PARTITION OF EXCRETED NITROGEN, SULPHUR, AND PHOSPHORUS BETWEEN THE FAECES AND URINE OF SHEEP BEING FED PASTURE

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Summary

Merino wethers in metabolism cages were fed a range of pasture samples at a level sufficient to maintain body weight nearly constant. The quantities of food eaten and of faeces and urine produced were recorded. The nitrogen, sulphur, and phosphorus contents of the feed and of the faeces and urine were determined. The phosphorus content of the faeces was further fractionated into organic and inorganic forms.

Faecal excretion of nitrogen, sulphur, and organic phosphorus per unit of feed eaten was not significantly affected by the nitrogen, sulphur, or phosphorus content (respectively) of the feed eaten, nor by the level of feed intake. Average values were 0.835 g of nitrogen, 0.114 g of sulphur, and 0.059 g of organic phosphorus per 100 g of dry matter eaten. The remainder of the nitrogen and sulphur was excreted in the urine, and hence the proportion excreted in the urine depended on the nitrogen or sulphur content (respectively) of the feed. Most of the remainder of the phosphorus was excreted in the inorganic form in the faeces, and hence the proportion of the faecal phosphorus in inorganic form depended on the phosphorus content of the feed. However, these proportions also depended on the level of feed intake, especially if this was so low that the animal was in negative balance.

Because the nitrogen/sulphur ratio of faeces (and also of wool) was smaller than that of the feed, the nitrogen/sulphur ratio of the urine tended to be larger than that of the feed.

The sulphur and phosphorus contents of faeces, although correlated with digestibility, were inferior to nitrogen as an indicator of digestibility and were too highly correlated with nitrogen to be of much value as additional measures.

I. INTRODUCTION

When animals graze a pasture a large proportion of the ingested plant nutrients is returned to the pasture in the excreta. However, there is only limited evidence on the composition of the excreta and on the partition of nutrients between the faeces and the urine (Petersen 1954). Further information on these aspects should help in understanding the nutrient cycle under grazing conditions and hence enable better use of fertilizer to be made.

Sears, Goodall, and Newbold (1948) and Sears (1950) found that for sheep grazing a high quality New Zealand pasture, 70–75% of the excreted nitrogen was in the urine. It seems unlikely that such a partition of nitrogen would always occur. For an animal in balance, the nitrogen excreted in the urine is equal to the difference between the nitrogen ingested and the nitrogen in the faeces. However, the faecal

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excretion of nitrogen tends to be approximately constant per unit of dry matter eaten (Blaxter and Mitchell 1948; Gallup and Briggs 1948; Lancaster 1949a, 1949b). Hence the proportion in the urine would be expected to vary with the nitrogen content of the feed eaten.

Information on the partition of sulphur between the faeces and the urine appears to be limited to reports by Kellermann (1935), Starks et al. (1953), and Kulwich, Struglia, and Pearson (1957) for sheep, and Ejury (1937, 1940) for cattle. It seemed possible that the partition might depend on the sulphur content of the feed, and this hypothesis was tested.

All reports in the literature indicate that for healthy sheep, only trace amounts of phosphorus are excreted in the urine—though in a fasting sheep, levels of phosphate may rise above the renal threshold and excretion in the urine may occur (Watson 1933). Normally, however, phosphorus is excreted through the intestinal wall and consequently the faeces contain both organic and inorganic phosphorus. The proportion in the inorganic form has been determined by Peperzak et al. (1959), who also reviewed earlier work. More recently Bromfield (1961) suggested that the proportion of the phosphorus excreted in the organic form might depend on the phosphorus content of the feed eaten. This hypothesis also was tested.

II. METHODS

Since it was an essential requirement that the composition of the feed eaten be known, it was not possible to use freely grazing animals and consequently metabolism cages were used. The experimental animals were mature fine-wool Merino wethers with a body weight of about 90 lb.

