Studies on magnesium in ruminant nutrition

Balance experiments on sheep with herbage from fields associated with lactation tetany and from control pastures

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(*Received* 3 *May* 1958)

Although hypomagnesaemic tetany has been recognized in adult cattle for over a quarter of a century (Sjollema & Seekles, 1929; Dryerre, 1932; Blakemore & Stewart, 1933–4) its cause is still unknown. More recently the condition was identified in sheep (Stewart, 1954) but its cause in this species is also obscure. Though it is generally found that supplementation of the diet with magnesium compounds reduces the incidence on affected farms, the disease is still a serious economic problem owing to the very high mortality. Recent reports from the field indicate that it is becoming more widespread (Stewart, 1953, 1954; White, 1953).

The form of the disease known as lactation or grass tetany, which occurs in cows in the spring within a few days of turning out to pasture after winter feeding, was the first to be recognized and still causes serious losses. Previous workers (Sjollema, 1931; Blakemore & Stewart, 1934–5) have reported no difference between the magnesium content of pastures associated with lactation tetany and those on which the disease does not occur, which has led to the theory that the former contain some factor which causes a physiological disturbance (Green, 1939) for instance by depressing the absorption of this element from the alimentary tract (Head & Rook, 1955). On the other hand, a recent estimate of the magnesium requirements of the lactating cow suggests that the amount of the element in some spring pastures may be insufficient to meet these requirements (Blaxter & McGill, 1956).

The primary object of the investigation was to find if such an interfering factor could be detected by balance experiments on sheep with herbage from fields in which lactation tetany had occurred in cows. Although these experiments yielded no evidence of the existence of such a factor they did enable the metabolic fate of dietary magnesium to be followed in individual sheep over a wide range of intake. This information was then used to estimate the amount of magnesium required by the sheep in relation to the aetiology of hypomagnesaemic tetany in this species. The results, although derived from only two animals, demonstrate large differences in the metabolism of dietary magnesium by individual animals and they permit tentative figures to be calculated for the different efficiencies with which these animals are able to utilize magnesium from grassland herbage. Data of this kind have not hitherto been reported and may help to explain the differences in susceptibility to the disease which have frequently been observed in members of the same herd or flock.

Calcium was also included in these studies since hypocalcaemia frequently accompanies hypomagnesaemia and there is some evidence that excess calcium increases the magnesium requirements of rats (Tufts & Greenberg, 1938) and depresses the level of this element in the serum of calves (Blaxter & McGill, 1956).

EXPERIMENTAL

Animals

The experiments were carried out during the autumn and winter of 1956 with two apparently healthy North Country Cheviot wethers (nos. 2914 and 2916, hereafter called A and B), aged about 18 months and weighing about 59 and 50 kg, respectively, bought in the open market 3 months previously to allow time for training in the metabolism crates.

Pasture samples

Herbage was collected, usually in two batches, from seven fields during May and June in 1956. It was cut in dry weather, care being taken to minimize soil contamination, and exactly 5 or 6 lb. were weighed out immediately into Polythene bags which were then closed with an elastic band and deposited within 4 h in a local commercial cold store at -15 to $-20°$. A sample weighing about 6 lb. was taken for chemical analysis from each batch, which usually weighed between 150 and 200 lb. This sample was made by pooling single samples taken from each bag before weighing.

Details of the chemical and botanical composition, the fertilizer treatment and the age of the swards are given in Table 1, from which it can be seen that both highly productive leys and permanent pastures were studied. Two fields, nos. 7 and 8, were being strip-grazed by dairy cows and herbage was collected from the ungrazed area immediately ahead of them. Hypomagnesaemic tetany had occurred regularly in cows each year since 1954 in field no. 8 and occurred again less than 24 h before the first batch of herbage (H 3) was collected and during the 3 days which elapsed before the second collection (H 4). The disease occurred in fields nos. 6 and 7 about a week before herbage was collected. Three of the other fields were free of the disease so far as could be ascertained and served as controls, and no. 1, a 1st-year ley, was not grazed. Additional experiments were carried out for comparative purposes with mature herbage collected in October from a permanent pasture and with dry pellets made from similar material. Three of the samples, N 1, N 5 and H 3 were given only to sheep A.

