Studies on magnesium in ruminant nutrition

7*. Excretion of magnesium, calcium, potassium and faecal dry matter by grazing sheep

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1. The excretions of magnesium, calcium, potassium and faecal dry matter (DM) by sheep grazing the same pasture have been determined at intervals throughout two grazing seasons. Two groups of four wethers, 2 and 7 years old, were used. Collections of faeces were total and of urine only partial; creatinine was used as an indicator of urine volume.

2. The overall mean outputs of DM in the faeces of the young and old sheep were 509 and 387 g/day respectively.

3. The values for the percentage digestibility of herbage DM ranged from 81·1 in spring to 63·2 in winter. The overall means for the estimated intake of DM by the young and old sheep were 1859 and 1405 g/day respectively and the difference was highly significant ($P < 0{\cdot}001$).

4. The mean values for overall excretion of Mg by the young and old sheep were respectively 0·452 and 0·292 g/day in the urine and 2·70 and 2·21 g/day in the faeces. For all sheep there was a highly significant rectilinear relationship between the amount in urine and in faeces, but there were significant differences between the regression coefficients for the individual sheep.

5. The values for the excretion of Ca in urine and faeces were significantly higher for the young than for the old sheep; the respective means were 0·385 and 0·306 g/day for urinary Ca and 13·2 and 10·8 g/day for faecal Ca.

6. The mean values for the excretion of K by the young and old sheep were respectively 28·2 and 29·1 g/day in the urine and 7·1 and 3·9 g/day in the faeces, the latter difference being highly significant.

7. High values for the total excretion of Mg, Ca and K occurred in June and low values in winter.

8. Intakes of Mg, Ca and K by the sheep have been calculated from the information on intake of DM and chemical composition of the cut herbage and compared with total excretion in urine and faeces. Good agreement between the two sets of values was obtained for Mg, but not for either Ca or K. The possible causes of these findings have been discussed and it was concluded that the sheep selected herbage with concentrations of Ca and K different from those in the samples of cut herbage.

The similarity in the decreases in the concentrations of magnesium in serum and urine of ruminants after a sudden change in diet from winter rations to cut spring herbage (Rook & Balch, 1958; Field, 1961) and after being given an Mg-deficient diet (L'Estrange & Axford, 1964; Storry & Rook, 1963) suggests that grass tetany is caused by a simple or conditioned deficiency of Mg. Furthermore, a reduction in the incidence of grass tetany follows supplementation of the diet with Mg compounds. It is thought that the deficiency of Mg is caused by low intake and low availability of herbage Mg (Rook & Campling, 1962), the latter possibility arising from a cation imbalance, since the availability of Mg is known to be dependent upon the concentration of other cations in the diet (De Groot, 1961; Oyaert, 1962).

Unfortunately, there are no values in the literature for the intake of Mg, Ca and K by grazing ruminants in the spring and at other times of the year. A major difficulty

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in obtaining such information has been selective grazing, since wide differences in cationic composition occur not only between grasses and clover but also between different parts of the same plant (Pritchard, Pigden & Folkins, 1964). Results from balance trials with both sheep and cattle given cut herbage, however, suggest that much indirect information on the adequacy of Mg, Ca and K in the diet of the grazing ruminant may be obtained from changes in the excretory pattern of these elements in urine and faeces (Field, McCallum & Butler, 1958; Kemp, Deijs, Hemkes & van Es, 1961; Stillings, Bratzler, Marriott & Miller, 1964). This paper describes the excretory pattern of Mg, Ca, and K in two groups of sheep of different ages grazing the same pasture at different times of the year.

EXPERIMENTAL

Animals. The sheep used in the experiment were North Country Cheviot wethers weighing between 70 and 100 kg. Sheep 1–4 were about 2 years old and sheep 5–8 about 7 years old at the commencement of the experiment. Sheep 8 died of a ruptured aorta during 1962 and was replaced by one (8A) similar to those in the younger group. Sheep 7 was withdrawn from the experiment in 1963, when it was found that, although the animal was apparently healthy, its urine turned black on standing.

Design of experiment. The experiment commenced on 1 May 1962, when the sheep were transferred from indoor pens to pasture. The first 5-day period for the collection of faeces and urine was started on 10 May 1962 and repeated at intervals throughout the experiment, nine periods in 1962 and eight in 1963. The sheep were alternated between two plots, A and B, transfer taking place at least 14 days before a collection period. The sheep were weighed on the days before and immediately after each collection period. On the 5th day of each experimental period samples of venous blood were taken and collected into heparin as anticoagulant. The mean daily output of creatinine in the urine of each sheep was determined before and after the experiment; the output (g/day) ranged from 1·09 to 1·68 for the individual sheep.