In each trial a uniform area of pasture was chosen and fresh samples were cut daily. Each trial consisted of an initial period of at least 4 days during which no samples were collected, and this was followed by a 10 day collection period. It is not practicable to use longer periods in pasture work because the material being sampled may change rapidly. As far as possible trials were consecutive, but occasionally the sheep were allowed to graze in pasture similar to that which was to be used in the next experimental period.

The sheep were weighed twice weekly and the amount of pasture fed was adjusted so that, over long periods, liveweight was maintained constant. In individual trials, however, gains or losses in weight occurred and consequently the sheep were not always in nutrient balance (see later). With pastures of poor quality and with low nitrogen, sulphur, and phosphorus contents, voluntary intake tended to be low, and with these samples weight losses were largest and the animals tended to be in negative balance.

The pasture samples were collected both from unfertilized "native" pastures and from sown pastures which had been fertilized with superphosphate and included as great a range of maturity as was available. The range of nitrogen, sulphur, and phosphorus content is shown in Figures 2, 3, and 4 respectively.

On each collection day proportionate samples were taken of feed and faeces and these were air-dried and bulked at the end of the experiment. These were
subsequently ground and were oven-dried before analysis. Urine was not collected in all cases, because the experiments were not originally planned for the present study. When urine was collected, daily samples were acidified with hydrochloric acid, and at the end of the experiment the bulked sample was saturated with chloroform.

![Fig. 1.—Relationship between the dry matter intake (I, g/day) and: (a) the faecal excretion of nitrogen (N, g/day); (b) the faecal excretion of sulphur (S, g/day); (c) the faecal excretion of organic phosphorus (P, g/day). The equations to the regression lines are:

(a) \( N = 0.00959 \cdot I - 0.405; \ r = 0.925. \)

(b) \( S = 0.00125 \cdot I - 0.0248; \ r = 0.864. \)

(c) \( P = 0.00075 \cdot I - 0.0525; \ r = 0.870. \)

Total nitrogen was determined by the Kjeldahl method and total sulphur by the method of Iismaa (1959). (For total sulphur determinations by Iismaa’s method, urine samples were evaporated onto a piece of filter paper.) For total phosphorus determinations, the samples were digested with a mixture of nitric, perchloric, and sulphuric acids. For inorganic phosphorus the samples were extracted with 0.2N
hydrochloric acid (Bromfield 1961). In both cases the phosphorus was determined by the method of Truog and Meyer (1929). Organic phosphorus was usually determined by difference, but in some cases the values were checked by direct determination of the phosphorus content of the residue after the extraction with 0.2N hydrochloric acid.

Fig. 2.—Relationship between the nitrogen content of the feed and excretion of nitrogen (g/100 g of feed eaten). The broken line is not fitted to the data, but is drawn to indicate the position of balance between intake and excretion. When the total excretion is above the line the animal is in negative balance, below the line in positive balance. Because the excretion of nitrogen in the faeces (per unit of feed eaten) was not significantly affected by the nitrogen content of the feed, a horizontal unbroken line is drawn through the mean value. ○ Nitrogen excreted in faeces (trials in which no urine was collected). • Nitrogen excreted in faeces (trials in which urine was collected). × Sum of nitrogen excreted in urine and faeces.

III. RESULTS

(a) Influence of Level of Intake on Excretion.

Hutchinson (1958) has pointed out that the practice of expressing values for faecal excretion of nitrogen in terms of unit intake of feed depends on the assumption that excretion per unit of feed intake is independent of the level of feed intake. The effects of level of intake on excretion were therefore tested. Firstly, the regressions of excretion (in grams per day) on intake were calculated (Fig. 1). For all three
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elements the value for the intercept was small, negative, and not significantly different from zero. Secondly, the relation between intake and faecal excretion (per unit of intake) was tested. The correlation coefficients for nitrogen, sulphur, and organic phosphorus were 0.106, 0.086, and 0.182 respectively and were non-significant. Thus, for the present data, there is no evidence that faecal excretion (per unit feed intake) of nitrogen, sulphur, or organic phosphorus in faeces was affected by the level of intake of feed, and excretion may therefore be expressed in terms of unit intake of feed.

