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The leaching of nutrients from ash- and PK-fertilised peat

Ravinteiden huuhtoutuminen tuhka- ja PK-lannoitetusta turpeesta

Klaus Silfverberg

Klaus Silfverberg, The Finnish Forest Research Institute, P.O. Box 18, FIN-01301 Vantaa, Finland (e-mail: klaus.silfverberg@metla.fi)

The nutrient concentrations of the water percolating through fertilised peat cores were investigated in a greenhouse experiment. The nutrient concentrations in the peat cores were also determined before and after the experiment. The fertiliser treatments were 500 kg ha^{-1} of PK peatland fertiliser, 5 000 and 25 000 kg ha^{-1} of birch ash, and an unfertilised control. The cores were watered on three occasions after application of the fertilisers. The percolation water collected from the fertilised cores contained significantly more nutrients than the control. The total amounts of leached nutrients were equivalent to 0.01–20.1 % of the nutrients in the peat cores, K clearly being leached the most. The susceptibility of the nutrients to leaching followed the order K > Mg > Ca > Mn > P. The fertiliser treatments also increased the leaching of nitrate and ammonium. The amount of leached nutrients was relatively the highest from the PK treatment, but in absolute terms the highest from the largest dose of wood ash. According to the peat analyses, the concentrations of most of the nutrients had increased only in the surface layer of the peat (0–5 cm). In contrast, the K concentrations had increased throughout the whole profile (0–20 cm). The application of large amounts of ash fertiliser should be avoided in order to minimise nutrient leaching losses. Although the fertilisers used in this experiment have been or are being replaced by new types of fertiliser, the results of this study can be used to facilitate the interpretation of the results of field experiments in which these fertilisers have been used.

Keywords: nutrient loss, peat core, percolation water, phosphorus, potassium

INTRODUCTION

The leaching of nutrients from peat and fertilisers in ditched forest areas has been studied for a long time (Karsisto 1970, Ahti 1983, Haveraaen 1986, Finer 1991). The leaching of P has usually been only a fraction of that of K (Kaunisto & Paavilainen 1988, Nieminen & Ahti 1993). Although the leaching of P is quantitatively very small, it frequently results in the eutrophication of the watercourses. The most serious problem associated with the leaching of K is the reduced availability of K for the tree stand.

In recent years increasing attention has been paid to the use of ash fertilisers in peatland forestry (Ekologiska ... 1996, Finer et al. 1996). A joint research project "Exploitation of Bioash as an Ameliorative Agent in Forestry", co-ordinated by Metsäteho Oy, was started in 1997. The project also included an investigation into the environmental impacts of different types of ash (Anttila 1997). Stand growth in old wood-ash experiments has usually been the greater, the higher the amounts of ash applied (Ferm et al. 1992, Silfverberg 1996). However, the application of large amounts of nutrients may increase nutrient leaching. The questions of ensuring a sufficient supply of K and the leaching of P have become especially topical (e.g. Nilsson & Lundin 1996). The high pH of wood ash may both decrease (some macronutrients) and promote (N, P) nutrient availability in peat (Pätilä 1990, Nieminen & Ahti 1993). Furthermore, the nutrients present in ash are in a less soluble form than those in commercial fertilisers (e.g. Haveraaen 1986). The development of the tree stand on peatlands fertilised with ash is slower during the first few years than that on sites given commercial fertilisers (Silfverberg 1991). The nutrients in ash and its high pH increase nitrogen mineralisation (Karsisto 1979). The nitrification process, in which ammonium is converted into nitrate, is stimulated when the pH of the peat is high (Nohrstedt & Palmer 1988/89, Haveraaen 1994). Thus ash fertilisation may increase the leaching of nitrate. In this study the leaching of nutrients from peat is investigated by analysing the water percolating through peat cores treated with fertilisers. The distribution of the added nutrients within the peat profile is also studied.

