Dry Mass and the Amounts of Nutrients in Understorey Vegetation before and after Fertilization on a Drained Pine Bog

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Dry mass and nutrient (N, P, K, Ca, Mg, B) contents of field layer vegetation and a combination of bottom layer vegetation and litter (referred to as bottom/litter layer in the text) were studied one year before and three years after fertilization (NPK and PK) on a drained low-shrub pine bog in eastern Finland. The results of an earlier study on the tree layer were combined with those of this study in order to estimate the changes caused by fertilization in the total plant biomass and litter. Before fertilization the average dry mass of the field and bottom/litter layers was 8400 kg ha^{-1} and 7650 kg ha^{-1}, respectively. The above-ground parts accounted for 25 % of the total field layer biomass. The dry mass of the field and bottom/litter layers together was < 20 % of the dry mass accumulated in the total plant biomass and litter. The corresponding figures for N, P, K, Ca, Mg and B were 44 %, 38 %, 30 %, 38 %, 31 % and 17 %, respectively. Fertilization did not significantly affect the dry mass of either the field layer vegetation or the bottom/litter layer. 33 % of the applied P was accumulated in the total plant biomass and litter on the PK-fertilized plots, and 25 % on the NPK-fertilized plots. For the other elements, the proportions on the PK-fertilized plots were K 31 %, Ca 6 %, Mg 11 % and B 13 %. On the NPK-fertilized plots, the corresponding figures were N 62 %, K 32 %, Ca 6 %, Mg 9 % and B 13 %. Except for B and K, the accumulation of fertilizer nutrients in the understorey vegetation and litter was of the same magnitude or greater than the uptake by the tree layer.

Keywords biomass, litter, peatland, root systems, Scots pine

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1 Introduction

The understorey vegetation and litter layer account for a considerable proportion of the total nutrient storage in forested ombrotrophic peatlands (Haveraaen 1967, Paavilainen 1980, Brække 1988). Consequently, the processes which bind and/or release nutrients in these layers contribute significantly to the overall nutrient cycling in such ecosystems (Paavilainen 1980, Brække 1988). However, the proportion of nutrients bound by the understorey vegetation and litter layer varies according to the structure and density of the tree layer. When the tree layer reach a certain density, the shrub, field and moss layers are shaded out and the litter layer builds up (Reinikainen et al. 1984, Brække1988). Thus, nutrient cycling becomes gradually more and more dominated by the tree layer growing on the site.

Scots pine stands usually respond to fertilization on drained ombrotrophic bogs (e. g. Meshechok 1968, Brække 1979, 1983, Paavilainen 1979). The composition of the understorey vegetation is also affected, i.e. some species suffer while others are better able to compete and expand due to the change in nutrient availability (Heikurainen and Laine 1976, Finér and Brække 1991). Increased total biomasses and nutrient concentrations of the above-ground parts of field layer species have been reported (Haveraaen 1967, Päivänen 1970, Vasander 1982), while the biomass of the moss layer decreases during the first years after fertilization (Vasander 1982, Jäppinen and Hotanen 1990, Vasander et al. 1993).

Several studies have been carried out on the dry mass and the amounts of nutrients in different vegetation layers on drained and fertilized peatlands (e.g. Haaveraen 1967, Paavilainen 1980, Brække 1988, Finér 1991a). However, only one study was found about the accumulation of fertilizer nutrients in the total plant biomass (including tree, field and bottom layers and root systems) (Vasander 1981). These results are important for achieving efficient and economical use of fertilizers, and for assessing the risk of nutrients leaching into water bodies. Information about the rates of accumulation can also be used for modelling purposes.

The aim of the study was to estimate the effects of PK and NPK fertilization on the dry mass and nutrient accumulation in 1) field layer vegetation, 2) bottom/litter layer, and 3) total plant biomass and litter on a drained ombrotrophic pine bog in eastern Finland. In order to determine the effects of fertilization on the total plant biomass and litter, the results of an earlier study (Finér 1991a) from the same site were used as an estimate of the fertilizer-induced changes in tree layer.

