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Effect of refertilization of pine and birch stands on a drained fertile mire

Eero Paavilainen

TIIVISTELMÄ: JATKOLANNOITUKSEN VAIKUTUS VILJAVAN SUON MÄNNIKÖSSÄ JA KOIVIKOSSA

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Refertilization with PK, about 15 years after the first fertilizer application, increased tree growth and the amount of nutrients in tree litter in Scots pine (*Pinus sylvestris* L.) and birch (mainly *Betula pubescens* Ehrh.) stands on a drained fertile mire in Northern Finland (65°34'N, 25°42'E). The increase in growth and nutrient contents after refertilization was greatest in the mature pine stand where the application of nitrogen and micronutrients gave an additional response compared to the PK-application.

PK-jatkolannoitus n. 15 vuotta ensimmäisen lannoituksen jälkeen lisäsi puuston kasvua ja karikkeiden ravinnemääriä viljavan suon männikössä ja koivikossa Pohjois-Suomessa (65°34'N, 25°42'E). Lannoitusreaktio oli voimakkain varttuneessa männikössä, jossa typen ja hivenravinteiden käyttö tehosti PK:n vaikutusta.

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Corrrespondence: Eero Paavilainen, Finnish Forest Research Institute, P.O. Box 18, SF-01301 Vantaa, Finland.

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1. Introduction

Forest fertilization on nitrogen-rich mires is usually more complicated than on peatland sites of medium quality where the mineral nutrition is better balanced. The use of nitrogen together with phosphorus and potassium on fertile sites may cause growth disorders, although positive results in some experiments have also been reported (Veijalainen 1978; Paavilainen 1978, 1979b, 1984b; Moilanen 1982; Paavilainen and Penttilä 1983; Veijalainen et al. 1984). The cause of growth disturbances is often a lack of micronutrients, especially boron (e.g. Huikari 1977; Braekke 1977,1979; Kolari 1983).

More basic information particularly about refertilization on nitrogen-rich peatland sites is needed at present. A series of experiments in Scots pine (*Pinus sylvestris*) and birch (mainly *Betula pubescens*) stands on a fertile mire was established in order to study the growth response and the amount of nutrients returning to the soil after different refertilization treatments. In this report the main results from these experiments are presented and discussed (see also Paavilainen 1984a,1987).

The field work was supervised by Mr Jorma Issakainen, For. Eng., and Mr Kauko Kylmänen at the Muhos Research Station, and Mr Heikki Takamaa, For. Eng. Computing was managed by Ms Mirjami Niskanen, B.Sc. and Ms Inkeri Suopanki. Prof Eino Mälkönen and Dr Seppo Kaunisto kindly reviewed the manuscript. The English language was revised by Ms Leena Kaunisto, M. A. My best thanks to all of them.

2. Material and methods

The experimental area is located at Katosoja, Northern Finland (65°34'N, 25°42'E). The mire was ditched in 1934 and complemented in 1970. The area was fertilized for the first time in 1961–1962 using finely-ground rock phosphate (14.2 % P) at a dose of 600 $kgha^{-1}$ and potassium sulphate (33.2 % K) at a dose of 200 $kgha^{-1}$.

Four experiments were established in the area in May 1978, two of them in a Scots pine stand and two in a birch stand. The refertilization treatments were as follows:

Treatment	N	P	K	Ca	Mg	Mn	B	Cu
			$kgha^{-1}$					
1. 0	–	–	–	–	–	–	–	–
2. PK	10.0	43.5	83.0	88.5	0.5	–	1.0	–
3. NPK	110.0	43.5	83.0	88.5	0.5	–	1.0	–
4. NPK+ micronutrients	110.0	43.5	83.0	103.0	8.5	5.5	3.5	12.8

The size of the sample plots was 600–625 m^2. Phosphorus and potassium were given as PK-fertilizer which also contains, as the recent analyses have shown, 2 % N, among other nutrients. The nitrogen fertilizer was given as calcium ammonium nitrate (27.5 % N). In NPK+micronutrient treatment, the micronutrient mixture (1.1 % B, 12.8 % Cu, 5.5 % Mn, 9.8 % Fe, 5.5 % Zn, 1.4 % Mo and 0.7 % Na) + borax (14 % B) was given. Every treatment was replicated twice in each experiment.

