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NUTRIENT STORES IN OLD DRAINAGE AREAS AND GROWTH OF STANDS

SEPPO KAUNISTO &
EERO PAAVILAINEN

SELOSTE

TURPEEN RAVINNEVARAT VANHOILLA OJITUSALUEILLA JA PUUSTON KASVU

HELSINKI 1988

COMMUNICATIONES INSTITUTI
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(METSÄNTUTKIMUSLAITOS)

Unioninkatu 40 A
SF-00170 Helsinki
FINLAND

Director:
Professor Aarne Nyyssönen

telex: 121286 metla sf

phone: 90-661 401

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Cover (front & back): Scots pine (*Pinus sylvestris* L.) is the most important tree species in Finland. Pine dominated forest covers about 60 per cent of forest land and its total volume is nearly 700 mil. cu.m. The front cover shows a young Scots pine and the back cover a 30-metre-high, 140-year-old tree.

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Approved on 27.5.1988

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The investigation was carried out on 50 experimental plots representing different site types in old (53—78 a) drainage areas that had all reached the transformed stage (i.e. the ground layer was dominated by species typical of mineral soil sites). The total nitrogen and phosphorus amounts and concentrations explained fairly well the total yield of stemwood as well as growth in the period preceding the latest measurement. The amount of easily soluble phosphorus, however, correlated negatively with the yield. Compared to the nutrient amounts required by trees there were large amounts of nitrogen and phosphorus in the surface peat layer, but little potassium, boron and zinc. The peat surface was usually covered with a raw humus layer, whose density and nutrient amounts were low, although the nutrient concentrations were high.

On open mires the phosphorus fertilization applied 33 years previously still had some effect on the phosphorus amounts of peat, although larger applications (140 and 280 kg/ha of P) had resulted in leaching of a considerable part of phosphorus. From the simultaneously applied potassium fertilizer (KCl) there was very little (a. 10 kg/ha) left in peat, although the largest potassium applications amounted to 800 kg/ha of K. Trees had used part of potassium, while the majority of it had leached away from the area.

Tutkimus toteutettiin 50 vanhalla (53—78 v) erilaisten korpien, rämeiden ja nevojen ojituskoealalla, jotka kaikki olivat saavuttaneet turvekangasvaiheen. Turpeen kokonaistypen ja -fosforin määrä ja myös niiden pitoisuudet selittivät verrattain hyvin runkopuun kokonaistuotosta ja myös kasvua viimeistä mittausta edeltävänä jaksona. Sen sijaan liukoisen fosforin määrä korreloi negatiivisesti tuotoksen kanssa. Puuston tarvitsemiin ravinnemääriin verrattuna pintaturpeessa oli runsaasti typpeä ja fosforia. Sen sijaan kaliumia, booria ja sinkkiä oli niukasti. Turpeen pinnalle oli yleensä kehittynyt raakahumuskerros, jonka tiheys ja ravinnemäärät olivat vähäisiä, vaikkakin ravinnepitoisuudet olivat korkeita.

Avosuolla 33 vuotta aikaisemmin tehty fosforilannoitus vaikutti vielä jonkin verran turpeen fosforimääriin, mutta varsinkin suurimmilla määrillä (140 ja 280 kg/ha P) huomattava osa fosforista oli huuhtoutunut. Samaan aikaan annetun kalilannoituksen (KCl) vaikutus näkyi turpeessa enää erittäin vähäisenä kaliumin lisäyksenä (n. 10 kg/ha), vaikka kaliumia oli enimmillään annettu 800 kg/ha. Puusto oli käyttänyt osan kaliumia, mutta valtaosa oli huuhtoutunut kokonaan pois alueelta.

Key words: peatlands, fertilization, leaching
ODC 2--114.444+114.31+237.4+56

Authors' addresses: *Kaunisto:* The Finnish Forest Research Institute, Parkano Research Station, SF-39700 Parkano; *Paavilainen:* The Finnish Forest Research Institute, Department of Peatland Forestry, PL 18, SF-01301 Vantaa, Finland.

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PREFACE

The results from the National Forest Inventories show that the growth of peatland stands in Finland has strongly increased as a result of drainage and fertilization particularly during the last decade. The predictions imply that the growth increment on drained peatlands and on those still drainable for forestry, approximately 6.5 million hectares in all, may be 15 million m^3 a year at the beginning of the next century.

The prerequisite for the favourable development in the growth of standing crops is that no unexpected factors weaken the wood production ability of peatland sites. In this respect, the future situation should be very closely estimated. It is particularly important to find out whether the natural peat nutrient resources are sufficient to ensure the long-term growth of stands. Nutrient shortages lead to a decreased growth of trees on peatlands quite rapidly and may in the worst cases lead to death, as shown by the results from fertilization and nutritional growth disturbance investigations.

For further information on peatland nutrient resources and their sufficiency for growing forests on different peatland site types, the authors started this investigation in 1985 as part of a more extensive research series. Mr Heikki Takamaa, the For. Eng., was in charge of peat sampling and field measurements. The nutrient analyses were mostly carried out at the Parkano Research Station by Ms Arja Ylinen and Ms Eeva Pekonen. The analyses were checked at the Central Laboratory of the Finnish Forest Research Institute under the supervision of Dr Maija Jarva. Typing was done by Ms Tuire Kilponen and Ms Tiina Luoto. The figures were drawn by Ms Anja Ripatti. Mr Tauno Suomilammi, Mr Lauri Hirvisaari and Mr Markku Nikola were responsible for the handling of the material and Ms Riitta Heinonen, M.A., and Ms Riitta Saarinen supervised the statistical analyses. Ms Leena Kaunisto, M.A., translated the text from Finnish into English. Prof. Eino Mälkönen, Prof. Juhani Päivänen and Mr Antti Reinikainen, Lic. Sci, read the manuscript giving worth-while suggestions.

We wish to thank all persons involved for their valuable contribution.

Parkano and Vantaa, April 1988

Seppo Kaunisto   Eero Paavilainen

1. INTRODUCTION

The growth of trees on drained unfertilized mires depends on the natural nutrient resources of peat. Additional nutrients may come to the root layer only from the air or the underlying mineral soil. The drainage system prevents nutrients from spreading to mires from the surrounding mineral soil sites. On virgin ombrotrophic mires the amount of nutrients from the surrounding mineral sites is in any case confined to rather a narrow area between the mire and firmland. As trees on mires have rather superficial roots and their penetration deeper even after effective drainage is quite ineffective (e.g. Heikurainen 1955, Paavilainen 1966), the subsoil is not a remarkable source of nutrients except on mires with thin peat layers.

When assessing the sufficiency of the natural nutrient resources of the substrate for growing trees on mires, the focus should be on the top layer of peat, where most of the nutrient-taking roots lie. The concentrations of mineral nutrients, for example potassium and phosphorus, are at their highest right in the surface layers and decline abruptly when going down even during the first tens of centimetres (e.g. Vahtera 1955, Kaila and Kivekäs 1956, Holmen 1964, Pakarinen and Tolonen 1977, Westman 1981). This surface layer is also most strongly affected by drainage. Removal of water, consequent subsidence of peat, increasing weight of trees and enhanced decomposition of peat increase the bulk density, and the activated microorganisms speed up the nutrient cycle.

At the time of the first drainage peatland tree stands are not usually fully stocked and have incomplete crown coverage. Nutrients become bound in large amounts by the recovering trees as well as by the ground vegetation after drainage. The nutritional balance will change further when nutrients are removed from the site in the harvested biomass as cutting possibilities increase. The amount of removed nutrients depends on what parts of biomass are utilized, as the majority of nutrients are in crowns, particularly in foliage (Holmen 1964, Mälkönen 1974, 1976, 1977, Miller et al. 1980, Paavilainen 1980). Out of the nutritionally important elements nitrogen and potassium are removed in largest amounts at harvesting. On the basis of the nutrient resources on both virgin pine mires (Westman 1981) and pine and spruce mires drained for a few decades earlier (Holmen 1964, 1967) there have been doubts about the sufficiency of potassium reserves, as there are smaller amounts of it than nitrogen and phosphorus in relation to the amount used by the trees.

As the drainage areas become older, they come to a greater extent and more frequently in the sphere of cuttings and thus more nutrients than before will be removed. It is important to find out the nutrient resources that the tree stands in drainage areas depend on in different situations. In this respect old drainage areas where the trees have repeatedly been measured are important sources of knowledge. The nutrient amounts both in peat and trees as well as the nutritional balance at different times after drainage can be compared.

This study focuses on finding out the nutrient resources of originally different peatland site types 53-78 years after drainage, during which time the stands have undergone several cuttings. In addition to the surface layer (0-20 cm) of peat, which is of the greatest importance for the growth of the tree stand, also the nutrient concentrations and amounts in deeper peat layers were included in the study. In addition the dependence between the natural nutrient resources of the peat and the yield of tree stands is investigated and the sufficiency of nutrients is discussed. Furthermore the effect of fertilization on the nutritional balance is being investigated in two experiments. The investigation is the first part in a series dealing more extensively with the nutrient resources of peatlands drained for forestry.

2. MATERIAL AND METHODS

The material was collected from 50 permanent sample plots established on drained peatlands by the Department of Peatland Forestry of the Finnish Forest Research Institute. The sample plots are in the experimental areas of Vilppula (Jaakkoinsuo and Kaakkosuo) and Vesijako in southern Central Finland. The basic drainage had mostly been carried out in the first decades of this century, while the stand measurements started at the turn of the 1920s and 30s (Table 1).

All the sample plots of Kaakkosuo were established on deep-peat open mires and those of Vesijako on moderately deep-peat spruce mires. The widest range of peatland site types was in Jaakkoinsuo where sample plots were on open, spruce and pine mires. In Jaakkoinsuo the peat layers were usually rather thin. The average peat depth on dwarf-shrub pine mires was about 1.3 m and on the other site types about 0.4 m (0.1—0.6 m). By the time of sampling all the sample plots were transformed peatlands (the ground layer was dominated by species typical of mineral soil sites).

Ditch spacings varied to a great deal on the sample plots and ditches had been made manually. Mainly unfertilized sample plots were chosen for the investigation with the exception of some fertilized plots in Kaakkosuo and Jaakkoinsuo.

The following fertilization treatments were chosen from the experiments on the dwarf-shrub pine mire in Jaakkoinsuo:

	Fertilization, kg/ha					
	in 1965			in 1974		
	N	P	K	N	P	K
1.	0	0	0	0	0	0
2.	70.5	30.5	41.5	0	0	0
3.	0	0	0	104.0	51.5	62.5
4.	70.5	30.5	41.5	104.0	51.5	62.5

The fertilizers used were as follows: in 1965 NPK-fertilizer (14-7.7-8.3) where phosphorus was as superphosphate and in 1974 calciumammoniumnitrate (26 % N) + PK-fertilizer (0-10.3-12.5) where phosphorus was as rockphosphate.

Four plots established on an open tall-sedge mire were included from Kaakkosuo. They had been fertilized with renophosphate (finely ground rock phosphate 13.8 % P) and potassium chloride (39.8 % K) in 1953 as follows:

	P	K
	kg/ha	
1 =	0	0
2 =	70	200
3 =	140	400
4 =	280	800

Table 1. Basic information about the sample plots.
Taulukko 1. Perustietoja koealoista.

Location *Paikka*	Basic drainage[1)] *Perusojitus[1)]*	Stand measurements started *Puuston mittaukset aloitettu*	Fertilization *Lannoitus*	Plots *Koealoja*	Original site types[2)] (No of plots) *Alkuperäiset suotyypit[2)] (Koealojen lukumäärä)*	Peat depth *Turpeen paksuus, m* Min./Max.	x̄	Raw humus *Raakahumus cm* Min./Max.	x̄	Ditch spacing *Sarkaleveys m*
Vesijako 61°23′N 25°03′E	1907–32	1932	—	10	RhK (2), MK (5) PK (3)	0.5–5.2	1.8	5.0–10.0	6.6	65–120
Jaakkoinsuo 62°03′N 24°30′E	1909–23	1928	1965/74	24[3)]	RhK (2), VNK (2), RäK (1), KR (1), RhSR (4), VSR (3) IR[3)](9), VSN (2)	0.1–2.5	0.7[4)]	0.0–10.0	4.5	20–125
Kaakkosuo 62°04′N 24°29′E	1915	1957	1953	16	VSN (16)	1.6	1.6	0.0–6.0	3.8	20–61

1) In Vesijako most plots were drained in 1907 or 1914, and in Jaakkoinsuo with two exceptions all in 1909. — *Vesijaolla useimmat koealat ojitettiin 1907 tai 1914, Jaakkoinsuolla kahta poikkeusta lukuunottamatta 1909.*

2) RhK = Herbrich spruce mire
MK = *Vaccinium myrtillus* spruce mire
PK = *V. vitis idaea* spruce mire
VNK = Sedge-rich spruce mire
RäK = *Carex globularis* spruce mire
KR = Spruce-pine mire
RhSR = Herb-rich pine mire
VSR = Tall-sedge pine mire
IR = Dwarf-shrub pine mire
VSN = Tall-sedge open mire

3) Three plots fertilized. — *Kolme koealaa lannoitettu.*

4) IR 1.3 m, others — *muut 0.4 m*

Each sample plot in Kaakkosuo had been further divided into four subplots, each of which had been fertilized either with borate 10 kg/ha (14 % B = 1.4 kg/ha), zinc sulphate 50 kg/ha (23 % Zn = 11.5 kg/ha) copper sulphate 50 kg/ha (25 % Cu = 12.5 kg/ha) or manganosulphate 50 kg/ha (26 % Mn = 13 kg/ha). Thus PK fertilization had only one replicate, but micronutrient fertilization four.

The sample plots of Kaakkosuo had been set up in a peatland area that had originally been an open mire, but which had been sown with birch in the 1930s. In 1960 (seven years after fertilization) the fertilized plots were stocked with a gapped mixed stand of 0.2—2.0 -metre-tall and the unfertilized ones with 0.1—1.0 -metre-tall *Betula pubescens* and *Pinus sylvestris.* At the time of drainage (in 1909) the sample plots on the open mire in Jaakkoinsuo had some birch, pine and spruce seedlings. All the other sample plots were stocked with trees at the time of drainage.

Stand characteristics have been repeatedly measured on the plots. The times of measurements have, however, varied considerably between the plots. The last measurement was carried out in 1982—1986. Stand data were converted to the level of 1985 by utilizing the annual mean growth of the last measurement period.

In the autumn of 1985 peat samples for nutrient analyses were taken from each sample plot systematically from five points: in the middle of the plot and on diagonals some 4—5 metres from the corners of the plots. In each sampling point two adjacent samples from a level surface were taken. In Kaakkosuo the samples were taken from each subplot fertilized with micronutrients, so that 20 double samples came from each PK fertilized sample plots.

In most cases quite a loose raw humus layer of varying thickness, consisting of litter and *Pleurozium schreberi,* was found on peat surface. The raw humus layer was separated to its own subsample. Peat samples were taken as 10-cm-thick layers down to 50 cm. If the peat layer was shallower than 50 cm, sampling went down to the mineral soil. The volume of the peat subsample was 200 cm^3.

Subsamples from five points were combined by layers, stored in the freezer and analyzed at the Parkano Research Station. One of the double samples was determined for easily soluble P (from NH_4OAc extract, pH 4.65), NH_4 nitrogen and exhangeable Ca and K. The other was analyzed for the bulk density and the total N, P, K, Ca, Mg, Zn, B, Cu and Mn by the usual methods of the Finnish Forest Research Institute (see Halonen et al. 1983), phosphorus and boron by spectrophotometer and the other nutrients by the atomic absorption spectrophotometer.

The values of all the other nutrients except nitrogen and boron were further checked by the inductively coupled plasma emmission spectrometer (ICP) at the Central Laboratory of the Finnish Forest Research Institute from solutions made of samples representing layers 0—10 and 10—20 cm. In the case of zinc there were three distinctly deviating observations. Considerably higher values were obtained by AAS than ICP. These samples were omitted when calculating a regression line for zinc. The correlation between different analyses in all the cases was fairly solid (Table 2). The correlations between the phosphorus values were the weakest, yet above 0.90. The parallel analyses carried out at the Central Laboratory of the Finnish Forest Research Institute confirmed thus the reliability of nutrient analyses performed in Parkano.

Table 2. Regression equations between the nutrient concentrations carried out from the same solution with atomic absorption spectrophotometer or spectrophotometer (y) and with ICP emission spectrometer (x).

Taulukko 2. Samasta liuoksesta atomiabsorptiospektrofotometrillä tai spektrofotometrillä (y) ja ICP plasma-analysaattorilla (x) määritettyjen ravinnepitoisuuksien väliset regressioyhtälöt.

Nutrient *Ravinne*	Equation *Yhtälö*	r
P	$y = 1.09x - 0.016$	0.906
K	$y = 0.94x + 0.005$	0.985
Ca	$y = 0.96x + 0.091$	0.990
Mg	$y = 1.04x - 0.007$	0.990
Cu	$y = 1.08x - 0.000$	0.990
Zn1)	$y = 0.96x + 0.001$	0.990
Mn	$y = 1.14x - 0.001$	0.954

1) The deviating zinc values (3 observations out of 71) of one sample plot were omitted. — *Yhden koealan muista poikkeavat sinkkiarvot (3 havaintoa 71:stä) poistettu.*

Table 3. Regression equations between the total nutrient concentrations carried out with nine months' interval from homogenized peat samples1). The first determination y, the second x.

Taulukko 3. Homogenisoiduista turvenäytteistä 9 kk:n välein määritettyjen kokonaisravinnepitoisuuksien väliset regressioyhtälöt 1). Ensimmäinen y, toinen x.