2 Material and Methods

2.1 Site Description and Experimental Design

The study site was located in eastern Finland (62°14'N; 29°50'E, 81 m a.s.l.). The peat layer was > 1 m thick and consisted of *Sphagnum* peat with remnants of wood and *Carex* species below the 20 cm surface peat layer. The chemical properties of the peat have been presented by Brække and Finér (1991). A naturally regenerated Scots pine (*Pinus sylvestris* L.) stand, with an average volume of 81 $m^3 ha^{-1}$ in 1984, was growing on the site. According to the peatland site type classification used in Finland (Heikurainen and Pakarinen 1982), the site was a low-shrub pine bog. A detailed description of the vegetation is presented by Finér and Brække (1991). The site was drained in 1967 with a 50 m ditch spacing. The climatic data and fluctuation in the water table during 1984–1987 were reported by Finér (1991b).

A 3 × 3 Latin square design with a 1500 m^2 plot size was used. The treatments were: unfertilized (0), fertilized with PK(MgB), and with NPK(MgB). The amounts of the elements (kg ha^{-1}) applied were: N 150, Ca 135, P 53, K 100, Cl 95, Mg 25, S 28 and B 2.4. The fertilizers were applied in spring 1985 as ammonium nitrate, Moroccan phosphate rock, potassium chloride, magnesium sulphate, and sodium borate.

2.2 Field Work

Sampling was carried out twice: prior to fertilization during 12.–27.9.1984 and after fertilization during 18.8.–3.9.1987. The above-ground parts of the understorey vegetation were harvested from 20 systematically located quadrates (0.25 m^2) on each plot. The understorey vegetation was divided into bush, field and bottom/litter layers. Zero level for sampling of all layers was taken as the lower level of the living moss layer. The bush layer consisted of trees (*Pinus sylvestris* L., *Picea abies* (L.) Karsten, *Betula pubescens* Ehrh.) with height > 0.5 m and breast height diameter < 2.5 cm. However, the bush layer was very sparse and even missing from several of the plots. It was therefore excluded from the study. The sampled field layer consisted of the above-ground parts of dwarf shrubs, sedge-like species, juvenile trees (height < 0.5 m) and herbs. The coverage of the field layer was 42 % prior to fertilization in 1984 (Finér and Brække 1991). The bog dwarf shrubs (*Betula nana* L., *Ledum palustre* L., *Calluna vulgaris* L. Hull, *Chamaedaphne calyculata* L. Moench, *Vaccinium uliginosum* L.) and the forest dwarf shrubs (*Vaccinium myrtillus* L., *Vaccinium vitis-idaea* L.) both had a coverage of 19 %. *Eriophorum vaginatum* L. and *Carex globularis* L., the only sedge-like species, had a total coverage of 3 % in the field layer. The total coverage of the field layer was not affected by fertilization (Finér and Brække 1991). *Dryopteris* spp. and *Epilobium* spp. became established after fertilization, but occurred only sporadically.

The bottom layer consisted of bryophytes and lichens. Their total coverage before fertilization was 90 %, of which the coverage of *Sphagnum* species (*Sphagnum angustifolium* (Russow) C. Jens, *Sphagnum russowii* Warnst., *Sphagnum nemoreum* Scop.) was 31 % and that of *Pleurozium schreberi* (Brid.) Mitt. 52 % (Finér and Brække 1991). Fertilization did not affect the total coverage of the bottom layer. The *Sphagnum* species suffered from fertilization and were partly replaced by *Pleurozium schreberi*. A detailed description of the vegetation composition in the field and bottom layers before and after fertilization is presented by Finér and Brække (1991).

In the early stages of the field work it was evident that the accurate separation of the living bottom layer vegetation from the litter accumulated on and between living bryophytes was technically very difficult. Thus, a composite sample including both the living bottom layer vegetation and all the litter (tree litter, field layer vegetation litter and bottom layer vegetation litter) that had accumulated in it was collected.

After collecting the above-ground parts of the understorey vegetation and the litter, a square peat core (24.7 cm^2) was taken down to a depth of 40 cm in the middle of each vegetation harvesting quadrate. The living roots, rhizomes and buried stems (diameter ≤10 mm) of the field layer vegetation were extracted by hand from each subsample. The changes in the biomass of the field layer roots after fertilization have already been presented by Finér (1991b).

The changes in the dry mass and nutrient contents of the tree layer were presented by Finér (1991a). These results were combined with our data to calculate the changes in the total plant biomass and litter.

