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A Preliminary Survey of Potassium Circulation in the Moor House Blanket Bog

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Introduction

The work described in this report was originally intended to form the preliminary background to a more detailed study of the circulation of potassium in the blanket bog vegetation (dominated by *Calluna vulgaris* *Eriophorum vaginatum* and *Sphagnum* spp.) of the Moor House National Nature Reserve.

The project arose from the need to collate information available on mineral nutrient cycling in the blanket bog sites, as one of the objectives of I.B.P. of which Moor House is a part. It was proposed to confine the study to potassium, because other studies were under way for phosphorus and nitrogen cycling (A. J. P. Gore and B. T. D'Sylva respectively). Potassium has been shown to be a serious limiting factor in growth trials for *Pinus sylvestris* at Moor House (Brown, Carlisle & White, 1964).

The information presented, therefore, has been extracted from existing data, and from this a flow diagram has been obtained (Figure 1), indicating the turnover of potassium in a hypothetical year in the main component of the vegetation, *C. vulgaris*. 80-90% of the standing crop of vegetation on the blanket bog is *C. vulgaris*. (In most cases the figures have been extrapolated, so any inaccuracies or misrepresentations are my responsibility).

The Potassium Cycle

1. Input

The main source of input of nutrient cations to an area of extensive blanket bog is the rainfall, as the deep peat deposits are assumed to cut off the supply of nutrients from the mineral rocks below. A preliminary investigation (Smith: Moor House 9th Annual Progress Report 1968) has shown, however, that tritium, injected at 25 cm depth, had moved, over a period of 21 months, through the whole depth of peat and into the underlying clay. This may have implications concerning the movement of cations upwards from the clay. In the upper layers of peat, however, where the plant roots are mainly confined, the main source of nutrient supply will be the decomposing organic matter. The cycle of production and decomposition of organic matter takes place very slowly, because microbial action is hindered by the lack of available nutrients, and by waterlogged conditions in the peat.

Over a two-year period, the amount of potassium entering the system via the rainfall was 0.25 g/m^2/annum (Gore, 1968). This was based on measurements on areas of the blanket bog not likely to be affected by smoke contamination from the field station. There was some seasonal variation in this input, over a range of 35% of the average value, though this did not appear to be correlated with fluctuations in rainfall supply.

2. Output

Crisp (1966) measured the output of nutrients in a stream. The catchment area, which included blanket bog, and limestone and alluvial grassland, was 83 hectares. The amount of potassium in solution in the stream water was equivalent to a loss of 0.9 g/m^2/annum over the catchment area, and the amount of potassium in the particulate peat matter washed downstream was equivalent to 0.2 g/m^2/annum. Both these figures may be overestimated for an area of uniform blanket bog. The loss through particulate peat matter would be higher if erosion was serious, but in an area of full vegetation cover, this loss would probably be unimportant. Approximately 5% of the catchment area was limestone grassland i.e. about 4 ha. Park, Rawes & Allen (1960) estimated by lysimetry that leaching losses in the limestone grassland areas were equivalent to about 0.2 g/m^2/annum. This means that 0.9 g/m^2/annum would be lost from the remaining 79 ha. of blanket bog. The figure may be an overestimate, however, due to the action of the acid water in dissolving the rocks forming the stream bed, which was composed of alternating bands of limestone, sand, shale and glacial drift. Crisp (1966) estimated that the limestone bands would contribute about 10 kg of the 744 kg lost from the catchment per annum. Therefore an estimated loss of 0.91 g/m^2/annum would have to be accounted for from the blanket bog and other rock bands.