Nutrient *Ravinne*	Equation *Yhtälö*	r
P	$y = 0.63x + 221.3$	0.794
K	$y = 1.04x - 4.429$	0.959
Ca	$y = 1.04x - 36.63$	0.970
Mg	$y = 1.11x - 49.30$	0.964
Cu	$y = 0.67x + 1.556$	0.866
Zn	$y = 0.89x - 0.580$	0.949
Mn	$y = 1.26x + 4.931$	0.906

1) One deviating observation out of 61 omitted.
1) Yksi poikkeava havainto 61:stä poistettu.

In addition, a recombustion of 61 homogenized samples from the 0—10 and 10—20 cm layers was carried out in order to find out the homogeneity of the milled sample. The nutrient analyses were carried out in Parkano. The correlations were high, although the dispersions were clearly larger than those between the two before-mentioned analysis methods (Table 3). Also in this case the correlations concerning phosphorus were the weakest. In the case of phosphorus and copper the latter analyses produced somewhat higher values with low nutrient amounts and lower values with high amounts than the first analyses. The situation was reverse in the case of potassium, magnesium and calcium. Thus even a careful treatment could not ensure full homogenizing, which increases the dispersion of the results to some degree.

In addition to the conventional variance, correlation and regression analyses also the principal component analysis was used for calculations (BMDP... 1985).

3. RESULTS

31. Peat bulk density

Bulk densities found in this investigation on pine mires (Table 4) were about the same as those introduced by Holmen (1964) and somewhat higher than those introduced by Päivänen (1973) for corresponding site types on drained peatlands, but two-threefold compared to the values presented by Westman (1981) for corresponding site types on virgin mires. The comparison to Päivänen's material is not altogether precise, as density in his study was investigated by peat types. The differences to Westman's findings are probably mainly due to a decrease in the water content of peat, increase in decomposition and the increased weight of the tree stand. On deep-peat spruce mires in Vesijako the bulk density increased when going down in peat profile. On the dwarf-shrub pine mires and open sedge mires in Jaakkoinsuo the greatest bulk density was found in the 10—20 cm layer. On the Kaakkosuo open sedge mire the bulk density was greatest in the 0—20 cm layer.

No references to the density of the raw humus layer often existing on transformed peatlands could be found in literature. The determination of the density of the raw humus layer was less accurate than that of peat, as it was often compressed at sampling. Similarly, it was difficult to determine its thickness. The average thickness of the raw humus layer on the plot was used for the calculation.

Table 4 shows that the bulk density of the raw humus layer was without exception only a fraction of the bulk density of peat on all the peatland site types. There was no raw humus layer on the unfertilized plots in Kaakkosuo, which was an open mire at the time of drainage.

32. Peat nutrients

321. Natural nutrient resources

3211. General

In some earlier investigations (e.g. Vahtera 1955, Kaila 1956, Kaila and Kivekäs 1956, Holmen 1964) the main focus was on

Table 4. Peat bulk density (g/cm^3) in different peatland site types.
Taulukko 4. Turpeen tiheys (g/cm^3) suotyypeittäin eri koealueilla.

Layer / *Kerros* [1]	Location and original site type[3] — *Paikka ja alkuperäinen suotyyppi* [3]											
	Vesijako			Jaakkoinsuo								Kaakkosuo
	RhK	MK	PK	RhK	VNK	RäK	KR	RhSR	VSR	IR	VSN	VSN
RH[2]	0.007	0.007	0.005	0.008	0.015	0.005	0.009	0.009	0.010	0.007	0.008	0.006
	±.003	±.002	±.001	±.003				±.001	±.003	±.004	±.000	±.002
0—10	0.116	0.133	0.114	0.180	0.144	0.091	0.135	0.169	0.155	0.094	0.138	0.131
	±.002	±.025	±.026	±.049	±.027	—	—	±.030	±.004	±.015	±.009	±.013
10—20	0.135	0.142	0.118	0.230	0.065	—	0.183	0.166	0.189	0.124	0.151	0.130
	±.027	±.016	±.011	±.079		—		±.019	±.064	±.032	±.008	±.014
20—30	0.143	0.161	0.150	0.165	0.063	—	0.189	0.158	0.131	0.117	0.128	0.114
	±.000	±.017	±.015	—	—	—		±.088	—	.019	±.006	±.017
30—40	0.159	0.168	0.162	0.155	0.044	—	0.050	0.142	—	0.108	0.108	0.107
	±.011	±.018	±.019	—				±.019	—	±.013	±.014	±.019
40—50	0.160	0.172	0.160	—	0.130	—		0.128	—	0.091	0.120	0.102
	±.038	±.017	±.028	—	—			±.050		0.011	±.063	±.20

1) 0—20 cm peat layers include only plots with peat thickness > 30 cm and 20—50 peat layers plots with peat thickness > 50 cm. — *0-20 cm turvekerroksissa mukana vain koealat, joissa turpeen paksuus on yli 30 cm sekä 30-50 cm:n kerroksissa koealat, joissa paksuus on yli 50 cm.*
2) Raw humus — *raakahumus*
3) Abbreviations in Table 1. — *Lyhenteiden selitykset taulukossa 1.*

Table 5. Main nutrient concentrations in the raw humus and surface peat layer in different peatland site types.
Taulukko 5. Pääravinnepitoisuudet raakahumuskerroksessa ja pintaturpeessa suotyypeittäin eri koealueilla.

Nutrient *Ravinne*	Layer *Kerros* [2]	Vesijako RhK	Vesijako MK	Vesijako PK	Jaakkoinsuo RhK	Jaakkoinsuo VNK	Jaakkoinsuo RäK	Jaakkoinsuo KR	Jaakkoinsuo RhSR	Jaakkoinsuo VSR	Jaakkoinsuo IR	Jaakkoinsuo VSN	Kaakkosuo VSN
N % [1]	RH	2.12	1.98	1.93	1.85	1.61	1.68	2.07	1.94	1.75	1.40	2.13	1.68
		±.15	±.27	±.13	±.28	—	—	—	±.14	±.13	±.19	±.07	±.13
	0—10	2.31	2.31	1.85	1.77	2.03	1.94	2.03	2.40	2.27	1.37	2.48	2.55
		±.16	±.22	±.13	±.16	±.18	—	—	±.20	±.04	±.19	±.24	±.29
	10—20	2.30	2.40	1.89	2.46	2.28	—	1.55	2.27	1.53	1.43	2.38	2.76
		±.07	±.05	±.02	±.59	—	—	—	±.49	±.77	±.19	±.30	±.38
P mg/kg	RH	1211	905	970	1120	910	957	896	1002	950	658	813	809
		±58	±56	±132	±11	—	—	—	±86	±172	±95	±88	±162
	0—10	920	766	907	718	798	912	772	698	847	481	669	570
		±151	±111	±36	±59	±18	—	—	±77	±112	±84	±172	±152
	10—20	832	739	681	550	592	—	611	708	645	327	620	534
		±172	±71	±118	±167	—	—	—	±145	±178	±75	±115	±130
K mg/kg	RH	897	785	676	486	853	765	545	543	540	546	465	510
		±47	±252	±22	±187	—	—	—	±119	±76	±130	±132	±96
	0—10	321	283	243	163	273	353	183	151	244	228	135	178
		±63	±103	±26	±9	±16	—	—	±32	±60	±57	±9	±30
	10—20	171	137	134	106	70	—	86	63	107	96	68	65
		±23	±52	±9	±14	—	—	—	±20	±27	±36	±8	±14
Ca mg/kg	RH	5688	4170	3511	2914	4307	3581	3258	2701	2506	2944	3655	2729
		±190	±1065	±1501	±221	—	—	—	±787	±936	±846	±998	±655
	0—10	5466	6327	2551	2108	2274	1008	1969	1482	2156	2348	3020	1365
		±1057	±1174	±394	±618	±715	—	—	±437	±300	±611	±141	±446
	10—20	5913	7141	2403	2030	1814	—	1510	1667	1515	1663	3470	1383
		±1888	±1647	±248	±715	—	—	—	±489	±563	±510	±305	±395
Mgmg/kg	RH	879	628	410	317	472	566	364	288	294	337	358	257
		±43	±116	±114	±2	—	—	—	±61	±106	±86	±119	±62
	0—10	610	732	333	188	205	147	156	145	165	306	252	99
		±213	±205	±33	±72	±28	—	—	±17	±16	±71	±39	±23
	10—20	668	741	233	208	106	—	88	99	122	218	186	71
		±306	±140	±19	±1	—	—	—	±9	±12	±64	±26	±17

Column heading: Nutrient concentrations — *Ravinnepitoisuudet*; Location and original site type — *Paikka ja alkuperäinen suotyyppi* [3]

1) From organic matter — *Orgaanista ainesta kohden*
2) RH = Raw humus — *Raakahumus*
3) Abbreviations in Table 1. — *Lyhenteiden selitykset taulukossa 1.*

the nutrient concentrations of peat, while nutrient amounts per unit area received less attention (cf. however, Holmen 1964, Paavilainen 1980, Westman 1981). Although the purpose of this investigation is primarily to study the nutrient amounts of peat in old drainage areas, it was also considered necessary to include results on nutrient concentrations, as then connections to many of the previous investigations can be obtained and as they are also easier to use in practical forestry than nutrient amounts based on volumetric samples. The nutrient concentrations only in the surface layers of peat (0—10 and 10—20 cm), which are the most important also from practical point of view, are discussed in the following passages.

3212. Nutrient concentrations

The total nitrogen concentrations of peat (Table 5) were usually higher on the average than for example those introduced by Westman (1981) for corresponding virgin peatland site types and by Vahtera (1955) for corresponding drained peatland site types, which may have been caused by increased density of peat resulting from a prolonged drainage effect and by an increase in the humification. Both in spruce mires at Vesijako and pine mires at Jaakkoinsuo the nitrogen concentration of peat increased along with the fertility of the peatland site type.

The total phosphorus concentrations of

Table 6. Concentrations of easily soluble and exchangeable main nutrients in the raw humus and surface peat layer in different peatland site types.

Taulukko 6. Helppoliukoisten ja vaihtuvien pääravinteiden pitoisuudet raakahumuskerroksen ja pintaturpeen suotyypeittäin eri koealueilla.

		Nutrient concentrations — *Ravinnepitoisuudet* Location and original site type — *Paikka ja alkuperäinen suotyyppi* [4]											
		Vesijako			Jaakkoinsuo								Kaakko-suo
Nutrient *Ravinne*	Layer [3] *Kerros*	RhK	MK	PK	RhK	VNK	RäK	KR	RhSR	VSR	IR	VSN	VSN
N_s mg/kg[1]	RH	409	420	322	224	—	132	213	255	176	157	396	—
		±122	±172	±46	±32	—	—	—	±99	±9	±134	±22	—
	0—10	226	215	230	108	113	105	183	168	171	176	337	98
		±26	±43	±10	±13	±28	—	—	±115	±25	±56	±21	±53
	10—20	157	141	141	73	165	—	121	90	71	90	208	67
		±9	±21	±29	±52	—	—	—	±16	±24	±50	±18	±45
P_s mg/kg[1]	RH	272.8	220.2	267.1	76.9	—	84.1	102.2	94.9	81.9	146.0	84.0	—
		±90.0	±54.1	±32.5	±5.8	—	—	—	±64.6	±21.5	±66.9	±38	—
	0—10	68.0	79.5	89.7	8.5	22.2	26.0	33.0	12.9	28.2	69.7	30.4	20.0
		±40.8	±8.4	±15.4	±3.6	±8.4	—	—	±5.2	±7.6	±25.1	±6.8	±16.3
	10—20	20.2	38.7	35.0	3.4	14.2		6.2	6.1	4.7	34.9	17.3	6.5
		±17.1	±15.9	±7.9	±2.3	—	—	—	±4.0	±2.2	±21.7	±5.6	±6.7
K_e mg/kg[2]	RH	1123	857	815	561	—	672	634	574	697	600	421	—
		±150	±133	±128	±45	—	—	—	±100	±357	±124	±124	—
	0—10	339	307	240	146	323	399	194	147	235	246	135	163
		±99	±118	±15	±3	±99	—	—	±45	±44	±93	±4	±40
	10—20	134	122	109	57	80	—	79	54	55	89	58	56
		±34	±49	±12	±21	—	—	—	±22	±17	±41	±1	±22
Ca_e mg/kg[2]	RH	4552	3519	3326	3033	—	1884	3016	2635	2321	2618	2679	—
		±237	±371	±791	±56	—	—	—	±577	±69	±432	±753	—
	0—10	3962	3797	2010	1389	1582	722	1135	1122	1490	1769	1977	1151
		±232	±653	±43	±302	±180	—	—	±374	±293	±594	±53	±451
	10—20	4056	4503	1547	1659	1629	—	891	1195	1025	1228	2446	1149
		±1041	±1021	±155	±1925	—	—	—	±451	±379	±413	±144	±384

1) Soluble N and P — *Liukoinen N ja P*
2) Exchangeable K and Ca — *Vaihtuva K ja Ca*
3) RH = Raw humus — *Raakahumus*
4) Abbreviations in Table 1. — *Lyhenteiden selitykset taulukossa 1.*

peat were at the same level with those introduced by Kaila (1956), Holmen (1964) and Westman (1981), but clearly lower than those by Vahtera (1955).

The results that most clearly deviated from the previous investigations dealt with the total potassium concentrations, which in the 10—20 cm layer were about 20—40 % of the figures presented by Vahtera (1955) for drained peatlands and also clearly lower than the values by Holmen (1964) for the 0—20 cm layer. Compared with the figures presented by Westman (1981) for corresponding virgin peatland site types the total potassium concentrations were only 13—22 % in the 0—10 and 10—20 cm peat layers.

Usually the calcium concentration of peat correlates to some degree with the site quality index (Kivinen 1948, Vahtera 1955, Holmen 1964, Westman 1981). A similar trend could be seen in deep-peat spruce mires in this investigation (Vesijako), but on pine mires at Jaakkoinsuo the situation was reverse. The calcium concentrations in these herb- and sedge-rich peatland site types were considerably lower than those introduced by Westman (1981) for corresponding virgin and by Vahtera (1955) for drained peatland site types.

The concentrations of the soluble and exchangeable main nutrients were somewhat higher on the deep peat spruce mires than on the other site types (Table 6). This also applied to boron and manganese (Table 7). With some exceptions (especially exchangeable calcium) the concentrations of micronutrients and soluble or exchangeable main nutrients were somewhat higher in the 0—10

Table 7. Micronutrient concentrations in the raw humus and surface peat layer in different peatland site types.
Taulukko 7. Hivenainepitoisuudet raakahumuskerroksessa ja pintaturpeessa suotyypeittäin eri koealueilla.

Nutrient *Ravinne*	Layer *Kerros* 1)	Vesijako RhK	MK	PK	Jaakkoinsuo RhK	VNK	RäK	KR	RhSR	VSR	IR	VSN	Kaakko-suo VSN
		Nutrient concentrations — *Ravinnepitoisuudet* Location and original site type — *Paikka ja alkuperäinen suotyyppi* 2)											
B mg/kg	RH	5.30	5.46	5.15	3.56	3.12	2.75	4.83	3.81	3.27	3.21	5.11	3.25
		±1.87	±1.43	±1.01	±.29	—	—	—	±.88	±.48	±1.02	±.07	±.64
	0—10	1.92	2.29	1.81	0.99	1.25	1.25	1.34	0.85	0.99	1.22	1.31	0.92
		±.43	±.46	±.41	±.07	±.14	—	—	±.41	±.23	±.44	±.21	±.28
	10—20	1.51	1.81	1.00	0.63	1.65	—	0.73	0.47	0.47	0.71	0.99	0.59
		±.39	±.29	±.34	±.30	—	—	—	±.20	±.06	±.28	±.50	±.26
Cu mg/kg	RH	7.3	7.7	6.8	51.1	79.3	28.8	27.1	92.6	18.2	12.3	11.1	21.6
		±.4	±.8	±1.0	±51	—	—	—	±143	±6	±4	±1	±31
	0—10	6.5	4.0	4.1	5.3	11.6	4.5	6.4	5.5	5.7	3.2	3.1	7.9
		±0.7	±2.6	±.3	±3.3	±1.6	—	—	±2.9	±3.3	±1.0	±1.1	±6.6
	10—20	7.5	4.9	8.3	3.2	2.5	—	9.7	3.8	2.6	1.7	2.8	2.8
		±1.0	±1.2	±1.2	±.5	—	—	—	±1.3	±.5	±.6	±.3	±1.9
Zn mg/kg	RH	30.3	36.7	38.0	31.1	35.4	32.9	43.5	40.4	30.8	96.3	23.4	41.1
		±12.7	±8.5	±5.1	±3.7	—	—	—	±5.8	±9.2	±144	±7.1	±14.2
	0—10	5.2	4.6	12.1	4.0	5.9	2.5	3.4	5.9	6.2	19.2	5.2	2.0
		±.9	±1.5	±4.5	±.1	±2.5	—	—	±.5	±2.6	±8.0	±1.7	±4.4
	10—20	2.2	3.0	2.8	1.9	1.9	—	1.5	2.7	1.6	7.8	4.0	3.5
		±.5	±.7	±.1	±.7	—	—	—	±.8	±.3	±9.3	±1.5	±2.0
Mn mg/kg	RH	426	627	253	485	109	142	281	257	152	139	122	71
		±95	±165	±84	±239	—	—	—	±80	±58	±46	±35	±71
	0—10	98.6	78.1	34.8	78.0	77.0	37.0	75.2	57.1	28.7	62.7	22.5	11.8
		±58.6	±36.8	±23.7	±6.2	±9.2	—	—	±34.3	±8.2	±30.0	±1.0	±4.4
	10—20	36.5	39.2	9.4	46.2	27.0	—	13.5	27.4	18.9	17.9	12.6	11.4
		±11.3	±6.7	±0.5	±19.0	—	—	—	±15.9	±4.3	±7.5	±1.6	±3.0

1) RH = Raw humus — *Raakahumus*
2) Abbreviations in Table 1. — *Lyhenteiden selitykset taulukossa 1.*

than 10—20 cm peat layer (Tables 6 and 7).