Diets. The sward grazed by the sheep was a perennial S 23 ryegrass–wild white clover mixture sown in 1959. Two compound fertilizers containing either potash and nitrogen (K_2O, 16%; N, 16%) or potash, nitrogen and phosphate (K_2O, 18%; N, 12%; P_2O_5, 11·8%) were used at the rate of 3 cwt/acre on the plots. The former was applied to plot A in August 1962 and April and August 1963 and to plot B in April 1963. The latter was applied to plots A and B in March 1962 and to plot A in May 1963. Samples of mixed herbage for chemical analysis were taken just before and on the last day of each collection period during the period May to October 1962. In 1963 the sampling procedure was the same except that the samples were divided into grass and clover fractions and analysed separately. The mean values for the concentration of Ca, Mg and K in the samples of herbage taken at each collection period are given in Table 1.

Collection of excreta. Faeces were collected from the sheep over 24 h periods with a modification in the equipment of McDonald (1958). The faeces were weighed daily and transferred to a Polythene bowl. After thorough mixing, one-fifth was weighed out into a Polythene bag which was closed with a rubber band and stored at 4°. Samples taken over the collection period were pooled in this bag.

Preliminary experiments showed that sheep at pasture in Scotland excrete up to 7 l. urine daily. Since the size of container for urine collection which can be fitted on a sheep is severely restricted, it was found more expedient to fit the container in the equipment of Budtz-Olsen, Dakin & Morris (1960) with an overflow and to use creatinine as an endogenous marker to predict urine excretion. Samples of urine were obtained daily at 09.00 and 16.00, and 10 ml from each sample were placed in a glass bottle containing 2 ml 50% (v/v) acetic acid. A few drops of toluene were then added and the bottle and contents stored at 4° until required for chemical analysis.

Table 1. *Concentrations (g/100 g DM) of calcium, magnesium and potassium in the samples of mixed herbage, grass and clover cut from the sward in periods* 1–8

		1	2	3	4	5	6	7	8
				1962					
Herbage		May	May	June	July	Aug.	Sept.	Oct.	Nov.
Mixed	Ca	0·491	0·527	0·598	0·387	0·594	0·503	0·426	0·405
	Mg	0·139	0·148	0·163	0·117	0·192	0·210	0·193	0·178
	K	3·29	3·15	2·01	1·69	2·15	2·76	3·57	3·51
				1963					
		March	May	May	June	July	July	Aug.	Sept.
Grass	Ca	—	0·461	0·437	0·424	0·398	0·414	0·490	0·447
	Mg	—	0·139	0·136	0·137	0·142	0·128	0·186	0·296
	K	—	3·76	3·30	3·22	3·65	3·21	3·44	4·38
Clover	Ca	—	1·60	1·33	1·68	1·03	1·09	1·24	1·45
	Mg	—	0·192	0·166	0·192	0·180	0·175	0·218	0·215
	K	—	3·44	2·62	2·96	2·40	2·74	3·53	3·06

Analysis of samples. The methods of analysis for Ca, Mg and K in the samples of urine and faeces, and creatinine in urine were those used by Field (1964). Samples of mixed herbage, clover, grass and concentrates were treated in the same way as faeces. The faeces were analysed for N by the macro-Kjeldahl method. Plasma was separated from whole blood by centrifugation and analysed for Mg and Ca by the methods used in previous experiments (Field *et al.* 1958). The concentration of K in plasma was determined with a flame photometer (Evans Electroselenium Ltd).

Estimation of herbage dry matter (DM) digestibility. Faecal N concentration was used as an index of DM digestibility of herbage. For the period May to June the relationship used was $y = 9{\cdot}95x - 0{\cdot}82x^2 + 53{\cdot}8$ ($\pm 1{\cdot}01$), where y represents percentage DM digestibility and x faecal N concentration (J. F. D. Greenhalgh, 1965, private communication). This relationship was obtained in Scotland in spring with four sheep fed on herbage from a ryegrass-dominant pasture and covered a range of values of y and x similar to that obtained here. For the rest of the year the relationship $y = 43{\cdot}6 + 9{\cdot}7x$ was used (Holmes & Osman, 1960).

RESULTS

Clinical condition of the sheep. No clinical abnormalities were observed in the experimental animals during the periods of collection of excreta.

