

## The effect of potassium on the sodium requirements of growing steers with and without $\alpha$ -tocopherol supplementation

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1. Hereford steers, housed in concreted yards and given demineralized water, were offered *ad lib.* a low-sodium (0.07 g Na and 4.5 g potassium/kg) basal diet of sorghum grain, urea and minerals, to which 0, 15 or 30 g K as  $\text{KHCO}_3$ /kg diet had been added. Mean daily intakes of K were 26, 107 and 168 g/steer respectively.
2. The steers were given daily supplements of 0, 3.25 or 6.50 g Na as  $\text{NaHCO}_3$ /steer, added to the food; mean daily intakes of Na (food plus supplemental  $\text{NaHCO}_3$  minus residues) were 0.41, 3.06 and 6.26 g/steer respectively.
3. Rate of gain of body-weight was positively related to the rate of Na supplementation and negatively related to the K content of the diet, but there was no interaction between Na and K contents of the diet.
4. The Na:K ratios for the parotid saliva from steers not given Na supplements was 0.3, whereas steers ingesting either 3.1 or 6.3 g Na/d had Na:K ratios of about 12. Increasing the amount of K in the diet had no consistent effect on the saliva Na:K ratio. The Na:K ratios for rumen fluid reflected changes in the saliva Na:K ratio in response to Na supplements and were inversely related to the amount of K in the diet.
5. The width of the adrenal zona glomerulosa from steers receiving the basal diet, without Na supplements, was significantly greater than that from steers given the Na supplements, but it was not affected by the amount of K in the diet.
6. Both Na supplements and the diet containing 30 g added K/kg significantly increased the Na:K ratio of the plasma.
7. The addition of 200 mg DL- $\alpha$ -tocopheryl acetate/steer per d to the diet had no significant effects on the growth rate of the steers.
8. It was concluded that the Na requirement of steers for growth was not significantly affected by the amount of K in the diet up to 168 g/d.

There is inadequate information about the quantitative sodium requirements of cattle for growth. Morris & Gartner (1971) reported that on the basis of rate of weight gain, saliva composition and adrenal histology, the Na requirement of steers given an all-grain diet was not greater than 3.1 g/d. Because diets containing a high proportion of roughage may contain considerably greater amounts of potassium than all-grain diets, the application of this requirement to diets other than all-grain diets was questioned. In this experiment the effect of the K content of the diet on Na requirements for growth was studied. Steers were given an all-grain diet to which 0, 15 or 30 g K/kg had been added and they received daily Na supplements of 0, 3.25 or 6.50 g.

The vitamin E requirements of cattle for growth have not been well defined (Agricultural Research Council, 1965), therefore the effect of the addition of 200 mg DL- $\alpha$ -tocopheryl acetate/steer per d to the diet was determined.

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Table 1. *Composition (g/kg dry matter) of the basal sorghum-grain\*–urea–mineral mixture, and of the oaten chaff used to accustom the steers to the all-grain diet*

	Ash	Nitrogen	Phosphorus	Calcium	Sodium	Potassium
Basal sorghum-grain–urea–mineral mixture	29	29	2.1	4.6	0.07	4.5
Oaten chaff	95	4.0	0.6	1.3	nd	nd

nd, not determined.

\* From hybrid varieties of *Sorghum vulgare*.

## EXPERIMENTAL

### *Animals*

Grade Hereford steers, about 12 months of age, were selected, on a beef cattle property in south-eastern Queensland, for uniformity of body-weight. They were transported to the Husbandry Research Farm, Rocklea, where they grazed pasture while they underwent the inoculations and passed the health tests described by Morris & Pepper (1969). At the start of yard feeding, each steer was given orally 16 g thiabendazole (Thibenzole; Merck, Sharp & Dohme (Australia) Pty Ltd, Granville, New South Wales) as an anthelmintic and 2.75 g retinyl palmitate (Rovimix A-325; Roche Products, Dee Why, New South Wales).

### *Diet*

About 100 t bulk grain from hybrid varieties of sorghum (*Sorghum vulgare*) were purchased from a local supplier. When required for feeding, it was prepared in 5 t batches by coarse rolling using a mill set just to fracture the grain.

Three mixtures based on sorghum grain and containing 0, 38.5 or 77 g  $\text{KHCO}_3$ /kg were prepared. The  $\text{KHCO}_3$  in the mixture replaced an equal weight of sorghum grain. Each Mg mixture contained 20 kg urea and the following mineral mixture (kg): 7.8 calcium hydroxide, 4.5 commercial gypsum, 2.0  $\text{NH}_4\text{Cl}$ , 0.100  $\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$ , 0.067  $\text{ZnSO}_4 \cdot \text{H}_2\text{O}$ , 0.032  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , 0.006  $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ . Before being added to the diet mixture, the minerals were made into an aqueous slurry and dried at  $105^\circ$  to remove free ammonia. The resulting lumps were then ground to a powder and 1 g potassium iodide was added.

Chaffed oaten stubble was used as a roughage to accustom the steers to the all-grain diet.