MATERIAL AND METHODS

Properties of the peat and fertilisers

In early autumn 1985 twelve 25 × 25 × 25 cm peat samples were taken from the lawn level of fertiliser experiment No. 21 b (64°51´N, 26°04´E) at Leppiniemi, Muhos, for a leaching experiment carried out in the greenhouse. The site was originally a mesotrophic *Sphagnum papillosum* bog, which was drained in 1933 and treated with 8 000 kg ha^{-1} of birch ash in April 1947. At the time of fertilisation the *Sphagnum*-dominated surface peat was weakly humidified and its pH was 4.5 (Silfverberg & Hotanen 1989).

Owing to the ash fertilisation carried out in 1947 the amounts of nutrients in the peat taken for this study are rather high (Silfverberg & Hotanen 1989, Table 1).

The ash used in the greenhouse experiment was dry, sieved birch ash from the Muhos Research Station. Both the ash and the PK fertiliser designed for peatlands, from Kemira Oy, dated from 1985. The amounts of nutrients given in the fertilisation treatments are given in Table 1.

There were 4 randomly applied treatments: 1) control, 2) PK = peatland forestry PK fertiliser, 500 kg ha^{-1}, 3) T5 = wood ash, 5 000 kg ha^{-1}, and 4) T25 = wood ash, 25 000 kg ha^{-1}. There were

Table 1. Amounts of nutrients in the original peat and in the fertilisers (kg ha^{-1}).

Taulukko 1. Ravinteiden määrä turpeessa ja lannoitteissa (kg ha^{-1}).

Nutrient *Ravinne*	Peat — *Turve**	Wood ash — *Puun tuhka*		PK
	0–20 cm	5000 kg	25 000 kg	500 kg
N	8165	21	105	10
P	420	119	595	44
K	91	453	2265	83
Ca	1385	1110	5550	118
Mg	148	215	1075	1.5
Mn	89	72	360	–
B	0.7	2	12	1

* Silfverberg & Hotanen (1989)

three replications. Treatments 2 and 3 were the doses recommended for peatland forests in the middle of the 1980's. The peat samples were cut to fit into plastic containers with a diameter of 20 cm. The volume of each peat profile was 314 cm^2 (surface area) × 20 cm (depth) = 6.28 l. The fertilisers were spread on the surface of the peat in the containers on 30.9.1985. In order to ensure even application, the fertilisers were added separately to each quarter of the peat surface. The vegetation on the surface of the peat profiles was not removed. The temperature in the greenhouse during the experiment was 15–20°C.

Watering with deionised water and the collection of percolation water in glass containers below the peat cores was performed on four occasions: 24.9, 30.9, 7.10 and 14.10.1985. These watering dates are in the following marked 0, 1, 2 and 3. The purpose of the water addition was to imitate natural rainfall. Water was added on each occasion as three 20 mm episodes, totalling 60 mm. The percolation water was collected during the following 24-hour period. Each treatment therefore received water equivalent to a total of 240 mm of rainfall. The first watering was a calibration watering. There were thus three (1, 2 and 3) waterings after the fertilisers had been added.

Nutrient analyses were made on the percolation water collected after each water addition. The peat was analysed in 0–5, 5–10 and 10–20 cm layers prior to the start of the experiment, and then again at the end of the experiment. The peat analyses carried out before the start of the experiment were made on the peat trimmed off the cores when they were shaped to fit into the containers. Acidity (pH(H_2O), 1:2.5), total P, K, Ca, Mg and Mn were determined from the peat and water samples, but NO_3-N and NH_4-N only from the water samples. Total B was determined only on the peat samples. Total nutrients in the peat were determined by dry digestion (550°C) followed by extraction of the ash with HCl and analysis of the metals in the solution by atomic absorption spectrometry (AAS). Total P was analysed spectrophotometrically, and total B spectrophotometrically by the azomethine method (Halonen & Tulkki 1981). The metals in the percolation water were determined by AAS, and NH_4-N, NO_3-N and total P by spectrophotometry.

The in situ bulk densities of the peat, 143 g l^{-1} for 0–10 cm and 165 g l^{-1} for 10–20 cm (Silfverberg & Hotanen 1989), were used in calculating the total amounts of nutrients in the peat cores. The proportion of added nutrients was greatest in the case of potassium in treatment T25: the proportion of added K was 97 % of the total amount of K in the whole peat core (Table 2).