Levels of Mg, Ca and K in plasma. The mean values for the concentration of Mg and Ca in the plasma of sheep remained within the normal range (1·8–4 mg Mg/100 ml and 9–13 mg Ca/100 ml) throughout the experiment. The mean values for the levels of K in the plasma of the sheep were greater during May and August 1962 and May,

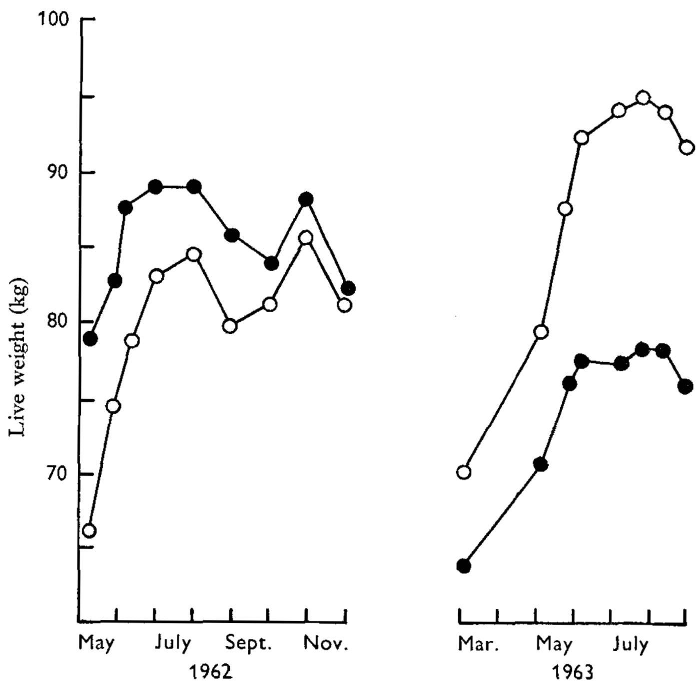

Fig. 1. Change in weight (kg) of young (○) and old sheep (●) during the experimental period.

July and September 1963 than the normal range (17–22 mg/100 ml) found in this laboratory. They were respectively 25·0, 24·9, 26·4, 29·2 and 24·6 mg/100 ml. There were no correlations between the plasma levels and total excretions for any of the three elements.

Weight of sheep. Since no significant differences were found between the weights of the sheep before and after each collection period, the values for each period have been pooled. The changes in the mean weight of the young and old sheep between experimental periods are shown in Fig. 1. The changes in weight of the two groups showed the same trend; the mean weights rose during spring, remained relatively constant throughout summer and autumn and fell during winter. The old sheep were heavier in 1962 and lighter in 1963 than the young sheep.

Faecal DM *excretion.* The mean daily values for the weight of faecal DM of the young and old sheep are given in Table 2, together with those for the concentration of

N in faeces; the values ranged from 255 to 666 g/day for the young and from 269 to 504 g/day for the old sheep. The overall means for the old and young sheep were 509 and 387 g/day respectively and the difference was significant at the 0·1% level. The values for the concentration of N in faeces of the sheep ranged from 2·20% to 4·20% in 1962 and from 2·02% to 3·54% in 1963, low values occurring in winter and high ones in spring. There was a small but significant ($P < 0·01$) difference between the two age-groups; the overall means for the young and old sheep were 2·90% and 2·81% respectively.

Table 2. *Mean excretion (g/day) of faecal dry matter (F) and mean percentage concentration of nitrogen in faeces of young and old sheep in* 1962 *and* 1963, *periods* 1–9

Age of sheep		1	2	3	4	5	6	7	8	9
					1962					
		May	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Young	F	255	403	666	632	499	509	525	544	539
	N	4·20	4·15	2·63	2·28	2·50	2·33	2·39	2·64	2·45
Old	F	275	321	431	504	379	407	454	467	428
	N	3·88	3·95	2·59	2·36	2·50	2·37	2·41	2·55	2·20
					1963					
		March	May	May	June	June	July	Aug.	Sept.	
Young	F	396	504	511	532	580	537	486	538	
	N	2·14	3·25	3·54	3·06	2·90	2·89	2·61	3·42	
Old	F	269	313	359	397	420	396	364	397	
	N	2·02	3·15	3·40	3·05	3·02	2·75	2·49	3·23	

Table 3. *Mean percentage digestibility (D) and mean estimated dry-matter intake (I) (g/day) of herbage eaten by young and old sheep in* 1962 *and* 1963, *periods* 1–9

