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Peat properties and vegetation along different trophic levels on an afforested, fertilised mire

Turpeen ominaisuudet ja kasvillisuus metsitetyn ja lannoitetun avosuon eri trofiatasoilla

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Relationships between the peat nutrient concentrations and the degree of humification, the ground vegetation and the botanical composition of the peat were studied on an afforested, originally treeless mire with a wide nitrogen gradient. The afforestation was carried out in 1971 using spot sowing and spot fertilisation. A broadcast fertilisation experiment that involved six replicates with four treatments, (i) a control, (ii) PK (rock phosphate and KCl), (iii) PK+ B, Cu and (iiii) wood ash was established in 1981–82. The surface peat layers were sampled for nutrient analyses in 1995 and for peat type determinations in 1997. The ground vegetation was inventoried in 1995. In 1995, the peat total nitrogen concentration varied from 8.7 to 29.1 mg g^{-1} in the 0–5 cm peat layer.The total nitrogen, phosphorus and iron concentrations and the degree of humification in the peat were all positively correlated with the proportion of *Carex* components and with each other. The frequency of *Sphagnum* mosses correlated negatively but that of forest mosses positively with the peat total nitrogen concentration. Broadcast fertilisation with wood ash increased the concentrations of phosphorus, potassium, calcium, magnesium, manganese, boron, copper and zinc especially in the 0–5 cm peat layer but did not affect other peat properties or the ground vegetation.

Keywords: nitrogen, mineral nutrients, peat component, degree of humification, *Carex*, *Sphagnum*, forest mosses

INTRODUCTION

Peat is formed of incompletely decomposed organic plant residues. The chemical and physical properties of peat depend on the species composition of the peat forming plant communities and their nutritional and hydrological requirements (e.g. Kivinen 1934, Tolonen 1982, Laine et al. 2000). Herbs and tall sedge species demand more nitrogen and phosphorus than low sedge species or shrubs and most *Sphagnum* species. Therefore they also contain more of these nutrients in their tissues (Kivinen 1934). Accordingly, *Carex* peats are generally richer in nitrogen and phosphorus than *Sphagnum* peats (Kivinen 1934, Urvas et al. 1979) and also contain more nitrogen than *Sphagnum* peats at the same humification level (Kaunisto 1987). The study by Nieminen & Jarva (1996) shows that also the concentrations of iron and phosphorus correlate with each other and the studies by Kivinen (1934) and Urvas et al. (1979) that the phosphorus and iron concentrations increase with the proportion of the *Carex* peat component.

On the other hand, ground vegetation reflects peat type and peat nitrogen (Kivinen 1934, Vahtera 1955, Heikurainen 1960, Holmen 1964, Westman 1981) and also phosphorus conditions (Vahtera 1955, Holmen 1964, Westman 1981), although the variation may be quite wide even within the same site type (Westman 1981, Sundström et al. 2000).

Forest drainage causes peat subsidence, increases the humification of peat and concentrates organically bound nutrients such as nitrogen and phosphorus (Kaunisto & Paavilainen 1988, Laiho & Laine 1994) and also changes the composition of plant communities. The species typical of mineral soil forests become more common along with the time elapsed from ditching (Sarasto 1957, Laine & Vasander 1990, Laine et al. 1995).

Also fertilisation has been shown to affect the species composition in many studies (e.g. Huikari 1951, Reinikainen 1965, Päivänen & Seppälä 1968, Päivänen 1970). It may also affect the amount of nutrients in peat (e.g. Silfverberg & Huikari 1985, Kaunisto & Moilanen 1998, Sundström et al. 2000).

As indicated above, there are several studies dealing with peat nutrients and other peat properties, ground vegetation, and also with the effect of fertilisation on these. However, a single study usually covers only a couple of different subjects at a time.

This study aims at clarifying the relationships between peat nitrogen and ground vegetation and between the peat nutrient concentrations, the humification degree and the composition of peat focusing especially on the role of peat total nitrogen concentration in these contexts, and also the effect of fertilisation on these subjects on an afforested, fertilised open mire with a wide nitrogen gradient. The study is the first part of an investigation the aim of which is to find out the effects of the peat nitrogen concentration on the nutrition and growth of Scots pine in moderate temperature sum conditions in Finland.

MATERIAL AND METHODS

Site and treatments

The experimental area (Särkkä) is located (62° 45' N, 31° 00' E and 148 m a.s.l.) about 13 km NE from Ilomantsi in easternmost Finland (Kaunisto 1987). In 1961–1990 the mean annual precipitation in Ilomantsi was 649 mm, the mean annual temperature 1.7° C and the temperature sum 1084 d.d.° C with the 5 ° C threshold value. The mean temperature in January was –12.1° C and in July +15.8 °C. The parent rock is acid, nutrient-poor precambric granite (Alalammi 1992). The region of Särkkä lies at the northern edge of the southern boreal zone and the peatlands are mostly eccentric bogs and southern aapa mires (Ruuhijärvi 1982). The Särkkä area is part of a large peatland area on the east side of the river Koitajoki. Before drainage the site types ranged from a treeless *Sphagnum fuscum* bog (RaN) to a herb-rich sedge fen (RhSN; Kaunisto 1987, Laine & Vasander 1990). The peat layer was more than one metre deep.

The area had been drained in 1970–71 with 40-metre ditch spacing and ploughed with a double mould board plough that makes a shallow furrow with low ridges on both sides. Scots pine was sown on spots in 1970 and 1971. There were 2500 spots per hectare. All sowing spots were fertilised with a NPK multinutrient fertiliser for peatland forests (Suomaiden Y-lannos: 14–8–8) 30 g per spot (= 0.25 m^2).

The area was broadcast fertilised in 1981–1982 (Kaunisto 1987). The study involved 24 plots with four fertilisation treatments that were selected from a larger experiment (Kaunisto 1987). Every treatment was thus replicated six times. The treatments were (A) control, (B) rock phosphate + KCl, (C) the same as B, but added with fertiliser borate and copper oxide and (D) wood ash 5000 kg ha^{-1} (Kaunisto 1987). Accordingly, the amounts of nutrients applied were 0, 45, 45 and 28 kg ha^{-1} for phosphorus, 0, 78, 78 and 91 kg ha^{-1} for potassium, 0, 0, 1.0 and 5.5 kg ha^{-1} for boron, and 0, 0, 8.0 kg ha^{-1} for copper. Copper was not determined from wood ash. The materials for this study could not be affected in any significant way by the former spot fertilisations because all samples were collected from a distance of at least two metres from the trees.

The plots were separated with ditches from two sides, but in the strip direction there were no buffer zones between the plots. The plots measured mainly 40×40 m or 40×50 m each. The experimental plots were in three blocks that were different in regard to peat nitrogen concentration and drainage conditions (Fig. 1). Block 1 was the most nitrogen-rich and Block 3 the most nitrogen-poor (Table 1). Drainage on Block 3 was somewhat hampered by the spring floods of the nearby river Koitajoki. To improve the drainage conditions supplementary ditches were dug in the middle of the strips on Block 3 in 1981–82.

The plots were chosen in order to establish a wide and even peat total nitrogen gradient for each treatment (Fig. 1). In 1995 the peat nitrogen concentrations in the 0–5 cm peat layer varied from one block to another as follows: Block 1 1.87–2.91, Block 2 1.15–2.38 and Block 3 0.87–1.80% (means of four sampling times, see Table 1). Thus the peat nitrogen concentrations of the blocks slightly overlapped. The plots chosen were not evenly divided between the blocks (9, 7, 8 for Blocks 1, 2 and 3 respectively). It was considered more important to have a proper series of nitrogen concentrations for different treatments than an even number of experimental plots in different blocks, although this slightly hampered the statistical comparisons between the treatments.