3. Content of the Upper Peat Horizon

a) 0-5 cm depth. The exchangeable potassium content (extracted with N ammonium acetate) was 0.036% dry wt. peat (Allen, 1964). The bulk density measurement of 0.03 g/cm^3 was recorded by Latter, Cragg & Heal (1967). Based on these figures the exchangeable potassium content of 1 m^2 to a depth of 5 cm would be 0.54 g. This is of a similar order to the total potassium content for this horizon. Gore & Allen (1956) found that nearly all the potassium present in the blanket peat was in exchangeable form.

b) 5-10 cm depth. The potassium content per unit dry weight of peat was taken to be the same as for the 0-5 cm horizon (Allen, 1964). The bulk density was 0.07 g/cm^3 (Latter, Cragg & Heal, 1967). This would correspond to a potassium content of 1.26 g/m^2 in a depth of 5 cm. As the roots of C. vulgaris are mainly confined to the top 10 cm of peat, a) and b) will represent the amount of potassium potentially available to this species.

c) 10-20 cm depth. The amount of potassium present per m^2 of this horizon would be 3.6 g, based on a potassium content of 40 mg/100 g dry wt. and a bulk density of 0.09 g/cm^3 (Latter, Cragg & Heal, 1967).

More data are required on the variations in potassium content within the top 10 cm of peat. Latter & Cragg (1967) found a very marked decrease in the potassium content of the ash in the Juncus moor peat profile, so that the percentage in the ash at 5-10 cm was only 10% of the percentage in the ash at 0-1 cm. As the proportion of ash in the peat increased down the profile, however, the potassium content expressed as concentration per g dry wt. of peat only decreased from 0.14% to 0.056%.

If leaching occurs to a significant extent then there may be loss of potassium to horizons below the rooting zone. Conversely, since a permanent water table exists at these depths, leaching losses may not be important. . This requires further study, which might be attempted with the use of organic matter tagged with radioactive tracers, or containing elements related to potassium, such as lithium or rubidium.

A further factor affecting the nutrient availability of the upper horizons at any one time is the rate of release from the organic matter, which is directly dependent on decomposition rates. As potassium is a readily leachable ion, however, it is less dependent on the rate of organic matter breakdown for its release than other important nutrients such as phosphorus.

4. The concentration in the Roots and Annual uptake based on Production

The root standing crop has been estimated as approximately 80% of the shoot standing crop, and the potassium content as 0.1% dry wt. (Forrest - personal communication). The amount of potassium in the 700-740 g/m^2 of root material would, therefore, be 0.70-0.74 g. Root production was approximately 160 g/m^2 (Forrest - pers. comm.), so the annual potassium uptake through production alone would be 0.16 g/m^2. This generalised annual uptake figure would vary over the period of a year due to seasonal variation in growth rates and potassium content.

Without further experimentation, no account can be made of the influence of root death, root exudation and back-translocation from the shoots on these figures.

5. The Concentration in the Shoots and Annual Uptake based on Production

The standing crop estimate of 860 g/m^2 of C. vulgaris (Forrest - pers. comm.) and the potassium content of 0.28% dry weight (Allen, 1964) would give 2.41 g/m^2 of potassium in the standing crop. Annual production of shoots was 100 g and potassium content 0.48% dry weight. Therefore, 0.48 g/m^2 would be taken up in shoot production. Wood production was 60 g per annum and potassium content 0.2% dry wt. (Forrest - pers. comm.) so an additional 0.12 g/m^2 would be taken up through this.

To study the systems in detail, allowance would be required for seasonal variation in production and potassium content of the shoots (Forrest - pers. comm., found that the shoot potassium content was 0.37% dry wt. in spring, 0.59% dry wt. in summer and 0.48% dry wt. in autumn). Seasonal variation in litter fall and back-translocation, and the possibly considerable leaching effect of rainwater on the leaves of the live vegetation would also be important factors. These factors could be elucidated using radio-active tracers, or related 'marker' substances. The extent of rainwash from the leaves could be studied by sealing small areas with a waterproof substance, and collecting and analysing the run-off. Comparison of the potassium content of this, with rainfall at the same point would indicate the importance of the leaching effect.

6. Return in the Litter

Litter production was estimated as 120 g/m^2/annum, and the potassium content as 0.07% dry wt. (Forrest - pers. comm.). Thus 0.084 g/m^2/annum potassium would be returned to the peat in litter from above-ground parts. This would become incorporated in the peat over a period of time, but more data are required on the rate of loss of potassium from the litter. This has been shown to be very rapid for Juncus (Latter & Cragg, 1967) where only 55% of the original potassium remained after 2 months, and 10% after 6 months.