2.3 Laboratory Analyses and Calculations

All the samples were dried to constant mass at 60 °C. Subsamples were taken for dry mass determination at 105 °C. The samples were homogenized in a stainless steel mill (sieve mesh diameter 2 mm). Total N was determined by the Kjeldahl method, K, Ca and Mg by atomic absorption spectrophotometry after HCl digestion, P spectrophotometrically by the molybdate-hydrazine method, and B by the azomethine method (Halonen et al. 1983).

The change from 1984 to 1987 (i.e. the difference between three years after fertilization and prior to fertilization) was chosen as the parameter for determining the effect of fertilization on dry mass and nutrient accumulation in different vegetation compartments. Analysis of variance and Tukey's test were used to test whether the changes in dry mass and the amounts of nutrients from 1984 to 1987 differed between the treatments (0, PK, NPK). The statistical tests were done using the BMDP (1990) software package.

3 Results

3.1 Understorey Vegetation and Litter

Before fertilization the average above-ground dry mass of the field layer was 2100 kg ha^{-1}, and that of the bottom/litter layer 7650 kg ha^{-1} (Tables 1 and 2). Neither the dry mass of the above-ground field layer nor the bottom/litter layer was affected by fertilization (Fig. 1).

Before fertilization the average amount of N in the above-ground field layer, field layer roots and bottom/litter layer was 16.8 kg ha^{-1}, 42.8 kg ha^{-1} and 78.2 kg ha^{-}, respectively (Tables 1, 2 and 3). Fertilization did not significantly affect the N contents of different layers (Fig. 2). Most of the understorey vegetation P was found in the bottom/litter layer, i.e. 6.4 kg ha^{-1}. The corresponding figure for the above-ground field layer was 1.6 kg ha^{-1}, and that for the field layer roots 2.6 kg ha^{-1}. Fertilization increased the amounts of P only in the bottom/litter layer on the PK-fertilized plots. The average amount of K prior to fertilization in the above-ground field layer, field layer root systems and bottom/litter layer was 5.0 kg ha^{-1}, 4.1 kg ha^{-1} and 16.0 kg ha^{-1}, respectively. Fertilization did not increase the amounts of K in different layers.

The average amount of Ca in the above-ground field layer was 9.8 kg ha^{-1} before fertilization. The corresponding figure for the field layer root systems was 9.2 kg ha^{-1}, and for the bottom/litter layer, 35.7 kg ha^{-1}. Fertilization increased the amounts of Ca only in the bottom/litter layer on the PK-

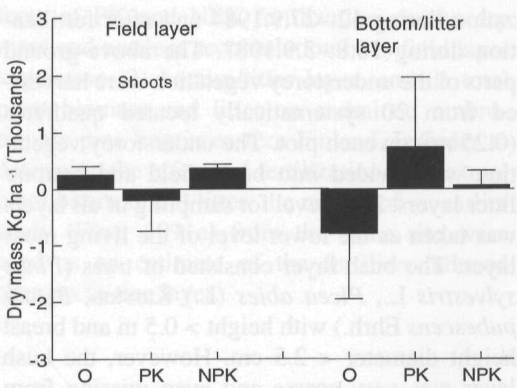

Fig. 1. Changes from 1984 to 1987 in the amount of dry mass stored in the above-ground field layer vegetation and the bottom/litter layer. The changes do not differ statistically significantly between treatments. Standard deviations are indicated by lines in the bars.

fertilized plots. The average amount of Mg in the above-ground field layer, field layer root systems and bottom/litter layer was 2.2 kg ha^{-1}, 2.2 kg ha^{-1} and 5.7 kg ha^{-1}, respectively. There were no significant changes in the amounts of Mg after fertilization. The average amount of B in the above-ground field layer prior to fertilization was 0.021 kg ha^{-}. The corresponding figure for the field layer root systems was 0.032 kg ha^{-1}, and for the bottom/litter layer 0.042 kg ha^{-1}. The bottom/litter layer B contents increased significantly after fertilization both on the PK- and NPK-fertilized plots.

Table 1. Dry mass and the amounts of nutrients stored in the above-ground field layer vegetation in the control (= 0) plots and the PK and NPK fertilized plots prior to fertilization in 1984. Standard deviations in parentheses.