There were considerable differences in the ground water level, in the peat total nitrogen concentration and in the stand volume between the blocks. The ground water table was deepest on Block 1 and most superficial on Block 3 which was bordering the river Koitajoki, whereas the stand volume and the peat nitrogen concentration were highest on Block 1 and lowest on Block 3 (Table 1).

The ground water level was measured once a week from July through August in 1995. On Blocks 1 and 2, where the strip width was 40 m,

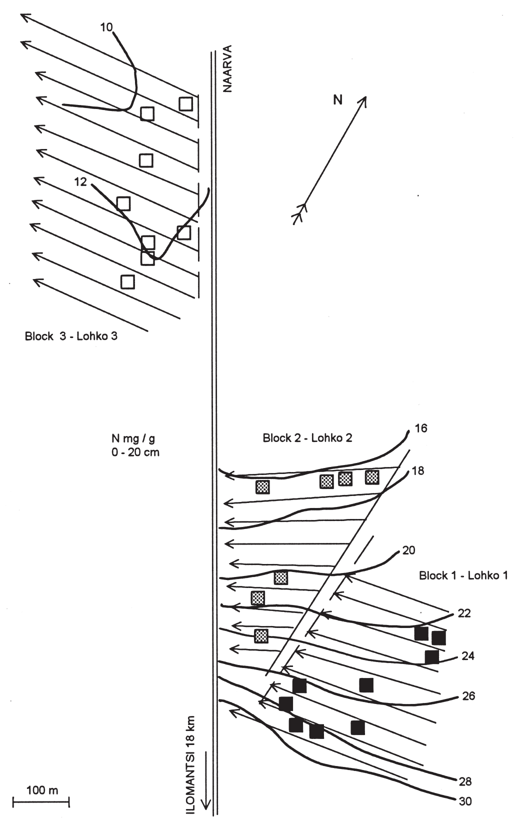

Fig. 1. Layout of the experiment with ditches (and road). Isolines indicate concentrations of nitrogen in peat, 0–20 cm.

Kuva 1. Koealojen sijainti ojitusalueella. Isokäyrät osoittavat pintaturpeen (0–20 cm) typpipitoisuuden.

Table 1. The means and standard deviations of the total nitrogen concentration in peat (N_{peat},; 0–5 cm), the depth of the groundwater table (WT) in July–August 1995 and the stand volume (V) on the different blocks.

Taulukko 1. Turpeen kokonaistyppipitoisuuden (N_{peat}; 0–5 cm), pohjaveden syvyyden (WT) heinä-elokuussa 1995 ja puuston kuutiomäärän (V) keskiarvot ja standardipoikkeamat eri lohkoilla.

Measured quantity *Mitattu suure*	Block – *Lohko* 1	2	3
N_{peat}, %	2.27±0.2	1.66±0.3	1.22±0.2
WT, cm	55.0±5.7	41.5±5.3	28.4±2.6
V, m^3 ha^{-1}	63.8±8.1	37.3±12.1	20.9±3.9

three wells per plot were placed at 3, 10 and 20-metre distances from the original strip ditch. On Block 3, where the distance between the ditches was 20 m, the mean distances from the wells to the ditches were 3, 10 and 3 m from the nearest ditch. The wells consisted of one-metre-long, perforated plastic tubes, placed on the mire lawn surface.

Data collection and analyses

The samples for the peat nutrient analyses were taken in May, August, September and October 1995. Four subsamples at every sampling time were taken from each experimental plot and pooled by 0–5, 5–10 and 10–20 cm layers. The samples were dried at 60° C for 72 hours and then milled and homogenised. A portion of each sample was further dried at 105° C for dry weight determination. The total nitrogen concentration was analysed with the Kjeldahl method. The total phosphorus, potassium, calcium, magnesium, iron, manganese, copper, zinc and boron concentrations were analysed from ashed samples using the standard methods of the Finnish Forest Research Institute (Halonen et al. 1983). Boron was extracted with a mixture of sulphuric and phosphoric acid and the others with hydrochloric acid. Phosphorus and boron were determined spectrophotometrically, phosphorus with the vanado-molybdate method and the other nutrients with AAS at Muhos research station.

The samples for the peat type determinations were collected only once — in July 1997. Four subsamples per plot were collected. The samples were divided into 0–10 cm and 10–20 cm layers. Initially, the degree of humification was determined from the fresh peat samples using the method of von Post (1922). After the fresh weight determination, the samples were dried at 60° C for 72 hours. The dry weight was determined and the samples were then milled and homogenised. A portion of the homogenised sample was taken aside for microscopic study. The determination of the peat components (Dombrovskaja et al. 1959, Nyholm 1969, Kats et al. 1977, Lange 1982, Daniels & Eddy 1985, Laine et al. 2000, Vitmossor...1993) was done with a light microscope according to the method described by Heikurainen & Huikari (1952, see also Haihu & Etelämäki 1986 and Laine et al. 2000).

The vegetation was mapped in late July 1995. The coverage of all species on each plot was determined on six 0.5 m^2 circles, placed along two lines parallel to the strip ditches. The distance from the lines to the nearest ditch was 10 m. The abundance scale was +, 1, 2, 5, 10, 20 ...100%.

ANOVA and correlation analysis in the SYSTAT 8.02 (1998) package was used in the statistical analyses dealing with the physical properties and the botanical composition of the peat. The SPSS 8.0 for Windows was used in the calculation of the physical measurement results and the vegetation data. The effect of fertilisation on the peat total nutrient concentrations was calculated on the basis of the four sampling times in 1995 by the BMDP (1990) software package of the repeated measures analysis of variance. Correlation analyses were calculated separately for the controls and for the whole group of fertilised treatments. The mean values of the four peat sampling times for the nutrients were used in the correlation analysis with peat components and humification.

The abundance of plant species and some soil variables were analysed with the DECODA package (Minchin 1991). The species included were the 27 most frequent ones added with 7 species, considered having a specific indicator value (Appendix 1, Reinikainen 1984). The environment variables were the *Carex* and *Sphagnum* peat components, nitrogen concentration in the 0–20 cm peat layer and the degree of humification (0–10 cm) according to von Post.

RESULTS

Components and humification of peat

The surface peat consisted mainly of *Carex* and *Sphagnum* residues (Fig. 2). The average occurrence in the 0–20 cm peat layer was 37% for *Carex* components and 34% for *Sphagnum*. The *Bryales* peat component had a mean occurrence of 10%, *Eriophorum vaginatum* 9% and the wood residue fraction, 10% (Fig. 2). There were significant differences in the amounts of *Carex* and *Sphagnum* peat components (0–20 cm) between the three blocks. On the most nitrogen-rich Block