![Graph showing relationship between sulphur content of feed and excretion of sulphur](image)

Fig. 3.—Relationship between the sulphur content of the feed and excretion of sulphur (g/100 g of feed eaten). The figure is constructed in an analogous fashion to Figure 2. ○ Sulphur excreted in faeces (trials in which no urine was collected). ● Sulphur excreted in faeces (trials in which urine was collected). × Sum of sulphur excreted in urine and faeces.

(b) Distribution of Nutrients between Faeces and Urine

(i) Nitrogen.—The mean excretion of faecal nitrogen was 0.835 g of nitrogen per 100 g of dry matter consumed, and the scatter of data is indicated in Figure 2. This compares with the values of 0.72 (Lancaster 1949a), 0.48–0.86 (Gallup and Briggs 1948), and 0.57–0.76 (Blaxter and Mitchell 1948). In contrast to the results of Blaxter and Mitchell (1948) the faecal excretion of nitrogen (per unit of feed eaten) was not significantly affected by the nitrogen content of the feed (correlation coefficient \( r = 0.103 \)). This would suggest that there was a tendency for the digestibility
of the nitrogen to vary with the nitrogen content of the feed. If this were so, then
the proportion of the faecal nitrogen which was of exogenous origin would not
necessarily decrease as the nitrogen content of the feed decreased.

When the nitrogen content of the feed was high, 80% of the excreted nitrogen
was in the urine. When the nitrogen content of the feed was lower, the fraction of
excreted nitrogen in the urine fell, the lowest proportion recorded being 43%.
However, a low nitrogen content in the feed tended to be associated with low intake.

![Graph](image)

Fig. 4.—Relationship between the phosphorus content of the feed and
excretion of phosphorus (g/100 g of feed eaten). The figure is constructed
in an analogous fashion to Figure 2. ◯ Organic phosphorus excreted in
faeces. ● Total phosphorus excreted in faeces.

It is therefore probable that much of the urinary nitrogen was derived from
catabolism of tissue proteins. It is possible that, if the intake had been higher, a
smaller proportion of the excreted nitrogen would have been in the urine.

(ii) *Sulphur.*—The faecal excretion of sulphur was not significantly affected
by the sulphur content of the feed eaten ($r = -0.088$). The mean value was 0.114 g
of sulphur per 100 g of feed eaten (Fig. 3).

Unfortunately there were few feeds with very high sulphur content available
and hence the partition of sulphur is not as well marked as for the other elements.
Nevertheless, the proportion of the sulphur excreted in the urine varied from 90% for the feed with the highest sulphur content to only 6% for a feed with low sulphur content.

(iii) Phosphorus.—For those animals from which urine was collected, the urinary excretion of phosphorus was negligibly small compared with the excretion in the faeces, and consequently has not been presented in Figure 4.

The excretion of organic phosphorus in the faeces was not significantly affected by the phosphorus content of the feed eaten \((r = 0.147)\). The mean value was \(0.059\) g of organic phosphorus per 100 g of feed eaten.

The highest proportion of inorganic phosphorus in the faeces was 90% and the lowest 61%. With feeds of low phosphorus content voluntary intake of feed was low and the sheep were in marked negative phosphorus balance (Fig. 4). It is possible that if intake had been higher a smaller proportion of the excreted phosphorus would have been in the inorganic form.

(c) Interrelations between the Nitrogen, Phosphorus, and Sulphur Contents of Faeces

There was a strong tendency for the nitrogen, phosphorus, and sulphur contents of the faeces to be interrelated. The correlation coefficients were:

- Between \(N\) and \(S\) \(0.802\)
- Between \(N\) and \(P\) \(0.834\)
- Between \(P\) and \(S\) \(0.609\)

where \(N\) is the percentage nitrogen, \(P\) is the percentage phosphorus, and \(S\) the percentage sulphur in the faeces dry matter.

The ratios of the means were: \(N/S = 7.32\) and \(N/P = 3.05\).