Technique

The metabolism crates and the equipment for the separate quantitative collection of urine and faeces were similar to those recently described by McDonald (1958).

When the sheep had been trained to eat freshly cut herbage, from a field where tetany had not been known to occur, it received the experimental diet. The samples from the tetany control fields were studied alternately. Sixteen to twenty bags of herbage were removed from the cold store at a time and stored at about 4° until required. Each sheep received the contents of one bag at 10 a.m. and that of another

Table 1. *Details of herbage samples*

Herbage sample	Field no.	Month of collection, 1956	Type of sward	Fertilizer* treatment	Dominant species†	Dry matter (%)	Mg in dry matter (%)	Ca in dry matter (%)	Crude protein in dry matter (%)
N 1	1	May	1st-year ley	N.C.	I.R.G., P.R.G., C., B.R.C.	25·2	0·094	0·548	11·6
N 2	2	October	Natural sward	None	Uncultivated grass and weeds	14·7	0·211	0·570	25·8
N 3	3	June	2nd-year ley	C.	P.R.G., C., W.W.C.	19·3	0·173	0·783	21·9
						21·6	0·150	0·639	—
N 4	4	May	Natural sward	None	Uncultivated grass and weeds	23·1	0·183	0·574	20·9
						26·2	0·173	0·635	—
N 5	5	May	Natural sward	None	Uncultivated grass and weeds	22·8	0·231	0·596	—
						19·3	0·238	0·528	—
H 1	6	May	3rd-year ley	P.	P.R.G., C.	25·6	0·105	0·737	16·6
						24·8	0·109	0·711	—
H 2	7	May	1st-year ley	P.R.	I.G., P.R.G., C.	19·9	0·118	0·683	16·4
						19·4	0·142	0·645	—
H 3	8	May	4th-year ley	S.A., K.	P.R.G., C., W.W.C.	19·5	0·155	0·650	19·4
						22·2	0·147	0·663	—
H 4	8	May	4th-year ley	S.A., K.	P.R.G., C., W.W.C.	17·7	0·169	0·765	20·4
						15·2	0·175	0·757	—
Grass nuts		Unknown	Unknown	Unknown	Unknown	87·5	0·211	1·00	13·4

N, herbage from control field; H, herbage from fields associated with lactation tetany.

* P., potato manure (10 % N, 10 % P_2O_5, 15 % K_2O); C., compound (8 % N, 9·5 % P_2O_5, 13 % K_2O); S.A., sulphate of ammonia; K., potassium superphosphate (15·5 % P_2O_5, 10 % K_2O); N.C., nitro-chalk.

† I.R.G., Italian rye-grass; P.R.G., perennial rye-grass; C., cocksfoot; B.R.C., broad red clover; W.W.C., wild white clover.

containing the same amount of herbage at about 4 p.m. each day. Herbage from each field was given for 9 days with one exception, namely sample H3 from a tetany field which was given to sheep A for 18 days. When two collections of herbage had been made bags from each batch were used alternately. On the last day of the training period and each experimental period each sheep was passively immunized against pulpy kidney disease.

The herbage was usually entirely eaten but there were some residues, less than 5% of the amount eaten, at the end of the 9-day periods when the sheep received herbage from two of the leys. The refusals appeared to be due to the unpalatability of the sample rather than to its dry-matter content. The residue was not analysed directly, since it was heavily contaminated with soil, and the amount of calcium and magnesium ingested was calculated from the dry weight of the residue, the total dry matter offered and the analytical data for the batch sample. Distilled water was always available to the sheep and the volume drunk was recorded.

Faeces and urine were collected over 24 h periods, the urine being collected into 50 ml. glacial acetic acid in a Pyrex bottle to prevent the formation of a precipitate. After the volume of fluid had been measured, about 200 ml. were filtered through linen to remove adventitious particles and stored at about 4° until analysed. The faeces were weighed immediately and were then transferred from the Polythene bags in which they had been collected to a Polythene bowl. After mixing as thoroughly as possible, exactly one-fifth of the faeces was weighed out into another Polythene bag which was closed with a rubber band and stored at 4°. The samples for 3 consecutive days were pooled in the same Polythene bag and then prepared for analysis.