Details of the stand volume and nutrient concentrations of the peat substrate and needles/leaves at the start of the experiments are presented in Table 1. The average peat depth in the 60-year-old birch stand was 0.6 m and in other stands > 1.0 m.

Table 1. Some stand characteristics and nutrient contents of peat and tree foliage. Mean values for different stands.

	Pine Age 35a	Pine Age 60a	Birch Age 45a	Birch Age 60a
Total volume, m^3ha^{-1}	30.6	100.0	35.1	70.5
– % of birch	18.1	18.9	82.0	99.4
Total number of stems, stems/ha	1650	1465	1685	1785
– % of birch	17.8	18.2	84.9	99.7
Peat (0–20cm) nutrient concentrations				
N, %	2.86	2.84	2.62	2.68
P_{tot}, mg/g	1.40	1.62	1.54	2.51
K_{tot}, mg/g	0.35	0.36	0.36	0.36
Ca_{tot}, mg/g	4.09	4.18	3.15	4.68
Foliar nutrient concentrations				
N, %	1.60	1.47	3.84	3.20
P, %	0.25	0.21	0.29	0.27
K, %	0.54	0.46	0.97	0.77

Peat samples (0–20 cm layer) were taken in November 1977 from each sample plot systematically from five points. Samples for foliar analysis were taken from 5 dominant trees/plot in the 35-year-old pine stand in November 1977, in the 60-year-old pine stand in April 1978, and in the birch stands at the end of June 1978.

The nitrogen, phosphorus, and calcium concentrations in peat were higher than those reported by Kaunisto & Paavilainen (1988) for herb-rich pine mires. Foliar nutrient concentrations were also high (cf. Paarlahti et al. 1971; Paavilainen 1979a).

Litterfall was collected monthly during the period May-October each year after refertilization using eight collectors (0.25 m^2) in each plot. The dry weight and nutrient concentration of the litter were determined. The results for the dry-weight and nitrogen, phosphorus and potassium concentrations of the litter refer to the period 1978–1987. The results for other nutrient concentrations (Ca, Mg, Mn, B, Cu) refer to the period 1980–1987. Since 1980, the samples taken in May also included litter that had fallen during winter. Nutrient analyses were made at Muhos Research Station using the standard methods used by the Finnish Forest Research Institute (Halonen et al. 1983).

The stand characteristics were computed using the KPL computing program of the Finnish Forest Research Institute.

Analyses of variance and covariance, correlation and regression analyses were used in handling the data.

3. Results

31. Tree growth

Refertilization with phosphorus and potassium increased the growth of trees in all the stands studied (Fig. 1). The difference in the mean annual growth during 1978–87 between PK-treatment and control was 0.45–1.29 m^3ha^{-1} in the pine stands and 0.96–1.29 m^3ha^{-1} in the birch stands. The application of nitrogen or N+micronutrients together with phosphorus and potassium gave still better growth response than the PK-treatment in the 60-year-old pine stand whereas in the birch stands the NPK— and NPK+micronutrient application had the same or even a weaker effect than PK. The differences between the treatments were, due to a small number of sample plots, statistically significant only in the young birch stand.

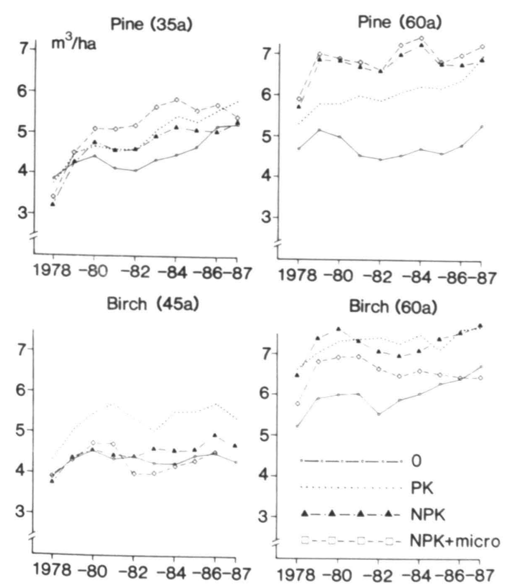


Fig. 1. Effect of refertilization on the volume growth of pine (35a, 60a) and birch stands (45a, 60a). For refertilization treatments, see p. 84.