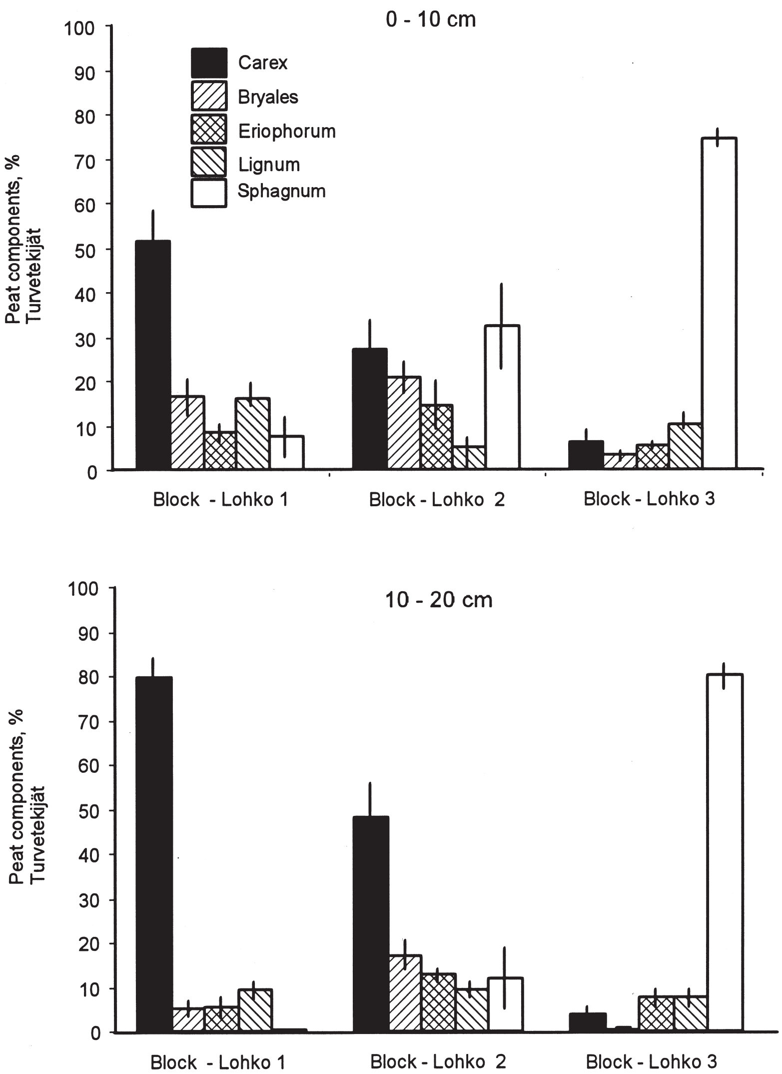

Fig. 2. Percentage of the peat components in the peat layers 0–10 and 10–20 cm by blocks.

Kuva 2. Turvetekijöiden prosentuaaliset suhteet 0–10 ja 10–20 cm syvyyksillä lohkottain.

1 the *Carex* component was dominant. On Block 2 *Carex* and *Sphagnum* were roughly equal, while *Sphagnum* residues dominated on the nitrogen-poor Block 3 (Fig. 2).

The *Sphagnum* components could only partly be separated into the sections of *Acutifolia*, *Cuspidata*, *Palustria* and *Subsecunda*. In the more humified (classes 4–6 according to von Post) samples the stem and branch leaf structure had disintegrated, making an accurate section determination uncertain. Only 15% of the *Sphagna* could be identified to the sections on Blocks 1 and 2 compared to about 70% on Block 3, which had the lowest degree of humification. *Acutifolia* and *Cuspidata* were the most common sections on Block 3.

There was a significantly positive relationship between the percentage of the *Carex* peat components and the peat nitrogen, phosphorus and iron concentrations (Fig. 3, Table 2). The potassium concentrations did not correlate with any peat component in either layer. The correlations between the *Sphagnum* peat component and the peat nitrogen, phosphorus and iron concentrations were negative (Table 2). The *Bryales* fraction correlated positively only with the peat nitrogen concentration in the 0–10 cm layer (Table 2). The *Eriophorum* and *Lignum* components did not

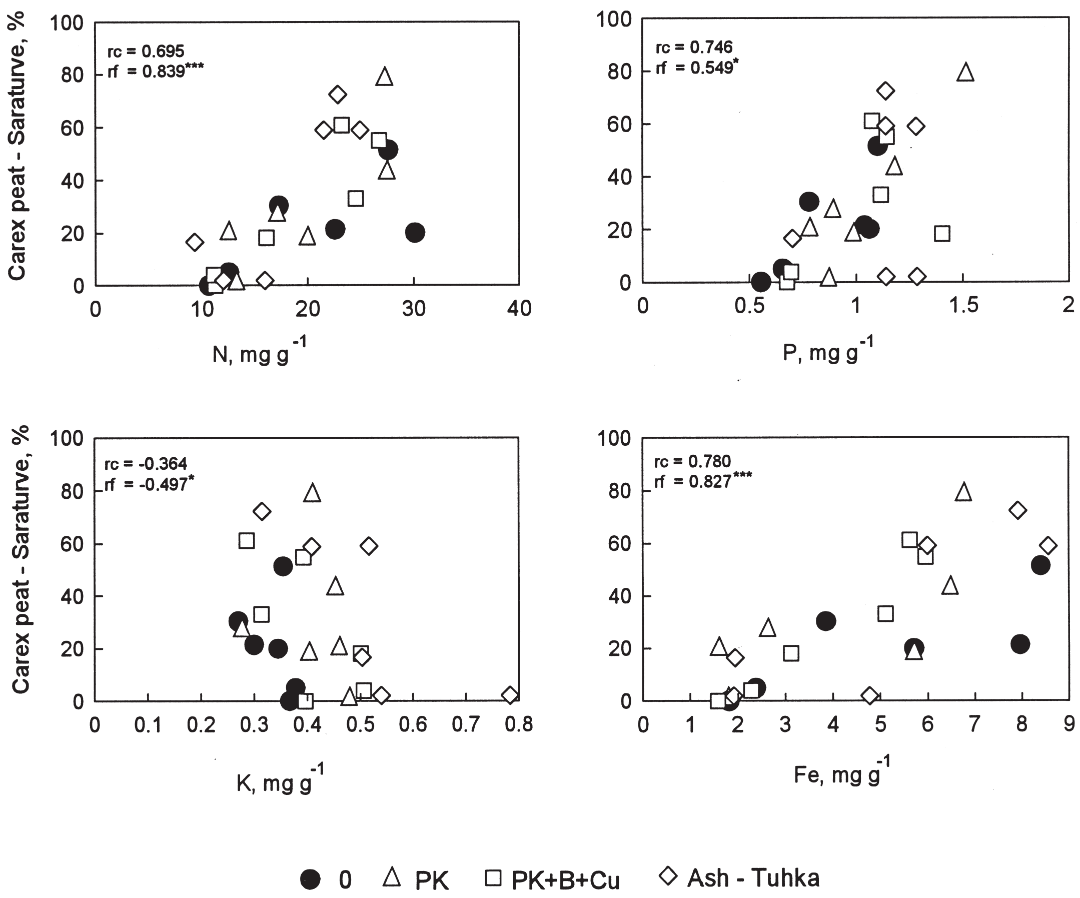

Fig. 3. Relationship between the total N, P, K and Fe concentrations and the proportion of *Carex* component in the peat layer 0–10 cm by different fertilisation treatments. The nutrient concentrations are the means of the concentrations in the 0–5 and 5–10 cm layers. Abbrevations: rc = r for the control plots (n = 6), rf = f for the fertilised plots (n = 18).

Kuva 3. Turpeen typen (N), fosforin (P), kaliumin (K) ja raudan (Fe) kokonaispitoisuuksien ja saraturvetekijän väliset suhteet 0–10 cm:n turvekerroksessa lannoituskäsittelyittäin. Ravinnepitoisuudet ovat 0–5 ja 5–10 cm:n kerrosten keskiarvoja. Lyhenteet: rc = r kontollikoealoille (n=6) ja rf = r lannoitetuille koealoille (n = 18).

correlate significantly with N-, P-, K- or Fe-concentrations in peat.

The degree of humification varied between 2 and 6 (Fig. 4). *Sphagnum* peat was dominant in low humified (2–3) peat, while *Carex* peat components dominated in degrees 5 and 6. *Sphagnum* and *Carex* peat were almost equal in degree 4. The proportion of amorphous matter increased with a higher degree of humification. The ash content in the 0–10 cm peat layer increased from about 3.1% at H 2 to 10.6% at H 6 and in the 10–20 cm layer from 1.7 to 3.4%. The concentrations of peat nitrogen, phosphorus, and iron — but not potassium — increased along the increasing degree of humification (Fig. 5).

The fertilisation treatments had no significant effect on the occurrence of peat components or the degree of humification.