On the 9th day of each experimental period samples of venous blood and serum were taken for calcium and magnesium estimations, the whole blood being collected into citrate as anticoagulant.

Analytical methods

Faeces and herbage samples were first dried in an electric oven at 100–105° and ground in an Ato-mix blender (Measuring and Scientific Equipment Ltd, London) or a Christy Norris Mill with a 1 mm sieve. For the determination of calcium and magnesium about 1 g herbage or faeces, 100 ml. urine or 20 ml. blood were wet-ashed in a 600 or 800 ml. Pyrex or Vitreosil beaker with a mixture of nitric and sulphuric acids by the procedure of Middleton & Stuckey (1954). The residue was dissolved by first heating with 10·1 ml. 5% (w/v) NaOH and then adding 25 ml. of approximately N-HCl. Interfering elements such as iron, aluminium and manganese were then removed by the method recommended by Davidson (1952) and the solution was made up to 50 or 100 ml. Suitable portions were taken for the estimation of magnesium with 8-hydroxyquinoline (Davidson, 1952; Butler & Field, 1956) and calcium by a modification of the method described for the EEL flame photometer by Powell (1953).

Serum was analysed for calcium by the Clark & Collip (1925) modification of the Kramer–Tisdall method and for magnesium by the method of Denis (1922) as modified by Hawk, Oser & Summerson (1947).

RESULTS

Clinical condition of the sheep

No clinical abnormalities were observed in either sheep at any time, although herbage from a tetany field (H 3) was given to sheep A continuously for 18 days. Sheep B was found dead one morning having broken out of the crate during the night. The cause of death could not be ascertained at the post-mortem examination, but it may have been strangled by a collar which had been used to restrain its movement in the crate. Death from tetanic convulsions could not be eliminated. It had been receiving herbage from a fertilized ley (N 1).

Magnesium content of herbage samples

The values obtained for the magnesium content of the samples of spring herbage were similar to those recently found in Britain by other workers (Allcroft, 1954; Bartlett, Brown, Foot, Rowland, Allcroft & Parr, 1954; Blaxter & McGill, 1956; Bartlett, Brown, Foot, Head, Line, Rook, Rowland & Zundel, 1957), and those for the samples from the fields in which tetany occurred do not appear to be unusual.

Levels of magnesium and calcium in serum and whole blood

It can be seen from Table 2 that the levels of magnesium and calcium in the serum of both sheep remained throughout the experiment within the generally accepted normal ranges (2–4 mg Mg/100 ml. and 9–13 mg Ca/100 ml.).

The values for magnesium in whole blood (2·14–2·81 mg/100 ml.) were lower than those reported by Eveleth (1937) (3·1–3·5 mg/100 ml.) and are very close to the serum values, indicating that there is little difference between the magnesium content of red cells and plasma. On the other hand, the values for the calcium content of whole blood (6·86–8·40 mg/100 ml.) were consistently lower than the corresponding serum values (9·3–12·5 mg/100 ml.). There appear to be no values for the whole blood of sheep in the literature.

There were significant differences ($P < 0{\cdot}05$) between the two sheep for the levels of magnesium in the serum and whole blood and it will be seen below that the sheep that had the higher levels also excreted more magnesium in the urine. There was no correlation between the blood and serum levels and the magnesium intake, a finding in agreement with the failure to increase normal levels in cattle by the oral administration of magnesium compounds (Allcroft, 1947; Allcroft, 1954).

The calcium values for the two sheep were not significantly different and showed no correlation with intake.