The proximate analyses of the basal sorghum-grain–urea–mineral mixture and of the oaten chaff are shown in Table 1.

### *Design*

A  $3 \times 3 \times 2$  factorial experiment was used to study the effect of the three rates of Na supplementation and the three amounts of K in the diet on the growth rate, food intake and Na and K metabolism of steers receiving two rates of  $\alpha$ -tocopherol supplementation. Sixty-three steers were randomly allocated as follows: fifty-four to the

experimental treatments, resulting in three animals/treatment group, and nine to a pretreatment slaughter group to measure initial carcass weight.

The three rates of Na supplementation (g Na as  $\text{NaHCO}_3$ /steer per d) were: basal (0.07 g Na/kg diet), basal + 3.25, basal + 6.50; the three amounts of K (g/kg) in the diet were: basal (4.5 g K/kg diet), basal + 15 (38.5 g  $\text{KHCO}_3$ /kg), basal + 30 (77 g  $\text{KHCO}_3$ /kg). The two rates of  $\alpha$ -tocopherol supplementation were 0 and 200 mg DL- $\alpha$ -tocopheryl acetate as a stabilized powder (Rovimix E-25; Roche Products, Dee Why, New South Wales)/steer per d.

The pretreatment steers were slaughtered at the start of yard feeding. The remaining fifty-four steers were given the experimental rations for 126 d after which time they were slaughtered.

#### *Feeding schedule and yards*

For the first 6 d of yard feeding each of the eighteen groups of steers was offered a diet containing equal parts by weight of the grain diet and of roughage. The allocation of grain was gradually increased and that of roughage was progressively decreased until an all-grain diet was given *ad lib.* on the 28th day.

The yards had concreted floors and each group of three steers had a food trough 3.7 m in length. Until the 27th day of yard feeding, water from the Brisbane city supply (about 0.04 g Na/l) was given, thereafter demineralized water (less than 0.001 g Na/l) was given *ad lib.*

Supplements of  $\text{NaHCO}_3$  and  $\alpha$ -tocopheryl acetate were added daily to the food trough for each group of steers, starting on the 28th day of yard feeding.

#### *Measurements*

*Body-weight and carcass-weight gain.* The steers were weighed after being without food for 24 h and without water for 12 h (fasted body-weight), both before entering the experiment and 24 h before slaughter. At weekly intervals body-weight was recorded without food or water restriction (non-fasted body-weight).

Carcass-weight gain was calculated as the difference between the final hot carcass weight and the product of the initial fasted body-weight and the mean dressing percentage of the pretreatment groups.

*Food and water intake.* Residues of uneaten food were removed at weekly intervals from the food troughs and weighed, and a representative sample was retained for analysis for Na and K. The intake of water was measured daily for 14 d, from day 81 to day 93 of yard feeding.

*Saliva.* Samples of saliva were collected from each steer over a 2 d period immediately before the start of all-grain feeding and after 28, 56, 84 and 91 d of all-grain feeding. The method of saliva collection has been described by Morris & Gartner (1971).

*Blood, urine and rumen fluid.* Samples of blood and urine were collected from the steers at the end of the 91st day of all-grain feeding (1 week before slaughter). Rumen fluid samples were obtained at slaughter. Samples of saliva, whole blood, plasma, urine and rumen fluid were analysed for Na and K, the plasma samples were also analysed for chloride.

*Organs and glands.* At slaughter the parotid salivary glands and adrenals were collected, weighed and prepared for histological examination as described by Morris & Gartner (1971).

#### *Analytical methods*

The analytical methods used were those described by Morris & Gartner (1971), except for the tocopherol content of the sorghum grain which were estimated by the method of Nobile (1963, and personal communication). This method involved digestion of the milled grain with enzymes in water at 45° in the presence of an antioxidant; treatment with ammonia and ethanol, and extraction with a diethyl ether-petroleum spirit (b.p. 40°-60°). The extract was purified by saponification and extraction procedures, and one-dimensional, thin-layer chromatography using Kieselgel G (E. Merck AG, Darmstadt, West Germany) and fluorescein plates with chloroform as the developing solvent. The separate bands of  $\alpha$ -,  $\beta$ - +  $\gamma$ - and  $\delta$ -tocopherols were removed from the plates and eluted with ethanol followed by diethyl ether. The amount of tocopherols was estimated from the colour developed by the addition of 1,1'-bipyridyl and ferric chloride. Two-dimensional, thin-layer chromatography using chloroform as the developing solvent in the first dimension and di-isopropyl ether-petroleum spirit (b.p. 40°-60°) (1:4, v/v) in the second dimension, was used to check the purity of  $\alpha$ -tocopherol.

Results were analysed by analysis of variance. The effects were tested *v.* Na, K and  $\alpha$ -tocopherol  $\times$  animals as error, with the exception of food and water intake as the animals were group-fed. For the analysis of growth rate a linear regression ( $y = a + bx$ ) of body-weight ( $y$ ) *v.* time ( $x$ ) was computed and the 'b' values used in the analysis of variance.