In addition to the nutrient concentrations in the percolation water, the amounts of leached nutrients (mg) were studied in relationship (%) to the total nutrient pools in the peat. The bottom layer of the peat (20–25 cm) was omitted from the calculations because the nutrient concentrations in this layer were the lowest both before and after the experiment. The retention of nutrients in this layer was obviously negligible.

Statistical analyses were carried out using one- and two-way analysis of variance with the BMDP programme. The independent variables were the fertiliser treatments and the watering times, and

Table 2. Total amount of nutrients in the peat cores (mg in 6.28 l^{-1}) prior to the start of the experiment.

Taulukko 2. Ravinteiden kokonaismäärä turveprofiileissa (mg 6,28 l^{-1}) ennen kokeen alkua.

Nutrient *Ravinne*	Control — *Vertailu*		PK		T5		T25	
	Original *Alunperin*	Added *Lisäys*	Original *Alunperin*	Added *Lisäys*	Original *Alunperin*	Added *Lisäys*	Original *Alunperin*	Added *Lisäys*
P	1763	–	1568	137	2186	372	1337	1860
K	267	–	241	261	318	1422	219	7112
Ca	4563	–	5707	371	4943	3483	6254	17419
Mg	443	–	474	5	486	673	452	3368
Mn	176	–	285	–	521	225	322	1123
B	2	–	3	3	4	7	5	37

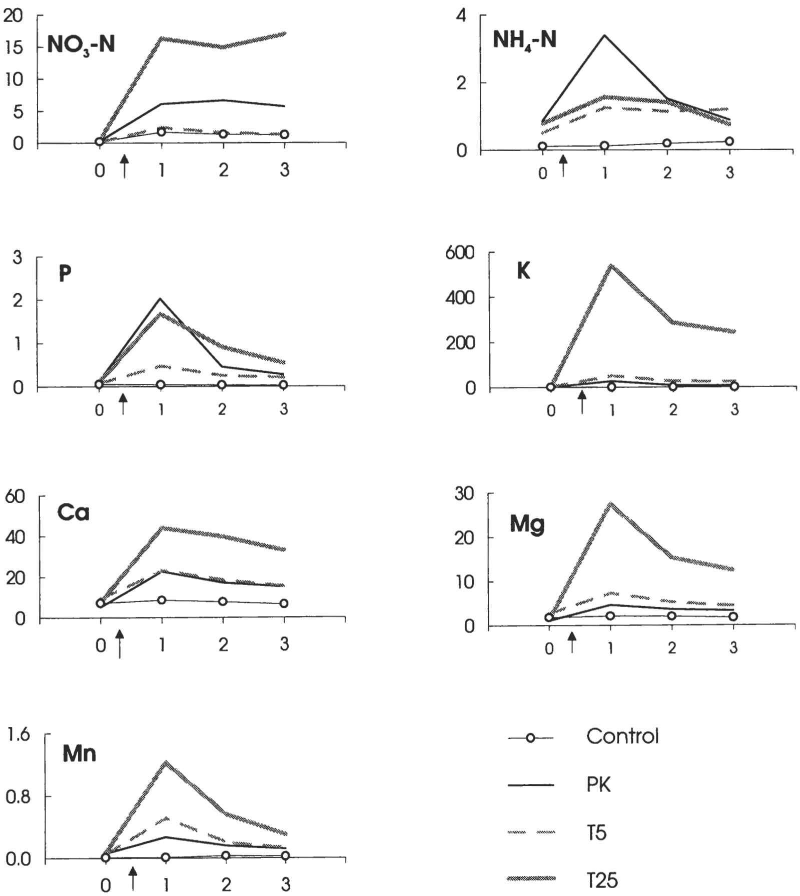

Figure 1. Nutrient concentrations in the percolation water (mg l^{-1}) collected after each watering date. Arrow indicates fertilisation.

Kuva 1. Perkolaatiovesien pitoisuudet (mg l^{-1}) kastelukertojen jälkeen. Lannoitus merkitty nuolella.

the dependent variables the nutrient concentrations (mg l^{-1}) and total leached nutrients (mg) in the percolation water. The differences between the nutrient concentrations at different depths in the peat cores before and after the experiment were tested using the t-test.