32. Amount of tree litter

The application of NPK or NPK + micronutrients somewhat increased the amount of tree litterfall in the 60-year-old pine stand (Fig. 2).

In the birch stand of the same age also PK-fertilization increased the amount of litter. The yearly variation of litter amount was greatest in the 60-year-old birch stand.

33. Nutrient concentrations of tree litter

The annual nutrient concentration of the litterfall was calculated by weighting the concentrations at different sampling dates with corresponding litter amounts.

The average nutrient concentrations of

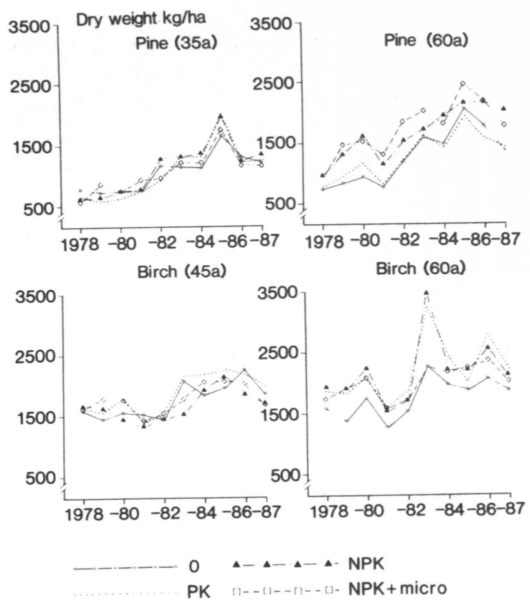


Fig. 2. Effect of refertilization on the amount of the litterfall of pine (35a, 60a) and birch stands (45a, 60a). For refertilization treatments, see p. 84.

litter in the pine stands were considerably lower than in the birch stands (Figs. 3 and 4). Fertilization clearly increased the concentrations of most nutrients. Only magnesium and manganese concentrations decreased after refertilization in the birch stands.

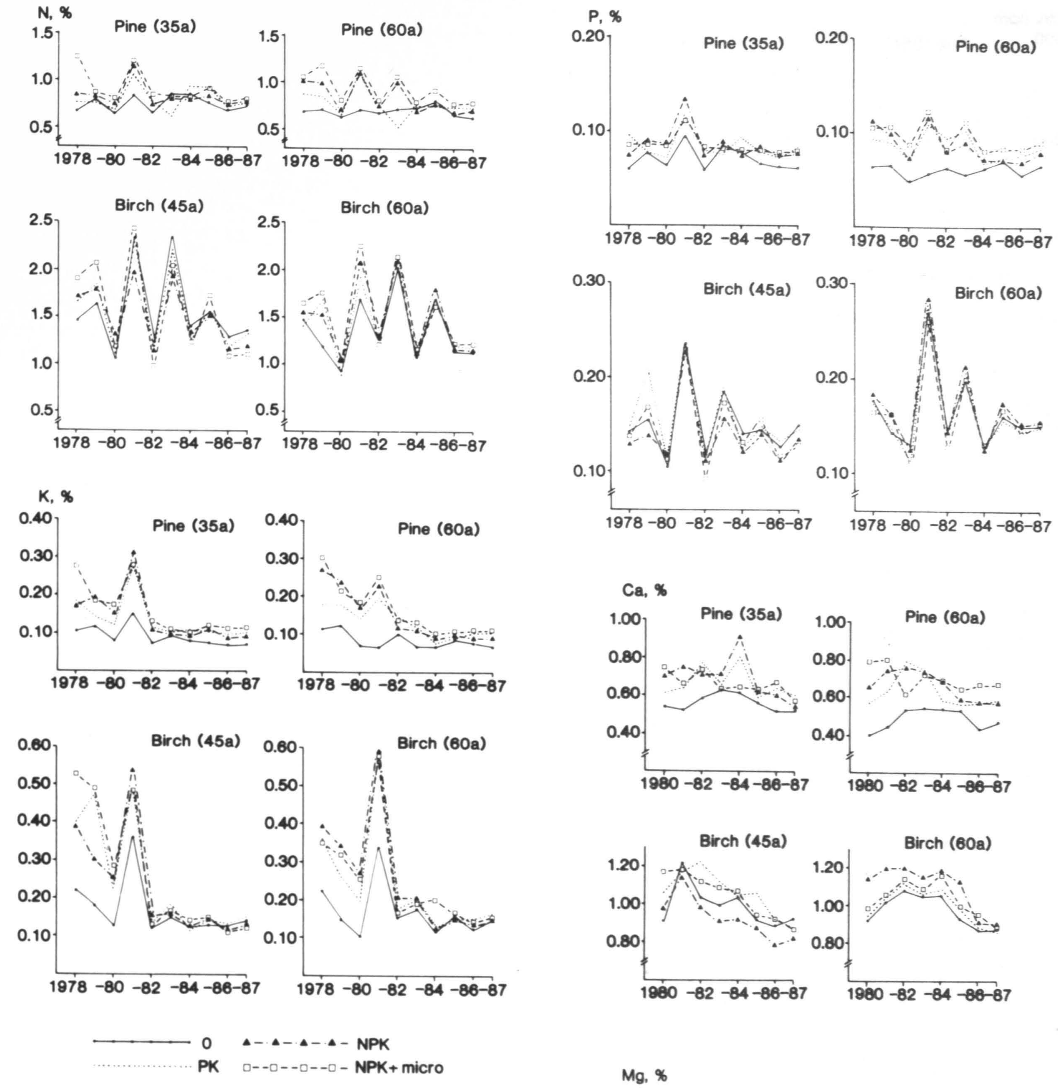
The effect of fertilization on litter nutrient concentrations was of shorter duration in the birch than in the pine stands. The concentrations of macro- and micronutrients in the pine stands were still higher on the fertilized than on the control plots ten years after refertilization, whereas in the birch stands nitrogen, phosphorus and potassium concentrations had already reached the level of the unfertilized plots. The effect of fertilization on the biological cycling of nutrients in litter appears to be very effective and long lasting, particularly in the 60-year-old pine stand, where the growth response to fertilization was strongest.