Age of sheep		1	2	3	4	5	6	7	8	9
					1962					
		May	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Young	D	81·1	81·0	74·3	65·7	67·8	66·2	66·8	69·2	67·4
	I	1350	2120	2590	1840	1560	1510	1580	1760	1660
Old	D	80·1	80·3	74·1	66·5	67·8	66·6	67·0	68·3	64·9
	I	1380	1630	1660	1500	1180	1210	1380	1470	1220
					1963					
		March	May	May	June	June	July	Aug.	Sept.	
Young	D	64·4	77·5	78·7	76·6	75·8	71·6	68·9	76·8	
	I	1110	2240	2400	2270	2400	1890	1560	1770	
Old	D	63·2	77·0	78·2	76·5	76·4	70·3	67·8	74·9	
	I	732	1360	1650	1690	1780	1330	1130	1590	

Digestibility and intake of herbage DM. The mean values for the percentage digestibility and intake of herbage DM are given in Table 3. The digestibility of DM ranged from 64·9% to 81·1% in 1962 and from 63·2% to 78·7% in 1963, low values occurring in winter and high values in spring. No difference in digestibility was observed between young and old sheep, the overall means being 72·3% and 71·8% respectively.

The values for the intake of DM ranged from 1110 to 2590 g/day for the young sheep and from 732 to 1780 g/day for the old sheep. The overall means for the young and old sheep were 1895 and 1405 g/day respectively and the difference was highly significant ($P < 0·001$). There were no significant correlations between digestibility and intake of herbage DM for either the young or old sheep.

Excretion of Mg. The mean daily values for the excretion of Mg in urine (UMg), in faeces (FMg) and in urine plus faeces (TMg) in each collection period by the young and old sheep are given in Table 4. In general, values for the UMg and FMg in each collection period were larger for the young than for the old sheep. The overall means for the young and old sheep were respectively 0·452 and 0·292 g/day for UMg, 2·70 and 2·21 g/day for FMg and 3·15 and 2·50 g/day for TMg. The values for UMg for the young and old sheep in each collection period were highly correlated ($r = +0·960$; $P < 0·01$), as were those for FMg ($r = +0·818$; $P < 0·01$), indicating that the factors which controlled excretion of Mg by each of the two routes were common to both age-groups.

Table 4. *Mean excretion (g/day) of magnesium in urine (U) and faeces (F) by young and old sheep in* 1962 *and* 1963, *periods* 1–9

Age of sheep		1	2	3	4	5	6	7	8	9
				1962						
		May	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Young	U	0·27	0·48	1·01	0·59	0·42	0·55	0·36	0·40	0·25
	F	1·86	2·66	3·67	2·10	2·64	2·88	2·60	2·44	2·46
	U+F	2·13	3·14	4·68	2·69	3·06	3·43	2·96	2·84	2·71
Old	U	0·23	0·33	0·61	0·40	0·27	0·34	0·21	0·20	0·06
	F	2·04	2·31	2·63	1·69	2·07	2·53	2·49	2·21	1·92
	U+F	2·27	2·64	3·24	2·09	2·34	2·87	2·70	2·41	1·98
				1963						
		March	May	May	June	June	July	Aug.	Sept.	
Young	U	0·11	0·26	0·40	0·55	0·52	0·54	0·43	0·54	
	F	1·56	3·27	3·27	3·37	2·81	3·00	2·37	2·99	
	U+F	1·67	3·53	3·67	3·92	3·33	3·54	2·80	3·53	
Old	U	0·04	0·12	0·27	0·37	0·30	0·40	0·36	0·45	
	F	1·08	2·24	2·45	2·69	2·28	2·30	1·87	2·85	
	U+F	1·12	2·36	2·72	3·06	2·58	2·70	2·23	3·30	

The proportion of TMg excreted in the urine ranged from 6·6% in winter to 21·9% in June and July 1962 with an overall mean of 14·3%. The relationships between UMg and FMg and between UMg and TMg were rectilinear ($P < 0·01$) for all sheep. The values for the regression coefficients of UMg on TMg ranged from 0·122 to 0·260 and there was no significant difference between the mean values for the young and old sheep. This relationship accounted for between 26% and 88% of the variation in UMg of the individual sheep.

Since UMg and FMg were correlated, they showed similar seasonal trends. High values occurred in June and low values in winter. No relationship was found for either the young or the old sheep between TMg and the concentration of Mg in the cut samples of herbage in 1962.

Excretion of Ca. The mean daily values for the excretion of Ca in the urine (UCa), in faeces (FCa) and in urine plus faeces (TCa) in each collection period by the young and old sheep are given in Table 5. The values for UCa and FCa in each collection period were significantly higher (UCa, $P < 0.05$; FCa, $P < 0.001$) for the young than for the old sheep. The overall means for the young and old sheep were respectively 0·385 and 0·306 g/day for UCa and 13·2 and 10·8 g/day for FCa. The correlation between the values for FCa for the young and old sheep in each collection period was highly significant ($r = +0.945$; $P < 0.01$).