No references to the nutrient concentrations in the raw humus layer that may accumulate on the surface of transformed peatlands was found in literature. The total nitrogen concentrations in the raw humus layer were somewhat lower than those in the underlying peat layers (Table 5). However, all the other investigated total as well as the soluble and exchangeable nutrient concentrations in the raw humus layer were higher and in some cases even manifold compared to the underlying peat (Tables 5—7).

3213. Nutrient amounts

General

The shallowness of peat on some plots in Jaakkoinsuo makes it slightly difficult to compare peat nutrient amounts between different peatland site types (Table 1, Figs. 1—3). All the sample plots are characterized by the fact that the raw humus layer owing to its low density (Table 4) has had very little effect on the nutrient amounts, although rather thick layers of raw humus (even up to 10 cm, Table 1) with high nutrient concentrations were found on peat (Table 5, Chapter 3212).

Nitrogen

The total nitrogen amount in the 0—20 cm peat layer varied between 3000 and 7000 kg/ha (Fig. 1). On oligotrophic pine mires the amounts were slightly larger and on the best spruce mires slightly smaller than those presented by Holmen (1964) for drained peatlands. On the pine mire sample plots in Jaakkoinsuo the nitrogen amounts in the 0—20 cm layer were two-fourfold compared to those presented by Westman (1981) for corresponding virgin peatland site types.

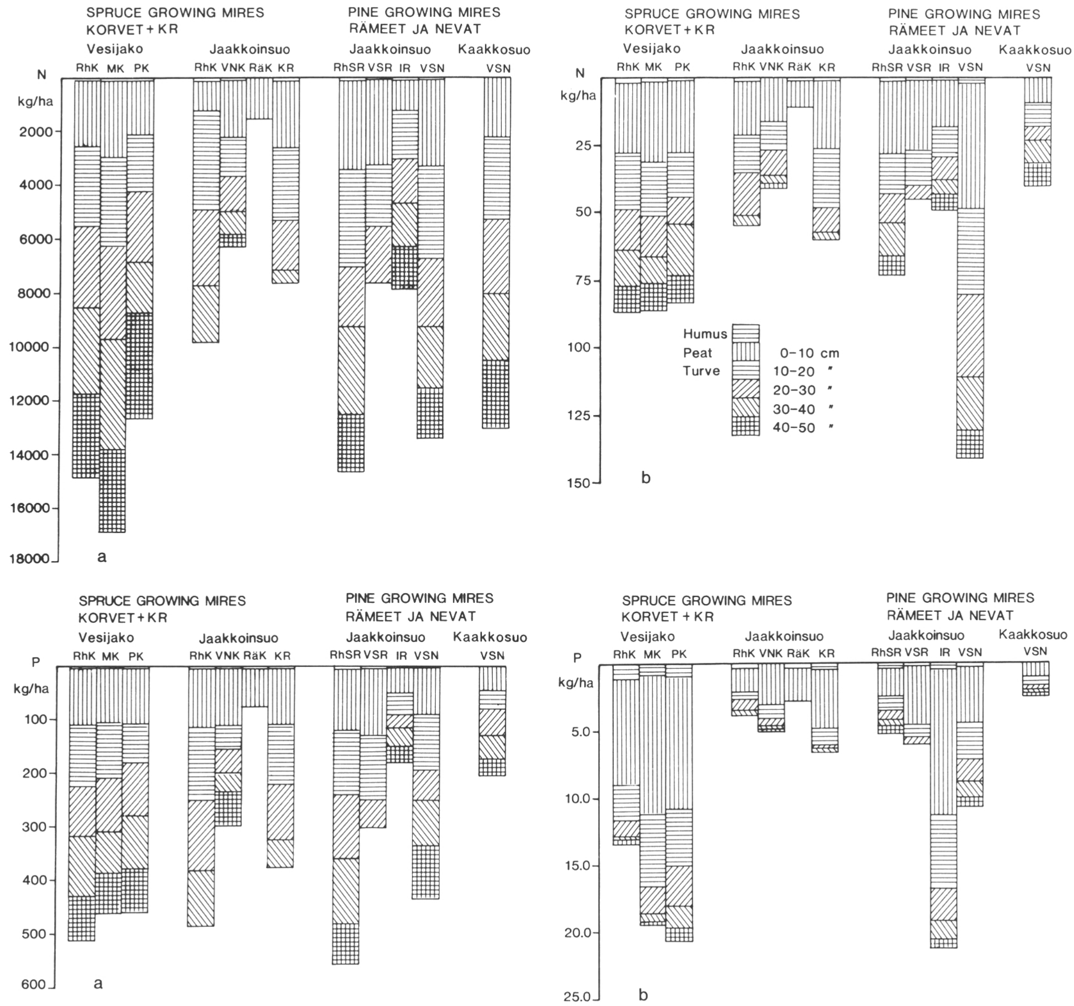


Fig. 1. Total (a) and soluble (b) amount of nitrogen and phosphorus in raw humus and 0—50 cm peat layer. Key to the abbreviations of peatland site types in Table 1.
Kuva 1. Typen ja fosforin kokonais- (a) ja liukoinen (b) määrä raakahumuksessa ja 0–50 cm:n turvekerroksessa. Suotyyppien lyhenteiden selitykset taulukossa 1.

Otherwise the differences were varied. The total nitrogen amounts differed little from each other in different peat layers. There was usually less than 1 % of mineral nitrogen out of the total nitrogen amount. The highest amounts were found in the 0—10 cm peat layer.

Phosphorus

The total phosphorus amount in the 0—20 cm layer varied between 90 and 250 kg/ha in different peatland site types (Fig. 1). Compared to the material by Westman (1981) from virgin pine mires, the total phosphorus amount was 1.5—2-fold in the corresponding site types of this investigation, but approximately at the same level or slightly higher than in Holmen's (1964) material. Smaller amounts of soluble phosphorus was usually in herbrich peatland site types than in sedgerich site types. A remarkably large difference was found between herbrich pine mires and dwarf-shrub pine mires in Jaakkoinsuo (Fig. 1).

Only slight differences in the amounts of total phosphorus were between different peat layers. The largest amounts of soluble phosphorus were in the 0—10 cm layer and more in the 10—20 cm layer than deeper down. The proportion of soluble phosphorus out of the total phosphorus amount varied between 1 and 8 % (see also Kaila 1956, Holmen 1964, Paavilainen 1980 and Braekke 1987).

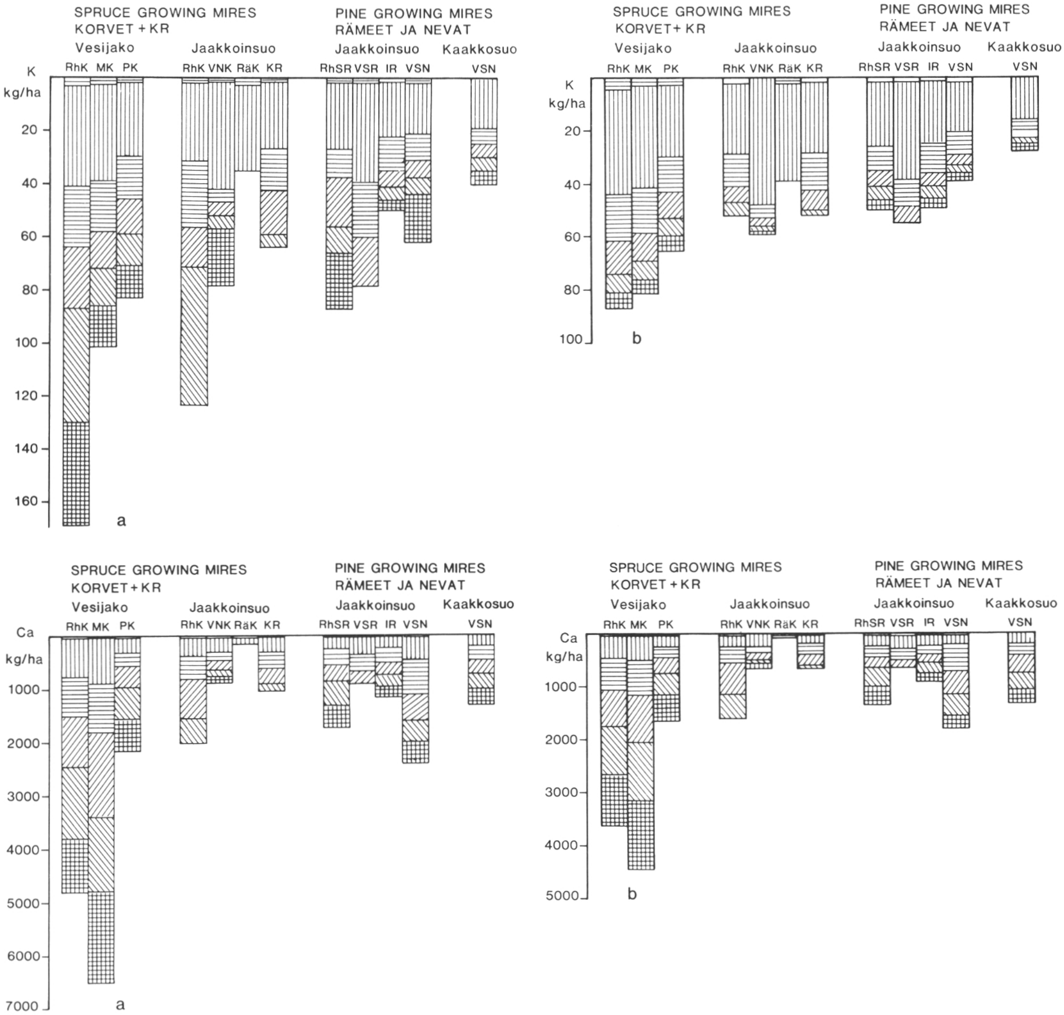
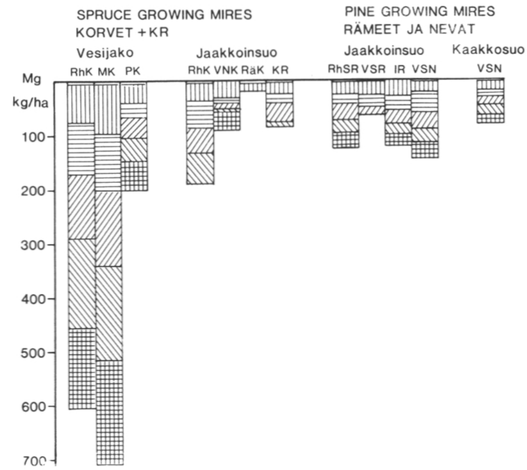


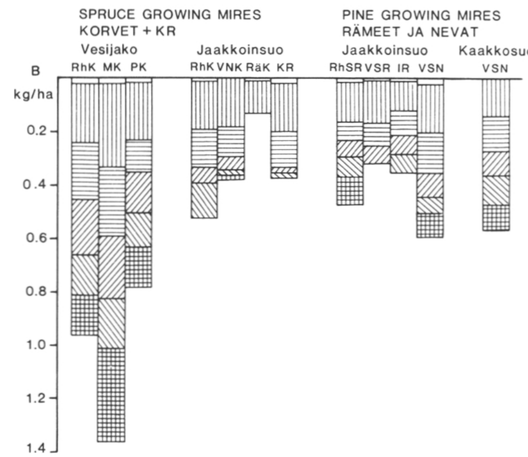
Fig. 2. Total (a) and exchangeable (b) amount of potassium and calcium in raw humus and 0—50 cm peat layer. Key to the abbreviations of peatland site types in Table 1. Other symbols in Fig. 1.
Kuva 2. Kaliumin ja kalsiumin kokonais- (a) ja vaihtuva (b) määrä raakahumuksessa ja 0-50 cm:n turvekerroksessa. Suotyyppien lyhenteiden selitykset taulukossa 1. Muut kuvaselitykset kuvassa 1.

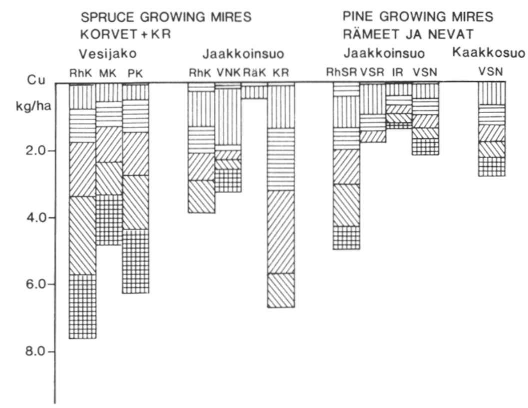
Potassium

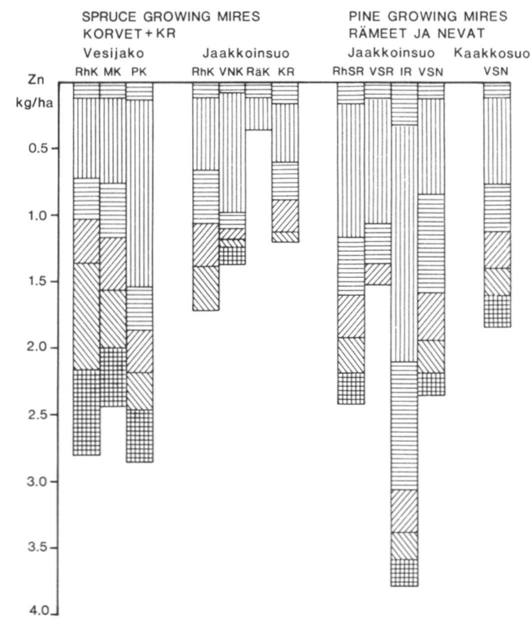
The average amount of total potassium varied between 30 and 65 kg/ha in the 0—20 cm layer (Fig. 2). There was only half the amount of potassium as compared to Westman's (1981) material collected from virgin pine mires and to the material collected earlier by Paavilainen (1980) on dwarf-shrub pine mires in Jaakkoinsuo including a few sample plots that are also in this study. There was also somewhat less potassium in the peats of this study than in Holmen's (1964) material.

Clearly the largest amounts of potassium were found in the 0—10 cm surface layer. The difference was more distinct than for example in Westman's (1981) material (see also Braekke 1987). Exceptions were the deep-peat grass and herbrich spruce mires in Vesijako and the shallow-peat spruce and pine mires in Jaakkoinsuo. In Jaakkoinsuo clearly larger amounts of potassium in the layer next to mineral soil was found than in the intermediary layers. Over half the amount of potassium in the whole investigated peat layer (see also Kaila and Kivekäs 1956), but nearly all in the top layer (0—20 cm) was in the exchangeable form (see also Braekke 1987).









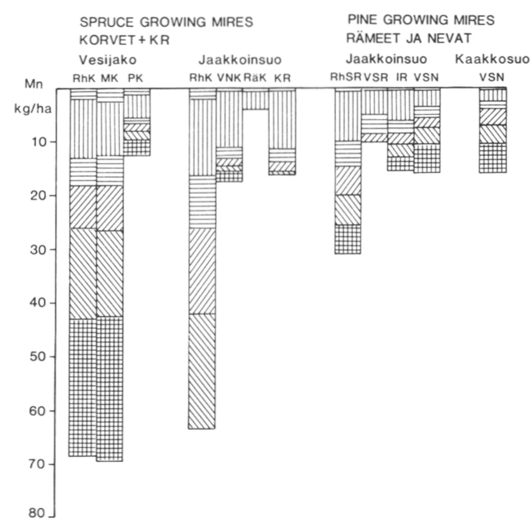


Fig. 3. Total amounts of magnesium, boron, copper, zinc and manganese in raw humus and 0—50 cm peat layer. Key to the abbreviations of peatland site types in Table 1. Other symbols in Fig. 1.

Kuva 3. Magnesiumin, boorin, kuparin, sinkin ja mangaanin kokonaismäärät raakahumuksessa ja 0-50 cm:n turvekerroksessa. Suotyyppien lyhenteiden selitykset taulukossa 1. Muut kuvaselitykset kuvassa 1.

Calcium

The total amounts of calcium varied between 500 and 1,800 kg/ha on average (Fig. 2). The amounts were somewhat larger than those introduced by Westman (1981) for corresponding site types on virgin pine mires. On the most oligotrophic pine mires the amount of calcium was approximately the same as in Holmen's (1964) material, but considerably smaller on more fertile pine and spruce mires. There was calcium, particularly in the exchangeable form, somewhat less in the 0-10 cm top layer than deeper down. The amount of exchangeable calcium was about 2/3 of the total calcium amount.

Magnesium

The amount of magnesium varied between 50 and 200 kg/ha in the 0-20 cm layer (Fig. 3). The nutritionally best deep-peat spruce mires in Vesijako had the largest magnesium amounts. On oligotrophic pine mires the magnesium amounts were about the same as in Westman's material (1981), but on the nutritionally best pine mires somewhat smaller.

Boron

There were extremely small amounts of boron in all the peatland site types. The amounts varied between 200 and 600 g/ha on average in the 0—20 cm layer (Fig. 3). Slightly larger amounts could be detected in the 0—10 cm layer than in the deeper layers.