Table 2. Average nutrient amounts returning annually to the soil in tree litter in 1980–1987.

Nutrient	Pine 35a 0	Pine 35a PK	Pine 35a NPK	Pine 35a NPK+micro-nutrients	Pine 60a 0	Pine 60a PK	Pine 60a NPK	Pine 60a NPK+micro nutrients
N, kg ha^{-1}	8.58	9.69	10.22	9.97	9.87[a]	10.21[a]	14,01[b]	16.09[b]
P "	0.81[a]	0.99[ab]	1.05[b]	0.97[ab]	0.86[a]	1.16[ab]	1.41[b]	1.66[c]
K "	0.93[a]	1.40[b]	1.53[b]	1.52[b]	1.08[a]	1.63[b]	2.07[b]	2.45[c]
Ca "	6.32[a]	7.74[ab]	8.27[b]	7.51[ab]	6.93[a]	8.70[a]	11.61[b]	12.69[b]
Mg "	1.33	1.42	1.48	1.41	1.44[a]	1.77[ab]	2.06[b]	2.37[c]
Mn "	0.86	1.02	1.10	1.03	0.91[a]	1.02[a]	1.63[b]	1.82[b]
B, g ha^{-1}	9.5[a]	21.5[b]	19.9[b]	36.8[c]	13.6[a]	27.2[b]	33.1[b]	50.4[c]
Cu "	3.8[a]	4.4[ab]	4.2[ab]	4.9[b]	4.5[a]	5.2[a]	6.9[b]	10.2[c]