The results of the DECODA analysis is presented in Fig. 6, where the sample plots are plotted with the soil variable vectors. There is a clear differentiation between the plots of Blocks 1 and 3, while those of Block 2 are more shattered and adhered either to the clusters of Blocks 1 or 3. The vectors for the Carex and Sphagnum peat components are closely connected to Block 1 and

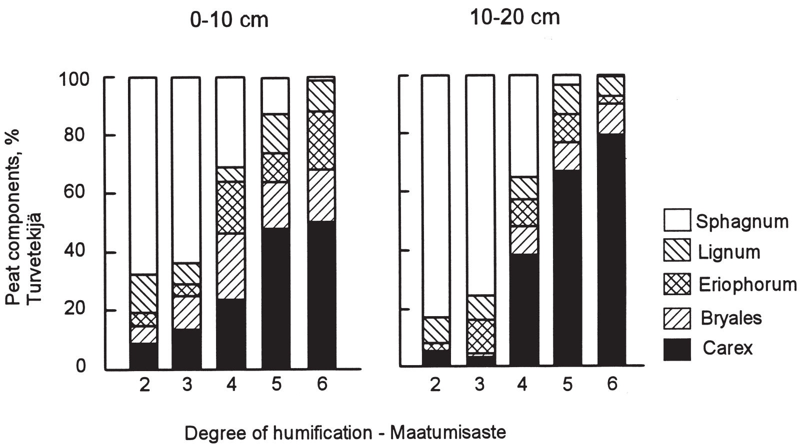

Fig. 4. Proportion of peat components by degree of humification (von Post) for the layers 0–10 and 10–20 cm.

Kuva 4. Turvetekijöiden osuudet von Postin maatumisasteilla 0–10 ja 10–20 cm:n kerroksissa.

Block 3, respectively. As expected, the humification degree and the Carex peat component increased along the nitrogen gradient from Block 3 to Block 1.

Nutrient concentrations in peat

Fertilisation with wood ash increased significantly the concentrations of all mineral elements, except iron (Table 3). The concentrations of calcium and magnesium increased significantly in all the peat layers. In the 0–5 cm layer the concentrations of Ca and Mg were 2–3 -fold and those of Mn more than 15-fold compared with the other treatments. The application of wood ash increased also the boron concentrations, pH and peat ash contents significantly, the last mentioned, however, only in the 0–5 cm layer. Also, the increase of P, K and Zn was limited to the 0–5 cm layer. The application of copper increased the Cu concentrations more than tenfold in the 0–5 cm layer and still fourfold in the 5–10 cm layer.

There was a close correlation between the P and N concentrations in all the peat layers (Fig. 7). The potassium concentrations did not correlate with the peat total N concentration except in the 0–5 cm layer of the fertilised plots where the correlation was negative. The concentrations of peat iron and nitrogen correlated significantly in both control and fertilised plots and in all the peat

Table 2. Correlations between peat components and N, P, K and Fe total concentrations at peat layers 0–10 and 10–20 cm. The risk levels (n=24): 5% = *, 1% ** and 0,1% =***.

*Taulukko 2. Turvetekijöiden sekä typen (N), fosforin (P), kaliumin (K) ja raudan (Fe) kokonaispitoisuuksien korrelaatiot 0–10 ja 10–20 cm:n syvyydessä. Merkitsevyyksien riskitasot (n=24): 5% = *, 1% = ** and 0,1% = ***.*

Layer	Nutrient	Peat components				
Kerros	*Ravinne*	*Carex*	*Sphagnum*	*Eriophorum*	*Bryales*	*Lignum*
0–10 cm	N	0.750***	–0.924***	0.336	0.545**	0.265
	P	0.597**	–0.653***	0.109	0.369	0.147
	K	–0.353	0.402	–0.135	–0.331	0.076
	Fe	0.760***	–0.820***	0.168	0.336	0.293
10–20 cm	N	0.863***	–0.913***	0.053	0.325	0.124
	P	0.597**	–0.682***	0.152	0.385	0.050
	K	0.048	0.109	–0.224	–0.289	–0.309
	Fe	0.862***	–0.779***	–0.325	0.158	–0.066

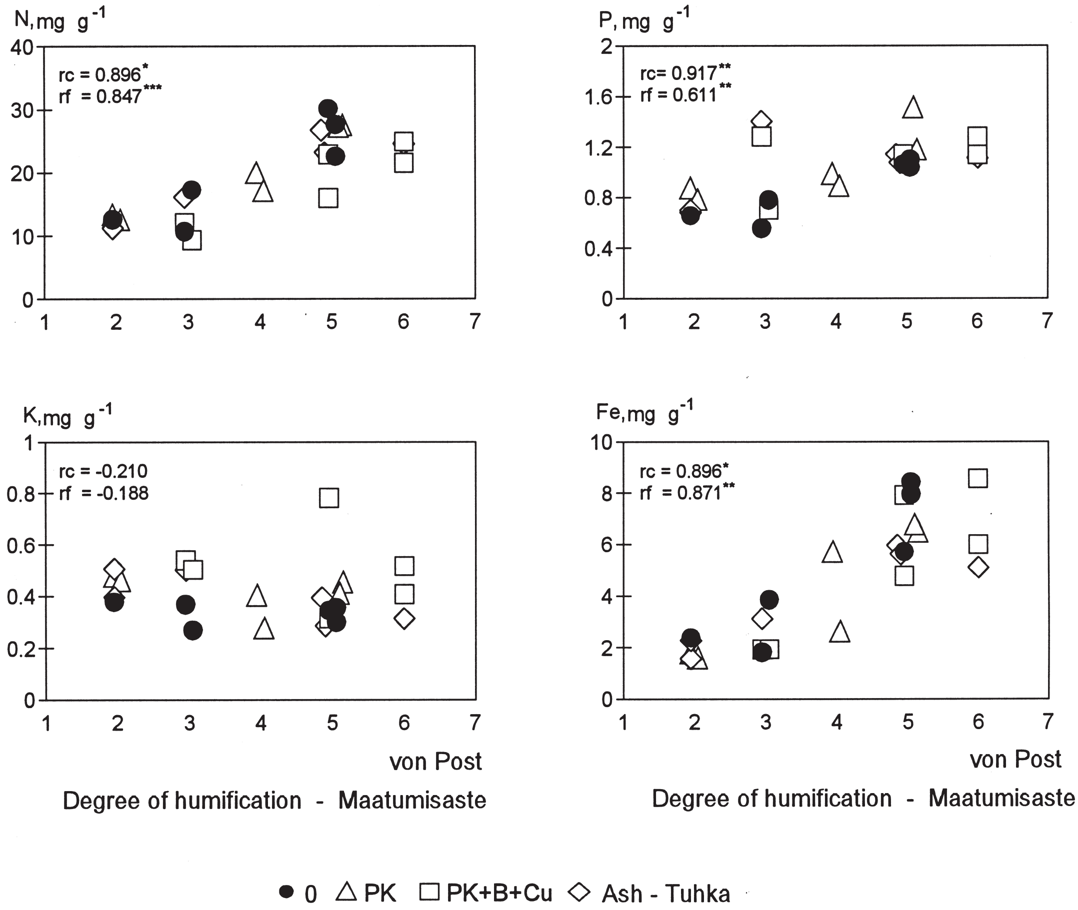

Fig. 5. Relationships between degree of humification and concentrations of N, P, K and Fe in the 0–10 cm peat layer. Explanations as in Fig. 3.

Kuva 5. Turpeen maatumisasteen ja turpeen typen (N), fosforin (P), kaliumin (K) ja raudan (Fe) kokonaispitoisuuksien väliset suhteet 0–10 cm:n kerroksessa. Selitykset, kuten kuvassa 3.

layers (Fig. 7). On the other hand, the correlations between the nitrogen and zinc concentrations were negative except in the 0–5 cm layer. In all the peat layers, except in the fertilised 0–5 cm layer, there was a close positive correlation between the P and Fe concentrations (Fig. 8).