Copper

The amount of copper varied between 0.7 and 3.2 kg/ha on average in the 0—20 cm layer in different peatland site types (Fig. 3). The entire investigated profile indicated that slightly larger amounts of copper were on spruce mires and herbrich pine mires than in other peatland site types.

Zinc

The amount of zinc varied between 1 and 3 kg/ha on average in the 0—20 cm peat layer (Fig. 3). Usually the largest amounts of zinc were found in the 0—10 cm top layer. There were relatively small amounts of zinc on the shallow-peat spruce mires in Jaakkoinsuo, while exceptionally large amounts were found on the dwarf-shrub pine mires.

Manganese

The amount of manganese varied between 3.5 and 25 kg/ha on average in the 0—20 cm peat layer (Fig. 3). Largest amounts of this element were on the nutritionally best spruce mires both in Vesijako and Jaakkoinsuo. Slightly more manganese was found on herbrich sedge pine mires than on other pine mires.

Variation between different site type groups

When investigating the nutrient amounts in the 0—20 cm top layer with the principal component analysis, two most important factors explained 50.6 % of the variation. Three sample plot groups could be distinguished (Fig. 4). Group 1 consisted of dwarf-shrub pine mires and two *Vaccinium* spruce mires, group 2 *Myrtillus* and herbrich spruce mires except one sample plot. The rest of the plots fell to group 3, while one plot on a dwarf-shrub cotton-grass pine mire and *Vaccinium* spruce mire fell to the intermediary zones between the groups.

In order to get more distinct groups based on the site type classification according to vegetation, the two *Vaccinium* spruce

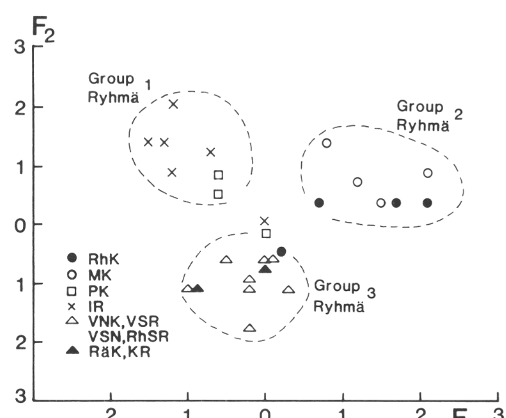


Fig. 4. Distribution of peatland site types into groups as calculated with the principal component analysis based on peat nutrient amounts. Key to the abbreviations of peatland site types in Table 1. See the text.

Kuva 4. Pääkomponenttianalyysillä turpeen ravinnemäärien perusteella laskettu suotyyppien jakaantuminen eri ryhmiin. Suotyyppien lyhenteiden selitykset taulukossa 1. Katso tekstiä.

mire plots in group 1 and the above-mentioned two intermediary sample plots were omitted from the comparison in the analysis of variance.

According to the analysis of variance oligotrophic dwarf—shrub pine mires were characterized by smaller amounts of total nitrogen and phosphorus as well as copper in comparison to other peatland site types (App. 1). There was more zinc on these than on more fertile peatland site types.

The group of mesotrophic spruce mires (*Myrtillus* and herbrich) was characterized by larger amounts of potassium, calcium, magnesium and boron as well as exchangeable potassium and calcium as compared to other peatland site types.

Sample plots of the third group (including e.g. sedge pine mires and open mires) had less soluble phosphorus in the top layer than the sample plots belonging to the other groups.

3214. The relationships between the amounts of the main nutrients

The relationships between the amounts of different main nutrients in peat and raw humus were compared with correlation analysis. Only the three topmost peat layers were included in this report as no essential differences existed deeper in the profile.

In all the peat layers the total amounts of N and P as well as those of Ca and Mg had solid positive correlations (App. 2, see also Westman 1981). Also the amounts of N and Ca and in deeper layers (> 20 cm) the amounts of N and Mg correlated positively. The soluble or exchangeable amounts of N, K and Ca correlated positively but those of P negatively with the corresponding total nutrient amounts in peat.

In the raw humus layer the total amounts of only N, Ca and Mg correlated (+) with the corresponding total, exchangeable or easily soluble amounts in peat.

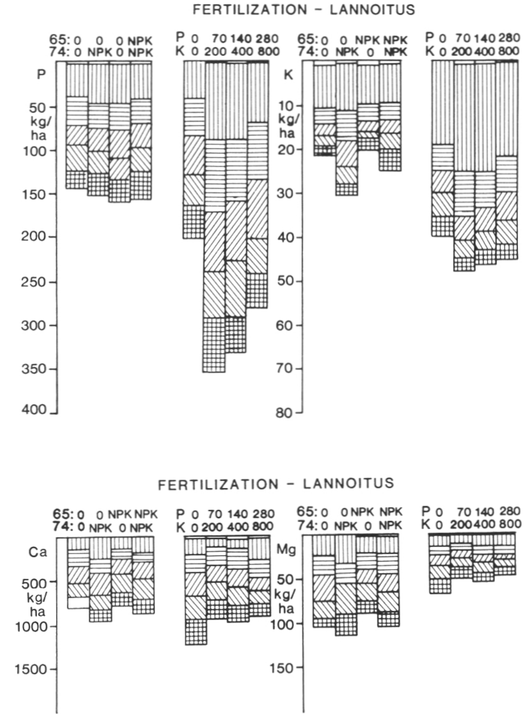


Fig. 5. Effect of fertilization on the amounts of phosphorus, potassium, calcium and magnesium in raw humus and 0—50 cm peat layer in Jaakkoinsuo and Kaakkosuo. Fertilization in Jaakkoinsuo in 1965 and 1974, in Kaakkosuo in 1953. Soil samples taken in the autumn of 1985. Key to the abbreviations in Fig. 1.

Kuva 5. Lannoituksen vaikutus fosfori-, kalium-, kalsium- ja magnesiummääriin raakahumuksessa ja 0–50 cm:n turvekerroksessa Jaakkoinsuolla ja Kaakkosuolla. Jaakkoinsuolla lannoitus vuosina 1965 ja 1974, Kaakkosuolla v. 1953. Maanäytteet otettu syksyllä 1985. Lyhenteiden selitykset kuvassa 1.

322. Effect of fertilization on nutrient amounts

The effect of fertilization on nutrient amounts was investigated on four sample plots of dwarf-shrub pine mires in Jaakkoinsuo (NPK fertilization) and four (PK fertilization) sample plots in Kaakkosuo. Each Kaakkosuo sample plot had been further divided into four micronutrient treatments.

The effect of NPK fertilization on the Jaakkoinsuo sample plots was no more perceptible in the total amounts of phosphorus, potassium, calcium and magnesium 12 and 21 years after fertilization (Fig. 5).

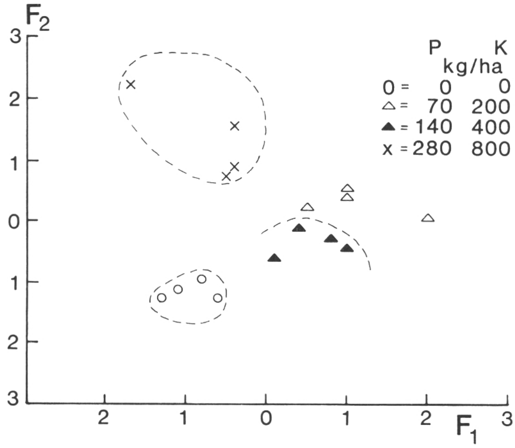


Fig. 6. Distribution of fertilization treatments into groups calculated with the principal component analysis based on peat nutrient amounts. See the text.

Kuva 6. Pääkomponenttianalyysillä turpeen ravinnemäärien perusteella laskettu lannoituskäsittelyjen jakaantuminen ryhmiin Kaakkosuolla. Katso tekstiä.

In the principal component analysis calculated from the nutrients of the top peat layer (0—20 cm) in Kaakkosuo, the unfertilized sample plots and those that had received the highest rate of PK could be clearly distinguished as their own group in relation to factor 2 (Fig. 6). Above all, easily soluble phosphorus was the distinguishing element (see also Fig. 7). The difference between the sample plots that had received two lowest rates of PK was not very clear. In relation to factor 1 they could be distinguished from the unfertilized plots mainly by the total amounts of the main nutrients (N, P, K), exchangeable potassium and larger amounts of mineral nitrogen. Two most important factors presented in Fig. 6 explained 51.0 % of the variation. Yet, differences in the amounts of both exchangeable and total potassium between fertilized and unfertilized sample plots were rather small and the amounts of total phosphorus, total and exchangeable potassium on fertilized sample plots remained unchanged or decreased as fertilizer amounts rose (Figs. 5 and 7). Fertilization affected the nutrients of the entire peat profile (0—50 cm) in much the same way as in the 0—20 cm layer (Figs. 5 and 7).

Compared to the amount of fertilizer potassium there was very little potassium in the soil even if considering the entire 50 cm profile examined (Figs. 5 and 7). In order to investigate the phosphorus and potassium balance in the 20 cm surface peat layer most important for roots, the total amount of these nutrients was calculated in the tree stand (the present tree stand + removal in total drain, calculation method explained on pages 24—25) and in the soil minus the nutrient amounts of the unfertilized sample plot (Table 8).

Although the share of ground vegetation as nutrient users could not be taken into account in the investigation, it is quite evident that part of phosphorus had penetrated below the 0—20 cm layer at least when large phosphorus amounts were applied (Table 8, see also Fig. 5) and part of it had probably leached in ditch networks. Only a very small part of the fertilizer potassium was still left in the 0—20 cm peat layer or bound by the tree stand (Table 8).

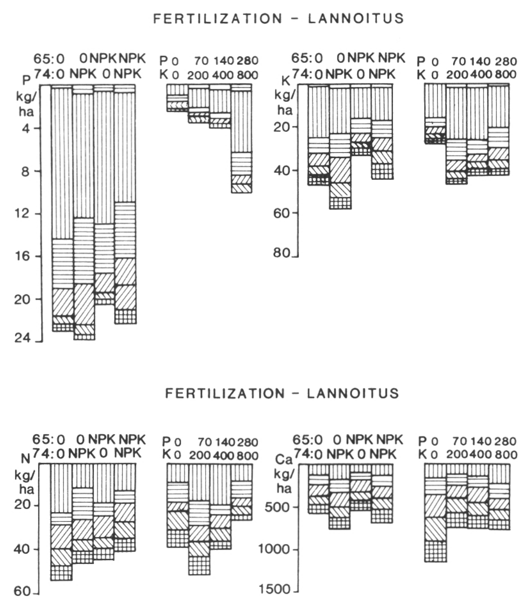


Fig. 7. Effect of fertilization on the amount of soluble phosphorus and nitrogen and exchangeable potassium and calcium in raw humus and 0—50 cm peat layer in Jaakkoinsuo and Kaakkosuo. Fertilizations and sampling as in Fig. 7. For other symbols see Fig. 1.

Kuva 7. Lannoituksen vaikutus liukoisen fosforin ja typen sekä vaihtuvan kaliumin ja kalsiumin määriin raakahumuksessa ja 0-50 cm:n turvekerroksessa Jaakkoinsuolla ja Kaakkosuolla. Lannoitukset ja näytteiden otto, kuten kuvassa 7. Muut selitykset ks. kuva 1.

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Table 8. Fertilizer phosphorus and potassium in the soil (0—20 cm) and bound by the tree crop in Kaakkosuo.

Taulukko 8. Lannoitefosforin ja -kaliumin pidättyminen maahan (0-20 cm) ja puustoon Kaakkosuon nevakoealoilla.

Nutrient — *Ravinne*					
P, kg/ha			K, kg/ha		
a In soil and trees [1] *Maassa ja puustossa* [1]	b Fertilization *Lannoitus*	(a—b) — P on unfertilized plots *(a-b) - P lannoittamattomilla koealoilla*	a In soil and trees [1] *Maassa ja puustossa* [1]	b Fertilization *Lannoitus*	(a—b) — K on unfertilized plots *(a-b) - K lannoittamattomilla koealoilla*
88	0	0	31	0	0
194	70	+36	107	200	−124
177	140	−51	89	400	−342
155	280	−213	92	800	−739

1) Includes the nutrients in bark and stems of harvested trees.
Sisältää myös poistuman ravinteet.

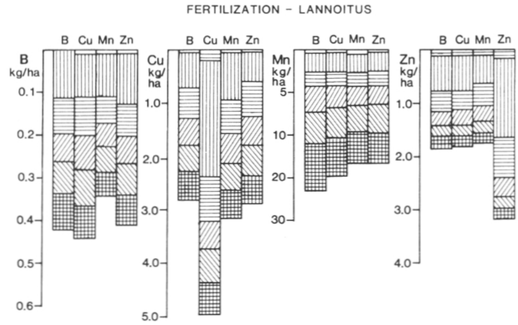


Fig. 8. Effect of fertilization on the total amounts of micronutrients in raw humus and 0-50 cm peat layer. Fertilization as in Fig. 7. For other symbols see Fig. 1.

Kuva 8. Lannoituksen vaikutus hivenaineiden kokonaismääriin raakahumuksessa ja 0-50 cm:n turvekerroksessa. Lannoitus, kuten kuvassa 7. Muut selitykset ks. kuva 1.

The proportion was the smaller the larger amounts of this nutrient had been applied. As the effect of fertilization could not be found even in the potassium amounts in the 20—50 cm peat layer, it is likely that large amounts of potassium have leached away from the area in runoff.

Potassium is extremely susceptible to leaching (Kivinen 1948, Paarlahti 1976, Malcolm and Cuttle 1983, Kaunisto and Tukeva 1984) because it is mainly in water-soluble or exchangeable form in peat (Kaila and Kivekäs 1956, Holmen 1964, Paavilainen 1980, Westman 1981). The material of Kaunisto and Tukeva (1984) indicated that 166 kg/ha of potassium did not influence the potassium concentrations any longer after three years in the 0—5 cm or after five years in the 0—15 cm peat layer with any statistical significance.

The prolonged influence of phosphorus fertilization along with a shortage of potassium shown by the soil analysis appears also in the following table introducing the results of pine needle analysis from Kaakkosuo (Veijalainen, unpublished material). The sampling took place in March in 1987.

Fertilization 1953, kg/ha		Nutrient contents of needles in 1987	
P	K	P mg/g	K mg/g
0	0	0.87	3.15
70	200	1.52	2.37
140	400	1.22	2.28
280	800	1.78	2.86

According to the foliar analysis the trees on the fertilized sample plots suffered from an acute shortage of potassium, although the top peat layer contained more exchangeable potassium than the unfertilized plots (Fig. 7).

The effect of copper and zinc fertilization was seen in the amounts of these elements in Kaakkosuo especially in the top layer of peat (Fig. 8). The effect of boron and manganese fertilization could not be detected in the B and Mn amounts of peat.

33. Yield of the tree stands

The volume of stem wood (with bark) removed at cuttings varied between 90 and 310 m^3 and that of total yield between 210 and 550 m^3 on originally tree growing mires on average (Fig. 9). The total yield on dwarf-shrub pine mires was clearly lower than on other pine mires. A surprising finding was that the yield in deep-peat herbrich spruce mires in Vesijako was lower than on *Myrtillus* and *Vaccinium* spruce mires.

The development of the trees on Kaakkosuo sample plots was satisfactory only on PK-fertilized plots. The best total yield (185 m^3/ha) was received on sample plots fertilized with the smallest nutrient amounts (70 kg of P and 200 kg of K). At the time of

Table 9. Correlation coefficients between the total yield up till 1985 and peat nutrient amounts in the combined material of Jaakkoinsuo and Vesijako. Peat samples in 1985.

Taulukko 9. Vuoteen 1985 mennessä saavutetun puuston kokonaistuotoksen ja turpeen ravinnemäärien väliset korrelaatiokertoimet Jaakkoinsuon ja Vesijaon yhdistetyssä aineistossa. Turvenäytteet v. 1985.

Nutrient Ravinne	RH[1]	Peat Layer — *Turvekerros, cm* 0—10	10—20	20—30	30—40	40—50	0—20	0—30
Tot.N	0.504**	0.616***	0.411*	0.335	0.421*	0.458*	0.562**	0.571**
P	0.306	0.730***	0.494**	0.399*	0.468*	0.487*	0.651***	0.541**
K	0.278	0.363*	0.125	0.248	0.298	0.423*	0.251	0.310
Ca	0.255	0.308	0.233	0.282	0.345	0.394	0.336	0.334
Mg	0.173	0.200	0.160	0.236	0.311	0.398	0.214	0.237
Zn	−0.200	−0.487**	−0.573***	−0.045	0.178	0.498*	−0.610***	−0.541**
Cu	0.143	0.535**	0.387*	0.307	0.419*	0.582**	0.536**	0.317
Mn	0.442*	0.438**	0.249	0.230	0.254	0.247	0.317	0.306
B	0.278	0.409*	0.267	0.210	0.269	0.348	0.392	0.322
Sol. -Liuk. N	—	0.147	0.032	0.177	0.158	0.221	0.150	0.148
Sol. -Liuk. P	—	−0.457**	−0.585***	−0.430*	−0.296	−0.211	−0.529**	−0.456*
Exch. -Vaiht. K	—	0.284	0.014	0.265	0.399	0.437*	0.164	0.191
Exch. -Vaiht. Ca	—	0.260	0.228	0.264	0.340	0.418*	0.355	0.341
n		30	28	26	22	20	26	26

1) RH = Raw humus — *Raakahumus*

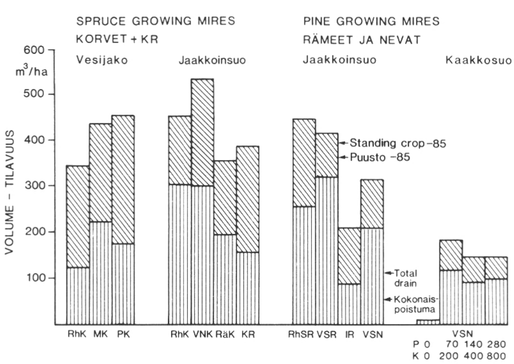


Fig. 9. Total drain up till 1985 and the standing crop in 1985 in different peatland site types. Key to the abbreviations of the peatland site types in Table 1.