7. Losses through Burning

Allen (1964) estimated that approximately 0.1 g/m^2 of potassium would be lost through increased leaching and smoke in one burn, if the standing crop was 1000 g/m^2. In the estimate of 860 g/m^2 taken in this report, this would be equivalent to a loss of approximately 0.08-0.09 g/m^2 in one burn. If a burn occurred every 10-12 years this would average at approximately 0.008 g/m^2/annum, and correspondingly less with more infrequent burning. The major proportion of the potassium released from the organic matter by burning appeared to be retained through the adsorption properties of the peat and Sphagnum.

8. The Effect of Grazing Animals

No account has been made in Figure 1 of the relative importance of grazing pressure in modifying the nutrient turnover. However, Crisp (1966) estimated that the sale of sheep and wool would correspond to a loss of 0.194 kg potassium over the 83 ha catchment area of Rough Sike, i.e. approximately 0.0002 g/m^2/annum. Most of this would represent a loss from the limestone grassland, since this is more heavily grazed. Invertebrate herbivores probably constitute a more important part of the animal biomass. As they complete their life cycle on the heather, however, they are unlikely to constitute a loss of nutrients to the system. Similarly grouse grazing may represent a negligible loss to the cycle, but be a significant alternative route for the nutrients. Based on an estimate of one bird per two hectares (one bird per 4-5 acres), eating 100 g per day (Moor House grouse file), approximately 3-4% of the shoot standing crop would be consumed in one year, or 0.06-0.08 g/m^2 of potassium.

The importance of the other dominant components of the vegetation in modifying the cycle

Of the potassium, only that cycling through the dominant component of the vegetation, C. vulgaris, has been considered in this report. To obtain any approximation of what occurs in natural conditions, however, the cycle would have to include E. vaginatum and Sphagnum species, although the pattern of nutrient turnover is likely to be quite different in these plants.

As E. vaginatum is deeper rooting than C. vulgaris, the potassium content of the deeper peat horizons may be available to this plant. (It may serve as a means of removing potassium from the deeper horizons back to the surface peats). The rate of decomposition is also more rapid (26.2% loss in weight in the leaves in one year, compared with 14.7% loss in weight in C. vulgaris leaves:

Heal & Latter, 9th Annual Progress Report, Moor House, 1968). It had been found at other sites that there was a very marked concentration of potassium in the living tissues of E. vaginatum and that much of this was retained in the tussock over winter (Goodman & Perkins, 1959). If this were generally true, then the species would act as a reservoir, and would, therefore be less independent on external supplies than C. vulgaris.

Sphagnum species are known to act as cation exchangers (Anschutz & Gessner, 1954; Clymo, 1963 & 1966) and this mechanism has been well demonstrated for the genus in experimental conditions (Clymo, 1963). It has been postulated that this mechanism is of ecological significance in an area of nutrient deficiency such as blanket bog (Bell, 1959). Clymo (1963) predicted that, with Sphagnum production of 100 g/m^2/annum, and rainfall of 125 cm, containing 2 meq./l of dissolved cations, about 2% of these would be retained within the exchange complex. As the rainfall is high at Moor House, and the growing season short, the percentage retained may be considerably less than 2%. Balanced against the small retention of cations is the leaching effect of the rainwater, which may be considerable during heavy storms.

Experiment to determine the effect of Sphagnum on the ionic composition of rainwater leached through it

An experiment was conducted in a greenhouse to determine whether the net effect of passing rainwater over Sphagnum species was an uptake of cations by the Sphagnum, or a leaching effect.

Methods and Materials

Four species were used: S. rubellum, S. papillosum, S. recurvum and S. cuspidatum. They were trimmed to remove the dead stem bases, blotted dry and 200 g fresh weight of each species placed in buckets. The buckets were arranged in sets to simulate the flow of water from hummock to hollow. Thus rainwater siphoned over from S. rubellum, to S. papillosum, and was collected for analysis after siphoning over from S. cuspidatum. The heights of the siphoning tubes were adjusted so that only the bases of the stems of S. rubellum, the 'hummock' species, were submerged, whereas the whole plant was submerged in the 'hollow' species, S. cuspidatum.

