressed to the nearest one-tenth of a contraction.

The pH of a sample of ruminal contents extracted through the fistula from various depths in the rumen was determined twice a week immediately after collection by means of a portable, battery operated, single electrode pH meter.

The ability of the ruminal organisms to ferment sugar was determined by measuring the volume of gas produced from glucose by the freshly collected sample of ruminal fluid. The method used was a slight modification of that described by Quin (1943). A solution of 0·4 gm of glucose in 1 ml of water was added to 50 ml of strained, freshly collected ruminal juice and the volume of gas produced during slow agitation in a water bath at 38° C for 15 minites was measured at atmospheric pressure. As control a duplicate 50 ml sample of ruminal fluid without glucose was subjected to the same treatment. The difference between the two volumes of gas was taken as due to fermentation.

The rate of cellulose digestion was estimated according to the method of Grosskopf (1964). The loss in weight of four cotton strands during suspension for 15, 18, 21 and 24 hours respectively in the rumen was determined. The percentages of the original weights lost on each set of four strands were plotted against time and the time taken to lose 50 per cent of the original weight then read from the graph. For clearer comparison a "cellulose digestion" index was calculated. This was done by multiplying the reciprocal of the "half life" of the cotton threads in the rumen (in hours) by 1000. Estimated in this way, an index figure of 50 or more represented a very high rate of cellulose digestion while a figure of 10 or lower indicated a rather poor rate of cellulose digestion.

Where the rate of cellulose breakdown was poor, extrapolation of the graph was necessary to determine the "half life" of the cotton threads. The possible error that could be made through this was, however, not regarded as being significant as the method of calculating the index of cellulose digestion would again reduce such an error to a minimum.

The index of cellulose digestion for each of the four sheep was estimated twice a week during the course of the experiment.

The sheep were weighed once a week.

After a period of four weeks on normal Onderstepoort water (alkalinity equivalent to 517 ppm of bicarbonate, as —HCO_3), the sheep were offered drinking water to which sodium bicarbonate had been added to obtain levels of alkalinity equivalent to 1000, 2000, 2500, 3000, 4000 and 5000 ppm of bicarbonate as —HCO_3. The sheep were kept on each of these levels of bicarbonate in their water for four weeks. These levels were determined titrimetrically by using 0·1N hydrochloric acid with methyl orange as indicator. Table 1 gives the levels of sodium bicarbonate added to obtain these concentrations as well as the pH of the final solutions.

The experiment was started on 8 November 1962 and concluded on 12 June, 1963.

TABLE 1.—*The levels of sodium bicarbonate added to tap water to obtain the required concentrations*

Alkalinity expressed as ppm of $-HCO_3$	$NaHCO_3$ added to drinking water (gm/l)	pH
517	—	7·6
1000	0·70	7·8
2000	2·03	7·9
2500	2·70	7·9
3000	3·36	8·0
4000	4·69	8·0
5000	6·02	8·0

Experiment No. 2

As the results obtained with the sheep fed on teff hay in the previous experiment were not satisfactory, it was decided to repeat the procedures on another group of sheep fed on teff hay. Four six-tooth German Merino rams with permanent ruminal fistulae and two similar sheep without fistulae were kept in individual pens and fed on teff hay *ad lib.* and 50 gm of crushed yellow maize daily. A six weeks adaptation period was allowed before the start of the experiment. The small amount of maize was added to minimize the loss of weight normally encountered when feeding teff hay alone.

The four fistulated sheep were subjected to all the experimental procedures described above. The two normal sheep were kept as controls to determine the effect of the poor diet alone. Because of practical difficulties the two control sheep could not be subjected to all the procedures and therefore only their feed and water intake was determined.