#### RESULTS

*Net intakes of Na and K.* The food residues from all steers contained a higher percentage of ash and Na than the basal diet, apparently the result of sedimentation of the mineral additives. The mean net daily intakes of Na, calculated from the Na in the basal diet, NaHCO<sub>3</sub> supplement, and residues, were 0.41, 3.06 and 6.26 g for the three treatments: basal (0.07 g Na/kg), basal + 3.25 and 6.50 g Na/d respectively. The mean daily intakes of K for groups given 0, 15 and 30 g added K/kg diet, were 26, 107 and 168 g K/steer respectively.

*Food and water intake.* The mean daily food intake was greater for the steers receiving Na supplements (6.4 and 6.6 kg at intakes of 3.1 and 6.3 g Na/d respectively) than for those given no Na supplement (5.7 kg). These differences were significant ( $P < 0.01$ ) when weeks  $\times$  Na  $\times$   $\alpha$ -tocopherol was used as error. However, the interaction of Na  $\times$  K  $\times$   $\alpha$ -tocopherol was significant when tested *v.* Na  $\times$  K  $\times$   $\alpha$ -tocopherol  $\times$  weeks as error. When Na  $\times$  K  $\times$   $\alpha$ -tocopherol was used as error, none of the treatments had a significant effect on food intake. As the steers were fed in groups, it was not possible to obtain a within-group measure of variance.

Similarly, treatments had no significant effect on water intake because the Na  $\times$  K  $\times$   $\alpha$ -tocopherol error term was large.

*Body-weight changes.* The initial and final fasted body-weights of the steers are

Table 2. Mean body-weight, rate of body-weight gain and carcass weight of steers given a basal diet of sorghum grain, urea and minerals to which was added potassium as  $KHCO_3$  and which was supplemented with sodium as  $NaHCO_3$  and with  $\alpha$ -tocopherol\*

	(Mean values for three animals/group)						$\alpha$ -Tocopherol supplement (mg $\alpha$ -tocopheryl acetate/ steer per d)		SE
	Mean Na intake (g/steer per d)		Mean K intake (g/steer per d)		SE				
	0.4	3.1	6.3	26	107	168	0	200	
Initial fasted body-wt (kg)	185.8	182.5	184.9	184.9	184.2	184.2	185.0	183.9	2.7
Final fasted body-wt (kg)	275.9 <sup>a</sup>	286.7	294.9 <sup>a</sup>	300.4 <sup>d</sup>	289.1 <sup>a</sup>	267.9 <sup>a,d</sup>	283.3	288.4	5.3
Body-wt gain (kg)	90.1 <sup>a</sup>	104.2	109.2 <sup>a</sup>	115.4 <sup>d</sup>	106.1 <sup>e</sup>	82.0 <sup>d,e</sup>	98.3	104.1	4.1
Daily body-wt gain (kg/d)	0.81 <sup>d</sup>	0.93	1.03 <sup>d</sup>	1.06 <sup>d</sup>	1.02 <sup>e</sup>	0.70 <sup>d,e</sup>	0.89	0.96	0.04
Carcass wt (kg)	158.0	163.6	168.4	170.0 <sup>d</sup>	167.2 <sup>e</sup>	152.8 <sup>d,e</sup>	162.6	164.1	2.9
Carcass-wt gain† (kg)	63.4 <sup>a</sup>	70.7	73.9 <sup>a</sup>	75.8 <sup>d</sup>	74.0 <sup>e</sup>	58.1 <sup>d,e</sup>	68.4	70.3	2.3

Mean values for different levels of Na or for different levels of K with the same superscript were significantly different: a,  $P < 0.05$ ; d, e,  $P < 0.01$ .

\* For details of diets and treatments, see p. 3 and Table 1.

† Final hot carcass wt - (initial fasted body-wt x mean dressing percentage of the pretreatment group).

Table 3. *Daily rate of body-weight gain (kg/d) for steers given a basal diet of sorghum grain, urea and minerals to which was added potassium as  $KHCO_3$  and which was supplemented with sodium as  $NaHCO_3$ \**

(Mean values for three animals/group for the period of all-grain feeding†)

Na intake (g/steer per d)	Mean K intake (g/steer per d)		
	26	107	168
0.4	0.99	1.12	0.73
3.1	1.22	1.16	0.67
6.3	1.27	1.14	0.89

Least significant difference: 0.26 for  $P < 0.05$ ; 0.34 for  $P < 0.01$ .

\* For details of diets and treatments, see p. 3 and Table 1.

† The animals were accustomed to an all-grain diet by giving decreasing amounts of roughage in a grain-roughage diet; for details, see p. 3.