	0	PK	NPK
Dry mass, kg ha^{-1}	2291 (149)	2140 (222)	1874 (41)
N, kg ha^{-1}	18.2 (0.8)	16.8 (1.4)	15.3 (0.9)
P, kg ha^{-1}	1.7 (0.1)	1.5 (0.3)	1.5 (0.0)
K, kg ha^{-1}	5.1 (0.3)	5.0 (0.9)	4.8 (0.4)
Ca, kg ha^{-1}	10.3 (1.1)	9.4 (1.3)	9.8 (0.9)
Mg, kg ha^{-1}	2.3 (0.1)	2.1 (0.3)	2.2 (0.2)
B, g ha^{-1}	23.2 (1.1)	20.7 (4.4)	20.1 (4.1)

Table 2. Dry mass and the amounts of nutrients stored in the bottom/litter layer in the control (= 0) plots and PK and NPK fertilized plots prior to fertilization in 1984. Standard deviations in parentheses.

	0	PK	NPK
Dry mass, kg ha^{-1}	7934 (700)	7805 (813)	7213 (1252)
N, kg ha^{-1}	81.8 (9.5)	79.3 (9.1)	73.6 (13.2)
P, kg ha^{-1}	6.8 (0.3)	6.3 (0.4)	6.1 (0.9)
K, kg ha^{-1}	16.4 (0.9)	16.2 (1.9)	15.5 (3.0)
Ca, kg ha^{-1}	38.9 (2.2)	34.0 (2.7)	34.1 (2.0)
Mg, kg ha^{-1}	6.2 (0.6)	5.4 (0.5)	5.4 (0.5)
B, g ha^{-1}	47.8 (5.7)	36.9 (1.2)	41.5 (5.7)

Table 3. Amounts of nutrients stored in the field layer roots in the control (= 0) plots and PK and NPK fertilized plots prior to fertilization in 1984. Standard deviations in parentheses.

	0	PK	NPK
N, kg ha^{-1}	48.6 (6.4)	34.3 (4.6)	45.5 (3.2)
P, kg ha^{-1}	2.7 (0.2)	2.2 (0.4)	2.9 (0.1)
K, kg ha^{-1}	4.6 (0.2)	3.4 (0.7)	4.3 (0.1)
Ca, kg ha^{-1}	9.7 (2.2)	7.2 (1.3)	10.8 (0.3)
Mg, kg ha^{-1}	2.3 (0.5)	1.7 (0.6)	2.5 (0.4)
B, g ha^{-1}	32.0 (7.1)	27.1 (3.3)	36.3 (8.2)

3.2 Total Plant Biomass

The field and the bottom/litter layers together accounted for < 20 % of the dry mass accumulated in the total plant biomass and litter (Fig. 3). The proportion of B (17 %) in the field and bottom/litter layers was also small, whereas the proportions of the other nutrients were greater. More than 40 % of N, 38 % of P, 30 % K, 38 % of Ca and 31 % of Mg was found in the field and bottom/litter layers.

Neither the dry mass of the tree layer nor the combination of the field and bottom/litter layers was significantly affected by fertilization (Table 4). Nitrogen accumulation in total plant biomass and litter increased by 46.2 kg ha^{-1} on the PK-fertilized plots and by 93.7 kg ha^{-1} on the NPK-fertilized plots. This increase was almost evenly distributed between the tree biomass and understorey vegetation and litter. The total fertilizer-induced increase in the amount of P was 17.3 kg ha^{-1} on the PK-fertilized plots and 13.3 kg ha^{-1} on the NPK-fertilized plots. Most of this increase (65 % on the PK fertilized plots and 59 % on the NPK fertilized plots) had occurred in the field and bottom/litter layers. The amount of K in the total plant biomass and litter increased by 32 kg ha^{-1} on both the PK- and the NPK-fertilized plots after fertilization. A high proportion of the K (87 % on the PK-fertilized plots and 79 % on the NPK fertilized plots) had accumulated in the tree layer.