The same procedures and methods were adopted as in the first experiment, except for the determination of the glucose fermentation rate which was adapted slightly to give more accurate readings. A water bath with finer temperature control and improved shaking device as well as thinner connecting tubes was used. Instead of 50 ml of ruminal fluid and 0·4 gm of glucose, 20 ml of strained ruminal contents and 0·16 gm of glucose were used and fermentation was allowed to continue for 60 min. The volumes of gas measured in this experiment are therefore not comparable to those obtained in experiment 1.

Sodium bicarbonate was added to the drinking water of the four fistulated sheep to obtain alkalinity levels equivalent to 1000, 2000, 4000 and 5000 ppm of bicarbonate as $-HCO_3$. They were kept on the normal Onderstepoort tap water for four weeks and then for periods of three weeks on each of the levels mentioned above in succession. Thereafter they received normal water for a period of four weeks.

The two control sheep were given normal tap water throughout.

The experiment was carried out during June to October 1964.

Results

Experiment 1

The average daily hay consumption and water intake, the average cellulose digestion index, the average volume of gas produced by the ruminal organisms from glucose, the average ruminal pH, the average number of ruminal mixing contractions and the live weight of the two sheep on lucerne hay during each week are presented in Table 2.

The two sheep on the teff hay diet gave disappointing results. Their feed and water intake decreased to such an extent that sheep No. 3 had to be withdrawn from the experiment at the end of the 18th week (on 3000 ppm bicarbonate in the water) and that the offering of bicarbonate water to sheep No. 4 had to be discontinued prematurely after the level of 4000 ppm had been reached.

Sheep No. 4 did not improve on normal tap water but grew worse. Sheep No. 3 rapidly regained its appetite when its teff hay diet was replaced by lucerne hay.

As can be seen from Table 2, the increased levels of bicarbonate in the drinking water had no effect on feed consumption. The sheep drank more water as the atmospheric temperature increased during the summer months and less as the weather became cooler during winter.

Apart from a small fluctuation in the rate of cellulose digestion in the rumen of sheep No. 1 during the first five weeks of the experiment, the cellulose digestion index remained remarkably constant throughout in both sheep.

The pH of the ruminal contents remained fairly constant and within normal limits. During the second week on 2000 ppm of bicarbonate in the drinking water the pH of the ruminal contents of sheep No. 1 rose to 7·4, but within a further two weeks it returned to 6·9.

The rate of ruminal contractions was unaffected by the addition of bicarbonate to the drinking water.

The estimation of the rate of sugar fermentation by the ruminal organisms gave disappointing results. The variations noted from day to day were even greater than those presented in Table 2. No trend in the sugar fermentation rate could be coupled with the levels of bicarbonate in the drinking water and it is suggested that these figures be ignored.

The sheep gained weight during the experiment probably due to wool growth and not an increase in body weight.

Experiment 2

The results of this experiment are presented in Tables 3 and 4. As the four sheep receiving additional bicarbonate in their drinking water reacted similarly, all the figures in Table 3 are presented as the mean of the four. Similarly, the figures in Table 4 represent the means of the two control sheep.

The feed consumption of the four experimental sheep decreased to approximately 87 per cent of the pre-experimental intake when they received the drinking water containing 2000 ppm of bicarbonate, but improved on the 4000 and 5000 ppm levels of bicarbonate and on normal tap water. The two control sheep maintained their level of feed intake.

As the experiment was started in mid-winter, it was expected that the water intake would increase gradually as the weather became warmer. This was indeed so, but when additional bicarbonate was no longer added to the water, the water intake dropped noticeably. This period coincided with the first summer rains, however, and the water intake of the control group dropped similarly.

The index of cellulose digestion improved slightly during the course of the experiment and reached its peak when the sheep drank water containing 5000 ppm.

The estimation of the ability of the ruminal micro-organisms to ferment sugar was satisfactory and gave more constant results than in the previous experiment. Apparently this ability of the ruminal organisms was not retarded by the higher levels of bicarbonate in the drinking water.

The pH of the ruminal contents remained between normal limits throughout the course of the experiment.

The contractions of the ruminal wall was not retarded by the added bicarbonate; it rather appeared to be stimulated slightly.