	Birch (45a) 0	Birch (45a) PK	Birch (45a) NPK	Birch (45a) NPK+micro-	Birch (60a) 0	Birch (60a) PK	Birch (60a) NPK	Birch (60a) NPK+micro
N, kg ha^{-1}	28.46	28.86	23.79	26.01	25.34	33.14	33.96	30.64
P "	2.70[ab]	2.85[a]	2.31[b]	2.53[ab]	2.99	3.71	3.81	3.30
K "	2.84	3.55	3.13	3.40	2.88[a]	4.60[b]	4.79[b]	4.34
Ca "	17.75[ab]	20.21[a]	15.19[b]	18.48[a]	17.77[a]	22.57[b]	24.72[b]	21.18[b]
Mg "	4.64[a]	4.43[a]	3.32[b]	3.81[b]	4.82	5.80	5.74	5.21
Mn "	2.23	1.94	1.72	1.82	2.96	3.32	3.24	2.98
B, g ha^{-1}	23.7[a]	33.0[b]	24.8[a]	60.0[c]	31.2[a]	56.2[b]	54.9[b]	73.0[b]
Cu "	9.6[a]	11.3[ac]	7.7[b]	12.2[c]	11.9[a]	14.7[b]	14.8[b]	15.6[b]

The values indicated with the same letter do not differ from each other significantly



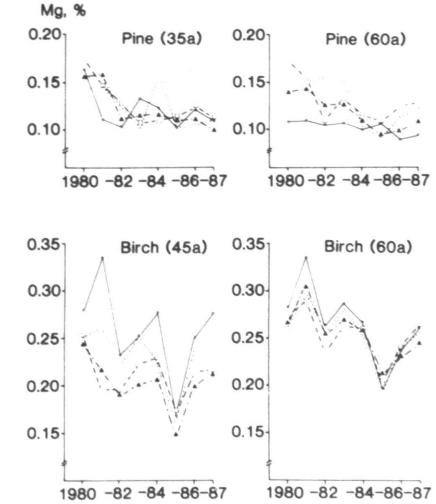
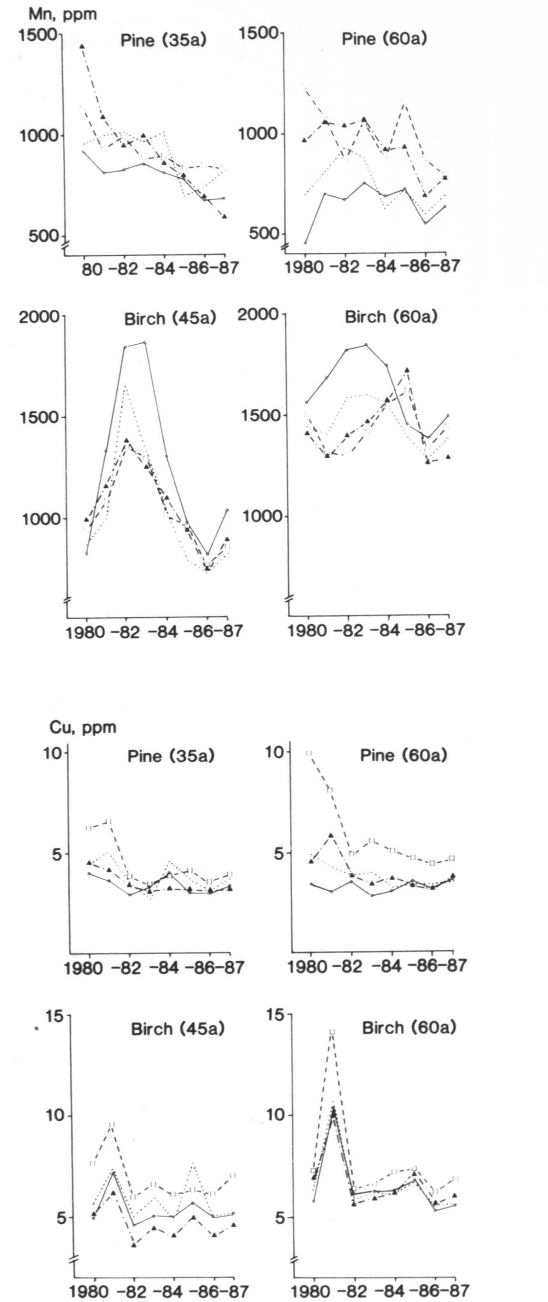


Fig. 3. Effect of refertilization on the concentrations of various macronutrients in the litterfall of pine (35a, 60a) and birch stands (45a, 60a). For refertilization treatments, see p. 84.

34. Nutrient amounts of tree litter

The amount of nutrients in the litter was considerably smaller in the pine than in the birch stands (Table 2). On the unfertilized plots the nutrient amount returned to the soil in birch litter was 2.5–3.5 -fold that returned in pine litter.