Table 4. *Mean concentrations of sodium, potassium and Na + K (mmol/l) and the Na:K ratio for saliva from steers given a basal diet of sorghum grain, urea and minerals to which was added K as  $KHCO_3$  and which was supplemented with Na as  $NaHCO_3$ \**

(Mean values for three animals/group)

Period <sup>‡</sup> of all-grain feeding† (d)		Mean Na intake (g/steer per d)			Mean K intake (g/steer per d)			SE
		0.4	3.1	6.3	26	107	168	
0	Na	116 <sup>d,f</sup>	148 <sup>d,e</sup>	129 <sup>e,f</sup>	134 <sup>d</sup>	134 <sup>e</sup>	124 <sup>d,e</sup>	2.23
	K	8.4 <sup>d,e</sup>	6.2 <sup>d</sup>	5.5 <sup>e</sup>	6.6	6.7	6.9	0.38
	Na + K	124 <sup>d,e</sup>	154 <sup>d,f</sup>	135 <sup>e,f</sup>	141 <sup>d</sup>	140 <sup>e</sup>	131 <sup>d,e</sup>	2.12
	Na:K	15.5 <sup>d,e</sup>	24.8 <sup>d</sup>	24.9 <sup>e</sup>	22.6	22.0	20.5	1.25
28	Na	53 <sup>d,e</sup>	134 <sup>d</sup>	140 <sup>e</sup>	107	115 <sup>d</sup>	104 <sup>d</sup>	2.85
	K	83.3 <sup>d,e</sup>	13.1 <sup>d</sup>	9.5 <sup>e</sup>	36.3 <sup>a</sup>	28.9 <sup>a,d</sup>	40.7 <sup>d</sup>	2.56
	Na + K	135 <sup>d,e</sup>	147 <sup>d</sup>	150 <sup>e</sup>	144	144	144	2.04
	Na:K	0.80 <sup>d,e</sup>	13.1 <sup>a,d</sup>	16.0 <sup>a,e</sup>	11.6 <sup>a</sup>	8.3 <sup>a</sup>	9.9	0.93
56	Na	34 <sup>d,e</sup>	130 <sup>d</sup>	128 <sup>e</sup>	97 <sup>d</sup>	106	89 <sup>d</sup>	3.66
	K	96.9 <sup>d,e</sup>	18.8 <sup>d</sup>	14.9 <sup>e</sup>	49.4 <sup>a</sup>	39.2 <sup>a</sup>	42.1	3.16
	Na + K	131 <sup>d,e</sup>	149 <sup>d</sup>	143 <sup>e</sup>	146 <sup>d</sup>	146 <sup>e</sup>	131 <sup>d,e</sup>	2.43
	Na:K	0.36 <sup>d,e</sup>	11.9 <sup>d</sup>	10.9 <sup>e</sup>	7.6	9.2	6.3	1.14
84	Na	24 <sup>d,e</sup>	136 <sup>d</sup>	135 <sup>e</sup>	92 <sup>a,b</sup>	102 <sup>a</sup>	100 <sup>b</sup>	2.58
	K	105.0 <sup>d,e</sup>	13.4 <sup>d</sup>	10.6 <sup>e</sup>	45.4	42.0	41.7	2.60
	Na + K	129 <sup>d,e</sup>	149 <sup>d</sup>	146 <sup>e</sup>	138	144	142	2.75
	Na:K	0.23 <sup>d,e</sup>	11.9 <sup>d</sup>	13.8 <sup>e</sup>	8.5	9.1	8.3	0.65
91	Na	28 <sup>d,e</sup>	134 <sup>d</sup>	137 <sup>e</sup>	102 <sup>a</sup>	101	95 <sup>a</sup>	2.17
	K	107.1 <sup>d,e</sup>	11.9 <sup>d</sup>	12.7 <sup>e</sup>	45.2	42.7	43.8	2.68
	Na + K	135 <sup>d,e</sup>	145 <sup>d</sup>	150 <sup>e</sup>	147 <sup>a</sup>	144	139 <sup>a</sup>	2.35
	Na:K	0.27 <sup>d,e</sup>	13.0 <sup>d</sup>	12.8 <sup>e</sup>	10.1	8.2	7.8	0.92

Mean values for different levels of Na, or for different levels of K with the same superscript were significantly different: a, b,  $P < 0.05$ ; d, e, f,  $P < 0.01$ .

\* For details of diets and treatments, see p. 3 and Table 1.

† The animals were accustomed to an all-grain diet by giving decreasing amounts of roughage in a grain-roughage diet; for details, see p. 3.

Table 5. Mean concentrations of sodium, potassium and Na + K (mmol/l) and the Na:K ratio for rumen fluid taken immediately before slaughter (91st day) from steers given a basal diet of sorghum grain, urea and minerals to which was added K as  $\text{KHCO}_3$  and which was supplemented with Na as  $\text{NaHCO}_3$ \*

	(Mean values for three animals/group)						SE
	Mean Na intake (g/steer per d)			Mean K intake (g/steer per d)			
	0.4	3.1	6.3	26	107	168	
Na	33.5 <sup>d,e</sup>	114.0 <sup>d</sup>	112.7 <sup>e</sup>	101.5 <sup>d,e</sup>	88.7 <sup>d,f</sup>	70.0 <sup>e,f</sup>	3.3
K	120.3 <sup>d,e</sup>	51.5 <sup>d</sup>	50.3 <sup>e</sup>	63.1 <sup>d</sup>	68.8 <sup>e</sup>	90.1 <sup>d,e</sup>	2.8
Na + K	153.9 <sup>d,e</sup>	165.4 <sup>d</sup>	163.0 <sup>e</sup>	164.7 <sup>a</sup>	157.5 <sup>a</sup>	160.1	2.2
Na:K	0.3 <sup>d,e</sup>	2.6 <sup>d</sup>	2.8 <sup>e</sup>	2.8 <sup>d,f</sup>	1.8 <sup>d,f</sup>	1.0 <sup>e,f</sup>	0.12

Mean values for different levels of Na, or for different levels of K with the same superscript were significantly different: a, b,  $P < 0.05$ ; d, e, f,  $P < 0.01$ .