The sheep lost weight during the experiment and regained a little during the four weeks on normal water.

Conclusions

There was no indication that the high levels of sodium bicarbonate in the drinking water of sheep on a lucerne hay diet had any harmful effect on their ruminal functions as shown in Table 2.

In the first experiment where the sheep on the teff hay diet lost their appetite and showed retarded ruminal functions, it was difficult to distinguish between the effects of the added bicarbonate and those normally experienced when Merino sheep are kept on a ration containing teff hay only for a long time. It was therefore decided to repeat that part of the experiment.

In the second experiment the four experimental sheep did not maintain their feed consumption as well as the two controls. After an initial drop the feed intake did, however, improve during the time that the level of bicarbonate in the drinking water was at its highest. It is therefore difficult to blame the bicarbonate for the temporary lower feed intake.

Both groups of sheep in experiment No. 2 gradually drank more and more water as the weather became warmer. Unfortunately the drop in water intake following on the withdrawal of bicarbonate coincided with the first general summer rains which could have caused the decreased thirst. It does, however, seem that the increased water intake of the experimental group before the rain was more pronounced than that of the control group.

As with the lucerne hay group in experiment 1, the high levels of bicarbonate in the drinking water of the four experimental sheep in the second trial had no influence on their ruminal cellulose digestion, rate of ruminal contractions, pH of the rumen or the ability of the micro-organisms to ferment glucose.

The sudden weight gains of the four experimental sheep after the discontinuation of the addition of bicarbonate to their water, cannot be explained by feed or water intake. It is possible that the lower sodium bicarbonate load on the kidneys and the more humid atmosphere favoured water retention, which in turn could have been responsible for these weight gains. Otherwise, the sheep's gradual loss of weight during the course of the experiment was to be expected with this particular diet.

TABLE 2.—*Mean feed and water intake, ruminal digestion indices and live weights of two sheep (No. 1 and 2) drinking water with high levels of sodium bicarbonate, determined weekly (lucerne hay diet)*