The sets of buckets containing the Sphagnum were replicated three times, and three empty sets acted as a control. They were randomly arranged. The buckets containing the Sphagnum were washed through with rainwater once, to remove peat and organic detritus, and to help to eliminate the influence of any bog water left in the plants on the ionic composition of the leachates. The rainwater used was collected in dustbins covered with 1 mm. terylene gauze, in the Merlewood grounds. The potassium content was shown by Allen et al, (1968) to be equivalent to 0.37 g/m^2/annum for the year 1965-55. This was rather higher than the 0.23 g/m^2/annum recorded at Moor House by Gore, (1968), although the two ranges overlap.

2.5 l of rainwater was passed through each set of buckets over a period of about 45 minutes. This would be roughly equivalent to the amount of rain during a heavy storm. A second washing was carried out on the following day, and the two samples analysed separately.

Experimental design : 2 treatments x 2 times x 3 replicates.

The rainwater was filtered through Whatman No.42 filter paper and analysed for soluble Na^+, K^+, Ca^{++}, Mg^{++}, NH_4^+ and NO_3^-. The experiment was carried out in March.

Results

The concentrations of soluble ions in the leached and unleached rainwater are shown in Figure 2, and the results for the different ions are presented in Table 1.

It is apparent from the results that there was a heavy leaching effect in the monovalent cations Na^+ and K^+, a lesser effect in the divalent cations (the difference was not significant in Ca^{++}), and NH_4^+ and NO_3^- ions were both taken up.

It is also apparent that, for Na^+, K^+ and Mg^{++}, the leaching effect of the rainwater was significantly greater on the first occasion than on the second.

It appears, therefore, that under these conditions the leaching effect of the rainwater on the *Sphagnum* may be particularly marked in potassium. The experiment was carried out in March, however, before the growing season, and smaller differences might be recorded if it were repeated during the summer. Also, under field conditions the rate of rainfall would not be so consistently high. It might be expected that at a slower rate of addition, the leaching would be less marked. These results do not agree with those obtained by Allen, (1964) who showed that the Ca^{++} and Mg^{++} content of synthetic rainwater that had percolated through a column of *Sphagnum* species was lower than in the untreated solution. The K^+ concentration was slightly, though not much, higher.

Further investigations carried out in the field would determine the importance of the leaching effect versus the adsorptive capacity of the *Sphagnum*.

Inferences

The flow diagram presented in Figure 1 is only a preliminary step in determining the cycling of potassium in the blanket bog. The amounts of potassium transferred within the cycle will vary considerably from year to year; and, within any one year, seasonal variation is likely to be important. However, in presenting in this form the data initially available, the shortcomings and missing links are more readily apparent. A dynamic model of the type shown by Gore & Olson (1967) into which seasonal variation, and other variable parameters, e.g. rainfall input, can be built, would appear to be the ideal solution. This was envisaged as the final aim of this project. As mineral nutrient uptake is dependent upon the growth of the plants and, therefore, upon photosynthetic processes, it may be necessary initially to understand how the flow of carbon and energy occurs in the blanket bog system, and the factors influencing their rates of turnover.

From Figure 1, however, certain features are apparent:-

1. The input in the rainfall is considerably less than the output in run-off and through erosion, even if allowance is made for the fact that these may be considerable over-estimates. Does this mean that the potassium supply of the system is continually running down, and, if so, how long will it take?

2. The various management techniques employed on the blanket bog, i.e. burning and sheep grazing, result in insignificant losses of potassium compared with the 'natural' losses, though indirectly, they may be important if they accelerate erosion.

3. A greater amount of potassium is locked up in the standing vegetation than is found in the top 10 cm of peat. This emphasises the importance of the recycling of nutrients by decomposition of the litter, and through leaching of the live vegetation. It also indicates the possible importance of *E. vaginatum* which, because of its deeper rooting system, may return potassium to the surface from the deeper peat layers. The higher concentration of nutrients in the vegetation than in the top layers of peat contrasts with the situation found on heathland overlying a mineral soil. On the Dorset heaths, overlying soil derived from the Bagshot sands, Chapman (1967) found that the total potassium content of the top 20 cm of soil was 28.8 g/m^2, compared with 5.4 g/m^2 in the top 20 cm at Moor House, and the amount in a 12 year stand of vegetation, mainly *C. vulgaris*, was 3.4 g/m^2 (about the same as at Moor House).