\* For details of diets and treatments, see p. 3 and Table 1.

shown in Table 2. Supplements of Na increased total body-weight gains. The effect of 3.1 g Na/d was significant at  $P < 0.06$ , whereas the effect of 6.3 g Na/d was significant at  $P < 0.02$ . The addition of  $\text{KHCO}_3$  to the diet decreased the total body-weight gain, the effect being most apparent in steers given the basal diet + 30 g K/kg. The effect of  $\text{NaHCO}_3$  and  $\text{KHCO}_3$  on the daily rate of body-weight gain for the period of all-grain feeding is shown in Table 3. While there is no significant interaction between  $\text{NaHCO}_3$  and  $\text{KHCO}_3$  treatments, it appeared that the effect of Na supplements on total and daily body-weight gain was greater for steers given the basal diet than for those receiving diets containing added  $\text{KHCO}_3$ .

$\alpha$ -Tocopherol supplementation had no significant effect on total body-weight gain or daily rate of body-weight gain or any of the subsequent measurements.

*Carcass-weight changes.* The effects of the Na and K supplements on carcass weight and carcass-weight gain (Table 2) were similar to those recorded for body-weight gain. There was also no significant interaction between the Na and K treatments on carcass-weight gain or any of the other measurements.

*Health of the steers.* There was a positive relationship between the incidence of rumen tympany and the  $\text{KHCO}_3$  content of the diet. Over-distension of the rumen was not found in steers given the diet with no added  $\text{KHCO}_3$ , whereas it was frequently found, particularly in the latter part of the experiment, in steers given the diets containing 38.5 and 77 g  $\text{KHCO}_3$ /kg. Tympany was more severe in steers given the diet containing 77 g  $\text{KHCO}_3$ /kg than in those given the diet containing 38.5 g  $\text{KHCO}_3$ /kg. On four occasions one or more steers given the diet with 77 g  $\text{KHCO}_3$ /kg required treatment with anti-bloat oil. One steer given the diet containing 38.5 g  $\text{KHCO}_3$ /kg died from primary rumen tympany 3 weeks before the end of the experiment.

*Saliva.* The concentration of Na in saliva from steers not given supplements of  $\text{NaHCO}_3$  decreased progressively during the period of all-grain feeding (Table 4) whereas the concentration of K progressively increased, resulting in a decrease in the

Table 6. Mean concentrations of sodium and chloride ion (mmol/l) and the Na:potassium ratio for plasma taken immediately before slaughter (91st day) from steers given a basal diet of sorghum grain, urea and minerals to which was added K as  $\text{KHCO}_3$  and which was supplemented with Na as  $\text{NaHCO}_3$ \*

	(Mean values for three animals/group)						SE
	Mean Na intake (g/steer per d)			Mean K intake (g/steer per d)			
	0.4	3.1	6.3	26	107	168	
Na	128.2 <sup>d,e</sup>	131.7 <sup>d</sup>	131.8 <sup>e</sup>	129.0 <sup>d</sup>	129.6 <sup>e</sup>	133.2 <sup>d,e</sup>	0.51
K	5.3 <sup>a,d</sup>	4.8 <sup>a</sup>	4.6 <sup>d</sup>	5.1 <sup>a</sup>	5.0	4.6 <sup>a</sup>	0.14
Na + K	133.5 <sup>d,e</sup>	136.6 <sup>d</sup>	136.4 <sup>e</sup>	134.1 <sup>d</sup>	134.6 <sup>e</sup>	137.8 <sup>d,e</sup>	0.54
Na:K	24.5 <sup>d,e</sup>	27.6 <sup>d</sup>	29.0 <sup>e</sup>	25.4 <sup>d</sup>	26.7 <sup>a</sup>	29.0 <sup>a,d</sup>	0.75
Cl	101.4 <sup>d</sup>	103.4 <sup>a,d</sup>	102.1 <sup>a</sup>	102.1	103.2 <sup>a</sup>	101.7 <sup>a</sup>	0.42

Mean values for different levels of Na, or for different levels of K with the same superscript were significantly different: a,  $P < 0.05$ ; d, e,  $P < 0.01$ .

\* For details of diets and treatments, see p. 3 and Table 1.

Na:K ratio for the saliva. Neither K levels nor the interaction  $\text{Na} \times \text{K}$  had a significant effect on the saliva Na:K ratio. At each sampling period Na + K content was less in the saliva from steers not given Na supplements than from those given the Na supplements. Although the differences between the composition of saliva from steers given diets with different  $\text{KHCO}_3$  contents were statistically significant for some days of the experiment, these differences did not show a consistent trend.