Kuva 9. Kokonaispoistuma vuoteen 1985 mennessä ja puustopääoma vuonna 1985 eri suotyypeillä. Suotyyppien lyhenteet taulukossa 1.

fertilization the plots were stocked only with short seedlings (see Chapter 2) so that the postfertilization yield (5.6 solid m³/ha/a) can be almost totally attributed to fertilization.

34. Peat nutrients and yield of tree stands

Dependence between the total yield of tree stands and peat nutrients was investigated only on the unfertilized sample plots of Vesijako and Jaakkoinsuo (a total of 30 plots). The dependence was studied by the correlation and multiple regression analyses. As the dependencies between individual nutrients and the yield of tree stands were usually linear, the main focus when presenting the results is on the correlation coefficients. However, the most important dependencies between the nutrient amounts and yield are also presented in figures and regression equations. The main emphasis is on the dependence between the yield and total nutrient amounts calculated for unit area. The dependence between the yield and nutrient concentrations of peat is investigated only as far as nitrogen, phosphorus and potassium are concerned.

In surface peat the most solid positive correlation was found between the total yield of the tree stands and the total nitrogen and phosphorus amounts in the 0—10 cm peat layer (Table 9, Fig. 10). A slightly positive correlation was also between the total yield and the total amount of potassium, copper, manganese and boron in the 0—10 cm peat layer. Usually the dependence was shown by a straight line or gently curving parabola (Figs. 10 and 11).

The amounts of zinc and soluble phosphorus especially in the 10—20 cm peat layer had a highly negative correlation with the total yield. Similarly, the mean annual increment during the last measuring period had a negative correlation with the amount

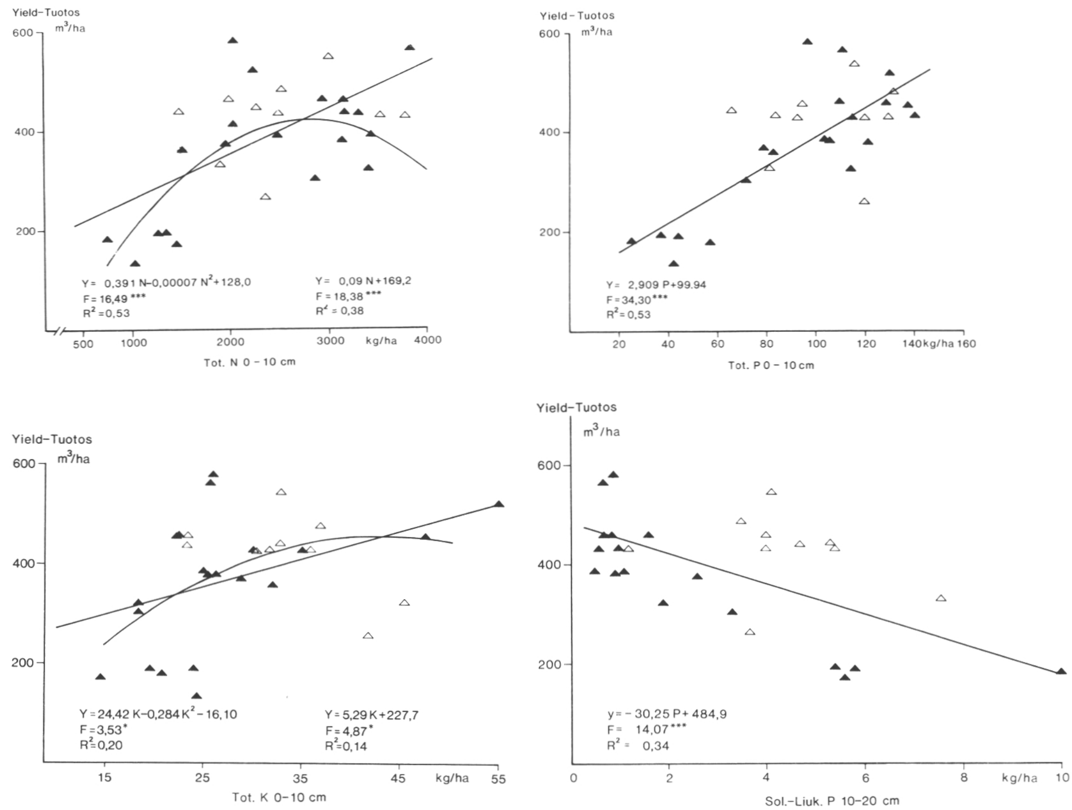


Fig. 10. Dependence of the total yield on the amounts of the main nutrients in the surface layer of peat in 1985. Black triangels = Jaakkoinsuo, open triangels = Vesijako.

Kuva 10. Puuston kokonaistuotoksen riippuvuus turpeen pintakerroksen pääravinnemääristä v. 1985. Mustat kolmiot = Jaakkoinsuo, avoimet = Vesijako.

Table 10. Dependence of the mean volume increment (m^3/ha) of the last measuring period on the amounts of easily soluble phosphorus and exchangeable potassium (kg/ha) in peat. Obligatory independent variable was the volume of standing crop (V) in 1985.

Taulukko 10. Viimeisen mittausjakson keskikasvun (k-m^3/ha) riippuvuus turpeen helppoliukoisen fosforin ja vaihtuvan kaliumin määristä (kg/ha) turpeessa. Pakollisena selittäjänä puuston tilavuus (V) v. 1985.

Nutrient *Ravinne*	Layer *Kerros*	Equation *Yhtälö*	F			R^2
			V	P, K	Model *Malli*	
Sol. P	0—10	$y = 0.012V - 0.016P^2 + 6.05$	4.77*	5.39*	5.60	0.31
Liuk.	10—20	$y = 0.010V - 0.065P^2 + 6.16$	4.90*	14.53***	11.09***	0.49
Exch. K	0—10	$y = 0.010V + 0.037K + 3.12$	4.77*	4.34*	4.86*	0.28
Vaiht. K	10—20	$y = 0.010V + 5.34$	4.90*	0.17	4.90*	0.17

of soluble phosphorus (Table 10). Also Holmen (1964) found a negative correlation between the phosphorus concentration in peat extracted by ammonium-lactate-acetic acid solution and the total yield of the tree stand, which he attributed to a larger uptake of phosphorus by the ground vegetation on fertile peatland site types.

The nutrient amounts in the surface (0—10, 10—20 or 0—20 cm) layer of peat usually correlated best with the total yield. The exceptions were copper and exchangeable potassium and calcium (Table 9). The correlations between the nutrient amounts of peat

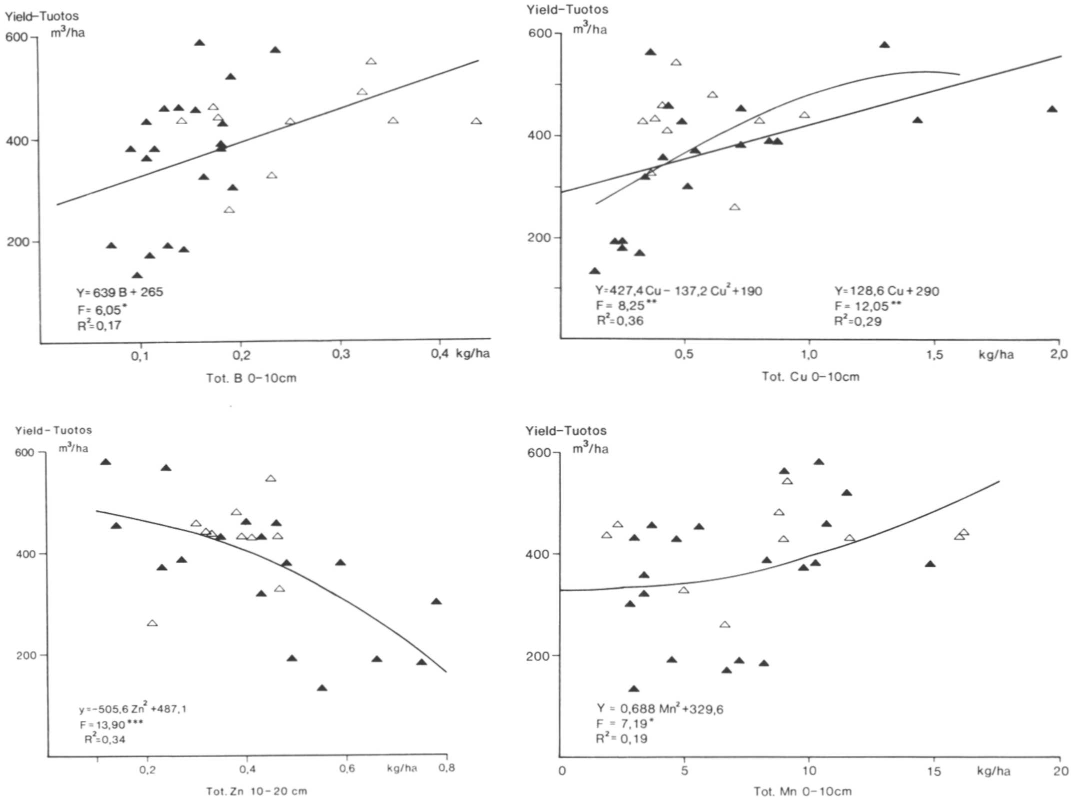


Fig. 11. Dependence of the total yield on the micronutrient amounts in the surface layer of peat in 1985. Key as in Fig. 10.

Kuva 11. Puuston kokonaistuotoksen riippuvuus turpeen pintakerroksen hivenravinnemääristä v. 1985. Selitykset, kuten kuvassa 10.

and total yield were very much the same in the submaterial collected from Jaakkoinsuo as those presented above.

There was a fairly solid positive correlation between the total nitrogen and phosphorus concentrations and the total yield in the same way as that in the total amounts of nitrogen and phosphorus and total yield (Table 11). A similar result has also been introduced by Haveraaen (1964) and Holmen (1964), although the dependence in Holmen's material was not statistically significant. There was no statistically significant dependence between the potassium concentration and the total yield (see also Holmen 1964).

The correlations between the total yield of the tree stand and total nitrogen and phosphorus concentrations were usually somewhat higher when the concentrations were calculated from the organic part of the peat sample, and still higher when the sample plots on shallow peat (< 30 cm) were omitted from the calculations (Table 11). Yet, the total amounts of nitrogen and phosporus calculated for a unit area had the best correlations with the total yield.

35. Nutrients bound by the tree stands and their sufficiency

The estimation of nutrient amounts bound by the pine stands is based on the material collected by Paavilainen (1980) from an unfertilized dwarf-shrub pine mire in Jaakkoinsuo and those bound by the spruce stands on Finér's material (1988) collected from spruce mires. The amount of nutrients bound by a) the stemwood and

Table 11. Correlation coefficients between the total yield and peat nutrient contents (g/kg and kg/ha).
Taulukko 11. Turpeen ravinnepitoisuuksien sekä ravinteiden kokonaismäärien (kg/ha) ja puuston kokonaistuotoksen väliset korrelaatiokertoimet.

Nutrient [1] Ravinne [1]	All — *kaikki* [2]		Peat — *Turve* > 30 cm [3]	
	Layer — *kerros*, cm			
	0—10	10—20	0—10	10—20
N, g/kg	0.423*	0.202	0.643**	0.671***
N org, g/kg	0.574***	0.467**	0.667***	0.672***
N, kg/ha	0.616***	0.411*	0.669***	0.710***
P, mg/kg	0.549***	0.489**	0.621**	0.636**
P org, mg/kg	0.264	0.616***	0.656***	0.644**
P, kg/ha	0.730***	0.494**	0.738***	0.766***
K mg/kg	0.123	0.021	0.176	0.082
K kg/ha	0.363*	0.125	0.325	0.340

1) org. = From organic part — *Orgaanisesta osasta.*
2) 32 sample plots — *32 koealaa.*
3) 21 same plots — *21 koealaa.*

Table 12. Nutrient amounts needed for one produced cubic metre of stemwood with bark in a pine (Paavilainen 1980) and spruce stand (Finér 1988).
Taulukko 12. Yhtä tuotettua kuorellisen runkopuun kuutiometriä kohden tarvittava ravinteiden määrä männyllä (Paavilainen 1980) ja kuusella (Finér 1988).

Species *Laji*	Compartment *Osa*	Nutrient — *Ravinne* kg/m³						g/m³		
		N	P	K	Ca	Mg	Mn	Zn	B	Cu
Pine [1] *Mänty* [1]	Stem + bark *Runkop. + kuori*	.250	.037	.144	.372	.103	.027	8.71	.849	.512
	Whole tree *Koko puu*	1.49	.157	.555	.902	.263	.065	19.6	2.31	1.38
Spruce [2] *Kuusi* [2]	Stem + bark *Runkop. + kuori*	.281	.020	.145	.537	.055	.065	7.30	1.60	.800
	Whole tree *Koko puu*	2.36	.180	.799	2.56	.245	.222	19.1	5.00	2.40

1) 136.6 m³/ha with bark — *136.6 m³/ha kuorineen*
2) 164.0 m³/ha with bark — *164.0 m³/ha kuorineen*

bark and b) by the entire stand according to the above-mentioned investigations was divided by the corresponding stand volume including bark. Then alternative a) was multiplied by the total drain and volume of the standing crop at the measuring time, which gave an estimate of nutrients removed from the area at cuttings as well as the amount of nutrients bound by the stemwood and bark at the observation time. In addition, alternative b) was multiplied by the volume of the present standing crop, which gave an estimate of the nutrient amounts bound by the entire stand at the observation time. Thus the nutrient amounts are directly proportional to the yield of the tree stand. As the estimate is based only on nutrient determinations from two experimental areas, it can only be suggestive of a trend. The coefficients are introduced in Table 12. The estimates of the nutrient amounts in tree stands are shown by Figures 12 and 13.

The comparison of Figures 1—3 (p. 12—14) to 12 and 13 gives a rough idea of the nutrient amounts in peat as compared to the amounts already removed at cuttings and presently bound by the tree biomass.

The nitrogen and phosphorus amounts in the 0—20 cm peat layer were still many tenfolds compared to the amount bound by stemwood and bark. Even in relation to the whole tree biomass the amount of nitrogen in peat was 10—15-fold and that of phosphorus 3—7-fold. About 10—45 % of calcium was bound by stemwood and bark and 15—70 % by the entire tree stand compared to the calcium in peat.

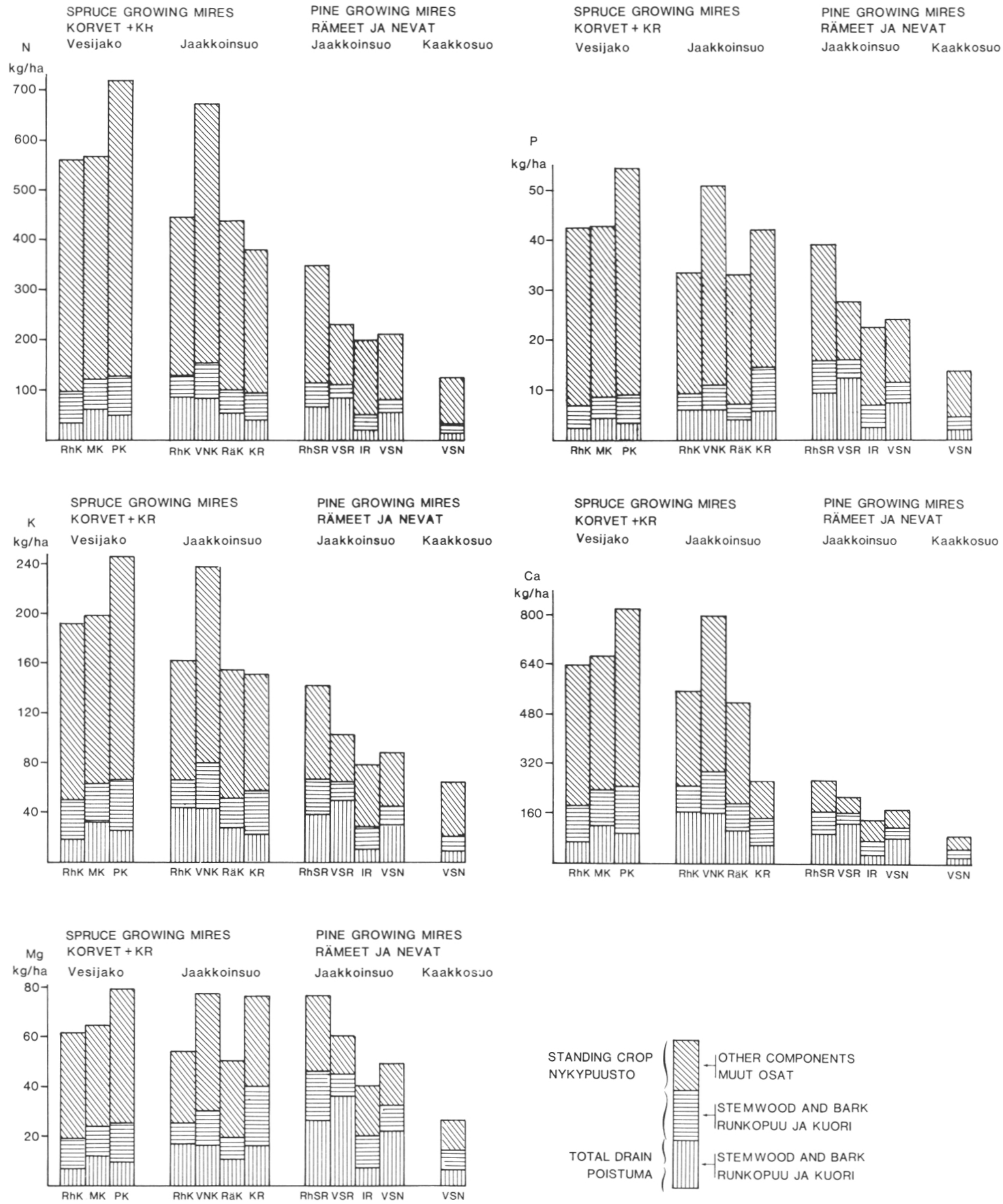


Fig. 12. Amounts of the main nutrients fixed to the total drain and present standing crop (1985). Estimation of the nutrient amounts on pine mires is based on Paavilainen's (1980) and on spruce mires on Finér's (1988) materials. See the text.