Vegetation

The most common field layer species such as *Rubus chamaemorus* (on average 5.9%), *Betula nana, Eriophorum vaginatum,* and *Vaccinium uliginosum* occurred in all the blocks (Appendix 1). Species like *Andromeda polifolia* and *Rubus chamaemorus* were less common in the nitrogen-rich parts of the experiment. Dwarf shrubs, *Rubus chamaemorus* and *Sphagnum* spp dominated the nitrogen-poorer Blocks 2 and 3, while grasses, herbs and forest mosses were most frequent on Block 1, which was the most nitrogen-rich part of the experiment (Appendix 1, Table 1). The relationship between the forest mosses and the peat nitrogen concentration was significantly positive (Table 4).

The number of species was not significantly correlated with the nitrogen concentrations, al-

Table 3. Effect of fertilisation on the total main nutrient concentrations in the different peat layers. Means of four sampling times in year 1995. The values with the same letter do not differ significantly from each other.

Taulukko 3. Lannoituksen vaikutus eräiden pää- ja hivenravinteiden kokonaispitoisuuksiin turpeessa. Luvut vuoden 1995 neljän analyysikerran keskiarvoja. Samalla kirjaimella merkityt arvot eivät eroa toisistaan merkitsevästi.

Nutrient *Ravinne*	Layer, cm *Kerros, cm*	Fertilisation – *Lannoitus* 0	PK	PK+B+Cu	Ash – *Tuhka* 5000 kg ha^{-1}	p value *p-arvo*
N, %	0–5	1.91	1.88	1.88	1.78	0.827
	5–10	2.06	2.28	2.20	2.00	0.657
	10–20	1.98	2.28	2.20	2.04	0.345
P, mg g^{-1}	0–5	0.98a	1.21ab	1.25ab	1.33b	0.011
	5–10	0.74a	0.87b	0.77ab	0.74a	0.013
	10–20	0.58	0.63	0.60	0.56	0.360
K, mg g^{-1}	0–5	0.48a	0.63ab	0.59a	0.80b	0.000
	5–10	0.20	0.26	0.20	0.23	0.069
	10–20	0.10	0.11	0.10	0.10	0.656
Ca, mg g^{-1}	0–5	2.42a	3.27a	3.43a	10.56b	0.000
	5–10	2.06a	2.29a	2.04a	4.66b	0.000
	10–20	2.23a	2.27a	2.09a	2.97b	0.000
Mg, mg g^{-1}	0–5	0.42a	0.48a	0.44a	0.88b	0.000
	5–10	0.29a	0.24a	0.24a	0.44b	0.000
	10–20	0.23a	0.20a	0.19a	0.35b	0.001
Fe, mg g^{-1}	0–5	6.12	5.06	4.83	5.97	0.417
	5–10	3.63	3.54	3.26	3.83	0.224
	10–20	3.01	2.49	2.55	2.70	0.537
Mn, mg g^{-1}	0–5	51.1a	52.3a	47.0a	819.1b	0.001
	5–10	11.0a	8.8a	7.5a	21.9b	0.002
	10–20	8.1a	7.4ab	5.5b	9.2a	0.018
Zn, mg kg^{-1}	0–5	28.6a	30.2a	30.8a	69.7b	0.012
	5–10	12.2	9.4	9.4	11.5	0.134
	10–20	7.2	5.8	5.2	6.5	0.318
Cu, mg kg^{-1}	0–5	5.3a	5.2a	72.2b	25.4a	0.001
	5–10	2.4a	2.5a	10.2b	4.6ab	0.000
	10–20	1.9	1.9	2.5	2.0	0.067
B, mg kg^{-1}	0–5	1.2a	1.7a	1.7a	6.2b	0.000
	5–10	0.6a	0.8ab	0.8ab	1.2b	0.008
	10–20	0.5	0.8	0.6	0.8	0.487
Ash, %	0–5	7.2a	6.7a	7.1a	11.0b	0.002
Tuhka, %	5–10	4.2	4.9	4.3	4.5	0.114
	10–20	2.5	2.7	2.6	2.8	0.333
pH	0–5	4.1a	4.0a	4.0a	4.8b	0.000
	5–10	4.0a	3.9a	3.9a	4.3b	0.000
	10–20	4.0ab	3.9a	3.9a	4.1b	0.040

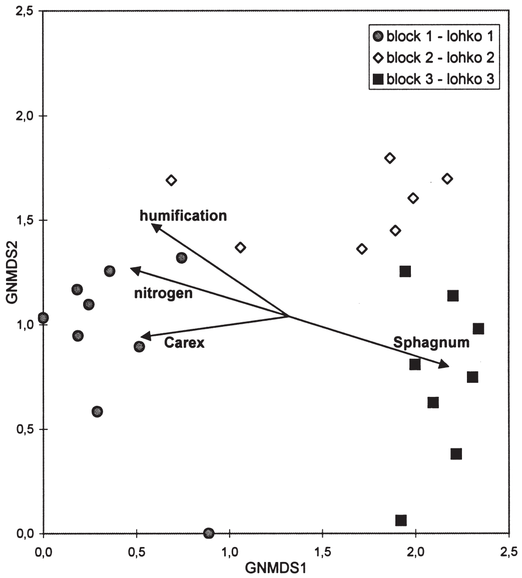

Fig. 6. GNMDS ordination of the sample plots based on the coverages of plant species. Carex = Carex peat component, Sphagnum = Sphagnum peat component, nitrogen = N_{tot} concentration in peat 0–20 cm, humification = humification in peat according to von Post's scale 1–10

Kuva 6. Kasvilajien peittävyyksiin perustuva koealojen GNMDS ordinaatio. Carex = saraturvetekijä, Sphagnum = rahkaturvetekijä, nitrogen = kokonaistypen pitoisuus turpeessa (0–20 cm), humification = turpeen maatumisaste (1–10) von Postin mukaan.

though there were clearly more species on the most nitrogen-rich Block 1 than on the other two blocks (Appendix 1). Some mesotrophic species, e.g. *Molinia caerulea* and *Dryopteris carthusiana,* were common on Block 1, but were not found on Block 3.

The results of the DECODA analysis, which included 34 plant species, indicated very similar trends. There was an axis representing a mesotrophic to oligo-ombrotrophic gradient which roughly followed the humification, nitrogen and Carex as well as the Shpagnum vectors that represented the environment variables (Fig. 6).

The ground water depth and the total nitrogen concentration in the 5–10 cm peat correlated closely (r = 0.891**). Consequently, the coverage of different plant species along the increasing ground water depth was quite similar to the peat total nitrogen gradient; the coverage of the *Sphagnum* species and *Rubus chamaemorus* decreasing and that of forest mosses increasing along the increasing ground water depth (Table 4). The vegetation resembled most that on mineral soil forests on Block 1, which had the lowest ground water level, the highest total nitrogen concentration in peat and the highest stand volume (Table 1).

The occurrence of *Vaccinium oxycoccos* and *Andromeda polifolia* (Appendix 1) reveals the original wetness of the site. *Eriophorum vaginatum* and *Betula nana* were relatively indifferent to the ground water depth (Table 4, App. 1).

The analyses of covariance, including the peat total nitrogen concentration and the depth of the ground water level as covariates, did not reveal any significant effect of fertilisation on the number of species or the proportion of any particular plant species or group.

The limited impact of fertilisation is also evident in Fig. 6, where the plots of blocks 1 and 3 are clearly separated.

Table 4. Vegetation versus N_{tot} in peat (5–10 cm) and groundwater level (WT) (Pearson´s correlation coefficient) in control (n=6) and fertilised (n=18) plots.