*Rumen fluid.* The concentration of Na in the rumen fluid taken immediately before slaughter (91st day) from steers not receiving Na supplements was significantly less and the K concentration was significantly greater than that from steers receiving daily Na supplements (Table 5). Steers given diets with added  $\text{KHCO}_3$  (107 and 168 g K ingested/d) had a significantly lower concentration of Na in their rumen fluid than those receiving the basal diet alone (26 g K ingested/d). The K concentration in the rumen fluid from the steers ingesting 168 g K/d was significantly greater than from those ingesting 26 g K/d ( $P < 0.01$ ).

*Na, K and Cl concentrations for plasma and erythrocytes.* The concentrations of Na and K in the samples of plasma taken immediately before slaughter (91 d of all-grain feeding) (Table 6) indicated that in the plasma samples from steers given the basal diet without Na supplements there was a small but significant decrease in Na concentrations, and a similar significant increase in K concentrations. The highest level of K intake (168 g/d) resulted in a significant increase in plasma Na concentration and a decrease in plasma K concentration.

The mean concentration of Cl for the plasma from steers ingesting the intermediate levels of Na and K was greater than that for the plasma from steers on either the high intakes of Na or K or the low levels of Na.

The concentration of Na and K in the erythrocytes (difference between whole blood and plasma corrected for packed cell volume) were not significantly affected by the treatments.



Table 7. *Weight of the adrenal and parotid salivary glands and the width of the zona glomerulosa and adrenal cortex from the steers given a basal diet of sorghum grain, urea and minerals to which was added potassium as  $KHCO_3$  and which was supplemented with sodium as  $NaHCO_3$ \**

Measurement	Mean Na intake (g/steer per d)			Mean K intake (g/steer per d)			SE
	0.4	3.1	6.3	26	107	168	
Weight of adrenal (g):							
Left	8.6 <sup>a,b</sup>	7.6 <sup>a</sup>	7.2 <sup>b</sup>	7.7	8.0	7.7	0.35
Right	8.2 <sup>a,b</sup>	7.0 <sup>a</sup>	7.0 <sup>d</sup>	7.4	7.4	7.4	0.31
Left + right	16.8 <sup>a,d</sup>	14.6 <sup>a</sup>	14.2 <sup>d</sup>	15.1	15.4	15.1	0.65
Relative weight of adrenal (mg/kg body-wt)							
Left	31.2 <sup>d,e</sup>	26.6 <sup>d</sup>	25.4 <sup>e</sup>	25.7 <sup>a</sup>	27.6	29.0 <sup>a</sup>	1.1
Right	29.8 <sup>d,e</sup>	24.8 <sup>d</sup>	23.6 <sup>e</sup>	24.7 <sup>a</sup>	25.8	27.7 <sup>a</sup>	0.9
Left + right	61.0 <sup>d,e</sup>	51.5 <sup>d</sup>	48.1 <sup>e</sup>	50.4 <sup>a</sup>	53.4	56.8 <sup>a</sup>	2.0
Width of adrenal cortex†	29.7 <sup>a,d</sup>	26.1 <sup>a</sup>	24.1 <sup>d</sup>	26.4	26.7	26.9	1.03
Width of zona glomerulosa†	9.29 <sup>d,e</sup>	3.3 <sup>d</sup>	3.0 <sup>e</sup>	4.5	5.6	5.4	0.48
Width of zona glomerulosa (% width of cortex)	31.0 <sup>d,e</sup>	12.9 <sup>d</sup>	12.8 <sup>e</sup>	16.5 <sup>a</sup>	20.7 <sup>a</sup>	19.6	1.39
Weight of parotid:							
Left + right: g	77.8	76.3	81.4	85.6 <sup>d</sup>	77.4	72.5 <sup>d</sup>	3.2
mg/kg body-wt	280	267	276	286	268	270	10

Mean values for different levels of Na, or for different levels of K with the same superscript were significantly different: a, b,  $P < 0.05$ ; d, e,  $P < 0.01$ .  
 \* For details of diets and treatments, see p. 3 and Table 1.  
 † Arbitrary units.

Table 8. *Tocopherol content (mg/kg) of whole sorghum grain and a sample of the sorghum-grain-urea-mineral mixture, with no added KHCO<sub>3</sub>, that was fed to steers*

Sample	$\alpha$ -Tocopherol	$\beta$ - + $\gamma$ -Tocopherol
Whole grain at day 0 of experiment	4.8	12.6
Whole grain after storage for 6 months	3.2	9.9
Sorghum-grain-urea-mineral mixture*	1.8	3.8

\* Sample derived from compositing weekly sub-samples of the grain fed to the steers and stored at  $-10^{\circ}$  until analysed 5 months after the start of the experiment.