Kuva 12. Kokonaispoistumaan ja nykypuustoon sitoutuneet pääravinteiden määrät. Ravinnemäärien arviointi on tehty rämeiden osalta Paavilaisen (1980) ja korpien osalta Finérin (1988) aineistojen perusteella. Ks. teksti.

Compared with the nutrient amounts presently in peat the trees have used much more potassium than nitrogen or phosphorus. The amount of potassium bound by the harvested timber and present stemwood and bark was 1—2-fold and by the whole produced tree biomass 2—4-fold as compared to the amount still in peat. Boron had

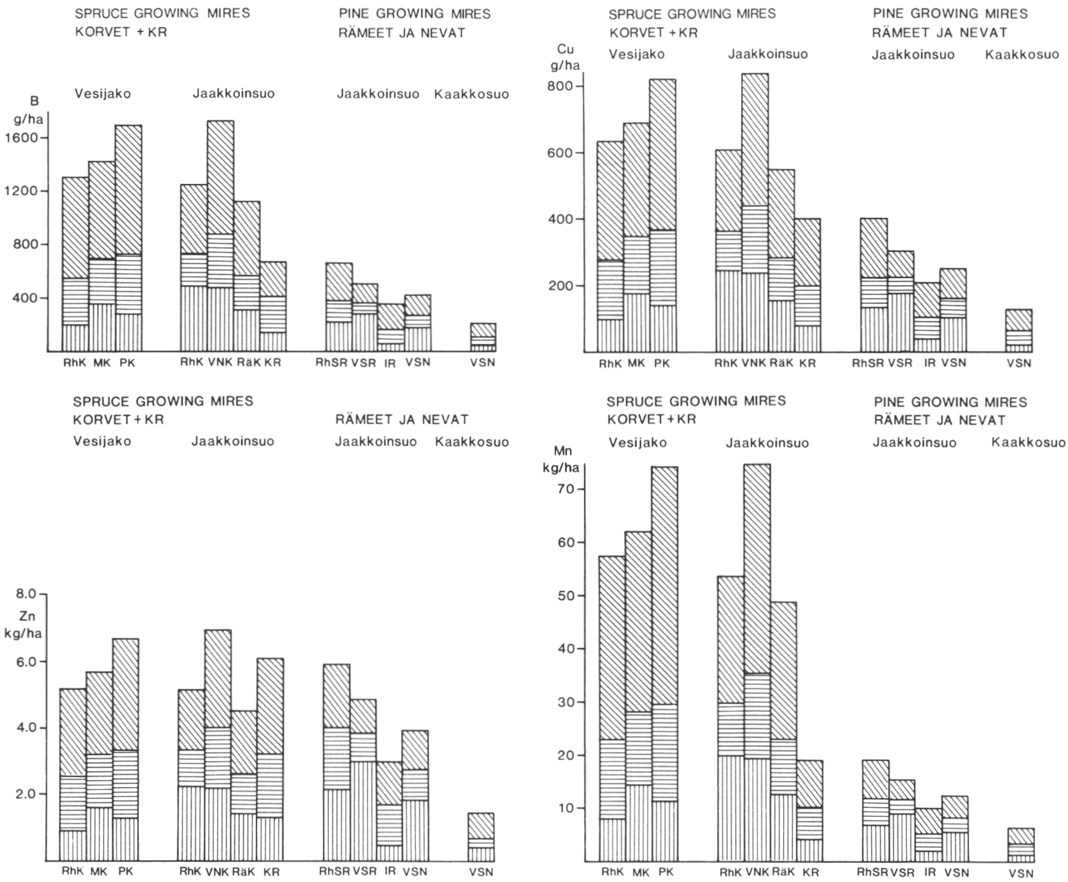


Fig. 13. Amounts of micronutrients fixed to the total drain and present standing crop (1985). Estimation of the nutrient amounts on pine mires is based on Paavilainen's (1980) and on spruce mires on Finer's (1988) materials. Key as in Fig. 12.

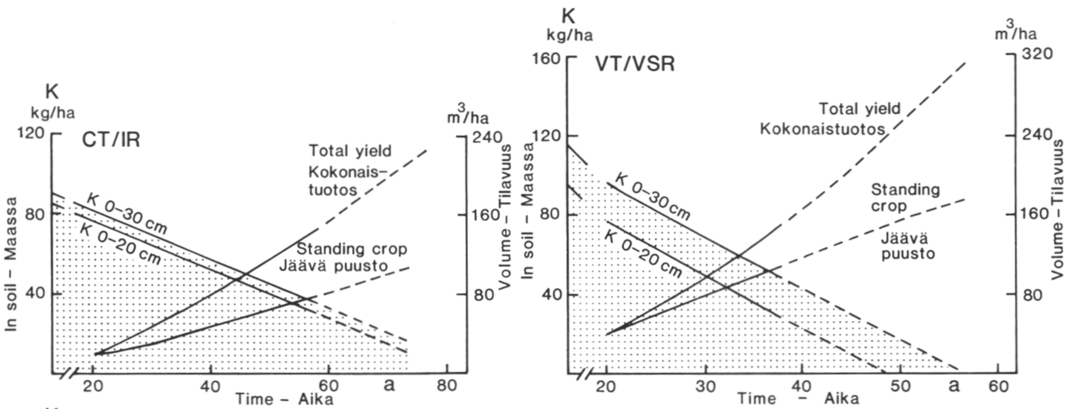
Kuva 13. Kokonaispoistumaan ja nykypuustoon sitoutuneet hivenravinteiden määrät. Ravinnemäärien arviointi on tehty rämeiden osalta Paavilaisen (1980) ja korpien osalta Finerin (1988) aineistojen perusteella. Selitykset kuten kuvassa 12.

a similar situation. There was especially small amount of zinc in soil as compared with the amount bound by the tree stand.

According to the above presented aspects, peat seems to contain very little potassium, boron and zinc. The following passages give a detailed account only of potassium, because its shortage may lead to a rapid deterioration of the trees (Kaunisto and Tukeva 1984).

Based on the peat nutrient amounts in this material, on the nutrient amounts in different components of trees on a pine mire as presented by Paavilainen (1980) and on the development series introduced by Nyyssönen (1954, 1978) for frequently thinned pine stands on mineral soils, calculations were made to predict the sufficiency of potassium on transformed peatland sites that had originally been sedge pine mires or dwarf-shrub pine mires. The development series of tree stands were selected so that the *Vaccinium* pine stand on mineral soil corresponds to an ordinary sedge pine mire and *Calluna* pine stand a dwarf-shrub pine mire. A corresponding estimate has been made for *Myrtillus* spruce mires by using the development series of frequently thinned spruce stands on *Myrtillus* site types on mineral soils (Vuokila 1956) and by using the nutrient amounts introduced by Finér (1988) for different components of trees on a spruce mire.

The basis for calculations was that one



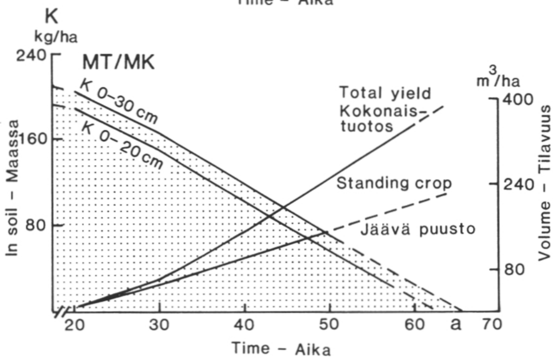


Fig. 14. Sufficiency of potassium during the second postdrainage tree generation in transformed peatlands developed from dwarf-shrub pine mires, ordinary sedge pine mires and *Myrtillus* spruce mires. Year 0 refers to the cutting time of the first tree generation after drainage. The amount of potassium in soil (dotted area) was obtained by adding the potassium returning with the crown and roots at cutting to the amount of potassium in the soil and, on the other hand, by subtracting the amount of potassium removed with the stemwood and bark at cuttings and that fixed to the standing crop. The calculation method is explained with greater detail in the text.

Kuva 14. Kaliumin riittävyys toisen ojituksenjälkeisen puusukupolven aikana isovarpuisista rämeistä, varsinaisista sararämeistä ja mustikkakorvista kehittyneillä turvekankailla. Vuosi 0 tarkoittaa ojituksen jälkeisen ensimmäisen puusukupolven päätehakkuun ajankohtaa. Kaliumin määrä maassa (rasteroitu alue) on saatu lisäämällä hakkuissa latvuksen ja juuriston mukana palautuva kaliumin määrä maassa olevaan ja toisaalta vähentämällä hakkuissa runkopuun ja kuoren mukana poistuva sekä myös kasvatettavaan puustoon sitoutuva kaliumin määrä. Laskentatapa on selitetty yksityiskohtaisemmin tekstissä.

tree generation would be grown after the first drainage and then clearcut. On most plots of the study this could have been done by the peat sampling time. The supposition was also that only the potassium bound by stemwood and bark would be removed from the area and that the potassium bound by other tree compartments would fully return to the nutrient cycle of the trees. This has been added by the amount of potassium in the 0—20 or 0—30 cm peat surface layer. The amount of potassium removed in stemwood and bark every ten years and that bound by the remaining trees were subtracted from the initial amount. Thus the amount of potassium in the soil continually decreases as the trees grow.

Figure 14 shows that on the dwarf-shrub pine mires the 0-situation with potassium is reached in about 80 years, but on the ordinary sedge pine mires already in 40—50 years and even on *Myrtillus* spruce mires in 60—70 years from the starting point. On none of these sites could trees be grown for the whole second rotation after the first drainage without applying potassium. If trees utilized the potassium in the 0—30 cm peat layer, potassium would suffice for about 10 years longer.

4. DISCUSSION

41. Reliability of results

The material for this investigation was collected from old permanent sample plots set up by the Department of Peatland Forestry of the Finnish Forest Research Institute. Sample plots were so few that some peatland site types are represented only by one or two sample plots, which is why the investigation of the variation within the site types is limited. On the other hand, a wide variety of peatland site types has been an advantage in attempting to find analytical methods for estimating the wood potential of the substrate. The stand data of the plots are most reliable, as the growth and tree harvesting have been followed by repeated measurements for decades.

The soil samples taken from each sample plot contained five subsamples, which is naturally a small number, and by increasing the number of subsamples the dispersion of the results would have been smaller. The sampling technique, where the raw humus layer was separated from the peat, however, quite likely decreased the dispersion of the analysis results of peat. The comparison with the earlier investigations (for example Vahtera 1955, Holmen 1964, Westman 1981) is somewhat vague, because no information about their sampling techniques (whether or not any surface layers were removed) was available. The further treatment of samples showed that dispersion could be decreased by improving the homogenization of samples. The nutrient analysis technique was checked by parallel analyses so that it can be regarded as most reliable.

42. Wood production and nutrient status of the site

In this investigation the original peatland site type described to some extent the nutrient conditions even at the transformed stage (the ground layer is dominated by species typical of mineral soil sites). Three different groups with different nutrient amounts could be distinguished in the principal component analysis: 1) dwarf-shrub pine mires + a few *Vaccinium* spruce mires, 2) the nutritionally best spruce mires and 3) others including open mires as well as ordinary and herbrich sedge pine mires. Out of the main nutrients the amounts of total nitrogen, in particular, but also total phosphorus, calcium and potassium were the nutrients that divided the sites into different groups. The group of dwarf-shrub pine mires was characterized by small quantities of nitrogen and phosphorus, while that of mesotrophic spruce mires was characterized by larger quantities of potassium and calcium that was found in the other groups.

It should be, however, remembered that the sample plots for this investigation had been chosen and the site type determined with special care, as they had been set up for fulfilling the needs of the investigations. A practical problem may be the reliability of the determination of the original peatland site type. Vahtera (1955) and Westman (1981) pointed out that there may be large variation in the main nutrient concentrations even within the same peatland site type. Westman (1987) even maintained in his later investigation dealing with young drainage areas that the fertility of the sample plots could be better described by the classification methods based on peat properties than on ground vegetation. Furthermore, difficulties may arise in how knowledge is correctly conveyed through decades, in this case even from nearly 80 years ago.

Thus it seems that also other measures than vegetation analysis for determining the wood production potential of a site are needed. In fact the amounts of total nitrogen and phosphorus had solid correlation with the wood production of the site.

The results on the positive significance of the total nitrogen concentration of peat as regards the wood production of the site are very similar in different investigations (Vahtera 1955, Holmen 1964, Westman 1981, 1987, Kaunisto 1982, 1987), although there are also indications that large amounts of nitrogen may be even detrimental for young pine stands due to imbalance in the N/P and N/B ratios (Kaunisto 1987).

Several former investigations have shown that pH, the amount of calcium or that of alkaline cations in general are in a positive correlation with the fertility of the site (Vahtera 1955, Holmen 1964, Westman 1987).

Some other investigations (Haveraaen 1964, Holmen 1964, Westman 1987) besides the present one have shown a fairly clear correlation between the yield and the total phosphorus concentration or amount in peat. Vahtera (1955) did not consider the total phosphorus concentration a very remarkable indicator of fertility, although he stated that an extremely low phosphorus concentration always referred to a poor yield and a high concentration to a good one. Vahtera had, however, taken the samples of surface peat from the depth of 10—20 cm, in which case usually the most phosphorus-rich top layer was excluded (e.g. Kaila 1956 b, Holmen 1964, Pakarinen and Tolonen 1977, see also Chapters 3211 and 3212). Paarlahti et al. (1971) found high total phosphorus concentrations even on poorly growing plots, although low concentrations were not found on well-growing plots. Their investigation consisted of different open mires and oligo-mesotrophic pine mires, where also other growth-limiting factors than the phosphorus concentration may exist. As both nitrogen and phosphorus in peat are nearly totally organically fixed and are released by the microbial activity in the same process, it would seem natural that yield would correlate with them in quite a similar manner. This was also indicated by the solid correlation between nitrogen and phosphorus amounts in peat in this investigation.

Several former investigations have shown that the concentration or amount of potassium in peat is not an indicator of the fertility of the site (Vahtera 1955, Holmen 1964, Paarlahti et al. 1971, Westman 1987). Although this investigation showed that there was a slight positive correlation between the amount of potassium and the total yield and that there was slightly more potassium in the best spruce mires than in other peatland site types, the differences were so small compared to the amount of potassium needed by a tree stand (see Chapter 43 and 44) that its significance is probably negligible. The difference between pine mires with different trophias was still smaller.

The amounts of some micronutrients also varied in different peatland site types. Oligotrophic pine mires were characterized by a large amount of zinc and small amount of copper in surface peat, whereas the peat in mesotrophic spruce mires contained more boron that the other investigated sites.

43. Nutrient amounts in transformed and virgin peatlands

The main nutrient (N, P, K) amounts in this investigation were quite similar to those introduced by Holmen (1964) for drained peatlands, but deviated clearly from the amounts introduced by Westman (1981) for virgin pine mires. The amount of nitrogen in this investigation was 2—4-fold and phosphorus 1.5—2-fold, but potassium only about half the amount introduced by Westman (1981).

The bulk density of peat increases after drainage. In this investigation the transformed peatlands that had originally been pine mires had over two-threefold bulk density as compared to the virgin pine mires presented by Westman (1981). Thus the amount of organically fixed nutrients such as nitrogen and phosphorus has increased per area and volume unit. In addition, the amount of nitrogen usually increases when going down the peat profile (e.g. Holmen 1964, Pakarinen and Tolonen 1977, Westman 1981).

The difference between phosphorus and potassium can be at least partly explained also by their different distribution in the peat profile and different fixation to peat. The largest amounts of both these nutrients can be found in the top layer, whereas the amount of potassium declines clearly more abruptly than that of phosphorus when going down in peat profile (Holmen 1964, Pakarinen and Tolonen 1977, Westman 1981, Braekke 1987, see also Chapters 3211 and 3212). As peat becomes compressed, the amount of phosphorus increases in relation to potassium, as there is more phosphorus than potassium deeper in peat.

This investigation as well as the former ones show that only a small part of phosphorus is in a soluble form (Kaila 1956, Holmen 1964), whereas potassium is almost totally in soil solution or in exchangeable form (Kaila and Kivekäs 1956, Braekke 1987). Consequently, potassium becomes easily leached from peat (Chapter 322, see also Kivinen 1948, Haveraaen and Steenberg 1967, Haveraaen 1978, 1986, Ahti 1983, Malcolm and Cuttle 1983, Kaunisto and Tukeva 1984, Braekke 1987). This may also be partly a reason for the small amounts of potassium in transformed peatlands.