(d) Interrelations between the Nitrogen, Phosphorus, and Sulphur Contents of Urine

The phosphorus content of the urine was small and is not considered. Figure 5 shows that when the animals were fed samples of pasture the nitrogen and the sulphur contents of the urine were closely related. The ratio of the mean concentration of nitrogen to the mean concentration of sulphur was 20.5. When the animals were fed kale with high sulphur content the nitrogen/sulphur ratio in the urine was 5.

(e) Alternative Indicators of Digestibility

The nitrogen content of faeces is commonly used as an index of digestibility. The principle is that, since excretion of faecal nitrogen tends to be constant per unit of feed eaten, the concentration of nitrogen in the faeces will increase with increasing digestibility. It seemed possible that either faecal phosphorus or sulphur might be useful as an additional index of digestibility. Inspection of the data showed that the most promising measure was the total phosphorus content. There are two reasons for this relationship with phosphorus. The more important one is that, since most of the ingested phosphorus is excreted in the faeces, the concentration in the faeces indicates the degree to which the feed has been concentrated. The subsidiary reason is that there tends to be a relationship between digestibility and the phosphorus content of the feed. Values were converted to the organic matter basis, which has
become conventional with digestibility measurements, and the correlation coefficients shown below were calculated:

- Correlation coefficient between \( D \) and \( P \)  
  \[ 0.820 \]

- Multiple correlation coefficient between \( D \) and \( P, P^2 \)  
  \[ 0.865 \]

- Correlation coefficient between \( D \) and \( N \)  
  \[ 0.931 \]

- Multiple correlation coefficient between \( D \) and \( N, N^2 \)  
  \[ 0.934 \]

- Multiple correlation coefficient between \( D \) and \( P, P^2 N, N^2 \)  
  \[ 0.944 \]

where \( D \) is the digestibility of organic matter; \( P \) is the percentage total phosphorus, and \( N \) is the percentage nitrogen, in the faecal organic matter.

Fig. 5.—Relationship between the nitrogen and sulphur content of the urine of sheep being fed grass-legume pasture. The value for kale is excluded. The correlation coefficient is 0.870, and the \( N/S \) ratio of the means 20.55. When the data are expressed as g of nitrogen and sulphur excreted per day the correlation coefficient is 0.908 and the \( N/S \) ratio of the means 21.34.

The relationship between digestibility and phosphorus was significantly improved by fitting the term for \( P^2 \), which indicated that the relationship was curvilinear. The relationship with nitrogen was not significantly curvilinear. Although phosphorus was strongly correlated with digestibility the relationship was inferior to that with nitrogen. Further, phosphorus was too strongly correlated with nitrogen (see above) to be of much value as an additional measure of digestibility, and the improvement in the correlation coefficient by fitting the terms for phosphorus was small and non-significant.

IV. DISCUSSION

(a) Distribution of Nutrients between Dung and Urine

It is clear that the partition of nitrogen and sulphur between the faeces and the urine varies with the nitrogen and sulphur contents respectively of the feed. In a
similar fashion, the partition of faecal phosphorus between organic and inorganic forms varies with the phosphorus content of the feed. It seems likely that the above partition also varies with the level of feed intake. The faecal excretion of nitrogen, sulphur, and organic phosphorus (per unit of feed eaten) was not found to be affected by intake, so that, when the animal is in negative balance at low levels of intake, the "extra" nitrogen, sulphur, and phosphorus must be excreted in the alternative form. The nitrogen and sulphur would be excreted in the urine and the phosphorus in the inorganic form in the faeces—though excretion in the urine can occur if intake is low enough (Watson 1933).

It is likely that the low intake of feed observed in these experiments was partly a consequence of using caged animals. Hutchinson (1958) and Lambourne (1961) have observed that the intake of grazing animals is often much higher than that of caged animals. This suggests that with grazing animals a somewhat different partition of nutrients would occur. With feeds of low nitrogen content the proportion of nitrogen excreted in the urine would be smaller than the 43% observed here. With feeds of low phosphorus content the proportion of phosphorus excreted in inorganic form would be less than the 61% observed here, and in fact Bromfield (1961) found that with grazing animals the inorganic phosphorus content of faeces varied from 90 to 22% of the total phosphorus.