Table 5. *Mean excretion (g/day) of calcium in urine (U) and faeces (F) by young and old sheep in 1962 and 1963, periods 1–9*

Age of sheep		1	2	3	4	5	6	7	8	9
					1962					
		May	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Young	U	0·3	0·3	0·3	0·3	0·5	0·5	0·5	0·4	0·4
	F	8·0	12·6	30·2	13·8	13·2	12·6	11·2	13·0	8·8
	U+F	8·3	12·9	30·5	14·1	13·7	13·1	11·7	13·4	9·2
Old	U	0·2	0·2	0·2	0·2	0·3	0·5	0·4	0·5	0·1
	F	9·1	11·3	19·8	11·5	11·5	11·1	11·1	10·4	6·5
	U+F	9·3	11·5	20·0	11·7	11·8	11·6	11·5	10·9	6·6
					1963					
		March	May	May	June	June	July	Aug.	Sept.	
Young	U	0·2	0·1	0·3	0·4	0·4	0·5	0·7	0·4	
	F	4·8	12·9	13·9	18·6	9·7	16·3	9·8	15·0	
	U+F	5·0	13·0	14·2	19·0	10·1	16·8	10·5	15·4	
Old	U	0·1	0·1	0·2	0·2	0·2	0·5	0·8	0·5	
	F	3·6	9·1	11·3	14·2	8·5	13·5	7·9	13·5	
	U+F	3·7	9·2	11·5	14·4	8·7	14·0	8·7	14·0	

The proportion of TCa excreted in the urine was small; on average only 3·1% was excreted by this route. For neither the young nor the old sheep were there significant correlations between UCa and FCa or between TCa and the concentration of Ca in the cut samples of herbage in 1962.

Although TCa and TMg showed similar seasonal patterns there was no overall relationship between these two variables.

Excretion of K. The mean daily excretions of K in urine (UK), in faeces (FK) and by both routes (TK) in each collection period are given in Table 6 for the two groups of sheep. The mean values for the young and old sheep were respectively 28·2 and 29·1 g/day for UK and 7·1 and 3·9 g/day for FK, the latter difference being highly significant ($P < 0.001$). The correlation between young and old sheep for UK, but not for FK, in each collection period was highly significant ($r = +0.861$, $P < 0.001$). There was no overall relationship for either young or old sheep between UK and FK in each collection period.

High values for UK occurred in spring and again in autumn, minimal values occurring in winter. The values for UK in June and July were much higher in the 2nd than the 1st year. In 1963 they ranged from 32 to 38 g/day, whereas in 1962 the range was from only 20 to 27 g/day. No relationship was found between UK and the concentrations of K in cut samples of herbage in 1962. The mean values for FK remained relatively constant throughout the experiment and appeared to be independent of either faecal water or DM.

Table 6. *Mean excretion (g/day) of potassium in urine (U) and faeces (F) by young and old sheep in* 1962 *and* 1963, *periods* 1–9

Age of sheep		1	2	3	4	5	6	7	8	9
					1962					
		May	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Young	U	27	29	27	20	24	29	26	19	18
	F	3	6	6	6	7	7	8	7	8
	U+F	30	35	33	26	31	36	34	26	26
Old	U	35	30	25	21	26	29	27	19	14
	F	3	3	2	2	3	4	6	5	5
	U+F	38	33	27	23	29	33	33	24	19
					1963					
		March	May	May	June	June	July	Aug.	Sept.	
Young	U	5	41	41	36	38	34	28	38	
	F	7	10	8	5	12	7	8	5	
	U+F	12	51	49	41	50	41	36	43	
Old	U	6	39	42	37	32	35	37	40	
	F	3	4	4	4	6	5	4	4	
	U+F	9	43	46	41	38	40	41	44	

Estimated intake of Mg, Ca and K. The mean value for the estimated intake of an element by a group of sheep in a collection period was obtained by multiplying the concentration of the element in the cut sample of herbage by the estimated intake of DM by the group of sheep. The values obtained for Mg, Ca and K for the two groups of sheep in May to October 1962 are given in Table 7. For comparison, the corresponding values for total excretion of each element are given in the same table. As expected, the estimated intakes of each of the three elements were higher for the young than for the old sheep. The mean intakes for the young and old sheep were respectively 2·97 and 2·30 g/day for Mg, 8·9 and 7·0 g/day for Ca and 48·4 and 39·1 g/day for K.