Urinary magnesium excretion

The values obtained for the daily urinary excretion of magnesium showed no significant change after 3 days from the time the diet was changed, provided the diet consisted entirely of spring herbage, and no further change could be detected when the usual 9-day period was extended to 18 days for herbage H 3. The results for the last 6 days of each period are summarized in Table 3, where it can be seen that there was

Table 2. *Concentration of Mg and Ca in the serum and whole blood of the sheep (mg/100 ml.)*

			Sheep A				Sheep B			
			Mg		Ca		Mg		Ca	
Herbage	Mg intake (mg/day)	Ca intake (mg/day)	Serum	Whole blood	Serum	Whole blood	Serum	Whole blood	Serum	Whole blood
H 1	1,250	6,850	2·34	2·19	11·9	7·49	3·00	2·67	11·3	6·86
H 2	1,380	7,060	2·14	2·36	11·9	8·31	2·72	2·86	12·5	8·05
H 3	1,400	5,650	2·32	2·36	10·4	7·68	—	—	—	—
H 4	1,530	6,770	2·20	2·26	9·33	7·97	2·76	2·69	10·7	7·72
N 1	1,060	6,200	2·40	2·12	11·5	8·11	—	—	—	—
N 2	1,670	4,530	2·44	2·24	11·7	7·18	2·52	2·76	10·9	7·18
N 3	1,780	7,820	2·30	2·41	12·0	8·40	2·60	2·54	11·6	7·97
Grass nuts	2,280	10,580	2·76	2·59	10·3	7·42	2·94	2·81	11·3	7·85
N 4	2,370	8,080	2·56	2·54	9·60	7·21	3·36	2·36	9·33	7·29
N 5	2,680	6,430	2·22	2·71	11·3	7·83	—	—	—	—

a marked difference in the urinary excretion of magnesium by the two sheep when the intake was the same, and that the excretion of both sheep tended to follow the intake.

Statistical analysis of these results showed that the urinary magnesium excretion of the two sheep could be expressed in terms of the following regression equations:

Sheep A: $U\,\text{Mg} = 0{\cdot}126\,D\,\text{Mg} - 99{\cdot}5$ (ten samples, $P < 0{\cdot}01$),
Sheep B: $U\,\text{Mg} = 0{\cdot}263\,D\,\text{Mg} - 249{\cdot}7$ (seven samples, $P < 0{\cdot}01$),

where U Mg represents the urinary excretion and D Mg the dietary intake of magnesium in mg/day. These equations and the values obtained experimentally are plotted in Fig. 1. The 0·95 fiducial intervals for the regression coefficients are 0·084 – 0·168 and 0·140 – 0·386, respectively.

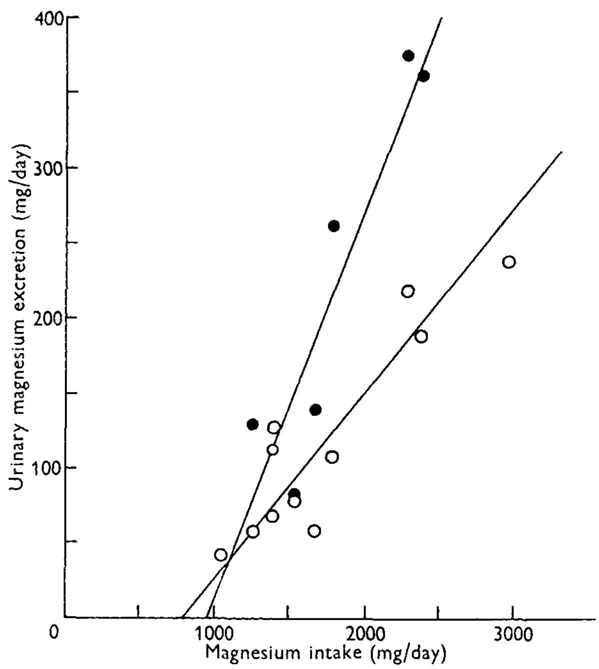

Fig. 1. Relationship between urinary magnesium excretion and dietary magnesium intake of two sheep. ○, sheep A; ●, sheep B.

Further analysis of the results obtained for the seven herbage samples which were given to both sheep showed that the two slopes differed at the 5 % level of significance, and the difference in urinary excretion produced by different herbage samples was determined mainly by their magnesium content. The influence of other characteristics of the samples, i.e. whether they came from tetany or control fields or from spring or autumn swards, was not detectable.