44. Amount and sufficiency of nutrients

This investigation shows that peat contains extremely small amounts of potassium in relation to other main nutrients (N, P). The scarcity of potassium in relation to nitrogen and phosphorus is clearly seen when comparing the amounts of nutrients bound by trees to those in peat (Table 13). The calculation of the sufficiency of potassium shows that even if all the potassium bound by the stand, except that in the harvested stemwood and bark, would become totally available to trees, it would run short when the second tree generation on a dwarf—shrub pine mire after drainage would be 80—90 years old, on an ordinary sedge pine mire about 40—50 years and even on *Myrtillus* spruce mire about 60—70 years old.

The calculation is of course only suggestive of a trend as the calculations of the nutrient balance are based only on two experiments (pine stands Paavilainen 1980, spruce stands Finér 1988) and the material of this investigation is rather limited. Their results do not, however, deviate essentially from those of other investigations carried out in climatically similar conditions (Holmen 1964). The calculation did not include other pertinent factors such as deposition, leaching and nutrient immobilization in the ground vegetation. On the other hand, the deposition and leaching values of both potassium and phosphorus seem to be fairly similar under normal circumstances (Table 14). It is, however, difficult to estimate to what extent clearcutting planned to be carried out at the end of the first rotation after the first drainage would affect the leaching of potassium. The experience gained from mineral soils has shown that potassium becomes leached from the logging waste relatively fast (Staaf 1983). Thus the sufficiency of potassium may have been overestimated in the calculation examples. The amount of potassium bound by the ground vegetation may be considered rather stable in the long term. On the other hand, there is very little knowledge about the migration of potassium from deeper peat layers or from the underlying mineral soil.

Although the scarcity of potassium may impair the growth of stands on peatlands,

Table 13. The range of nitrogen, phosphorus and potassium amount in the 0—20 cm surface peat layer according to this investigation and the amount of these nutrients in different tree stands according to literature.

Taulukko 13. Tämän tutkimuksen mukaan 0-20 cm:n pintaturvekerroksessa oleva typen, fosforin ja kaliumin määrien vaihteluväli sekä näiden ravinteiden määrä erilaisissa puustoissa kirjallisuuden mukaan.

	Stand — *Puusto*				Peat — *Turve* 0—20 cm
	Holmen 1) 1964		Mälkönen 2) 1974	Paavilainen 2) 1980	This investigation
Nutrient *Ravinne*	Pine *Mänty* 66 m³/ha	Spruce *Kuusi* 312 m³/ha	Pine *Mänty* 149 m³/ha	Pine *Mänty* 137 m³/ha	*Tämä tutkimus*
N, kg/ha	113	534	186	203	3000—7000
P, kg/ha	12	70	21	21	90—225
K, kg/ha	44	168	96	76	34—64

1) Only stem and crown — *Vain runko ja latvus*
2) Whole tree stand — *Koko puusto*

Table 14. Leaching and deposition of phosphorus and potassium according to some investigations.
Taulukko 14. Fosforin ja kaliumin huuhtoutuminen ja laskeuma eräiden tutkimusten mukaan.

	Author *Tekijä*	P	K
		kg/ha/a	
Leaching *Huuhtoutuminen*	Karsisto & Ravela 1971[1]	0.02—0.15	0.2—3.6
	Ahti 1983[2]	0.04—0.50	0.07—1.50
Deposition — *Laskeuma*	Järvinen 1986[3]	0.25—0.51	0.84—2.28

1) Post-drainage year. Ditch spacing and fertilization vary. — *Lannoituksen jälkeinen vuosi. Sarkaleveys ja lannoitus vaihtelevat.*
2) One year before and six years after fertilization. Ditch spacing and fertilization vary. — *Lannoitusta edeltänyt ja kuusi sen jälkeistä vuotta. Sarkaleveys ja lannoitus vaihtelevat.*
3) Mean values in 1971—82 in five observation stations closest to the experimental areas of this investigation. — *Vuosien 1971–82 keskiarvoja viidellä tämän tutkimuksen kohteita lähinnä olevalla havaintoasemalla.*

Table 15. Proportion of phosphorus and potassium as compared with nitrogen (100) in peat (0—20 cm) of different transformed peatland sites and in peatland tree stands.
Taulukko 15. Typen, fosforin ja kaliumin suhteelliset määrät erilaisten turvekankaiden turpeissa (0–20 cm) ja puustoissa.

Original site type [1)] *Alkuperäinen suotyyppi* [1)]	N	P	K
	Percentage in peat — *Osuus turpeessa*		
RhK	100	4	1
MK	100	3	1
Pk	100	4	1
RhSR	100	3	1
VSR	100	4	1
IR	100	3	1
	Percentage in stand — *Osuus puustossa*		
MK (Holmen 1964)	100	13	32
IR —”—	100	11	39
IR (Paavilainen 1980)	100	13	37

1) Key in Table 1. — *Selitykset taulukossa 1.*

one should bear in mind that wood production during the first tree generation after drainage has already been 210—550 m^3 in the material of this investigation depending on the peatland site type.

According to the above presented aspects it seems that in the long run there will be enough nitrogen and phosphorus but a shortage of potassium in the substrate. However, most of nitrogen and phosphorus is organically fixed and only a fraction readily available to plants (Kivinen 1948, Kaila 1956a, Holmen 1964, Westman 1981, Braekke 1987, see also Chapter 3212). The microbes that decompose organic matter are the primary users of the released nutrients. Fertilization experiments, for example, have shown that nitrogen will not be released from peat sufficiently for young pine stands on newly ditched open mires and transforming peatlands until the nitrogen concentration of the surface peat (5—10 cm) is about 1.2—1.6 % (Kaunisto 1982, 1987).

An interesting aspect in the investigation of the sufficiency of the main nutrients is the comparison of the nutrient ratios in peat and nutrients bound by trees (Table 15). The table shows that the P/N ratio in a tree stand is about 3—4-fold and K/N ratio as high as 30—40-fold as compared to the corresponding ratios in peat. When nitrogen and phosphorus are mineralized from the organic matter in the same ratio as they exist in it (Alexander 1961), it would seem likely that when sufficient amounts of nitrogen are released for the trees, there still may be shortage of phosphorus. A situation like this existed on moderately fertile sedge pine mires and former open mires, whose surface peat contained fairly large amounts of soluble nitrogen, but less soluble phoshorus than for example the spruce mires of corresponding fertility.

The P/K ratio in transformed peatlands of this investigation was about 3-4 in the 0-20 cm peat layer. The ratio calculated from the nutrient amounts of some virgin pine mires (Westman 1981) is about 2/3—4/3. When the P/K ratio in the tree stand is about 1/3—1/4 (see Table 15), it is obvious that the growing trees alone decrease the amount of potassium in relation to phosphorus, besides the reasons mentioned in Chapter 42.

45. Effect of fertilization on nutrient status

The effect of fertilization on the amounts of nutrients was studied in two experiments. In the Jaakkoinsuo experiment nitrogen, phosphorus and potassium had been applied 12 and/or 21 growing seasons before sampling. No differences between the amounts of these nutrients were found in peat between the fertilized and unfertilized plots.

In the Kaakkosuo material nutrients had been applied over 30 years before sampling. The fertilizations were different from those in Jaakkoinsuo, as at the highest rate manifold amounts of phosphorus and potassium as compared to the recommendations had been applied.

There was clearly more phosphorus on fertilized than unfertilized sample plots in Kaakkosuo. It is, however, apparent that with the largest amounts of phosphorus at least part of phosphorus applied as rock phosphate had leached from the area.

Depending on the amount of fertilizer only 8—38 % of the potassium applied as fertilizer could be traced from the peat or estimated to have become bound by trees. Although plenty of nutrients applied as fertilizers are fixed to the ground vegetation (Paavilainen 1980), apparently an extremely large proportion of fertilizer potassium had been leached either deeper than the sampling depth (50 cm) or totally away from the area. The used compound was potassium chloride, which is fully water soluble and which has been found to become easily leached also in earlier studies (Haveraaen and Steenberg 1967, Haveraaen 1978, 1986).

The results indicate that it is not possible to increase the potassium stores in peat permanently to any greater extent even with large applications of water-soluble fertilizer potassium. According to the investigations of both Ahti (1983) and Kaunisto and Tukeva (1984) it appears that potassium becomes leached away from the reach of roots very quickly. Thus the duration of the effect of potassium fertilization depends above all on its immobilization and circulation in the ground vegetation and trees.

46. Estimation of nutrient status

As mentioned above both the amounts and concentrations of nitrogen and phosphorus had very solid positive correlations with the total yield of the tree stands. The potential wood production ability of the substrate could probably be estimated at least to some extent by the amounts and concentrations of phosphorus and nitrogen in peat (see also Holmen 1964).

For the interpretation of the results the raw humus layer on peat seems to have an important role, as its nutrient concentrations may be very high, but the nutrient amounts calculated for unit area negligible because of its low density. To date little is known about the significance of the raw humus layer for the nutrient conditions of the substrate. It is, however, known to slow down the initial development of pine transplants (Kaunisto 1984). As it often appears in rather thick layers (even over 10 cm), it is likely that it impairs the heat conditions and aeration of the underlying peat and thus also slows down microbial activity and hence the mineralization of nutrients.

5. CONCLUSIONS

The results indicate that even a carefully determined original site type does not fully describe the nutrient conditions at the transformed stage of peatlands (the ground layer dominated by species typical of mineral soil sites). As the site type classification may be difficult because of changes in ground vegetation brought about by drainage and possible fertilization, soil analysis should be more frequently used to support the classification. Especially the amounts and concentrations of nitrogen and phosphorus in peat seem to indicate fairly well the wood production capacity of the site. As they are mainly organically fixed, changes in their availability to trees are very slow.

Although the amount of potassium does not usually correlate with wood production, its amount should nonetheless be determined in order to predict its sufficiency. This is very important as there is originally very little potassium in peat and its amount declines when the virgin peatland becomes transformed and may at some stage (according to this investigation during the second postdrainage tree generation) run short quite suddenly causing damages in the apical meristems and even death of trees.

Particular attention should be paid to originally deep-peat, at drainage inadequately stocked or treeless mires which originally have little potassium and where also only small amounts of potassium are bound into the ground vegetation and standing crop. Furthermore, harvesting methods deserve more attention, as more potassium than any other main nutrient is bound into the stand in relation to its amount in peat. Therefore whole-tree harvesting on peatlands should be considered with reserve.

Apparently no such acute shortage of nitrogen and phosphorus as of potassium is likely, as their amount in the surface layer seems to increase as more time elapses from drainage. There may, however, be imbalance in the ratio of these two nutrients. Therefore, the availability of phosphorus as compared to nitrogen should be observed. The results also show that shortage of boron and zinc may appear.

The raw humus layer, frequently found on peat surface, should be separated from peat in sampling in order to obtain reliable results from the nutrient status of the site, as the nutrient concentrations are high but amounts low in the raw humus layer. The thickness of the raw humus layer should be observed, as it supposedly affects the nutrient mineralization of the underlying peat. This aspect requires further investigation. In addition, more surveys of the nutritional balance of drainage areas of different ages, of different stands and peatland site types are needed.

Unbalanced nutritional conditions revealed by nutrient analyses or other methods can usually be improved by fertilization by applying one or more nutrients that are the minimum factors restricting growth. When applying phosphorus and potassium to nitrogen-rich peatlands, it is worth noticing that even moderate amounts, 70 kg P/ha and 200 kg K/ha in this investigation, already ensure a strong and in the case of phosphorus also a long-lasting effect.

Fertilizer potassium applied as KCl leaches easily and rapidly out of the reach of vegetation. Apparently, only the part of fertilizer potassium that is bound by the ground vegetation and standing crop in the first few years after fertilization will remain on the site. Therefore it is important that the trees are in good physiological condition before fertilization for catching as much of the fertilizer potassium as possible, before it leaches out from the area. Thus drainage conditions should be checked and, if necessary, improved some years before fertilization.

Further investigations are needed to find out how rapidly potassium leaches and the amount of potassium that is sufficient for a normal fertilization effect. Too large amounts of fertilizers should be avoided, not only because of too small a growth increment in relation to normal application rates, but also for environmental protection. The results show that if applied in large amounts not only potassium but also phosphorus is leached from the root layer and part of the nutrients may gradually be carried to waterways. Slowly soluble phosphorus fertilizers have already been used for decades. It is vitally important that they should be available also in the future. In addition, attention should be paid to developing also a slowly soluble potassium fertilizer.

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SELOSTE

Turpeen ravinnevarat vanhoilla ojitusalueilla ja puuston kasvu

1. Johdanto

Puuston kasvu metsäojitetuilla soilla ilman lannoitusta riippuu lähinnä turpeen luontaisista ravinnevaroista. Lisää ravinteita voi tulla puiden käyttöön vain ilmasta tai turpeen alla olevasta kivennäismaasta, sillä ojitus estää ravinteiden kulkeutumisen pintavalunnan mukana suolle sitä ympäröiviltä kankailta. Kun suopuiden juuristo on varsin pinnallinen ja sen syvyyttä voidaan lisätä tehokkaallakin kuivatuksella suhteellisen vähän, on pohjamaa merkittävä ravinteiden luovuttaja ainoastaan ohutturpeisilla soilla.

Tässä tutkimuksessa tarkastellaan alkuperäiseltä suotyypiltään erilaisten kasvupaikkojen ravinnevaroja 53—78 vuoden kuluttua ojituksesta, jolloin puustoja on ehditty käsitellä hakkuin jo useita kertoja. Puuston kasvun kannalta tärkeimmän turpeen pintakerroksen (0—20 cm) lisäksi ovat myös syvempien kerrosten ravinnemäärät tarkastelun kohteena. Lisäksi tutkitaan maan luontaisten ravinnevarojen ja tuotoksen välistä suhdetta sekä pohditaan ravinteiden riittävyyttä. Lannoituksen vaikutusta ravinnetaseeseen tarkastellaan kahden kokeen perusteella. Tutkimus on ensimmäinen osa laajemmasta metsäojitettujen soiden ravinnevaroja koskevasta tutkimussarjasta. Osia tutkimuksen tuloksista on julkaistu esitelmien pohjalta tehdyissä lyhyissä raporteissa (Kaunisto 1988a ja 1988b, Kaunisto ja Finér 1988).

2. Aineisto ja menetelmät

Aineisto kerättiin 50:ltä Metsäntutkimuslaitoksen suontutkimusosaston pitkäaikaiselta ojitettujen turvemaiden kestokoealalta eteläisestä Keski-Suomesta, Vilppulan (Jaakkoinsuo ja Kaakkosuo) ja Vesijaon tutkimusalueista. Perusojitus oli alueilla toteutettu pääasiassa 1900-luvun alkuvuosikymmeninä ja puuston mittaukset aloitettu useimmilla koealoilla 1920—30-lukujen vaihteessa. Koealojen ominaisuuksia on esitelty taulukossa 1. Kaikki koealat olivat turvenäytteitä otettaessa turvekankaita.

Tutkimukseen valittiin mukaan pääasiassa lannoittamattomia, mutta Kaakkosuolta ja Jaakkoinsuolta myös eräitä lannoitettuja koealoja. Jaakkoinsuon isovarpuiselle rämeelle perustetusta kokeesta valittiin mukaan seuraavat lannoitusvertailut:

	Lannoitus, kg/ha					
	v. 1965			v. 1974		
	N	P	K	N	P	K
1.	0	0	0	0	0	0
2.	70,5	30,5	41,5	0	0	0
3.	0	0	0	104,0	51,5	62,5
4.	70,5	30,5	41,5	104,0	51,5	62,5

V. 1965 käytettiin NPK-lannoitetta 500 kg/ha (14-7,7-8,3) ja v. 1974 oulunsalpietaria 400 kg/ha (26 % N) ja PK-lannoitetta 500 kg/ha (0-10,3-12,5).

Kaakkosuolta otettiin mukaan neljä varsinaiselle saranevalle perustettua koealaa, jotka oli lannoitettu v. 1953 renofosfaatilla (13,8 % P) ja kalisuolalla (39,8 % K) seuraavasti:

	P	K
	kg/ha	
1 =	0	0
2 =	70	200
3 =	140	400
4 =	280	800

Renofosfaatti on afrikkalaisesta raakafosfaatista jauhettua hienofosfaattia.

Kukin koeala oli jaettu lisäksi neljään osakoealaan, joille annettiin joko lannoiteboraattia 10 kg/ha (14 % B = 1,4 kg/ha), sinkkisulfaattia 50 kg/ha (23 % Zn = 11,5 kg/ha), kuparisulfaattia 50 kg/ha (25 % Cu = 12,5 kg/ha) tai mangaanosulfaattia 50 kg/ha (26 % Mn = 13 kg/ha).

Kaakkosuon koealat oli 1930-luvulla kylvetty koivulle. V. 1960 (seitsemän vuotta lannoituksen jälkeen) metsikkö oli lannoitetuilla koealoilla 0,2—2,0 m:n ja lannoittamattomilla 0,1—1,0 m:n pituista aukkoista hieskoivun sekaista mäntytaimikkoa. Jaakkoinsuon nevakoealoilla oli ojitushetkellä (v. 1909) jonkin verran koivun, männyn ja kuusen taimia. Kaikki muut koealat olivat olleet ojitushetkellä puustoisia. Viimeinen puuston mittaus tehtiin vuosina 1982—1986. Puustotiedot muunnettiin vuoden 1985 tasolle käyttämällä hyväksi viimeisen mittausjakson keskimääräistä kasvua.