4. From Figure 1 it appears that the uptake per annum out-weighs the loss through the litter. This would imply an increasing concentration of the potassium in the standing crop with increasing age. This does not occur; in fact, the concentration tends to decrease with age as the proportion of wood : green shoots increases and the wood contains less potassium. Again this may indicate the necessity to study the leaching losses from the live vegetation. As the concentration of potassium in freshly fallen litter is low, (0.07% dry weight), the leaching effect may be more pronounced from the older shoots before they fall as litter.

5. The annual uptake of potassium by the plants is of the same order of magnitude as the content in the top 10 cm of peat. This again emphasises the importance of recycling potassium, and may be an important factor in competition between species, particularly in the case of trees planted on the blanket bog.

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Table 1. (continued)

4. Mg^{++}

Experimental factors		Mean	Standard error	Significance from analysis of variance
Treatments	- Leached	0.67	± 0.08	P = 0.01
	- Control	0.45	± 0	
Times	- 1	0.64	± 0.09	P = 0.05
	- 2	0.48	± 0.02	
Interactions	- Leached 1	0.83	± 0.08	All differences significant at P = 0.05 except between control 1 and 2.
	- " 2	0.50	± 0.03	
	- Control 1	0.45	± 0	
	- " 2	0.45	± 0	

5. NH4^{+}

Experimental factors		Mean	Standard error	Significance from analysis of variance
Treatments	- Leached	0.17	± 0.03	P = 0.01
	- Control	0.55	± 0.03	
Times	- 1	0.37	± 0.09	Not significant
	- 2	0.36	± 0.09	
Interactions	- Leached 1	0.18	± 0.06	Not significant except between leached 1 & 2 and control 1 & 2 (P=0.05)
	- " 2	0.17	± 0.04	
	- Control 1	0.55	± 0.05	
	- " 2	0.55	± 0	

6. NO$_3^{-}$

Experimental factors		Mean	Standard error	Significance from analysis of variance
Treatments	- Leached	0.38	± 0.03	P = 0.01
	- Control	0.45	± 0.02	
Times	- 1	0.40	± 0.02	Not significant
Interactions	- Leached 1	0.35	± 0.05	Not significant except between leached 1 & 2 and control 1 & 2 (P=0.01)
	- " 2	0.33	± 0.06	
	- Control 1	0.44	± 0	
	- " 2	0.46	± 0.01	

Table 1. Results in the *Sphagnum* leaching experiment.
(soluble ion concentrations in p.p.m.)

1. Na^+

Experimental factors		Mean	Standard error	Significance from analysis of variance
Treatments	- Leached	7.33	± 0.61	P = 0.01
	- Control	3.47	± 0.06	
Times	- 1	6.03	± 1.18	P = 0.01
	- 2	4.77	± 0.54	
Interactions	- Leached 1	8.70	± 0.20	All differences significant at P = 0.01, except between control 1 and 2.
	- " 2	5.97	± 0.40	
	- Control 1	3.37	± 0	
	- " 2	3.57	± 0.09	

2. K^+

Treatments	- Leached	10.17	± 2.71	P = 0.01
	- Control	0.39	± 0.04	
Times	- 1	7.35	± 3.83	P = 0.01
	- 2	3.19	± 1.74	
Interactions	- Leached 1	14.37	± 0.80	All differences significant at P = 0.01 except between control 1 and 2.
	- " 2	5.97	± 0.74	
	- Control 1	0.36	± 0.02	
	- " 2	0.41	± 0.06	

3. Ca^{++}

Treatments	- Leached	1.92	± 0.54	No differences significant at P = 0.05
	- Control	1.62	± 0.07	
Times	- 1	2.10	± 0.58	
	- 2	1.43	± 0.10	
Interactions	- Leached 1	2.57	± 1.10	
	- " 2	1.60	± 0.12	
	- Control 1	1.63	± 0.82	
	- " 2	1.60	± 0.10	