Fertilization decreased the amount of Ca in the tree layer. However, the amounts of Ca in the field and bottom/litter layers increased significantly and the change in the total Ca accumulation was thus positive on both the PK- (7.9 kg ha^{-1}) and NPK-fertilized (8.7 kg ha^{-1}) plots. Fer-

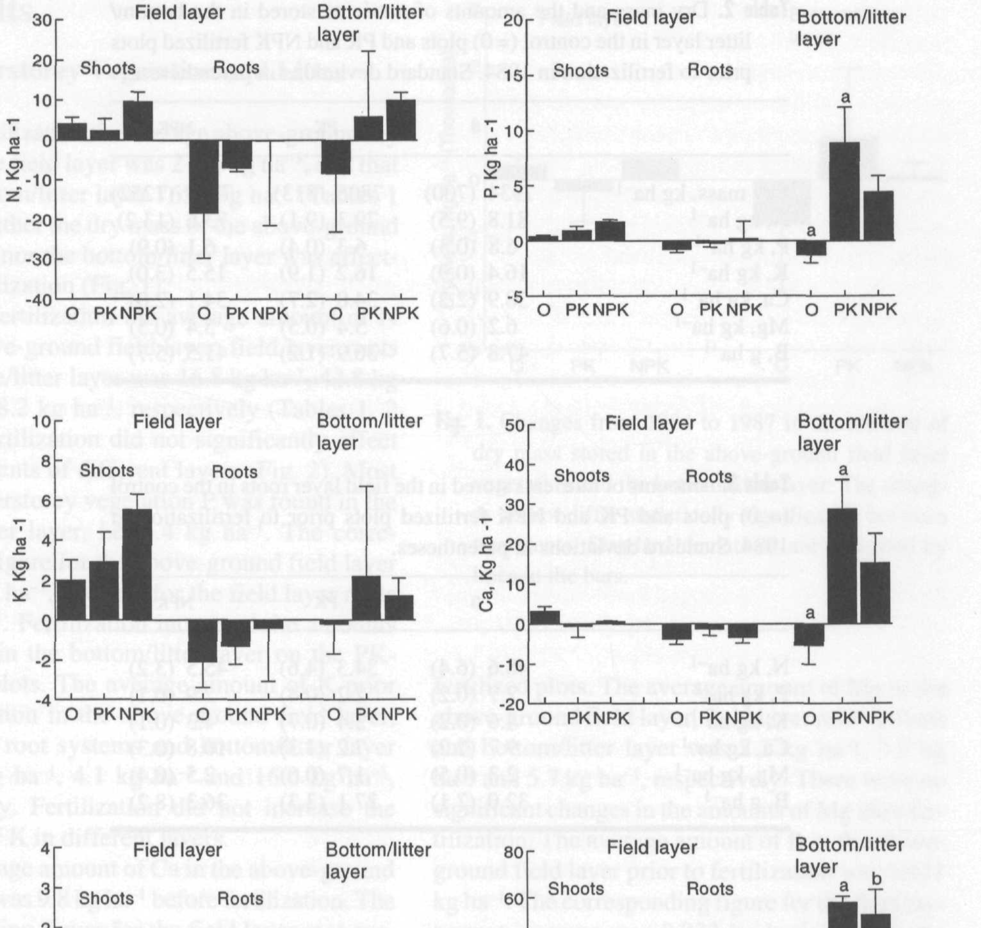

Fig. 2. Changes from 1984 to 1987 in the amounts of nutrients stored in the above-ground field layer vegetation, field layer roots and the bottom/litter layer. Standard deviations are indicated by lines in the bars. Values marked by the same letter differ statistically significantly ($p < 0.05$) from each other.

tilization did not significantly affect the amounts of Mg in either the tree layer or the field and bottom/litter layers. More B was accumulated in the tree layer than in the understorey vegetation and litter. More than 70 % of the total fertilized-induced accumulation of B (0.30 kg ha^{-1} on the PK-fertilized plots, 0.32 kg ha^{-1} on the NPK-fertilized plots) occurred in the tree layer.

The total increase in the stores of P caused by fertilization (the change in the control plots is

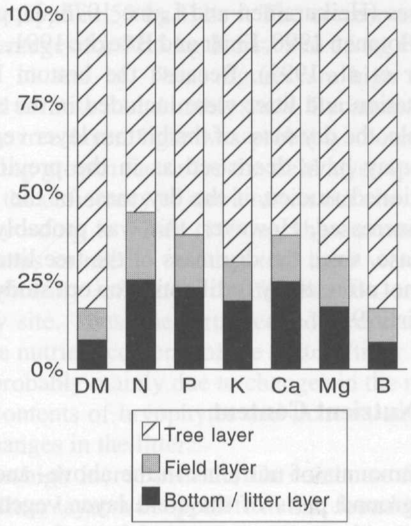

Fig. 3. Average percentual distribution of dry mass and nutrients in the tree, field and bottom/litter layers prior to fertilization in 1984.

accounted for as in Table 4) was 33 % of the applied P on the PK-fertilized plots. For the other elements, the percentages on the PK-fertilized plots were K 31, Ca 6, and B 13. On the NPK-fertilized plots, the corresponding figures were N 62 %, P 25 %, K 32 %, Ca 6 %, and B 13 %.