There were no significant differences between the estimated intake and the corresponding total excretion of Mg for the young and for the old sheep. On the other hand, the estimated intakes were less ($P < 0{\cdot}001$) for Ca and higher ($P < 0{\cdot}01$) for K than the corresponding total excretions for each of the two groups of sheep. The mean values for the estimated intake and total excretion by the young sheep were respectively 2·97 and 3·12 for Mg, 8·9 and 14·7 for Ca and 48·4 and 31·4 g/day for K. The corresponding values for the old sheep were 2·30 and 2·59 for Mg, 7·0 and 12·3 for Ca and 39·1 and 30·0 g/day for K.

In 1963, when the samples of herbage were separated into clover and grass fractions, it was possible to estimate theoretical intakes of each of the elements from a complete diet of clover or grass. For Ca and Mg, the values for total excretion lay intermediate between those for the intake from clover and from grass. For example, the mean total Ca excretion, and the theoretical Ca intakes from clover and from grass by the old sheep were respectively 11·5, 20·3 and 6·6 g/day. On the other hand, the values for the total excretion of K were lower than the intake either from clover or from grass. Thus the low excretion of K relative to the estimated intake cannot be simply explained in terms of differential grazing between clover and grass.

Table 7. *A comparison of the estimated intake (g/day) by young and old sheep of magnesium, calcium and potassium with the corresponding total excretion (g/day) in urine and faeces in* 1962

			Mg		Ca		K	
Period no.	Month	Age of sheep	Intake	Excretion	Intake	Excretion	Intake	Excretion
1	May	Young	1·88	2·13	6·6	8·3	44	30
		Old	1·92	2·27	6·8	9·3	45	38
2	May	Young	3·14	3·14	11·2	12·9	67	35
		Old	2·41	2·64	8·6	11·5	51	33
3	June	Young	4·22	4·68	15·5	30·5	52	33
		Old	2·24	3·24	9·9	20·0	33	27
4	July	Young	2·15	2·69	7·1	14·1	31	26
		Old	1·76	2·09	5·8	11·7	25	23
5	Aug.	Young	2·99	3·06	9·2	13·7	33	31
		Old	2·27	2·34	7·0	11·7	25	29
6	Sept.	Young	3·18	3·43	7·6	13·1	42	36
		Old	2·55	2·87	6·1	11·6	33	33
7	Oct.	Young	3·05	2·96	6·7	11·7	56	34
		Old	2·67	2·70	5·9	11·5	49	33
8	Nov.	Young	3·13	2·84	7·1	13·4	62	26
		Old	2·62	2·41	6·0	10·8	52	24

DISCUSSION

Existing information from balance trials with both sheep and cows given cut herbage have shown that daily changes in the body content of Mg of mature animals are negligibly small relative to daily intake of Mg and that intake and total excretion in urine, faeces and milk are approximately equal (Rook & Balch, 1958; Kemp *et al.* 1961; Rook & Campling, 1962; Field *et al.* 1958; Stillings *et al.* 1964). The present experiment differs from a well-conducted balance trial in a number of respects, and it is possible that the observed effects of season and age of sheep on total Mg excretion are not a reflection of Mg intake but of biases in the estimation of excretion. The sheep were not confined and undetected small losses of faeces from the collection bag may have occurred. For this error to explain the observed changes in total Mg excretion, it must be postulated that the losses of faeces during collection were greater for old than for young sheep and were greater at different times of the year. For technical reasons it was not possible to collect all urine voided and an indirect method had to be used to calculate urine volumes. Since urine Mg represents only 10–20% of total excretion, errors in urine volumes would have only small effects on total Mg excretion. A further error could arise from changes in the Mg content of the gastro-intestinal tract. Since the sheep were fully accustomed to a diet of herbage and there were no significant changes in the weight of the sheep or in the Mg concentration in the herbage during each collection period, it is thought that errors arising from this source would have been small. Thus it would appear that, although the errors in the estimates of total excretion would be greater in the present study than in a conventional balance trial, the estimates of total excretion can be used as estimates of Mg intake for purposes of comparison.

In the absence of reliable estimates of the intake of Mg by grazing ruminants, it has been generally assumed that in spring the low concentration of Mg in herbage (Reith, 1954), the absence of clover in the sward and low intake of DM by grazing animals (Rook & Balch, 1958) will lead to an unusually low intake of Mg. In the present study, the evidence for a relatively low intake by the sheep in spring was conflicting; in 1962 the estimated intake in May was the lowest for the year, whereas in 1963 it was similar to or greater than the values for the other months except June.