RESULTS

Nutrient concentrations in percolation water

Fertilisation with wood ash, 25 000 kg ha^{-1} and, to a lesser extent, PK 500 kg ha^{-1} strongly increased the nutrient concentrations in the percolation water. The highest NO_3-N values occurred in treatment T25. The NO_3-N concentrations in the PK treatment were also significantly higher than in the control (Fig. 1). The NH_4-N concentrations increased the most in the PK treatment, and were clearly lower in the two ash treatments (Fig. 1). The difference to the control was statistically significant in all the fertilised treatments.

The phosphorus concentrations were significantly higher in all fertilised treatments compared to control (Fig. 1). The highest phosphorus concentrations occurred in the T25 and PK treatments. The difference between the watering dates was statistically significant as leaching was at its greatest after the watering 1.

Potassium was the most soluble of the nutrients studied. The K concentrations in the T25 treatment were over 500 mg l^{-1} after the first watering, and clearly less after the second and third. The K concentrations in the T5 and PK treatments remained much lower throughout the experiment, and the control below 1 mg l^{-1} (Fig. 1). The differences between the fertiliser treatments and the watering dates, as well as their combined effect, were highly significant.

The calcium concentrations after the first water addition were almost 50 mg l^{-1} in treatment T25, and leaching continued at a relatively high level after the 2nd and even 3rd water addition (Fig. 1). The differences between the fertiliser treatments and the control were significant, as was the case between the watering episodes.

The magnesium concentration was highest (28 mg l^{-1}) in treatment T25. The concentrations in T5 (6 mg l^{-1}) were slightly higher than in the PK treatment (Fig. 1). The differences between the fertiliser treatments and the watering dates, as well as their combined effect, were statistically significant.

The manganese concentrations in the fertiliser treatments were 0.2–1.2 mg l^{-1} (Fig. 1).

The ash treatments reduced the acidity of the percolation water. The pH of the percolation water in treatment T25 was over 7 at all the watering dates. The PK fertiliser did not change the pH of the percolation water.

The losses of nutrients from the peat cores

With the exception of NH_4-N the losses (mg) were greatest in treatment T25 (Table 3). Phosphorus was, however, leached relatively the most (3.85 mg) in the PK treatment, i.e. 0.22% of the P in the peat core. Leaching in the case of the T25 treatment was 4.44 mg, or 0.14 % (Table 3), though the amount of phosphorus added was 13-fold compared to that added as PK. The total leaching losses of P from all the fertilisers were below 1%; PK and T25 differred significantly from the control (Table 3).

In treatment T 25 the amount of K leached was 1 477 mg, or 20.1 % of the total amount of K in the core (Table 3). Most of the potassium leached out of the profiles was thus the K added as ash (Table 2). The total losses of K in treatments PK and T5 were also relatively high; 9.1 and 12.2 % of the total potassium amount in the peat cores. The total leachate in the control was only 1.9 mg, i.e. 0.7 % (Table 3).

The total leaching losses of calcium, magnesium and manganese were between 0.03–3.8 % (Table 3).

Nutrient concentrations in the peat cores

Compared to the situation before fertilization most increments were found in the 0–5 and 5–10 cm layers of the ash treatments (Fig. 2). The phosphorus concentrations increased significantly only in the uppermost layer in treatment T25 (Fig. 2). The results for potassium were in agreement with the high concentrations of K found in the percolation water. The concentrations in every peat layer (0–5, 5–10, 10–20 cm) in treatments T5 and T25 were significantly higher than before fertilization. The difference in the PK treatment was significant only in the 0–5 cm layer.

Table 3. The amounts of nutrients leached out of the peat cores (mg and % of total amount in the peat cores), including the calibration watering. The underlined values differ significantly ($p < 0.05$) from the control.

Taulukko 3. Perkolaatiovesien mukana poistuneet ravinnemäärät (mg ja % turveprofiilin kokonaisravinnemäärästä) kalibrointikastelu mukaanlukien. Alleviivatut luvut poikkeavat merkitsevästi ($p < 0.05$) kontrollista.