Table 4. Fertilizer-induced change in dry mass and nutrient content (kg ha^{-1}) of the combined field layer vegetation and bottom/litter layer and tree layer during the study period (from 1984 to 1987). Fertilizer-induced changes have been calculated by either adding the decrease on the control plots from 1984 to 1987 to the change on the fertilized plots or subtracting the increase on the control plots from the change on the fertilized plots. Fertilizer-induced changes in the field and bottom/litter layers are based on this study and those in the tree layer on Finér's (1991b) study at the same site. The tree layer includes the following compartments: cones, needles, living branches, dead branches, stembark, stemwood, stump and coarse roots, and small and fine (∅ 10 mm) roots. NS indicates that the change from 1984 to 1987 does not differ statistically significantly ($p > 0.05$) between treatments (0, PK, NPK) according to the analysis of variance.

		Trees	Field and bottom/litter layers
Dry mass	PK	+711	+1923
	NPK	+1377	+1859
		NS	NS
N	PK	+22.7	+23.5
	NPK	+51.9	+41.8
P	PK	+6.0	+11.3
	NPK	+5.4	+7.9
K	PK	+27.3	+4.1
	NPK	+25.1	+6.7
			NS
Ca	PK	−18.9	+26.8
	NPK	−9.7	+18.4
Mg	PK	+0.82	+1.83
	NPK	+0.86	+1.32
		NS	NS
B	PK	+0.22	+0.08
	NPK	+0.23	+0.09

4 Discussion

4.1 Dry Mass

The dry mass of the above-ground field layer (2100 kg ha^{-1}) was within the range reported for drained mires in Fennoscandia (Tamm 1954, Paavilainen 1980, Vasander 1987, Brække 1988, Laiho 1996). The average root biomass of the field layer prior to fertilization was 6300 kg ha^{-1} on our study site (Finér 1991b). This was greater than that reported by Paavilainen (1980) for a drained low-shrub pine bog and by Laiho and Finér (1996) for tall-sedge pine fens in Finland, but almost similar to that presented by Håland and Brække (1989) for a pristine bog in Norway. Only 25 % of the total field layer biomass was in the above-ground parts. Our results are thus in accordance with previous ones showing that most of the dry mass of the field layer vegetation is located in the root systems on drained bogs (Paavilainen 1980, Wallén 1986).

The dry mass of the bottom/litter layer was only half of that on an old drained oligotrophic pine bog studied by Brække (1988) in southern Norway. However, Jäppinen and Hotanen (1990) reported a lower biomass for the bottom layer vegetation on a drained herbrich pine mire and spruce mire, as well as Vasander (1982) for a drained ombrotrophic bog and Laiho (1996) for drained tall-sedge pine fens. These differences probably result from differences in sampling. On Brække's (1988) site the living mosses had almost disappeared due to shading by the trees, and mainly tree litter that had accumulated on the soil surface was sampled. Jäppinen and Hotanen (1990), Vasander (1982) and Laiho (1996) sampled only living mosses, not litter.

The dry mass of the above-ground field layer did not respond to fertilization. These results are contradictory to those from poorly stocked raised bogs, where NPK-fertilization increased the above-ground dry mass of the field layer (Vasander 1982, Vasander et al. 1993). Tamm (1954) and Päivänen (1970) also reported a positive field layer response to fertilization on open mires. This positive response of field layer vegetation to fertilization is, however, probably a short-term phenomenon, since the field layer species are eventually shaded out due to the increased growth and consequent shading of the tree layer (Brække 1988, Laine et al. 1995).