Taulukko 4. Keskeisten kasvitaksonien sekä turpeen totaalitypen (N_{tot}) ja pohjavesipinnan syvyyden (WT) väliset korrelaatiot kontrolli- (n=6) ja lannoitetuilla (n=18) koealoilla.

Variable *Muuttuja*	Plots *Koealat*	Forest moss. *Metsäsamm.*	*Eriophorum vaginatum*	*Betula nana*	*Sphagna*	*Androm. polifolia*	*Rubus chamaem.*
Peat N_{tot},	control	0.897*	–0.452	–0.049	–0.172	–0.639	–0.849**
	fertilised	0.791**	0.129	–0.098	–0.520*	–0.653	–0.787**
WT	control	0.950**	0.520	–0.112	–0.282	–0.709*	0.890*
	fertilised	0.638**	–0.040	–0.070	–0.586**	–0.722**	0.621**

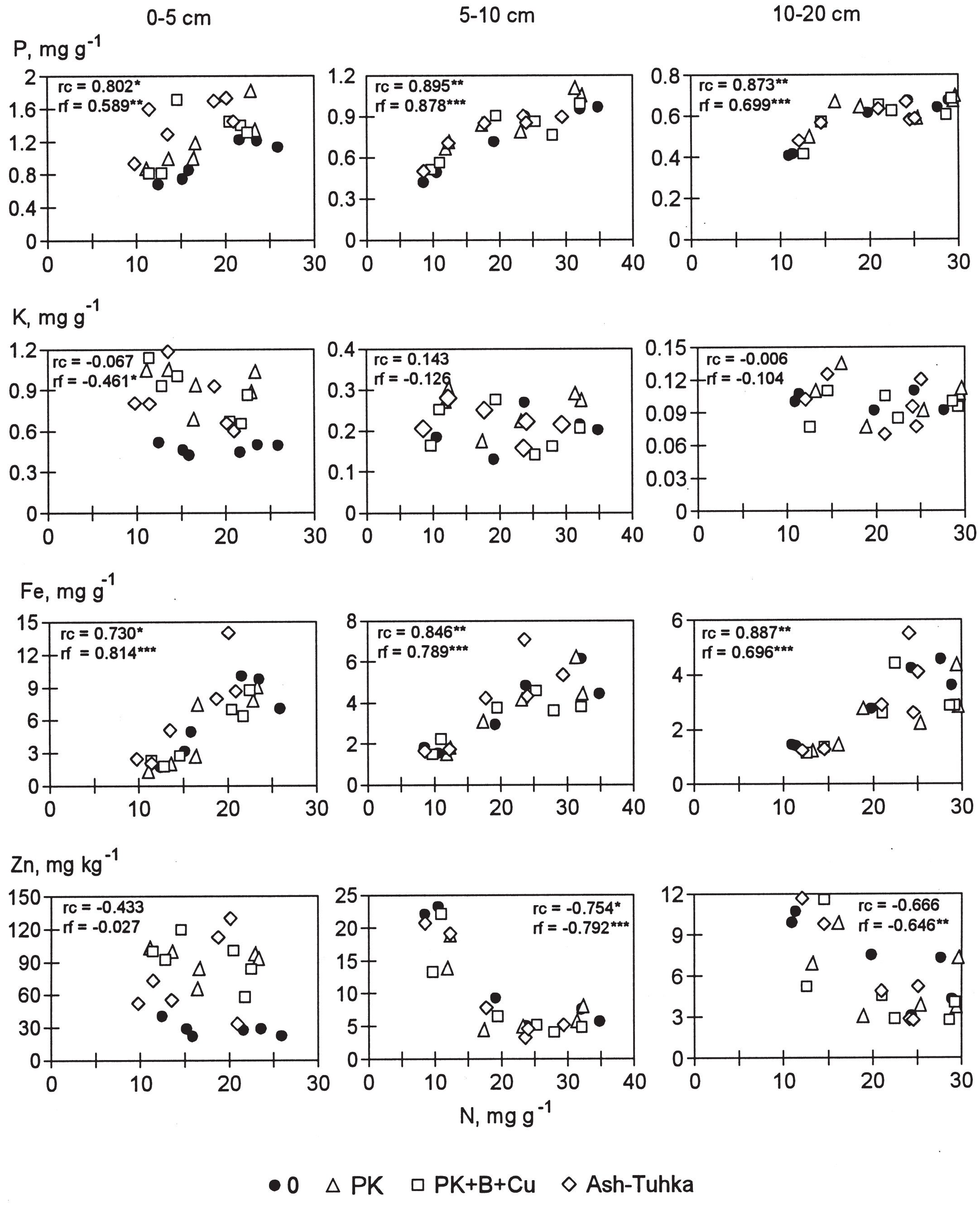

Fig. 7. Relationships between the peat total phosphorus, potassium, iron and zinc concentrations with the peat total nitrogen concentration in 0–5, 5–10 and 10–20 cm layers. Each mark is the mean of four sampling times. Explanations as in fig. 3.

Kuva 7. Turpeen kokonaisfosfori- kalium- ja sinkkkipitoisuuden sekä turpeen kokonaistyppipitoisuuden väliset vuorosuhteet 0–5, 5–10 ja 10–20 cm:n kerroksessa. Jokainen merkki on neljän havaintokerran keskiarvo. Selitykset kuten kuvassa 3.

DISCUSSION

Several studies have shown that the total nitrogen and phosphorus concentrations correlate positively in peat (Vahtera 1955, Holmen 1964, Westman 1981, Kaunisto & Paavilainen 1988 and Silfverberg & Hartman 1999) and also that the correlation between the concentrations of iron and phosphorus is positive (Nieminen & Jarva 1996). In addition, the phosphorus and iron concentrations increase with the proportion of the *Carex* peat component (Kivinen 1934, Urvas et al. 1979).

In this study it was possible to compare the relationships between the physical properties of peat and the peat nutrient concentrations within the same quite limited peatland area and within an originally similar main site type, although fertilisation slightly hampered the results. Nitrogen, phosphorus and iron were in close positive correlation with each other and their concentrations increased along with the increasing proportion of the *Carex* peat component. This result is interesting because tree growth has a highly positive correlation with the total nitrogen concentration of peat (Kaunisto 1987) and, on the other hand, the leaching of phosphorus is negatively correlated with the amount of iron in peat (Nieminen & Jarva 1996). It seems that the potentially best sites for growing trees in this study had higher proportions of *Carex* residues, higher concentrations of N and Fe and thus presumably lower susceptibility to leaching of fertiliser phosphorus than the nitrogen-poor parts of the research area.

In the microscopic study, most of the peat components could be further identified as types, sections and even individual species, exept the more humified *Sphagnum* samples. However, this added resolution did not give any significantly higher correlations between the peat nutrients and the peat components. Usually the occurrence of *Carex* residues on ombrotrophic and oligotrophic sites is much smaller than on oligo-mesotrophic or eutrophic sedge fens (Vahtera 1955, Laine & Vasander 1990), but it is also known that the *Carex* groups *Limosa* and *Chordorrhiza* have no differences in the trophic status (Laine et al. 2000).

Fertilisation did not affect the degree of humification. This contradicts somewhat with the results by Huikari (1953) who found a great increase in the bacterial body and by Karsisto (1979) who found a great increase also in the decomposition of cellulose due to the application of wood ash. A reason may be the low nutrient amounts of the applied wood ash.

There was, however, a significant rise, particularly in the 0–5 cm peat layer, in the concentrations of all the studied nutrients, except iron, after wood ash application. These results agree well with Silfverberg & Huikari (1985). The amount of applied phosphorus in practical forestry, and also in this investigation, is usually less than 30% (1/3–1/4) of the total amount of native phosphorus in the 0–20 cm peat layer on oligo-mesotrophic sites (Kaunisto & Paavilainen 1988, Laiho & Laine 1994). In this study phosphorus concentrations were higher on the fertilised plots than on the controls but statistically significantly only in the ash fertilised ones. This is somewhat surprising because the amount of applied phosphorus was 17 kg ha^{-1} higher in the PK fertiliser than in wood ash.