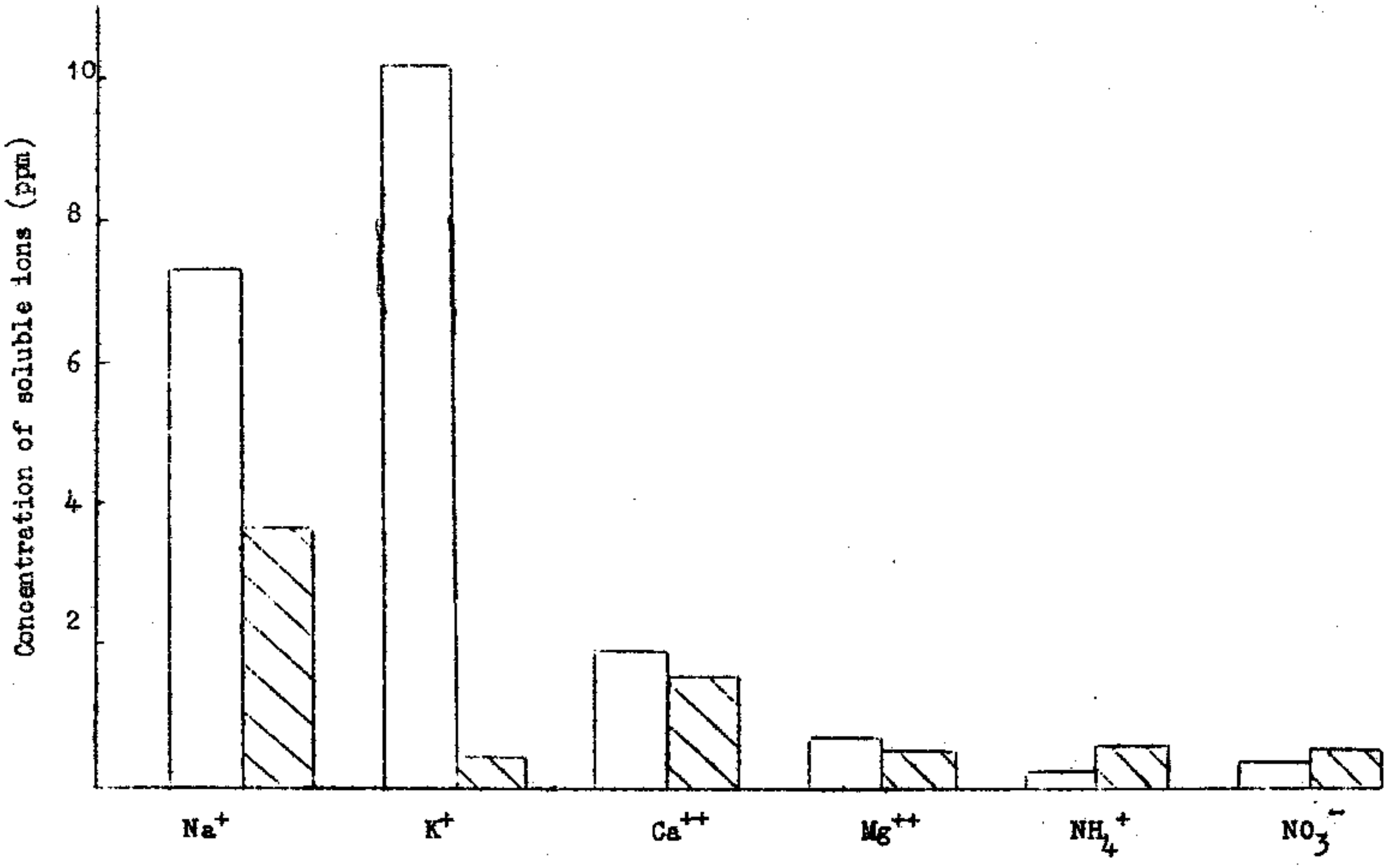

Figure 2. Concentration of soluble ions in rainwater leached through a series of Sphagnum species.
Plain histogram - leached rainwater
Hatched histogram - untreated rainwater.