The root biomass of the field layer decreased from 1984 to 1987 in all treatments (Finér 1991b). Finér (1991b) attributed this to the exceptionally cold winter in 1986–1987, which had probably damaged the living roots. Compared with the control plots, the decrease in root biomass was lower on the fertilized plots. This was interpreted to indicate a positive effect of fertilization on the root biomass (Finér 1991b).

The dry mass of the bottom/litter layer was not affected by fertilization. This may at first seem to be contradictory to the observations indicating that bryophytes suffer from direct contact with high doses of nutrients, especially those comprising readily soluble nitrogen and potassium (Jäppinen and Hotanen 1990, Finér and Brække 1991, Dirkse and Martakis 1992, Vasander et al. 1993). However, *Pleurozium schreberi* was the most common bryophyte on our site and it is known that fertilization has a more destructive effect on peat mosses than on forest mosses (Heikurainen and Laine 1976, Jäppinen and Hotanen 1990, Finér and Brække 1991, Vasander et al. 1993). Because the bottom layer vegetation and litter were included in the same sample, the dry mass of the bottom layer vegetation may have decreased as in the previously mentioned studies, if the dry mass of the litter had increased. However, this was probably not the case, since the dry mass of the tree litterfall was not affected by fertilization on our study site (Finér 1991a).

4.2 Nutrient Content

The amounts of nutrients in the above- and below-ground parts of the field layer vegetation were inside the range reported for ombrotrophic pine bogs by Paavilainen (1980), Vasander (1981), Håland and Brække (1989) and Brække and Håland (1990). However, they were substantially higher than those presented by Brække (1988) for a drained and fertilized oligotrophic pine bog, but of the same magnitude or lower than those reported by Brække for only a drained bog. The distribution of nutrients between the root systems and the above-ground parts of the field layer differed from that of the biomass. While almost 70 % of the total field layer dry mass was in the root systems, only N was clearly more abundant in the roots than in the above-ground parts. These results indicate that the below-ground parts of field layer species accumulate relatively more carbon than nutrients. The amounts of nutrients in the bottom/litter layer were generally lower in our study than those reported by Brække (1988).

Päivänen (1970) studied the changes in the nutrient contents of the above-ground parts of the field layer during the first three years after fertilization of an open low-sedge bog. He found that 36 kg ha^{-1} more N (36 % of applied N), 3.1 kg ha^{-1} more P (7 % of applied P) and 16 kg ha^{-1} more K (19 % of applied K) were fixed in the field layer on the fertilized plots. Haveraaen (1967) studied nutrient amounts in the above-ground field layer biomass of an afforested soligenous mire four years after fertilization. He found that fixation by the field layer accounted for 13 % of the applied 145 kg K ha^{-1} and 13 %

of the applied 50 kg P ha^{-1}. The corresponding percentages for 72.5 kg K ha^{-1} and 25 kg P ha^{-1} were 11 and 14. These figures are high compared to those found in this study. Because of the dense tree layer, light was probably more of a limiting growth factor for the field layer species than the deficiency of nutrients on our site.

According to Finér (1991a), the amounts of nutrients in needle or other tree litter were not significantly influenced by fertilization on our study site. Thus, the fertilizer-induced changes in the nutrient contents of the bottom/litter layer are probably mainly due to changes in the nutrient contents of bryophytes and lichens, and not to changes in the litter.

The high increase in the Ca contents of bottom/litter layer was opposite to that found in the tree and field layers, where Ca accumulation decreased after fertilization. There were also no changes in the Ca contents of needle or other tree litter after fertilization (Finér 1991a). The dissolution rate of Ca in Moroccan rock phosphate is probably slow. Thus, the bottom/litter layer samples probably still contained residual unreactive rock phosphate at the time of sampling. The solubility of phosphorus in rock phosphate is also slow (Yli-Halla and Lumme 1987). The high increase in P amounts in the bottom/litter layer after fertilization could thus partly result from the same reason.

The nitrogen amounts in the understorey vegetation and litter did not increase only on the NPK-fertilized plots, but also on the PK-fertilized plots after fertilization (Table 4). This indicates that the PK treatment had a priming effect on peat N mineralization and vegetation N uptake.

Except for B and K, the accumulation of fertilizer nutrients in understorey vegetation and litter was of the same magnitude or greater than the uptake by tree layer. The field and bottom/litter layers are thus of great importance in the biogeochemical nutrient cycle of ombrotrophic pine bogs.

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