Week No.	Level of bicarbonate in water (ppm)	Daily feed intake (gm)		Daily water intake (ml)		Cellulose digestion index		Sugar fermentation (ml gas formed)		Ruminal pH		No. of ruminal movements per 5 min		Body weight (lb)	
		1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	500	1324	1211	3402	3241	21·2	28·6	18·9	7·7	6·9	6·7	6·5	4·9	100	93
2	500	1121	1237	2584	3260	18·7	27·2	26·3	8·4	7·0	6·8	6·3	5·1	100	94
3	500	1340	1189	3526	2989	13·2	31·8	28·3	6·4	7·1	6·7	7·4	4·8	101	94
4	500	1325	1196	3466	3052	20·4	35·9	11·2	4·8	6·8	6·7	6·5	5·5	102	94
5	1000	1385	1222	3700	3161	5·8	34·1	30·2	1·0	7·0	6·8	6·9	5·2	103	94
6	1000	1279	1165	3326	3220	26·9	38·3	10·3	1·0	7·1	6·9	7·3	5·1	103	94
7	1000	1353	1179	3504	3164	24·0	30·0	5·8	0·7	7·0	6·7	5·7	5·3	103	95
8	1000	1354	1151	3440	3089	22·4	32·6	1·0	6·6	7·0	6·6	7·2	4·9	103	95
9	2000	1366	1093	4009	2969	23·6	37·0	5·3	20·0	7·0	6·7	6·4	5·0	104	95
10	2000	1379	1123	3661	3251	26·6	31·1	3·4	5·5	7·4	6·7	5·1	5·1	104	95
11	2000	1285	1156	3474	3160	32·9	27·8	2·0	6·7	7·2	6·8	5·3	5·2	104	94
12	2000	1301	1183	3119	3001	25·6	29·7	5·5	3·5	6·9	6·7	5·9	5·0	104	95
13	2500	1241	1146	3466	3218	26·1	28·2	6·4	6·0	7·0	6·9	5·5	5·6	104	95
14	2500	1236	1152	3484	3065	23·3	28·3	2·6	4·1	7·0	6·8	5·2	4·9	104	95
15	2500	1257	1153	3910	3172	25·7	24·8	5·5	4·2	6·9	7·0	6·1	5·2	104	95
16	2500	1253	1098	3611	3152	24·6	18·7	4·5	2·2	7·2	6·8	5·0	5·2	104	95
17	3000	1256	1142	3461	3076	15·4	23·7	3·2	3·4	7·0	6·7	6·0	5·2	105	96
18	3000	1230	1167	3446	3091	35·3	19·6	3·1	6·0	6·8	6·7	6·6	5·4	106	96
19	3000	1204	1175	3116	3004	30·2	25·0	4·4	1·8	6·8	6·8	5·1	5·1	105	96
20	3000	1221	1188	3463	2957	31·7	26·7	6·1	3·0	7·0	6·9	5·2	5·2	105	96
21	4000	1299	1191	3376	2992	33·0	29·1	9·9	5·8	7·1	6·7	5·4	5·1	105	96
22	4000	1154	1210	2874	2654	31·5	21·6	7·1	14·5	7·2	6·8	5·7	5·3	104	96
23	4000	1263	1197	3091	3108	28·3	30·1	7·5	22·0	7·1	6·8	5·6	5·3	104	96
24	4000	1216	1204	3043	2763	25·3	33·6	3·8	6·0	6·9	6·7	6·3	4·8	105	96
25	5000	1331	1226	3037	3015	35·9	37·9	5·2	7·5	7·0	6·8	5·2	4·9	104	96
26	5000	1261	1203	2914	2850	35·2	36·2	5·0	20·0	7·2	6·8	5·1	5·2	104	96
27	5000	1250	1175	2569	2467	31·6	39·3	12·6	8·5	7·1	6·8	5·6	5·0	104	96
28	5000	1277	1162	2807	2471	31·8	38·3	10·3	12·0	7·0	6·7	5·2	5·1	104	96
29	500	1254	1189	2477	2700	32·9	38·4	8·5	5·8	7·0	6·7	5·6	5·6	104	96
30	500	1224	1191	2506	2385	29·6	29·7	7·9	4·2	6·9	6·6	5·4	5·1	104	96
31	500	1247	1168	2567	2267	26·3	35·6	9·3	6·4	6·9	6·8	6·3	5·2	105	96

TABLE 3.—*The average values of four sheep drinking water with added bicarbonate, for daily feed and water intake, ruminal cellulose digestion index, glucose fermentation rate, pH of ruminal contents, rate of ruminal contractions and body weights, determined weekly. (Teff hay diet)*

Week ending	Level of HCO_3 in water ppm	Feed consumption (gm/day)	Water intake (ml/day)	Cellulose digestion index	Glucose fermentation (ml gas produced)	Ruminal contractions (no/5 min)	Ruminal pH	Body weight (lb)
21. 6.64	517	1366	1920	16·1	—	4·7	6·4	168
28. 6.64	517	1379	1699	17·4	1·89	5·0	6·4	165
5. 7.64	517	1308	1715	13·6	1·97	5·3	6·5	164½
12. 7.64	517	1198	1735	14·9	3·32	5·2	6·6	164
19. 7.64	1000	1174	1704	18·5	3·08	5·3	6·5	163½
26. 7.64	1000	1083	1572	19·9	4·20	5·2	6·5	160
2. 8.64	1000	951	1301	22·9	3·41	5·1	6·6	158½
9. 8.64	2000	979	1841	19·3	3·28	5·1	6·5	157
16. 8.64	2000	1068	1753	24·0	2·60	5·2	6·6	158¾
23. 8.64	2000	1070	1919	21·5	2·60	5·3	6·6	155¼
30. 8.64	4000	1083	2036	22·5	2·36	5·6	6·6	154½
6. 9.64	4000	1044	1943	21·2	2·26	5·3	6·5	155½
13. 9.64	4000	1045	2005	19·4	1·51	5·6	6·5	154
20. 9.64	5000	1094	2533	23·1	1·83	5·4	6·4	154¼
27. 9.64	5000	1133	3060	29·7	3·47	4·8	6·5	154¼
4.10.64	5000	1221	3281	26·0	5·49	4·7	6·4	152¾
11.10.64	517	1231	2999	23·8	3·36	4·4	6·4	158¾
18.10.64	517	1215	2701	20·9	4·06	4·4	6·4	159¼
25.10.64	517	1144	2305	21·9	3·64	4·8	6·4	157¼
1.11.64	517	1196	2363	20·4	3·35	4·1	6·4	156¾