The intercepts on the x axis in Fig. 1 represent the values for the magnesium intake which would be associated with zero urinary excretion if the regression equations were obeyed over the lower region of the graph. Under these circumstances the magnesium intake would exactly satisfy the maintenance requirements of the animal, provided the intestinal excretion had reached the endogenous level, so that the values obtained for the intake, 800 and 950 mg, may be taken as an estimate of the requirements of the two sheep when fed on grassland herbage. However, these figures are probably slightly lower than the true values, since it is unlikely that the regression equation is obeyed over the low-intake range. When the intake exactly balances requirement the urinary excretion will not fall to zero, but will reach a constant value representing the endogenous loss of magnesium in the urine. Our subsequent unpublished work has shown that this loss may be less than 10 mg/day, and recent work by Smith (1957) has indicated that the endogenous urinary loss in the calf is of the same order (4–10 mg/day).

Table 3. *Intake and excretion of magnesium by the sheep*

(Mean daily values with their standard errors for the last 6 days of each feeding period)

		Sheep A		Sheep B	
Herbage	Intake (mg)	Urinary excretion (mg)	Faecal excretion (mg)	Urinary excretion (mg)	Faecal excretion (mg)
N 1	1060	43 ± 3·8	980	—	—
N 2	1670	59 ± 2·7	1660	141 ± 3·6	1630
N 3	1780	108 ± 6·1	1530	262 ± 5·6	1440
N 4	2370	191 ± 22·4	2260	364 ± 24·5	2090
N 5	2680	241 ± 8·1	2140	—	—
H 1	1250	58 ± 8·5	1100	129 ± 8·8	1020
H 2	1380	68 ± 4·2	1150	114 ± 4·6	1130
H 3	1400	128 ± 3·3	994	—	—
H 4	1530	80 ± 6·1	1250	84 ± 6·0	1220
Grass nuts	2280	220 ± 8·0	2220	377 ± 4·7	2010

Magnesium balance and net absorption

The values obtained for the magnesium balance and net absorption are shown in Table 4. They were calculated from the combined results obtained for the faecal excretion over the last two 3-day periods of each 9-day experimental period in order to minimize end-period errors and those due to the irregular passage of intestinal contents. An examination of the results for all these periods showed that although there was a correlation between the change in dry-matter intake, and the difference in the dry weight of the faeces excreted over the first and third periods, there was no such correlation for the second and third periods, which indicates that the error due to incomplete elimination of material from the herbage samples given previously is not detectable for these two periods.

With one exception, the balance figures shown in Table 4 are less than 15 % of the magnesium intake, and the largest negative balance recorded is 6 %. However, the errors attached to these values and those for the net absorption are probably relatively large, since they are both calculated by subtracting two comparatively large values, namely those for the magnesium intake and faecal excretion, which are themselves associated with considerable experimental errors such as those involved in sampling for analysis. The fact that the balance figures for a particular herbage sample are of the same sign for both sheep indicates either that the errors operated in the same direction for both animals rather than at random, or that the magnesium balance of both sheep was influenced by unidentified factors in certain herbages. Since the magnitude of the experimental errors is unknown the significance of the individual values shown in Table 4 is obscure.

The values for the net absorption of magnesium are statistically different for the two sheep ($P<0.05$), sheep B with the higher absorption having the higher urinary excretion, but the balance figures show no significant difference. There was no detectable correlation between the net absorption and the urinary excretion such as McCance & Widdowson (1942–3) reported for man, but it is possible that it was masked by the errors discussed above.

Table 4. *Mean daily magnesium intake (mg) of the sheep, and magnesium absorption and balance expressed as a percentage of intake*

Herbage	Mg intake	Sheep A Net absorption	Sheep A Balance	Sheep B Net absorption	Sheep B Balance	Mean balance
N 1	1060	7·5	3·5	—	—	—
N 2	1670	0·6	−2·9	2·2	−6·2	−4·5
N 3	1780	14	7·8	19	4·7	6·2
N 4	2370	4·8	−3·3	12	−3·6	−3·4
N 5	2680	20	11	—	—	—
H 1	1250	12	7·3	18	8·1	7·7
H 2	1380	17	12	18	10	11
H 3	1400	29	20	—	—	—
H 4	1530	18	13	20	14	13·5
Grass nuts	2280	2·8	−6·9	12	−4·3	−5·6