(b) Nitrogen/Sulphur Ratios in Excrement

The mean nitrogen/sulphur (N/S) ratio of the feed samples used here was 12.9. In our experience this is fairly typical, and ratios below 9 or 10 are unusual in most pasture samples—though they do occur in Cruciferae. However, as shown in Section III(c), the N/S ratio of the faeces was only 7.32. (It is possible that this low value is partly due to excretion of the sulphur-containing taurocholic acid in faeces). Because the N/S ratio in the faeces was lower than that in the feed and also because the N/S ratio of wool is lower than that in the feed, it is to be expected that the N/S ratio of urine would be higher than that in the feed. This was the case here, and it is suggested that this will occur whenever the N/S ratio of the feed is higher than, say, 7. This conclusion differs from that of Walker (1957), who, without citing any evidence, suggested that a N/S ratio of 5 may be typical of urine. The difference is important in grassland management, since Walker and Adams (1958) have shown the importance of the N/S ratio in determining the balance between grass and clover.

A further consequence of the small N/S ratio of faeces and of wool is that the proportion of ingested nitrogen which is excreted in the urine will be higher than the proportion of ingested sulphur excreted in the urine.

(c) Minimum Requirements for Sulphur

In this work the average excretion of sulphur in the faeces was found to be 0.114 g of sulphur per 100 g of dry matter eaten. This would suggest a minimum sulphur content of feed, which when allowance is made for growth of wool, would (on the average) be somewhat higher than 0.11%. Starks et al. (1953) found that feed with 0.062% sulphur was deficient in sulphur for growth of lambs. However, Whiting et al. (1953) found that a ration which varied between 0.08 and 0.10%
sulphur was satisfactory for mature ewes. This result does not conflict with the present work, because Whiting et al. used only one type of feed and, as shown by Figure 4, with some feeds the faecal excretion of sulphur was much lower than 0.1 g of sulphur per 100 g of dry matter eaten. This variation may have been caused by variation in the digestibility of the sulphur in the feed. The possibility that the digestibility of sulphur may vary should be taken into account when considering minimum requirements for sulphur.

(d) Return of Nutrients by the Grazing Animal

As has been pointed out, there are some difficulties in extrapolating the results of the present experiment to the higher intakes of feed which occur with grazing animals. However, the results should be capable of giving an approximation to the return of nutrients under grazing conditions.

Consider the simple case of dry sheep, which over a yearly period eat the convenient amount of 1000 lb of dry matter, and are in nutrient balance. Let us further assume that the average composition of the feed eaten is 3.2% nitrogen, 0.25% sulphur, and 0.25% phosphorus (these were the mean values observed here, but similar calculations could be made for pastures of different composition). Then, of the 32 lb of nitrogen eaten, 8.4 lb will be excreted in faeces, almost 1 lb will be used to produce wool, and there will be other small losses. This will leave about 22.6 lb, or 70% of the ingested nitrogen, to be excreted in the urine. This compares with the value of 70–75% reported by Sears, Goodall, and Newbold (1948) and Sears (1950). Of the 2.5 lb of sulphur eaten, 1.1 lb will be excreted in the faeces, almost 0.2 lb will be used to produce wool, and after allowance for other small losses about 1.2 lb, or slightly less than 50% of the ingested sulphur, will remain to be excreted in the urine. Of the 2.5 lb of phosphorus eaten, 0.59 lb will be excreted as organic phosphorus in the faeces and a small amount will be excreted in the urine. This leaves about 1.9 lb, or 75% of the ingested phosphorus, to be excreted as inorganic phosphorus in the faeces. These somewhat hypothetical values for phosphorus compare fairly well with those obtained by Bromfield (1961), who concluded that in a year a grazing sheep would excrete 2.5–3 lb of inorganic phosphorus and 0.5–0.75 lb of organic phosphorus.

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VI. References

N, S, and P in Faeces and Urine