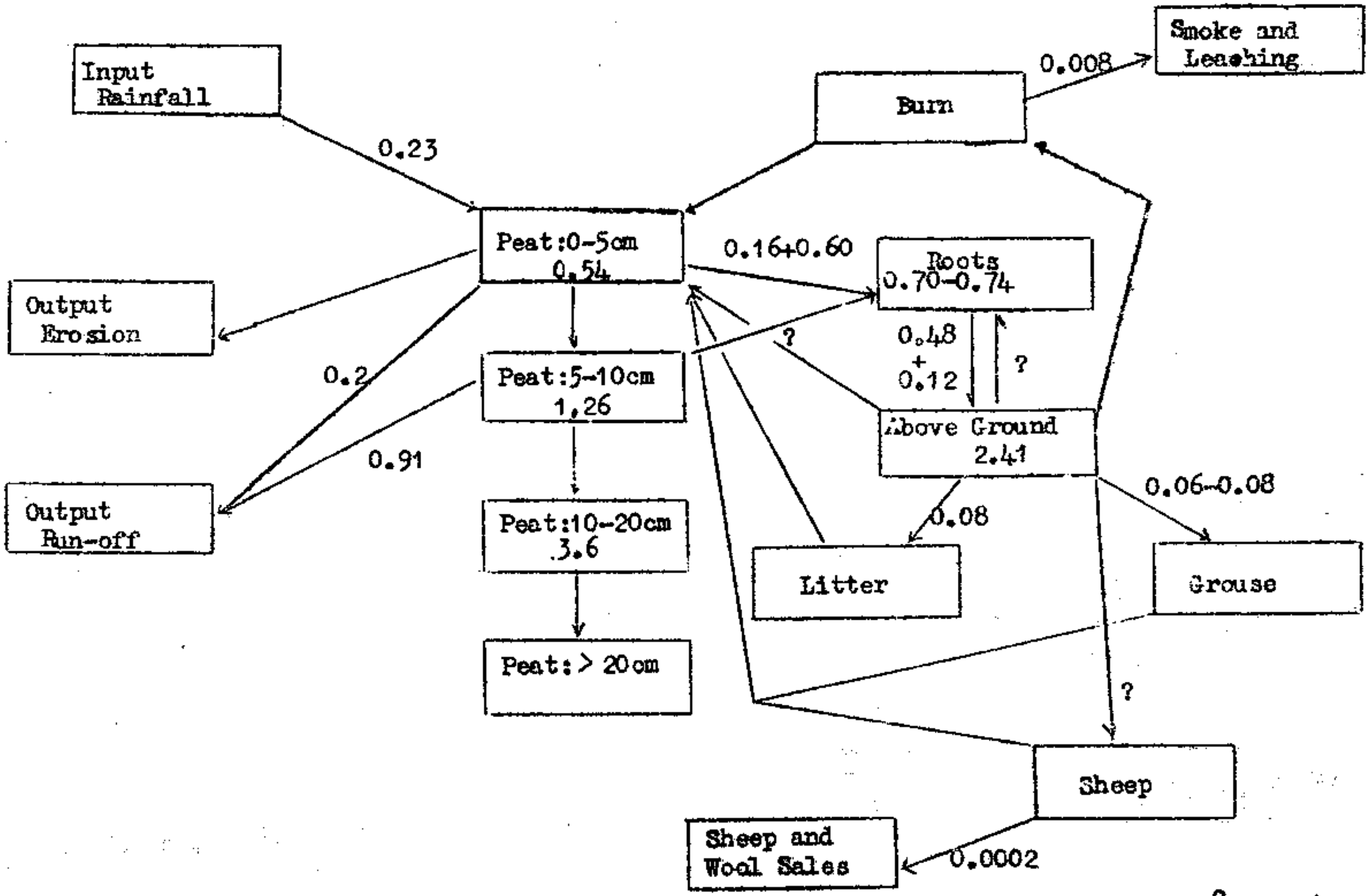

Figure 1. Potassium circulation in the Moor House blanket bog and *Calluna vulgaris* (g/m^2/annum)