*Na, K concentrations and pH of urine.* The mean concentration of Na for the urine, immediately before slaughter (91st day), was significantly ( $P < 0.01$ ) increased at both levels of Na supplementation (7.4, 14.5 and 32.8 mmol/l for Na intakes of 0.4 (basal), 3.1 and 6.3 g/d, respectively), but was not affected by the level of K in the diet when the effects of all levels of Na and K intake were analysed. For the steers given the low-Na (basal) diet, there did appear to be an increase in the Na concentration for the urine with increasing K intake, but this trend was not found in the groups receiving the Na supplements. Similarly, the urinary concentration of K was not affected by the Na supplementation, but was significantly ( $P < 0.01$ ) increased by the addition of K to the diet (70, 129 and 202 mmol/l for K intakes of 26 (basal), 107 and 168 g/d respectively). The pH of the urine from steers given diets with no added K was significantly ( $P < 0.01$ ) lower than that from steers given diets with added K (7.5, 8.6 and 8.7 for K intakes of 26 (basal), 107 and 168 g/d respectively).

*Adrenal and parotid salivary glands.* The weights of the adrenal glands from the steers given the experimental diets (Table 7) were considerably greater than the weights of those from the pretreatment group (left gland 4.9 g, right gland 4.5 g, total 9.3 g, SE 1.8 g). The weights of the individual left and right glands from steers given the Na supplements and the sum of their weights was significantly less than those for glands from steers given the basal diet. This effect was also apparent when the weight of the adrenal gland was expressed on a body-weight basis. The widths of the adrenal cortex and the zona glomerulosa (as a percentage of the width of the cortex) were also significantly greater for the adrenals from steers given the basal diet than for those from steers given Na supplements. However, there was no significant difference between the measurements for adrenals from the two groups of steers given Na supplements. The addition of KHCO<sub>3</sub> to the diet had no significant effect on the absolute adrenal gland measurements. The weights of the parotid salivary glands from steers given the basal diet were greater than those from steers given the high-K diet (168 g K ingested/d). When the weight of the parotid salivary gland was expressed on a body-weight basis these differences were no longer apparent.

*Tocopherol content of the diet.* Tocopherol analysis of a sample of whole grain, taken before the experiment began (Table 8), indicated that the  $\alpha$ -tocopherol and  $\beta$ - +  $\gamma$ -tocopherol contents were considerably higher than those of either the whole grain after storage for 6 months or the sorghum-grain-urea-mineral mixture. No  $\delta$ -tocopherol was detected in any of the samples. Storage of the grain for 6 months

resulted in a loss of about one-third of the original tocopherol potency, whereas storage for 6 months and combination with the mineral mixture (without added  $\text{KHCO}_3$ ) resulted in a loss of about two-thirds of the tocopherol potency. As the sorghum-grain-urea-mineral mixture was prepared in batches of about 5 t and not stored for periods longer than 1 month before it was fed to the steers, the amount of tocopherol ingested was probably similar to that of the whole grain after 6 months' storage.

#### DISCUSSION

Assessment of the nutritional adequacy of an essential nutrient in a diet demands the establishment of criteria by which adequacy or deficiency can be defined. In relation to the Na requirements of growing cattle we chose in our previous study (Morris & Gartner, 1971) the following criteria: growth rate, food intake, Na and K contents of the saliva and rumen, and adrenal histology, in particular the width of the zona glomerulosa as a percentage of the width of the cortex. When these criteria were applied to the Na and K treatments in this experiment, we found that for Na-supplemented steers, those ingesting 3.1 g Na/d had food intakes, Na and K contents of the saliva and rumen, and adrenal histology which were comparable with those of steers ingesting 6.3 g Na/d. However, the mean growth rate for steers ingesting 3.1 g Na/d was slightly less than that for steers ingesting 6.3 g Na/d, but the difference was not significant, and the mean growth rate for Na-supplemented steers was greater ( $P < 0.06$ ) than that for steers given the basal diet. It appears, therefore, that a net intake of 3.1 g Na/d was adequate for growth. The addition of  $\text{KHCO}_3$  to the diet resulted in a significant depression of growth rate and did not appear to increase the requirement for Na.

The changes in the composition of the saliva associated with the two rates of Na supplementation were similar to those reported in a previous experiment (Morris & Gartner, 1971) in which steers were given an all-grain diet with no added  $\text{KHCO}_3$ . The Na:K ratio for the saliva was not apparently affected by the amount of K in the diet, which is in agreement with Scott's (1967) report that K supplementation of the diet does not affect the Na content of saliva.

The positive relationship between the Na concentration for the rumen fluid and the rate of Na supplementation and the negative relationship between the K concentration of the rumen fluid and the rate of Na supplementation were similar to those reported by Morris & Gartner (1971). The addition of K to the basal diet significantly increased the K concentration of rumen fluid and decreased the Na concentration, in agreement with the report of Scott (1967) that infusions of K salts into the rumen increased the concentration of K in the rumen fluid but decreased the Na concentration.

The widths of the adrenal cortex and the zona glomerulosa (as a percentage of the width of the cortex), for steers given the basal diet, were greater than those for steers ingesting 3.1 or more g Na/d and were similar to those previously reported by Morris & Gartner (1971). Adrenal histology was not affected by the amount of K in the diet.