Nutrient *Ravinne*	Control — *Vertailu*		PK		T5		T25	
	mg	%	mg	%	mg	%	mg	%
NO_3-N	5.98	n.d.	28.68	n.d.	8.21	n.d.	<u>69.27</u>	n.d.
NH_4-N	0.91	n.d.	<u>8.80</u>	n.d.	<u>5.75</u>	n.d.	<u>5.36</u>	n.d.
P	0.16	0.01	<u>3.85</u>	0.22	1.45	0.05	<u>4.44</u>	0.14
K	1.90	0.70	<u>61.70</u>	12.2	<u>158.50</u>	9.10	<u>1477.00</u>	20.10
Ca	38.30	0.80	<u>85.40</u>	1.40	91.00	1.10	<u>166.10</u>	0.70
Mg	9.80	2.20	<u>18.00</u>	3.80	<u>26.90</u>	2.30	<u>75.20</u>	2.00
Mn *	~ 0.05	0.03	0.80	0.27	1.28	0.17	2.75	0.19

* Not tested statistically because many of the observations were below the analytical detection limit. — *Ei tilastollista testausta määritysrajan alittavien havaintojen vuoksi.*

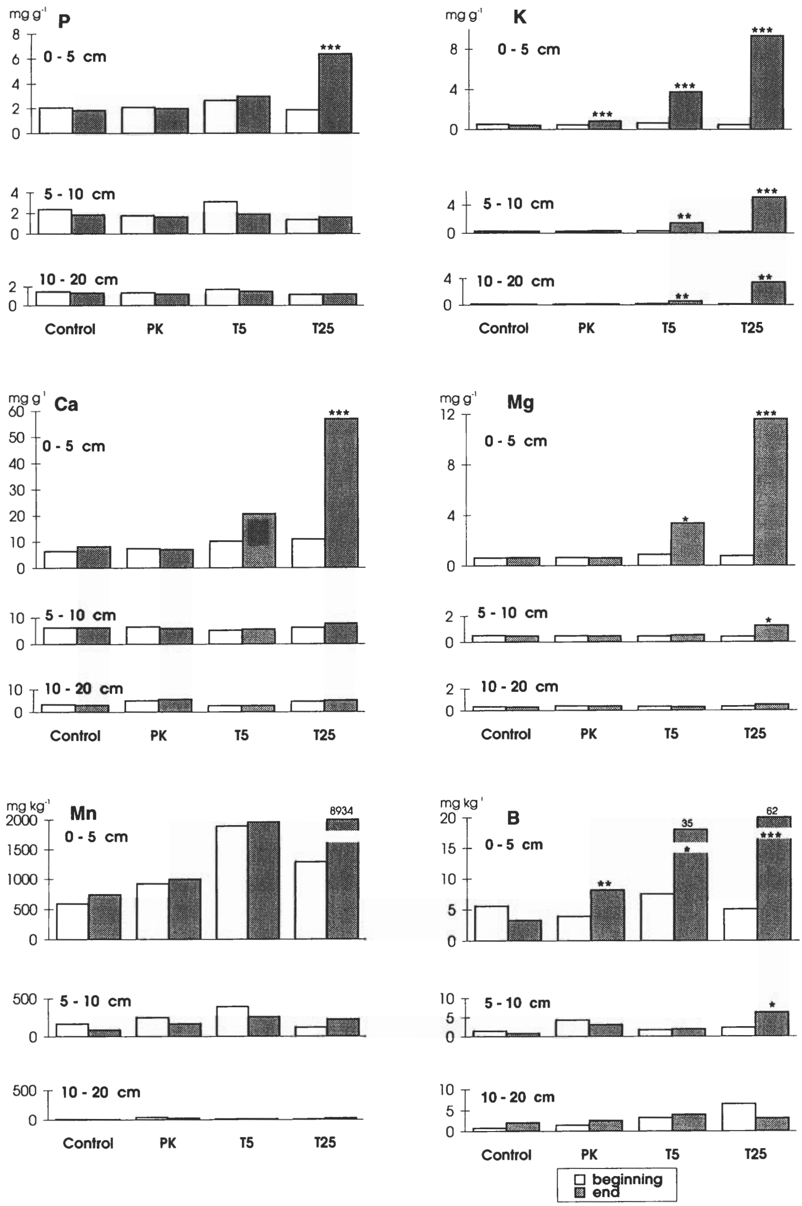

Figure 2. Total nutrient concentrations in the peat cores at the beginning and end of the experiment. The asterisks indicate the statistical significance of the difference (beginning, end), * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