The mean true availabilities of herbage Mg to the sheep throughout the grazing season are given by the regression coefficient of UMg on dietary intake of Mg at pasture (Field *et al.* 1958; Field, 1962). The values for the mean true availability of herbage Mg to the individual sheep ranged from 12% to 26%, which are of the same order as those generally reported for other diets (Field *et al.* 1958; Field, 1962). This relationship, however, only accounts for between 26% and 88% of the variation in UMg. Since these deviations from the regression may represent unusually low and high availabilities of herbage Mg, a factor of importance in the causation of hypomagnesaemia, the mean deviation at each collection period was calculated and its significance tested, using as the error term the variation in deviation from regression between sheep in the same collection period. It was found that at certain times of the grazing season deviations from the regression were signicantly ($P < 0.05$) positive or negative. In June and July 1962 and August 1963 the deviations were positive and in October and December 1962 and April 1963 they were negative. Thus it is possible that the Mg in spring herbage was of an unusually low availability in 1963 but not in 1962.

The increased susceptibility to grass tetany with age has been tentatively attributed to a reduction in the Mg reserves of ruminants with age (Blaxter & McGill, 1956). The results from the present work suggest that a reduction with age in the intake of Mg by grazing ewes may be an additional factor.

A striking feature of the results is the marked disparity between the values for the estimated intake and total excretion in urine and faeces of Ca and K, but not of Mg. For example, the overall mean differences between intake and total excretion, expressed as a percentage of total excretion, were 58·9 for Ca, 142·3 for K and 92·2 for Mg. These differences could arise *a priori* from a number of sources: errors in the measurement of excretion and intake of DM, changes in the content of the body and gastro-intestinal tract and through selective grazing.

The major route of excretion of Ca is the faeces and of K the urine. Thus, to explain the above differences in terms of errors in estimating excretion, it is necessary to postulate an overestimation of FCa and an underestimation of UK. The major source of error in the total collection of faeces is the loss of faeces from the bag, which would lead to an underestimation rather than an overestimation of FCa. Non-random errors in the estimation of UK might arise from differences between the actual and predetermined creatinine output due to changes in the fat-free content of the body (Van Niekerk, Reid, Bensadoun & Paladines, 1963) during the experiment and to diurnal variations in the ratio of K to creatinine in urine. The magnitudes of these errors are likely to be small because no significant difference in the actual output of creatinine was found before and after the experiment, the changes in weight from May to December 1962 were small and in the mature sheep probably reflect changes in state of fatness, the equipment for collecting samples of urine was designed to produce representative samples, and Field (1964) has shown that the diurnal variation in the ratio of K to creatinine is small. Furthermore, these errors would tend to produce constant proportional effects on UK, whereas it was found in 1962 that the differences between intake and excretion were small during July, August and September and larger at other times of the year. For K, the total excretion must be corrected for the loss of up to 1 g K/day through the skin (Blaxter & Rook, 1957*b*), insufficient to account for the observed difference between intake and excretion.

Differences between intake and excretion of an element could arise from changes in the amount of that element in the gastro-intestinal tract and in the body. The changes in gut fill were small, as shown by the non-significant changes in weight of the sheep during each collection period. To explain the difference between intake and total excretion in terms of changes in body composition, both groups of sheep must have consistently lost Ca and gained K in their bodies. Since the estimated intakes of Ca by the sheep were adequate according to generally recognized standards (National Research Council, 1957; Agricultural Research Council, 1965), it is unlikely that the sheep would consistently lose Ca from their skeletons. Furthermore, balance trials with mature wethers given cut fresh herbage have failed to find a difference between intake and excretion. Pooling the existing data for such trials gave mean values for the intake and excretion of Ca of 5·30 and 5·39 g/day and a highly significant correlation between these two values of +0·970 ($P < 0·01$, 15 degrees of freedom) (Field *et al.* 1958; Stillings *et al.* 1964). K is essentially an intracellular ion, so that changes in the K content of the body must be accompanied by similar changes in cell mass (Blaxter & Rook, 1957*a*). Since each kg gain in weight contains 1·6 g K (Agricultural Research Council, 1965), the difference between intake and excretion in May, June, October and September would require the sheep to gain between 3·5 and 20 kg/day, a value incompatible with our knowledge of growth in sheep. Stillings *et al.* (1964) found in a series of balance trials that the mean values for intake and excretion of K by adult wethers given fresh cut herbage were 28·2 and 27·9 g/day respectively, with a correlation coefficient between intake and excretion of +0·949 ($P < 0·01$, 6 degrees of freedom).