Von Bunge (1873) first drew attention to the relatively high content of K

relative to Na in the diet of herbivorous animals, and suggested that their desire to balance the Na:K ratio in the diet may account for their general avid consumption of NaCl. In short-term experiments, the oral and intravenous administration of KCl to sheep (Dewhurst, Harrison & Keynes, 1968; Scott, 1969) and intravenous administration of KCl to cattle (Anderson & Pickering, 1962) have been shown to produce an immediate natriuresis. However, from 8 d balance studies with dairy cows Kemp (1964) suggested that when  $\text{KHCO}_3$  is added to the diet, urinary Na excretion is only temporarily increased, whereas faecal Na excretion may be reduced. St Omer & Roberts (1967) have reported results from a balance trial in which urinary and faecal excretion of Na by heifers is not affected when the daily intake of K is increased from 6.26 to 42.6 g. As our measurements did not include urine volume, no firm conclusions about the effect of K on urinary Na loss can be made from our results. However, as the interaction between dietary levels of Na and K had no significant effect on criteria such as the saliva Na:K ratio, it did not appear that K supplements exacerbated Na deficiency. Therefore, apparently either the K supplements did not cause a marked diuresis and the concentration of urine Na was not significantly affected by K levels, or a natriuresis was compensated by reduced losses by other pathways e.g. faecal. Therefore, our results support those of Kemp (1964) and St Omer & Roberts (1967) and suggest that over a prolonged period cattle can fully compensate in their Na metabolism for a high intake of K. Therefore, the Na requirement of steers for growth is apparently not affected by the K content of the diet up to an intake of 168 g K/d.

The positive relationship between urine pH and the K content of the diet was probably a consequence of the greater urinary excretion of basic ions by steers receiving diets containing added  $\text{KHCO}_3$ . Dewhurst *et al.* (1968) found that about 90% of the dietary K and about 80% of a K load (KCl administered into the rumen) was excreted in the urine of sheep, and that urine volume increased after KCl administration.

Matrone, Ramsey & Wise (1959) demonstrated that the addition of bicarbonates of Na and K to an all-concentrate diet increased the food intake and growth rate of lambs. The effect of the addition of these salts and other buffers to high-concentrate diets on the performance of growing or lactating cattle and sheep has subsequently been reported by a number of workers. Wise, Blumer, Matrone & Barrick (1961) found that the addition of  $\text{NaHCO}_3$  and  $\text{KHCO}_3$  (40 and 70 g/kg respectively) to an all-concentrate diet reduced food intake and body-weight gain of beef steers. Similarly, Nicholson, Cunningham & Friend (1963) reported that in one trial the rate of body-weight gain was not increased compared with that of control animals when 30 g  $\text{NaHCO}_3$  + 10 g  $\text{KHCO}_3$  + 20 g ground limestone/kg was added to an all-concentrate diet, but, in another trial, the addition of 30 g  $\text{NaHCO}_3$ /kg diet, alone, increased food intake. These workers also reported (Nicholson & Cunningham, 1961; Nicholson, Cunningham & Friend, 1962) that the addition of  $\text{NaHCO}_3$  to mixed and all-concentrate diets does not result in an increased rate of body-weight gain. Woolfitt, Howell & Bell (1964) reported an increase in the efficiency of food conversion in lambs when 20 g  $\text{NaHCO}_3$ /kg was added to a high-concentrate diet but not when 20 g  $\text{NaHCO}_3$  + 20 g sodium citrate/kg were added. However, Packett & Butcher (1963)

found a marked increase in the growth rate of lambs given a cottonseed-hull-concentrate diet when 30 g Na citrate/kg was added to the diet.

We found a higher incidence of bloat in steers given the diet with added  $\text{KHCO}_3$  than in those given the basal diet, which agreed with findings of Emery & Brown (1961). They found that bloat in dairy cows given a high-concentrate diet is apparently aggravated by the addition of  $\text{NaHCO}_3$  or  $\text{KHCO}_3$  (0.45 kg/cow per d) to the diet. They suggested that bloat may contribute to the lower food intake of cows given diets containing bicarbonate, compared to that of cows given the control diet.

The mean concentration of Na found in the plasma of all steers in this experiment, irrespective of Na intake, was less than that reported by Morris & Gartner (1971). In this previous experiment, no consistent effect of dietary Na restriction on plasma Na was found, but in this experiment an effect was found. The difference in the response of the steers in the two experiments may have been due in part to age. Morris & Murphy (1972) showed a marked decrease in plasma Na and increase in K for young calves given a low-Na diet.

The concentration of  $\alpha$ -tocopherol for the whole grain before milling (4.8 mg/kg) was considerably less than the value estimated for the requirement of young calves by the (US) National Research Council (1970) (15–60 mg DL- $\alpha$ -tocopherol/kg diet). As the  $\alpha$ -tocopherol concentration of the diet eaten by our steers when they were not receiving an  $\alpha$ -tocopherol supplement was in the range of 1.8–4.8 mg/kg diet, it would appear that for older cattle given an all-grain diet, growth rate was not restricted by an  $\alpha$ -tocopherol concentration of 4.8 mg/kg diet.

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