*Kuva 2. Totaaliravinteiden pitoisuudet turveprofiilissa kokeen alussa ja lopussa. Tähdet ilmaisevat ajankohtien (ennen, jälkeen) välisen eron, * = p < 0.05, ** = p < 0.01, *** = p < 0.001.*

The concentrations of Ca, Mg and Mn increased clearly in the 0–5 cm peat layer, particularly in treatment T25 (Fig. 2). The boron concentrations (0–5 cm) increased significantly in all fertiliser treatments.

The pH-values (0–5 cm) of T25 and T5 were 7.6 and 6.3, respectively. In the 5–10 cm layer the corresponding values were 5.8 and 5.2.

DISCUSSION

The nutrient concentrations in the percolation water from the unfertilised peat cores were rather low, but clearly higher than those reported for unfertilised drained peatlands (Almberger & Salomonson 1979, Nieminen & Ahti 1993). After fertilisation, nutrient leaching increased strongly.

There was a clear peak in the leaching of P and Mn after the first water addition, while the leaching of Ca and Mg was clearly more continuous. The leaching of nitrate, the production of which is primarily due to mineralisation of the peat, was the most even. The relatively low ammonium concentrations in the ash treatment may be due to nitrification, which is at its strongest at relatively high pH values (e.g. Nohrstedt & Palmer 1988/89). The nutrient concentrations in the percolation water were, apart from in treatment T25, of the same order of magnitude as those reported for recently fertilised peatland (Ahti & Paarlahti 1988, Nieminen & Ahti 1993).

The total leaching losses ranged, depending on the nutrient and treatment, between 0.01 and 20.1% of the total amounts in the peat cores. Leaching susceptibility followed the order: K > Mg > Ca > Mn > P. This is in agreement with the results reported in earlier studies (Paavilainen & Kaunisto 1988, Pätilä 1990, Nieminen & Ahti 1993). The leaching percentages were clearly higher when the amounts leached are compared to the amounts of nutrients added only. In the case of the PK treatment, the leaching losses of P are thus 2.70 and not 0.22 %. The total leaching losses would probably have been still higher if more water had been added (Haveraaen 1986). As reported by Haveraaen (1986), considerably more P was leached from the commercial fertiliser than from the ash. The peatland forestry PK fertiliser at that time contained about 20% water-soluble P (Nieminen & Ahti 1993).

Despite the ash application in 1947, the amount of K in the peat cores was low before the start of the experiment (Silfverberg & Hotanen 1989). The leaching losses of K in the control treatment were low in absolute terms, but considerable when calculated as a proportion of the amount in the peat. The absolute loss of K is to a great extent dependent on the amount of K added. Concluded from the leaching figures for control and T25, 1,9 and 1477 mg, up to 99 % of the leached K could be derived from the ash. The leaching of K was also considerable in the 5 000 kg ha^{-1} ash treatment.

Apart from K over 90% of the added nutrients were retained in the peat. Most of the added nutrients had been retained in the 0–5 cm layer, as reported by Haveraaen (1986). Only the K, Mg and B concentrations had increased (treatment T25) significantly in the deeper layers. It is difficult to estimate the effect of the pH of the ash and peat on nutrient retention because the increase in pH was associated with nutrient additions. The pH of the 10–20 cm peat layer increased only moderately (4.6 -> 5.0) as a result of the ash treatment, even though percolation water of a much higher pH passed through this layer.

The total leaching losses of P were highest, 1.4 kg ha^{-1}, in the T25 treatment. This is a considerable amount of P from the point of view of its impact on the watercourses (Nieminen & Ahti 1993), but insignificant compared to the amounts applied and those in the P pool of the peat (cf. Nilsson & Lundin 1996). In the long term, however, the P load on the watercourses derived from slowly-soluble P fertilisers may become as large as that from rapidly-soluble P fertilisers (Nieminen 1997). The most important feature from the point of view of the nutrient status of the tree stand is the rapid and extensive leaching from the root layer of the K added in ash.