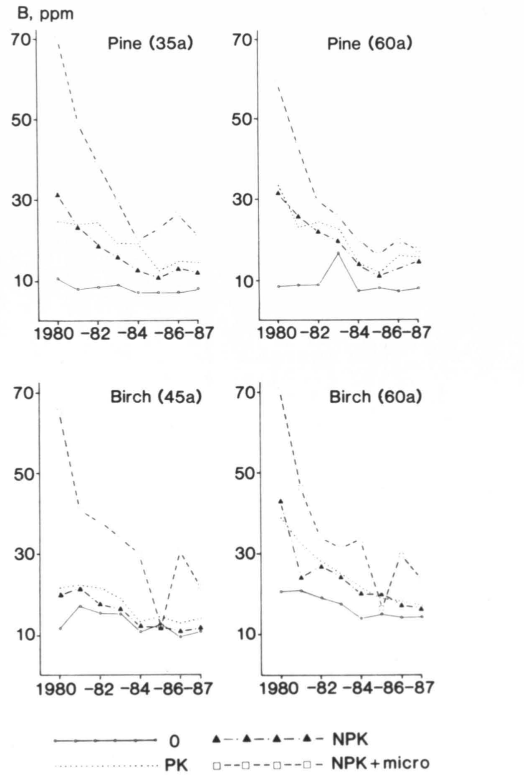


Fig. 4. Effect of refertilization on the concentrations of various micronutrients in the litterfall of pine (35a, 60a) and birch (45a, 60a) stands. For refertilization treatments, see p. 84.

In the 35-year-old pine stand PK-fertilization increased the amount of potassium and boron, and NPK-fertilization also the amount of phosphorus and calcium in litter fall. There was more potassium, boron, and copper on the sample plots receiving the NPK+micronutrient application than on the control plots. In the 60-year-old pine stand fertilization, especially with NPK and NPK + micronutrients, increased the amount of all the studied nutrients.

In the 45-year-old birch stand the amount of phosphorus, calcium, magnesium and copper was smaller on the NPK fertilized plots than on the plots fertilized with PK. The application of micronutrients had increased the amount of boron and copper in the litter. In the 60-year-old birch stand, refertilization increased the amounts of boron, potassium and calcium. In this stand there was no difference in the effect of different fertilization treatments. In the birch stands the application of nitrogen did not increase the amount of this nutrient in litterfall.

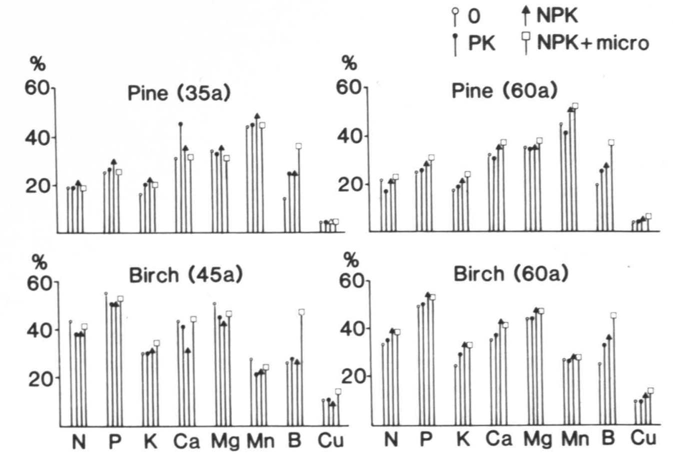


Fig. 5. Amount of various nutrients in the litterfall of refertilized pine (35a, 60a) and birch stands (45a, 60a) as % of the amount taken up by trees. For refertilization treatments, see p. 84.

35. Litter nutrients and tree growth

The amount of nutrients taken up by the trees was calculated in this study as the sum of the nutrient amounts in the tree litter measured and the amounts bound to the annual biomass production of pine and birch on a nutrient-rich mire according to Finér (1988).

In the pine stands 15–30 % of nitrogen, phosphorus and potassium returned in litter to the soil (Fig. 5). For calcium, magnesium and especially for manganese the value was higher, from 30 to 50 %, but only about 5 % of copper returned to the soil in litter. The need of boron in fertilization was clearly reflected by the amount of this nutrient returned in litter.