The potassium amounts applied were of the same magnitude as the amounts of native potassium in the 0–20 cm peat layer of pine mires and clearly higher than on treeless mires (Kaunisto & Paavilainen 1988, Laiho & Laine 1995, Kaunisto & Moilanen 1998, Sundström et al. 2000). Fertilisation increased potassium concentrations statistically significantly only on the wood ash fertilised plots. In the PK fertiliser potassium was added as water-soluble potassium chloride. Potassium is bound in peat only on cation exchange sites and is very susceptible to leaching (Malcolm & Cuttle 1983). In wood ash, potassium is in the form of K_2CO_3, which is more slowly soluble than KCl used in PK fertiliser (e.g. Haveraaen 1986, Silfverberg 1998). The amount of applied potassium in this study was slightly higher (13 kg ha^{-1}) in wood ash than in the PK fertiliser. The higher potassium concentrations on the ash plots may be due to the higher amount of potassium in wood ash but more probably due to its lower solubility in wood ash than in the PK fertiliser.

There was a decreasing trend in the total Zn concentrations along the increasing peat total ni-

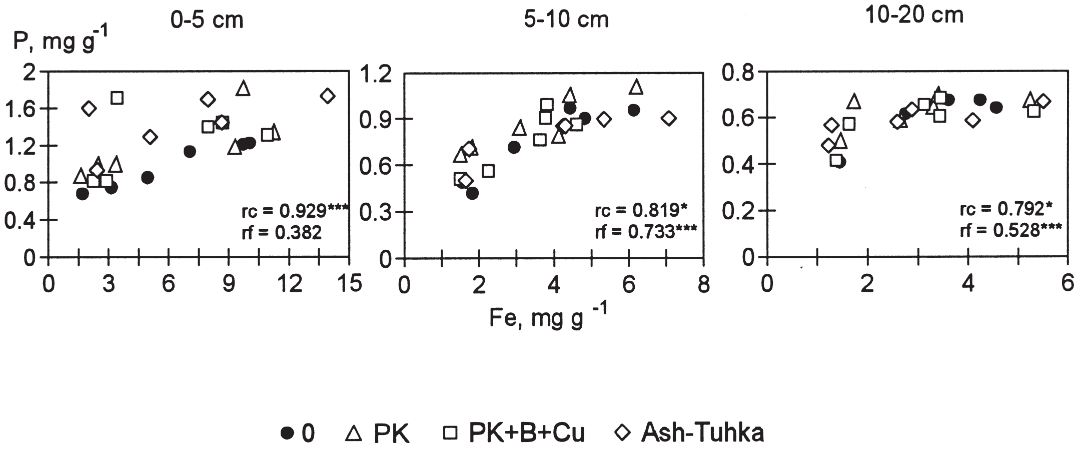

Fig. 8. Relationships between the total iron and phosphorus concentrations on unfertilized and fertilized plots at different depths in peat. Explanations as in Fig. 3.

Kuva 8. Turpeen kokonaisfosfori- ja kokonaisrautapitoisuuden väliset vuorosuhteet eri turvekerroksissa. Selitykset, kuten kuvassa 3.

trogen gradient. Also Kaunisto & Paavilainen (1988), Kaunisto & Moilanen (1998) and Sundström et al. (2000) have found quite low zinc concentrations in nitrogen-rich, old drainage areas.

The interpretation of the results as regards the ground vegetation is complicated because of the strong positive linkage of the peat nitrogen concentration and the stand volume and the linkage between these and the ground water depth. At least partly, the differences between the ground water levels were probably caused by differences in stand volumes between the blocks. In addition to the drainage intensity, the ground water table is dependent on tree growth and timber volume (Paavilainen & Päivänen 1995); the higher the timber volume and the more vigorous the tree growth, the lower is the ground water table. This is due to the increase in the interception and transpiration of trees (Päivänen 1974).

Sphagnum species were the most common and the forest moss species the most infrequent on the plots with a high ground water level and a low nitrogen concentration. The vegetation resembled most that of mineral soil forests on Block 1 that had the lowest ground water level, the highest total nitrogen concentration in the peat and the highest stand volume. This consequence of effective drainage and high site fertility corresponds well with earlier studies (Sarasto 1957, Reinikainen 1984, Vasander 1990, Vasander et al. 1993), which have shown that the mire vegetation on nitrogen-rich sites transforms to resembling heath forest vegetation more rapidly than that on nitrogen-poor sites.

The species composition of the ground vegetation was not significantly affected either by ash or PK fertilisation. These results are contradictory to the results by Huikari (1951), Reinikainen 1965, Päivänen & Seppälä (1968) and Päivänen (1970). E.g. Päivänen & Seppälä found a considerable increase in the proportion of forest mosses and *Eriophorum vaginatum* and decrease in *Sphagnum* species only three years after PK application. Huikari (1953) found great changes in the ground vegetation a little more than ten years after the application of wood ash. One reason for the insignificant differences in vegetation after wood ash fertilisation in the present study may be the nutrient-poor ash applied. However, as shown before, wood ash fertilisation increased nutrient concentrations in the surface peat. Some of the species studied (e.g. *Betula nana, Eriophorum vaginatum, Rubus chamaemorus*) were generalists occurring over the whole nitrogen gradient. They possess a wide tolerance against changes both in soil fertility, light and drainage conditions (Reinikainen 2000, Hotanen 2000).

CONCLUSIONS

The concentrations of nitrogen, phosphorus and iron in peat were in close positive correlation and also in keen correlation with the proportion of the *Carex* peat component. This implies that the potentially best sites (high N) for growing trees were the least susceptible to leaching of fertiliser phosphorus (high Fe). The occurrence of forest mosses increased with the increasing total nitrogen concentration of peat, indicating that the development of peatland sites from pristine to the transformed stage had occurred faster on the nitrogen-rich, *Carex*-dominated sites than on the nitrogen-poor sites. The reasons to the changes in the ground vegetation, however, were somewhat obscure because of the close connections between the peat nitrogen status, ground water level and the standing tree stock. Wood ash and PK fertilisation had little impact on the vegetation and the components and humification of the peat.

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TIIVISTELMÄ

Turpeen ominaisuudet ja kasvillisuus metsitetyn ja lannoitetun avosuon eri trofiatasoilla

JOHDANTO

Turpeen typpipitoisuus on avainasemassa arvioitaessa kannattavan puuntuotannon mahdollisuuksia suolla. Muiden ravinteiden lisääminen edistää puuston kasvua taloudellisesti kannattavasti vain olosuhteissa, joissa typpeä vapautuu riittävästi puille käyttökelpoiseen muotoon. Tässä tutkimuksessa selvitetään turpeen typpipitoisuuden ja eräiden eräiden muiden turpeen ravinteiden, turvetekijöiden, maatumisasteen ja pintakasvillisuuden välisiä riippuvuuksia ja miten lannoitus vaikuttaa näihin muuttujiin metsitetyllä ja lannoitetulla avosuolla.

AINEISTO JA MENETELMÄT

Aineisto koottiin vuosina 1995–97 Enso Gutzeit Oy:n maalle Ilomantsin Särkkään vuosina 1981–1982 perustetulta taimikon jatkolannoituskokeelta (koejärjestely, ks Kaunisto 1987). Ojitettaessa (1970–71) suotyyppi koealueella vaihteli rahkanevasta ruohoiseen saranevaan ja turpeen typpipoisuus v. 1995 vastaavasti 0,87 ja 2,91 %:n välillä. Niukkatyppisimmällä lohkolla koealuetta puuston tilavuus oli vain 1/3 runsastyppisimmän lohkon puustosta ja pohjavesi oli pinnallisin (Taulukko 1).