Calcium excretion and absorption

The values obtained for the urinary excretion of calcium are summarized in Table 5. They are of the same order of magnitude as those reported for cattle, i.e. less than 5 % of the dietary intake (Hansard, Comar & Davis, 1954; Visek, Monroe, Swanson & Comar, 1953; Hansard, Comar & Plumlee, 1952). The day-to-day variations were relatively much greater than they were for magnesium and there was no correlation

Table 5. *Intake and excretion of calcium by the sheep*

(Mean daily values with their standard errors for the last 6 days of each feeding period)

Herbage	Intake (mg)	Sheep A Urinary excretion (mg)	Sheep A Faecal excretion (mg)	Sheep B Urinary excretion (mg)	Sheep B Faecal excretion (mg)
N 1	6,200	15 ± 2·0	6,510	—	—
N 2	4,530	202 ± 24·9	5,250	54 ± 13·0	5,070
N 3	7,820	95 ± 4·1	8,020	16 ± 3·8	8,100
N 4	8,080	157 ± 35·6	8,320	51 ± 5·9	7,920
N 5	6,430	43 ± 4·4	6,430	—	—
H 1	6,840	202 ± 22·5	6,290	54 ± 4·7	6,570
H 2	7,060	181 ± 30·9	6,570	38 ± 5·0	6·280
H 3	5,650	138 ± 15·4	5,250	—	—
H 4	6,770	68 ± 9·5	6,090	2 ± 0·4	5,620
Grass nuts	10,580	48 ± 4·9	11,210	16 ± 5·1	11,110

with intake. Once again there was a significant difference between the two sheep (Table 6), sheep B having the lower urinary excretion. It is interesting to note that this sheep had the higher magnesium excretion.

Values were also obtained for the calcium balance and net absorption, but showed no significant differences or correlations and are therefore not recorded here.

Table 6. *Analysis of variance of the urinary Ca excretion of the sheep, expressed in mg/day*

Source of variation	Degrees of freedom	Mean square	F
Between sheep	1	218,179	32·8**
Between herbage	6	22,531	3·38
Interaction $S \times H$	6	6,666	—

** $0{\cdot}01 > P > 0{\cdot}001$.

DISCUSSION

In this experiment the feeding of wethers on herbage from fields in which lactation tetany had recently occurred in cows, caused neither clinical signs of the disease nor a detectable fall in the concentration of magnesium in the serum and blood. Furthermore, there was no evidence of any gross abnormality in the availability of the magnesium present in the herbage. At no time did the sheep show a large negative magnesium balance, and the amount excreted in the urine showed the same correlation with intake as it did when herbage from control fields was given. These results do not support the theory that pastures associated with the disease contain some toxic factor which inhibits the utilization of magnesium by the animal. Recent work by Head & Rook (1955, 1957) has indicated that excessive amounts of ammonia produced in the rumen from herbage with a high protein content may cause an inhibition of this kind. Although the majority of the samples used in our experiment had a similar protein content to those of tetany pastures examined by Bartlett *et al.* (1954) there was no correlation between this value and the deviation from the regression curve relating magnesium intake and urinary excretion.

Our failure to reproduce the disease or to produce any disturbance of magnesium utilization may be due to several factors. In the first place in adult non-lactating animals such as the wethers used in our experiments, the percentage of susceptible animals is likely to be small since their magnesium requirements are minimal, which will reduce the chance of using susceptible animals where it is necessary to confine experiments to small groups. It is also possible that the experimental conditions did not simulate sufficiently closely those under which the disease occurs in cows; for instance, there was no change in the nature of the diet like that experienced by cows when they are turned out to pasture from stall feeding. Our recent unpublished work has indicated that the physiological disturbances produced by this change may play a part in the aetiology of the disease. The possibility that sheep may be resistant to causative factors which affect cattle should also be borne in mind, and at the moment there is no evidence that the disease has the same aetiology in both species.