The percentage of nutrients in tree litter compared to the amount taken up by the trees was higher in birch than in pine stands, the only exception being manganese.

To compare the importance for tree growth of different nutrients returned to the soil as litter , the biomass production values of Finér (1988) were used for calculating the potential annual growth of the stands assuming that trees could utilize all nutrients returning to the soil in litter.

There seemed to be enough phosphorus, calcium and magnesium in the litterfall of pine stands for a growth of 1.5–2.0 $m^3ha^{-1}\ a^{-1}$ and manganese for 3–4 $m^3ha^{-1}\ a^{-1}$. The nitrogen, potassium, boron and copper amounts in litter would be adequate for a production of 0.5–1.0 $m^3ha^{-1}\ a^{-1}$. In birch stands there would be enough phosphorus for a production level of ca. 4 $m^3ha^{-1}\ a^{-1}$, calcium, magnesium and manganese for 2.5–3.5 $m^3ha^{-1}\ a^{-1}$, nitrogen, potassium and boron for 1.4–2.1 $m^3ha^{-1}\ a^{-1}$ and copper for a growth less than 1 $m^3ha^{-1}\ a^{-1}$.

There were distinct correlations between the annual growth of the pine stands during 1980–87 and the amount of nutrients in tree litter calculated as the sum of the amounts in the same and in the preceding year. In the 35-year-old pine stand the highest correlation with the tree growth was for micronutrients Cu and B (r = 0.592*, 0.574*) and significant also for Ca, P, N and Mn. In the 60-year-old pine stand the correlation was significant with all the nutrients, the highest coefficients being for P, Ca and Mg (r= 0.820**, 0.785**, 0.780**). In the birch stands the correlations between tree growth and the amount of nutrients in litter were not significant.

4. Discussion

The growth response of birch to fertilization is usually poor compared to that of conifers (Viro 1974; Jonsson and Möller 1975; Oikarinen and Pyykkönen 1981; Moilanen 1985; Paarlahti and Paavilainen 1985). Only on mined peatlands has a positive fertilization effect on birch been so far noticed (Kaunisto 1987; Lumme 1988).

According to this study, birch responded positively to refertilization with phosphorus and potassium 15 years after the first PK-application. A new observation was also that the need of nitrogen and micronutrients in Scots pine seemed to increase with the increasing stand age. Further studies are still needed to find out whether the fertilization of birch or the use of nitrogen in fertilization of mature pine stands on nitrogen-rich peatlands can be recommended for practical forestry.

The PK-fertilizer commonly used in peatland forests already contains boron . Other micronutrients are also included in the existing experiments (Veijalainen 1977, 1980,1981,1988). For fertile peatlands a special CuBK-fertilizer has been developed, but experimental results of its effect are not yet available.

Birch litter was more nutrient-rich than pine litter as reported also in many earlier studies (e.g. Viro 1955; Mälkönen 1974, 1977; Johansson 1982; Berg and Wessen 1984; Paavilainen 1984a, 1987; Berg and Staaf 1986; Finér 1988). As the initial release of plant nutrients during the first few years is more rapid from birch than from pine litter (Berg and Staaf 1981, 1986; Bogatyrev et al. 1983) the amount of nutrients deriving from tree litter and available to the trees is noticeably greater in birch stands than in pine stands. This is one of the biological reasons for the well-known favourable influence of birch litter on soil conditions (Hesselman 1926,1937; Mikola 1955; Nykvist 1963; Lundmark 1982) and supports the recommendation to leave a certain mixture of birch in pine stands. The larger amount of nutrients in litter in addition to the retranslocation of nutrients, may, on the other hand, be one of the reasons for the often observed weak response of birch to fertilization.

The strong and long-lasting effect of fertilization on the nutrient concentrations and amounts in tree litter is undoubtedly a positive factor for the production of pine stands on fertile mires. Tree litter is, especially in mature stands, for a long period after fertilization an important source not only of macronutrients but also for example of boron, which is often the growth limiting micronutrient on fertile mires. The decrease of manganese content in birch litter after fertilization, noticed also by Finér (1988), is an interesting result, which deserves further study.

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