Since the method for the estimation of the intake of DM by the sheep was indirect, the estimates are subject to error. However, these errors cannot account solely for the observed differences between estimated intake and total excretion for each of the three elements, otherwise the ratio of intake to excretion would be similar for Mg, Ca and K. The overall mean values for this ratio were 0·922 for Mg, 0·589 for Ca and 1·42 for K. Thus it must be concluded that the sheep select a diet with a higher concentration of Ca and a lower concentration of K than in the cut samples of herbage. Since the concentration of Ca is higher in clover than in grass and in leaf than in stem (Pritchard *et al.* 1964) the sheep probably select a diet with ratios of clover to grass and of leaf to stem higher than those in the cut herbage. This finding is consistent with subjective observations from studies of grazing behaviour that sheep show a preference to unsown species like white clover (Cowlishaw & Alder, 1960) and graze preferentially on leaf (Watson, 1951; Thomas, 1957; Meyer, Lofgreen & Hull, 1957). The much lower values for the concentration of K in herbage eaten by the sheep in spring and autumn as compared with the corresponding values for mixed herbage are more difficult to explain. Perhaps the sheep find young grass with its high concentration of K relatively unpalatable and select more mature grasses and clovers.

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REFERENCES

Agricultural Research Council (1965). *The Nutrient Requirements of Farm Livestock*, no. 2, *Ruminants*, p. 33. London: Agricultural Research Council.
Blaxter, K. L. & McGill, R. F. (1956). *Vet. Revs Annot.* **2**, 35.
Blaxter, K. L. & Rook, J. A. F. (1957*a*). *J. agric. Sci., Camb.* **48**, 194.
Blaxter, K. L. & Rook, J. A. F. (1957*b*). *J. agric. Sci., Camb.* **48**, 210.
Budtz-Olsen, O. E., Dakin, H. C. & Morris, R. J. H. (1960). *Aust. J. agric. Res.* **11**, 72.
Cowlishaw, S. J. & Alder, F. E. (1960). *J. agric. Sci., Camb.* **54**, 257.
de Groot, T. (1961). *Tijdschr. Diergeneesk.* **86**, 1265.
Field, A. C. (1961). *Br. J. Nutr.* **15**, 287.
Field, A. C. (1962). *Br. J. Nutr.* **16**, 99.
Field, A. C. (1964). *Br. J. Nutr.* **18**, 357.
Field, A. C., McCallum, J. W. & Butler, E. J. (1958). *Br. J. Nutr.* **12**, 433.
Holmes, W. & Osman, H. (1960). *Anim. Prod.* **2**, 131.
Kemp, A., Deijs, W. B., Hemkes, O. J. & van Es, A. J. H. (1961). *Neth. J. agric. Sci.* **9**, 134.
L'Estrange, J. L. & Axford, R. F. E. (1964). *J. agric. Sci., Camb.* **62**, 353.
McDonald, P. (1958). *Proc. Br. Soc. Anim. Prod.* p. 31.
Meyer, J. H., Lofgreen, G. P. & Hull, J. L. (1957). *J. Anim. Sci.* **16**, 766.
National Research Council (1957). *Publs natn. Res. Coun., Wash.* no. 504.
Oyaert, W. (1962). *Dt. tierärztl. Wschr.* **75**, 323.
Pritchard, G. I., Pigden, W. J. & Folkins, L. P. (1964). *Can. J. Pl. Sci.* **44**, 318.
Reith, J. W. S. (1954). *Emp. J. exp. Agric.* **22**, 305.
Rook, J. A. F. & Balch, C. C. (1958). *J. agric. Sci., Camb.* **51**, 199.
Rook, J. A. F. & Campling, R. C. (1962). *J. agric. Sci., Camb.* **59**, 225.
Stillings, B. R., Bratzler, J. W., Marriott, L. F. & Miller, R. C. (1964). *J. Anim. Sci.* **23**, 1148.
Storry, J. E. & Rook, J. A. F. (1963). *J. agric. Sci., Camb.* **61**, 167.
Thomas, J. F. H. (1957). *The Grassland Handbook*, ch. 17. London: Farmer and Stockbreeder.
Van Niekerk, B. D. H., Reid, J. T., Bensadoun, A. & Paladines, O. L. (1963). *J. Nutr.* **79**, 463.
Watson, S. J. (1951). *Grassland and Grassland Products*. London: E. Arnold and Co.

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