TABLE 4.—*Average daily feed and water intake of two control sheep (Teff hay diet)*

Week ending	Feed consumption (gm/day)	Water intake (ml/day)
16. 8.64	1636	3745
23. 8.64	1730	4010
30. 8.64	1816	3958
6. 9.64	1713	3679
13. 9.64	1745	3866
20. 9.64	1739	4336
27. 9.64	1794	5079
4.10.64	1733	4905
11.10.64	1759	4997
18.10.64	1671	4430
25.10.64	1576	3546
1.11.64	1678	3874
8.11.64	1628	4435
15.11.64	1545	3937
22.11.64	1646	2843
29.11.64	1789	3243
6.12.64	1784	3251
13.12.64	1835	3353
20.12.64	1852	3518

DISCUSSION

These experiments with sheep were carried out in stables and, although no definite harmful effects of the drinking water containing high levels of bicarbonate could be shown, the picture may be quite different when they are kept outside in the sun. On the other hand, the levels of bicarbonate tested were much higher than the highest levels found in some borehole waters. Of the last 50 samples of borehole water to be approved for stock drinking purposes by the National Veterinary Research Laboratories, 11 contained levels of bicarbonate exceeding 500 ppm as $—HCO_3$, the highest of these being 775 ppm of bicarbonate.

These experiments have not proved beyond doubt that high levels of bicarbonate in the drinking water of sheep on poor feed will have no harmful effects over long periods. It may be reasonably safe, however, to suggest that much higher levels than the accepted 500 ppm may be permitted in water without any fear of increased ruminal pH or ruminal atony.

Similar experiments should be carried out with cattle before any recommendations on the levels of bicarbonate in their drinking water can be made. It is assumed that the breeds of sheep which are better adapted to arid regions than the Merino or German Merino should be even less susceptible to high levels of bicarbonate in their water.

SUMMARY

Two groups of rumen fistulated sheep of two each fed on lucerne hay *ad lib.* (supra maintenance) and teff hay *ad lib.* (sub-maintenance) respectively, were offered drinking water containing different levels of bicarbonate, viz. 500 (normal tap water), 1000, 2000, 2500, 3000, 4000, 5000 and again 500 ppm. Each level of bicarbonate in the water was given for a four-week period. Feed and water intake was measured daily. Twice a week the pH of the ruminal contents, the ruminal cellulose digestion rate, the ruminal movements and the sugar fermenting ability of the ruminal organisms were determined. The sheep were weighed once a week.

The high levels of bicarbonate had no effect on feed and water intake or any of the ruminal functions studied in the well-fed group. The group on poor feed, however, lost their appetites and their ruminal functions were affected. This deterioration was ascribed rather to the poor diet than to the added bicarbonate.

Another group of four strong sheep was therefore also given a poor diet (teff hay plus 50 gm of crushed maize per sheep daily) and subjected to the same treatment. Their appetites decreased a little while on the lower levels of bicarbonate in the drinking water, but improved again while on the higher levels. Otherwise the high levels of bicarbonate had no significant effect on the indices estimated.

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