One of the most important conclusions to be drawn from the results of our experiment is that the amount of magnesium excreted in the urine is influenced by the amount ingested in the diet. Furthermore, this relationship is quantitative, since for each sheep these quantities were related by a regression equation. Clearly this factor must be taken into account when any attempt is made to relate the urinary excretion to the availability of magnesium in the diet. These equations were obeyed by the values for all the herbage samples used and there was no significant difference between those for tetany and control pastures and those for spring and autumn swards. Thus, there was no evidence that the magnesium in the herbage from the tetany fields was of abnormally low availability. Although the result for herbage H4 appears to be low for sheep B, it did not differ significantly from the regression equation for the sheep.

It has frequently been observed that individual cows differ greatly in their susceptibility to both hypomagnesaemia and hypomagnesaemic tetany. In principle this susceptibility will be determined by several factors, including the amount of magnesium required by the animal, its appetite, the efficiency with which it is able to utilize this element from the diet and the available reserves in the skeleton, which appear to decrease with age (Blaxter & McGill, 1956).

The experiment described here demonstrated that two healthy animals of the same breed and age may show a large difference in their metabolism of the same amount of dietary magnesium. Throughout the experiment one sheep had a higher urinary excretion, net absorption and concentration of magnesium in its serum and blood than the other and therefore may have been less susceptible to hypomagnesaemia. There is no information in the literature on differences in magnesium metabolism between ruminants. Though it is probable that the difference in urinary excretion reflected a difference in the amount of magnesium absorbed and hence in the efficiency with which the animals were able to utilize the element in the diet, it should be pointed out that a difference in urinary excretion could also arise from a difference in the partition of excreted magnesium between faeces and urine.

It will be seen from the following theoretical considerations that the slope of the individual regression curves relating urinary excretion to intake may be taken as a measure of the efficiency with which the animal was able to utilize the magnesium present in the herbage. For a non-lactating animal the percentage efficiency of absorption, $E=(F+S+U)/I\times 100$, where F = amount excreted into the intestine and not reabsorbed, S = amount stored in the tissues, U = amount excreted in the urine and I = amount ingested. If it is assumed that E was constant over the range of intake investigated, the following relations are obeyed

$$E=\frac{F_1+S_1+U_1}{I_1}=\frac{F_2+S_2+U_2}{I_2}=\frac{(F_1+S_1+U_1)-(F_2+S_2+U_2)}{I_1-I_2}, \qquad (1)$$

where F_1, S_1 and U_1 are the values associated with magnesium intake I_1, and F_2, S_2 and U_2 are those associated with a lower intake I_2. If it is assumed that the amount of magnesium excreted into the intestines and retained in the tissues by each adult sheep was in fact negligible, as it appears to be in human adults (McCance & Widdowson, 1939), i.e. $F_1=F_2$ and $S_1=S_2$, equation (1) becomes $E=(U_1-U_2)/(I_1-I_2)$.

Therefore, if E is constant, the relationship between U and I must be linear. This relationship was in fact shown on p. 439 to be linear for each sheep, the efficiency of absorption was therefore constant and equal to the regression coefficient, i.e. 13 and 26 % for sheep A and B, respectively. There are no experimental data in the literature on the availability of magnesium in this type of diet for adult animals.

The intercept of the regression line on the y axis represents the endogenous faecal loss. The figures obtained in this way (100 and 250 mg/day for sheep A and B, respectively, or 1·7 and 5 mg/kg/day) are in reasonable agreement with those reported for calves (3–4 mg/kg/day) by Blaxter & Rook (1954), and for cows (3–5 mg/kg) by Blaxter & McGill (1956). The fact that the latter are for the total endogenous loss does not invalidate the comparison since the loss in the urine is very small compared with that in the faeces.

The higher requirement figure of 0·95 g Mg/day for sheep B would be satisfied by herbage containing 0·07 g Mg/100 g dry weight, if a dry-weight intake of about 3 lb. a day is assumed. It is therefore unlikely that a simple dietary deficiency of magnesium will occur in adult wethers at pasture, unless certain individuals have a much lower efficiency of absorption than our experimental sheep. The dietary requirements of pregnant or lactating ewes have not so far been determined experimentally, but a figure of approximately 2·0 g/day can be calculated for the latter from the above values for wethers on the assumption that the amount secreted in the milk is about 1 g/day. (The latter figure in turn was calculated on the assumption that the milk yield is 2 l./day (Woodman, 1952), the magnesium content of the milk is the same as that of cow's milk, i.e. 135 mg/l. (Blaxter & McGill, 1956) and the efficiency of utilization is 25 %.) This requirement would be met by pasture containing on the dry basis about 0·1 % magnesium from a dry-matter intake of 4 lb./day, and is sufficiently high to suggest a simple dietary deficiency as a possible factor in the aetiology of the disease in lactating ewes.