As a result of the scarce material and limited study period no general conclusions can be made for practical ash-fertilization. The field study results from the Metsäteho-project (Anttila 1997) will probably give much and detailed information on nutrient leaching from ash-fertilized peatlands.

In theory, ash fertilisation is well suited for correcting the K/P ratio in drainage areas. The ratio in peat is 1:5, and in ash almost the opposite, 4:1. However, the P and K requirements of the tree stand and the recommended fertiliser doses (P 44, K 83 kg ha^{-1}) are very small compared to the amounts applied in ash fertilisation. The ash dose of 5 000 kg ha^{-1} contained 453 kg K ha^{-1}. As the K/P ratio in the percolation water was 100, it is clear that applying such a large amount of K in the form of ash will improve the K/P ratio of the peat only little. Potassium should preferably be given in a slow-release form, such as phlogopite (Kaunisto et al. 1993). The phosphorus in PK fertilisers at the present time is based on apatite (Paavilainen & Päivänen 1995).

Although the fertilisers used in this experiment have been or are being replaced by new types of fertiliser, the results of this study can be used to facilitate the interpretation of the results of field experiments in which these fertilisers have been used (*see* Issakainen et al. 1996).

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TIIVISTELMÄ:

Ravinteiden huuhtoutuminen tuhka- ja PK-lannoitetusta turpeesta

Mielenkiinto turvemaiden tuhkalannoitusta kohtaan on kasvanut voimakkaasti viime vuosina. Samalla huoli fosforin huuhtoutumisesta vesistöihin on lisääntynyt. Kaliumin ongelmana on ollut nopea huuhtoutuminen puuston juuristokerroksesta. Kaliumin rittävyyttä on pyritty turvaamaan käyttämällä hidasliukoisia kalilannoitteita.

Tässä tutkimuksessa selvitettiin kasvihuonekokeena lannoitettujen ja kasteltujen turveprofiilien läpi valuneiden vesien ja itse turpeen ravinnesisältöä. Turveprofiilit otettiin syksyllä 1985 mesotrofisen kalvakkanevan välipinnasta Muhoksen Leppiniemestä. Käsittelyinä olivat Suometsien PK 500 kg ha^{-1}, koivuhalon tuhkaa 5000 ja 25 000 kg ha^{-1} sekä lannoittamaton kontrolli. Lannoituksen jälkeisiä kastelukertoja oli kolme.

Perkolaatiovedet sisälsivät lannoituskäsittelyillä merkitsevästi enemmän ravinteita kuin kontrolli. Kokonaishuuhtoutumat olivat 0,01–20,1% turveprofiilin ravinnesisällöstä ollen selvästi suurimmat kaliumin kohdalla. Ravinteiden huuhtoutumisalttius oli K > Mg > Ca > Mn > P. Ammoniumtypen huuhtoutuminen kasvoi merkitsevästi kaikilla lannoitetuilla käsittelyillä. Nitraattitypen huuhtouma kasvoi merkitsevästi suuremmalla tuhkakäsittelyllä. Ravinteita huuhtoutui suhteellisesti eniten Suometsien PK:sta ja absoluuttisesti eniten suuremmasta tuhkamäärästä. Suurempi tuhkakäsittely nosti perkolaatioveden pH:n yli seitsemään, sensijaan PK-käsittely ei muuttanut veden pH-lukua.

Turveanalyysien mukaan useimpien ravinteiden pitoisuudet olivat nousseet vain pintaturpeessa (0–5 cm). Ainoastaan kaliumin pitoisuudet olivat kohonneet merkitsevästi koko (0–20 cm) turveprofiilissa.

Nyt tutkitut lannoitteet ovat vaihtuneet rakeistettuun tuhkan ja apatiittipohjaisiin fosforilannoitteisiin. Tämän tutkimuksen tuloksia voidaan käyttää hyväksi niiden maastokokeiden tulkinnassa missä irtotuhkaa ja rakeistettua, raakafosfaattipohjaista lannoittetta on käytetty. Käytännön lannoitustoiminnassa suurten ravinnemäärien käyttöä tuhkalannoituksessa tulisi välttää huuhtoumatappioiden minimoimiseksi.

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