Alue kylvettiin männylle v. 1970–71 ja laikkulannoitettiin. Vuosina 1981–82 alue jaettiin 0,16–0,20 ha:n koealoihin ja jatkolannoitettiin. Koealue jaettiin sijainnin ja turpeen typpipitoisuuden perusteella kolmeen lohkoon. Kokeen 14 erilaisesta lannoitus- ja maanparannuskäsittelystä tähän tutkimukseen valittiin neljä: lannoittamaton vertailu, raakafosfaatti + kalisuola, edellinen + lannoiteboraatti + kuparioksidi sekä tuhkalannoitus 5 000 kg ha^{-1}. Fosforia tuli koealoille vastaavasti 0, 45, 45 ja 28 kg ha^{-1} ja kaliumia 0, 78, 78 ja 90 kg ha^{-1} (muut ravinteet ks Kaunisto 1997). Jokaisesta käsittelystä valittiin kuusi koealaa siten, että ne edustaisivat mahdollisimman tasaista ja laajaa turpeen typpipitoisuuden vaihtelua (Kuva 1). Lohkolle 1 tuli tällä tavoin yhdeksän, lohkolle 2 seitsemän ja lohkolle 3 kahdeksan koealaa.

Kesällä 1995 koealoilta otettiin turvenäytteet neljä kertaa kemiallisia analyysejä varten ja kesällä 1997 kerran turpeen maatumisasteen ja turvelajin määritystä varten. Turpeesta analysoitiin kokonaistyppi, -fosfori, -kalium, -kalsium, -magnesium, -rauta, -mangaani, -sinkki, -kupari ja -boori. Turpeen maatuneisuus määritettiin sekä von Postin menetelmällä että mikroskooppisesti. Pintakasvillisuus inventoitiin kuudelta 0,5 m^2:n ympyrältä jokaiselta koealalta ottaen mukaan kaikki pohja- ja kenttäkerroksen kasvilajit v. 1995.

TULOKSET

Saraturvetta oli eniten runsastyppisimmällä ja vähiten niukkatyppisimmällä osalla koealuetta (Kuva 2). Turpeen typpi, fosfori- ja rautapitoisuudet lisääntyivät saraturvetekijän osuuden lisääntyessä (Kuva 3), turpeen kaliumpitoisuus ei korreloinut merkitsevästi saraisuuden kanssa. Saraturpeet olivat keskimäärin maatuneempia kuin rahkaturpeet (Kuva 4). Turpeen typpi- fosfori- ja rautapitoisuus kohosivat turpeen maatuneisuuden lisääntyessä (Kuva 5). Turpeen kaliumpitoisuus oli maatuneisuudesta riippumaton. Lannoitus ei vaikuttanut merkitsevästi turpeen maatuneisuuteen eikä turvelajien osuuksiin (Kuva 3).

Metsäsammalten osuus lisääntyi ja rahkasammalten peittävyys aleni turpeen typpipitoisuuden kohoamisen ja pohjavesipinnan syvenemisen myötä (Taulukko 4, Kuva 6). Lannoitus ei vaikuttanut tilastollisesti merkitsevästi pintakasvillisuuden peittävyyssuhteisiin tai lajikoostumukseen.

Tuhkalannoitus lisäsi turpeen fosforin, kaliumin, kalsiumin, magnesiumin, mangaanin, boorin, kuparin ja sinkin määriä 0–5 cm:n pintaturvekerroksessa sekä kalsiumin, magnesiumin ja mangaanin määriä myös syvemmissä turvekerroksissa (Taulukko 3). Tuhkalannoitettujen koealojen muita käsittelyjä korkeampaan kaliumpitoisuuteen lienee syynä lähinnä se, että tuhkassa kalium ei ole yhtä liukoisessa muodossa kuin PK-lannoitteessa, jossa se on täysin vesiliukoisena kaliumkloridina. Turpeen kokonaisfosfori- ja -rautapitoisuus korreloivat positiivisesti ja sinkkipitoisuus negatiivisesti turpeen kokonaistyppipitoisuuden kanssa (Kuva 7). Myös kokonaisfosfori- kokonaisrautapitoisuus korreloivat keskenään positiivisesti (Kuva 8). Turpeen kaliumpitoisuus ei korreloinut em. alkuaineiden kanssa. Turpeen typen, fosforin ja raudan välinen positiivinen korrelaatio on tärkeä suometsien kasvatuksessa, koska puuston hyvä kasvu edellyttää riittävää typen saantia ja toisaalta fosforin huuhtoutuminen on sitä vähäisempää, mitä enemmän turpeessa on rautaa.

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Appendix 1. Coverages (%) of plant species found in blocks 1–3. *Liitetaulukko 1. Kasvitaksonien peittävyydet (%) lohkoilla 1–3.*

	BLOCK – *LOHKO*		
PLANT SPECIES – TAKSONI	I	II	III
DWARF SHRUBS + SEEDLINGS – *VARVUT + TAIMET*			
Betula pubescens	1.3	0.1	+
Picea abies	0.4		
Pinus sylvestris	+	1.0	0.3
Sorbus aucuparia	0.2		
Betula nana	0.9	11.8	1.9
Juniperus communis	0.4		
Andromeda polifolia	0.5	6.4	9.7
Calluna vulgaris			0.4
Chamaedaphne calyculata		+	0.5
Empetrum nigrum	0.1	1.4	9.4
Lycopodium annotinum	0.4		
Vaccinium myrtillus	0.1	0.3	
Vaccinium oxycoccos	0.1	3.0	1.4
Vaccinium uliginosum	0.3	1.2	1.7
Vaccinium vitis-idaea	1.9	0.4	
GRASSES, SEDGES – *HEINÄT, SARAT*			
Agrostis capillaris	0.2		
Calamagrostis arundinacea	0.5		
Calamagrostis purpurea	0.4		
Carex brunnescens	0.4		
Carex canescens		+	
Carex globularis			+
Carex lasiocarpa	+		
Carex magellanica			+
Carex spp.	0.3		+
Deschampsia cespitosa	0.6		
Deschampsia flexuosa	2.8		
Eriophorum angustifolium	0.1	+	
Eriophorum vaginatum	0.2	5.6	1.3
Molinia caerulea	5.1		

	BLOCK – *LOHKO*		
PLANT SPECIES – *TAKSONI*	I	II	III
HERBS – *RUOHOT*			
Drosera rotundifolia			+
Dryopteris carthusiana	4.4	+	
Epilobium angustifolium	0.7	+	
Gymnocarpium dryopteris	+	0.2	
Orthilia secunda	0.1		
Rubus chamaemorus	1.2	3.5	
13.1			
Trientalis europaea	0.5		
MOSSES – *SAMMALET*			
Aulacomnium palustre	4.3	3.7	1.8
Dicranum polysetum	3.6	0.9	
Dicranum scoparium	0.1		+
Dicranum undulatum	0.6	0.7	+
Hylocomium splendens	+		
Pleurozium schreberi	10.2	10.4	2.0
Pohlia nutans		+	0.2
Polytrichum commune	28.5	3.5	
Polytrichum juniperinum		0.1	
Polytrichum strictum	3.7	23.0	7.7
Ptilium crista-castrensis		+	
Mylia anomala			0.3
Sphagnum angustifolium	1.9	2.8	0.2
Sphagnum fuscum		3.4	8.7
Sphagnum magellanicum			0.4
Sphagnum nemoreum		+	+
Sphagnum russowii	0.8	21.0	9.9
Sphagnum rubellum	0.4	0.7	0.3
LICHENS – JÄKÄLÄT			
Cetraria islandica	+		+
Cladonia arbuscula	0.1	0.2	0.2
Cladonia rangiferina	0.1	0.3	0.5
Cladonia spp.	+		0.1