SUMMARY

1. Magnesium and calcium balance experiments were carried out with two Cheviot wethers given as the sole dietary source of these elements spring herbage from three fields in which lactation tetany had occurred in cows, and from four control fields. For comparative purposes additional experiments were carried out with autumn herbage from one of the control fields and with grass nuts made of similar material. The magnesium content of the tetany pastures did not appear to be unusual.

2. No clinical signs of tetany were observed at any time during the experiments and the levels of magnesium and calcium in the serum remained within the normal range.

3. There appeared to be no difference in the availability of the magnesium in the two types of pasture, the autumn herbage and the grass nuts, and neither sheep showed a large negative magnesium balance at any time.

4. A change in the magnesium intake was quickly reflected in the urinary excretion of this element which became constant 3 days afterwards provided the diet consisted entirely of spring herbage.

5. For both sheep there was a highly significant positive correlation between the amount of magnesium excreted in the urine and the intake, but there was a significant difference between the regression equations for the two sheep.

6. The sheep that excreted more magnesium in the urine also had more of this element in its serum and blood and a higher net absorption, but its urinary excretion of calcium was significantly lower.

7. There was no correlation between the urinary excretion of calcium and the intake or net absorption of this element.

8. From the results it was possible to calculate tentative figures for the amount of magnesium, contained in herbage, required by the two sheep (800 and 950 mg/day) for maintenance, the efficiency with which they were able to utilize the magnesium present in the herbage (13 and 26%, respectively), and the endogenous faecal loss of magnesium (100 and 250 mg/day, respectively).

9. These results are discussed in relation to susceptibility to hypomagnesaemia and the possibility of a simple dietary deficiency of magnesium occurring in wethers and lactating ewes at pasture.

We are grateful to Dr J. T. Stamp, Director of Moredun Institute, for his interest in this work, to Dr P. McDonald, Edinburgh and East of Scotland College of Agriculture, for advice on the construction of the metabolism crates and equipment for collecting urine and faeces, and also for carrying out the nitrogen estimations, to Drs R. Osborne and E. C. R. Reeve for guidance in the statistical calculations, to Mr R. G. Heddle for examination of the botanical composition of the herbage, to Dr D. I. Nisbet for carrying out a post-mortem examination on one of the sheep, and to Miss I. Jean Macintyre, B.Sc., Miss A. Duncan and the technical staff of the Chemistry Department, Moredun Institute, for their assistance.

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Diet in pregnancy

1. Dietary survey technique and the nutritive value of diets taken by primigravidae

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(*Received* 17 *May* 1958)

Despite extensive investigation it remains uncertain whether the diet taken by a pregnant woman exerts an important influence upon the clinical course and outcome of her pregnancy. Diametrically opposed results have been obtained from combined dietary and clinical surveys. For example, Burke, Beal, Kirkwood & Stuart (1943) found striking correlations between their dietary and clinical findings in a study of 'middle-class' American women, whereas McGanity, Cannon, Bridgforth, Martin, Densen, Newbill, McClellan, Christie, Peterson & Darby (1954) found none in a study of women of 'low to moderate' income in another area of the United States. It is difficult, from the published material, to decide which of these two findings is more likely to be 'true'. There is certainly no obvious reason to believe that both are wholly credible, and that two apparently similar populations behaved in completely different ways.

When, in 1949, it was decided to study the diets and clinical histories of pregnant women in Aberdeen, much thought was given to the questions of how to select a group of patients and how to determine the nutritive value of the diets they were taking. In principle, it was thought that the subjects should be as nearly as possible representative of a clearly defined population, and that food intakes should be determined by methods of proved accuracy. These principles are not readily combined in practice. Accurate weighing and measuring of food, which must for practical reasons