Turvenäytteet ravinneanalyysejä varten otettiin syksyllä 1985. Pinnassa oleva raakahumuskerros erotettiin omaksi osanäytteekseen. Turvenäytteet otettiin 10 cm:n kerroksina 50 cm:n syvyyteen saakka. Näytteistä määritettiin helppoliukoinen P (NH_4OAc-uutoksesta, pH 4,65), NH_4- ja NO_3-typpi sekä vaihtuvat Ca ja K, turpeen tiheys sekä kokonais-N, -P, -K, -Ca, -Mg, -Zn, -B, -Cu ja -Mn. Osalla näytteitä vertailtiin analyysimenetelmän (taulukko 2) ja näytteiden homogenisoinnin (taulukko 3) luotettavuutta.

3. Tulokset

31. Turpeen tiheys

Turpeen tiheydet tämän tutkimuksen rämeillä (taulukko 4) olivat suuruusluokaltaan suunnilleen samanlaisia kuin aikaisemmin suotyypiltään vastaaville ojitetuille soille esitetyt, mutta kaksin-kolminkertaisia luonnontilaisilta vastaavilta suotyypeiltä saatuihin arvoihin verrattuna. Raakahumuskerroksen tiheys oli poikkeuksetta vain murto-osa turpeen tiheydestä kaikilla suotyypeillä (taulukko 4). Kaakkosuon lannoittamattomille koealoille ei raakahumuskerrosta ollut syntynyt lainkaan.

32. *Turpeen ravinteet*

321. Luontaiset ravinteet

Ravinnepitoisuudet

Turpeen typpi-, fosfori- ja kalsiumpitoisuuksissa oli verrattain vähän eroja aikaisempiin tutkimuksiin verrattuna (taulukko 5). Sen sijaan erittäin selvästi aikaisempien tutkimusten tuloksista poikkesivat turpeen kaliumpitoisuudet, jotka olivat vain 13—22 % aikaisemmissa tutkimuksissa vastaavilta luonnontilaisilta rämeiltä saaduista arvoista ja myös selvästi pienempiä kuin aikaisemmin ojitetuillekin turvemaille esitetyt arvot. Raakahumuskerroksen typpipitoisuudet olivat jonkin verran alempia kuin alla olevan turpeen (taulukko 5). Sen sijaan kaikki muut tutkitut ravinnepitoisuudet olivat raakahumuksessa huomattavasti korkeampia ja jopa moninkertaisia turpeeseen verrattuna (taulukot 5—7).

Ravinnemäärät

Typen kokonaismäärä 0—20 cm:n pintakerroksessa vaihteli 3000 ja 7000 kg/ha välillä ja fosforin 90—250 kg/ha välillä eri suotyypeillä (kuva 1). Kumpaakin ravinnetta oli selvästi enemmän kuin vastaavilla luonnontilaisilla rämeillä on aikaisemmissa tutkimuksissa todettu. Kokonaistypestä oli alle 1 % ja kokonaisfosforista 1—8 % liukoisessa muodossa.

Kaliumin kokonaismäärä vaihteli keskimäärin 30 ja 65 kg/ha välillä 0—20 cm:n kerroksessa (kuva 2). Kaliumia oli vain noin puolet luonnontilaisilta rämeiltä aikaisemmin saatuihin tuloksiin verrattuna. Pintakerroksessa lähes kaikki kalium oli vaihtuvassa muodossa.

Kokonaistypen ja -fosforin määrissä eri syvyyskerroksissa oli vain vähäisiä eroja, mutta kaliumia samoin kuin liukoista fosforiakin oli selvästi eniten turpeen pintakerroksessa.

Kalsiumin kokonaismäärät 0—20 cm:n kerroksessa vaihtelivat keskimäärin 500 ja 1800 kg/ha ja magnesiumin 50 ja 200 kg/ha välillä.

Booria oli erittäin vähän kaikilla suotyypeillä. Määrä vaihteli 0—20 cm:n kerroksessa keskimäärin 200 ja 600 g/ha välillä (kuva 3). Kuparin määrä vaihteli keskimäärin 0,7 ja 3,2 kg/ha, sinkin 1 ja 3 kg/ha ja mangaanin 3,5 ja 25 kg/ha välillä 0—20 cm:n turvekerroksessa (kuva 3).

Maan ravinteisuuden perusteella voitiin pääkomponenttianalyysillä muodostaa kolme eri ryhmää, jotka jossain määrin kuvastivat myös alkuperäistä suotyyppiä (kuva 4). Karuhkoille rämeille oli ominaista kokonaistypen ja -fosforin sekä kuparin vähäinen määrä muihin suotyyppeihin verrattuna (liite 1). Viljavien korpien ryhmää luonnehti kokonaiskaliumin, -kalsiumin, -magnesiumin ja -boorin samoin kuin vaihtuvan kaliumin ja kalsiumin suurempi määrä muihin suotyyppeihin verrattuna.

Pääravinteiden väliset riippuvuudet

Kaikissa turvekerroksissa typen ja fosforin samoin kuin kalsiumin ja magnesiuminkin totaalimäärien välillä vallitsi kiinteä positiivinen korrelaatio (liite 2, ks. myös Westman 1981). Samoin kokonaistyppi ja -kalsium sekä syvemmissä (> 20 cm) turvekerroksissa myös kokonaistyppi ja -magnesium korreloivat keskenään positiivisesti. Liukoisen typen sekä vaihtuvan kaliumin ja kalsiumin määrät korreloivat positiivisesti, mutta helppoliukoisen fosforin määrät negatiivisesti vastaavien totaaliravinteiden määrien kanssa turpeessa.

Raakahumuskerroksen ravinteista vain kokonaistypen, kalsiumin ja magnesiumin määrät korreloivat turpeen vastaavien kokonais— tai liukoisten/vaihtuvien ravinteiden määrän kanssa.

322. Lannoituksen vaikutus ravinnemääriin

NPK-lannoituksen vaikutus Jaakkoinsuon koealoilla ei ollut havaittavissa fosforin, kaliumin, kalsiumin ja magnesiumin kokonaismäärissä enää 10 ja 19 vuotta lannoituksen jälkeen (kuva 5).

Kaakkosuon pintaturvekerroksen (0—20 cm) ravinteista lasketussa pääkomponenttianalyysissä, jossa jokaista osakoealaa käsiteltiin erillisenä, lannoittamattomat ja 2000 kg/ha PK:ta saaneet koeruudut erottuivat kumpikin selvästi omaksi ryhmäkseen faktorin 2 suhteen (kuva 6). Erottelevana tekijänä oli lähinnä liukoinen fosfori (ks. myös kuva 9). PK:ta 500 ja 1000 kg/ha saaneiden koeruutujen välinen ero ei sen sijaan ollut kovinkaan jyrkkä.

Verrattuna lannoitteena annettuun kaliumin määrään maassa oli kaliumia koko profiilikin huomioon ottaen erittäin vähän (kuvat 5 ja 7). Fosfori- ja kaliumtasapainon selvittämiseksi puiden juurten toiminnan kannalta tärkeimmässä 20 cm:n pintaturvekerroksessa laskettiin näiden ravinteiden kokonaismäärä puustossa (nykypuusto + poistuma) ja maassa vähennettynä lannoittamattoman koealan ravinnemäärillä (taulukko 7).

Vaikka pintakasvillisuuden osuutta ravinteiden sitojana ei ole voitu ottaa huomioon, on ilmeistä, että ainakin suuria fosforimääriä käytettäessä osa fosforista on kulkeutunut 0-20 cm:n kerrosta syvemmälle (taulukko 7, ks. myös kuva 5) ja osa todennäköisesti huuhtoutunut. Lannoitteena annetusta kaliumista oli 0—20 cm:n turvekerrokseen ja puustoon pidättynyt vain pieni osa (taulukko 7).

Kupari- ja sinkkilannoituksen vaikutus näkyi Kaakkosuolla näiden alkuaineiden määrissä erityisesti turpeen pintakerroksessa (kuva 8). Boori- ja mangaanilannoituksen vaikutusta turpeen B- ja Mn- määrissä ei voitu todeta.

33. *Puuston tuotos*

Hakkuissa poistetun kuorellisen runkopuun määrä vaihteli keskimäärin 90 ja 310 m^3:n sekä kokonaistuotoksen määrä 210 ja 550 m^3:n välillä puustoisilla soilla (kuva 9). Kaakkosuon koealoilla puuston kehittyminen riippui täysin fosfori-kalilannoituksesta. Paras kokonaistuotos (185 m^3/ha) oli pienimmän lannoitemäärän saaneilla koealoilla.

34. *Puuston tuotos ja turpeen ravinteet*

Puuston kokonaistuotoksen ja turpeen nykyisten ravinnevarojen välistä riippuvuutta selvitettiin vain Vesijaon ja Jaakkoinsuon lannoittamattomilla koealoilla (yht. 30 kpl).

Turpeen pintaosassa voimakkaimmin (positiivisesti) puuston kokonaistuotoksen kanssa korreloivat turpeen kokonaistyppi- ja fosforimäärät 0—10 cm:n kerroksessa (taulukko 9, kuva 10).

Turpeen sinkin ja liukoisen fosforin määrät etenkin 0-10 cm:n kerroksessa sen sijaan korreloivat kokonaistuotoksen kanssa voimakkaasti negatiivisesti. Myös viimeisen mittausjakson keskikasvu korreloi negatiivisesti liukoisen fosforin määrän kanssa (taulukko 10).

Samoin kuin typen ja fosforin kokonaismäärien ja -tuotoksen välillä myös typen ja fosforin kokonaispitoisuuksien ja tuotoksen välillä oli verrattain kiinteä positiivinen riippuvuus (taulukko 11).

35. Puustoon sitoutuneet ravinteet ja ravinteiden riittävyys

Paavilaisen (1980) ja Finérin (1988) tutkimusten perusteella on laskettu kertoimet yhtä tuotettua runkopuun kiintokuutiometriä kohden runkopuuhun + kuoreen ja koko puustoon/ha sitoutuneille ravinnemäärille (taulukko 12). Näistä on edelleen laskettu sitoutuneet ravinnemäärät tämän tutkimuksen aineistossa (kuvat 12 ja 13).

Turpeessa 0—20 cm:n paksuisessa pintaturpeessa on typpeä ja fosforia vielä monikymmenkertainen määrä runkopuuhun sitoutuneisiin määriin verrattuna (kuvat 1—3, 12 ja 13). Koko puubiomassakin huomioon ottaen turpeessa on vielä 10—15 -kertainen määrä typpeä ja 3—7 -kertainen määrä fosforia.

Suhteessa jäljellä oleviin pääravinteisiin puusto on eniten käyttänyt kaliumia. Poistumaan ja nykyhetken runkopuuhun ja kuoreen on sitoutunut kaliumia 1—2 -kertainen ja koko tuotettuun puubiomassaan 2—4 -kertainen määrä turpeessa jäljellä olevaan verrattuna. Boorin osalta tilanne oli samantapainen. Sinkkiä maassa oli erityisen vähän puustoon sitoutuneeseen määrään verrattuna.

Kaliumin riittävyydestä tehty karkea laskelma osoitti, että kaliumista saattaa monissa tapauksissa tulla puutetta jo toisen ojituksen jälkeisen puusukupolven aikana (kuva 14). Ravinteiden määrää ja riittävyyttä koskevien tulosten tarkastelussa on kiinnitetty huomiota mm. eri ravinteiden välisiin suhteisiin turpeessa ja puustossa sekä ravinteiden huuhtoutumisen ja laskeuman merkitykseen (taulukot 13—15).

4. Päätelmät

Tulosten perusteella näyttää siltä, että huolellisestikaan määritettynä alkuperäinen suotyyppi ei täysin kuvaa kasvupaikan ravinnetaloutta enää turvekangasvaiheessa. Kun kasvupaikan luokittelu tällöin myös ojituksen ja mahdollisen lannoituksen pintakasvillisuudessa aiheuttamien muutosten vuoksi saattaa tuottaa vaikeuksia, pitäisikin luokituksen tukena entistä enemmän käyttää myös maa-analyysiä. Erityisesti turpeen typen ja fosforin määrät samoin kuin niiden pitoisuudetkin näyttävät verrattain hyvin indikoivan kasvupaikan puuntuotoskykyä. Koska nämä ravinteet ovat pääasiassa orgaanisesti sitoutuneina, niiden saatavuudessa tapahtuvat muutokset ovat hyvin hitaita.

Vaikka kaliumin määrä ei yleensä sanottavasti korreloikaan puuntuoksen kanssa, tulisi senkin määrä analysoida. Näin saataisiin viitteitä kaliumin riittävyydestä. Tämä on erittäin tärkeätä sen vuoksi, että kun turpeessa on kaliumia alunperinkin vähän, sen määrä vielä vähenee suon muuttuessa luonnontilaisesta turvekankaaksi ja saattaa jossakin vaiheessa (tämän tutkimuksen arvion perusteella toisen ojituksen jälkeisen puusukupolven aikana) loppua puiden kannalta hyvinkin äkillisesti.

Erityisesti tulisi tarkkailla alkuperäiseltä suotyypiltään paksuturpeisia, ojitushetkellä vähäpuustoisia tai puuttomia vetisiä soita, joilla kaliumia alunperinkin on vähän ja joilla myös pintakasvillisuuteen ja puustoon sitoutuneet kaliumin määrät ovat vähäisiä. Edelleen tulisi kiinnittää huomiota puunkorjuumenetelmiin, koska puustoon suhteessa maassa oleviin sitoutuu enemmän kaliumia kuin muita pääravinteita. Tämän vuoksi kokopuukorjuuseen turvemailla on suhtauduttava varauksella.

Tulosten mukaan puutetta saattaa tulla myös boorista ja sinkistä. Sen sijaan typestä ja fosforista ei nähtävästi synny yhtä helposti samanlaista akuuttia puutetta kuin kaliumista, koska niiden määrä pintakerroksessa ojituksen ikääntyessä näyttää pikemminkin lisääntyvän. Näiden kahden ravinteen keskinäisissä suhteissa saattaa kuitenkin esiintyä epätasapainoisuutta. Kohtalaisen runsastyppisillä soilla tulisikin tarkkailla fosforin saatavuutta typpeen verrattuna.

Luotettavan tuloksen saamiseksi tulisi turpeen pinnalla usein esiintyvä raakahumuskerros erottaa varsinaisesta turvenäytteestä, koska raakahumuskerroksessa ravinnepitoisuudet ovat korkeat, mutta niiden määrät vähäisiä. Raakahumuskerroksen paksuutta tulisi tarkkailla, koska on oletettavissa, että se saattaa vaikuttaa alla olevan turpeen ravinteiden mineralisoitumiseen. Tässä asiassa tarvitaan ilmeisesti vielä runsaasti tutkimustyötä. Lisäksi tarvitaan lisää ravinnetasekartoitusta eri-ikäisiltä ojitusalueilta, erilaisista puustoista ja erilaisilta suotyypeiltä.

Puuston ravinneanalyysein tai muutoin todettu tasapainoton ravinnetila voidaan yleensä korjata lannoituksella antamalla puiden kasvun kannalta minimitekijänä olevaa yhtä tai useampaa ravinnetta. Käytettäessä fosforia ja kaliumia runsastyppisillä soilla on huomattava, että jo kohtuullisilla käyttömäärillä, tässä tutkimuksessa 70 kg P/ha ja 200 kg K/ha, saadaan voimakas ja fosforin osalta myös pitkäaikainen vaikutus.

Normaalisti lannoitteessa kloridina oleva kalium huuhtoutuu erittäin helposti ja nopeasti kasvillisuuden saavuttamattomiin. Ilmeisesti verrattain pian lannoitekaliumista on kasvupaikalla jäljellä vain se osa, mikä muutamana ensimmäisenä vuotena lannoituksen jälkeen on sitoutunut pintakasvillisuuteen ja puustoon. Tämän vuoksi on tärkeätä, että lannoitushetkellä puut ovat hyvässä fysiologisessa kunnossa voidakseen käyttää hyväkseen mahdollisimman suuren osan lannoitekaliumista, ennen kuin se huuhtoutuu pois alueelta. Tästä syystä esim. kuivatuksen tulisi olla kunnossa jo muutamia vuosia ennen lannoitusta. Tällä hetkellä tarvitaan lisäselvityksiä siitä, miten nopeasti kalium huuhtoutuu ja minkälainen kaliumin määrä on riittävä normaalin lannoitusvaikutuksen aikaansaamiseksi.

Ylisuurien määrien käyttöä on vältettävä ei pelkästään normaaliin käyttömäärään nähden saavutettavan liian vähäisen kasvun lisäyksen vuoksi, vaan myös ympäristön suojelemiseksi. Saadut tulokset osoittavat, että suuria lannoitemääriä käytettäessä kaliumin lisäksi myös fosforia huuhtoutuu puiden juurikerroksen ulottuvilta ja osa ravinteista voi aikaa myöten myös kulkeutua vesistöihin. Hidasliukoisia fosforilannoitteita on ollut käytössä jo kymmeniä vuosia. On erittäin tärkeää, että niitä on saatavissa tulevaisuudessakin. Tämän lisäksi tulisi kiinnittää huomiota myös hidasliukoisen kalilannoitteen kehittämiseen.

Appendix 1. Peatland site type groups distinguished with the principal component analysis, their nutrient amounts (kg/ha) and significant differences. The values indicated with the same letter do not differ from each other significantly.

Liite 1. Pääkomponenttianalyysillä erotellut suotyyppiryhmät, niiden ravinnemäärät (kg/ha) ja merkitsevät erot. Samalla kirjaimella merkityt eivät eroa tilastollisesti merkitsevästi toisistaan.

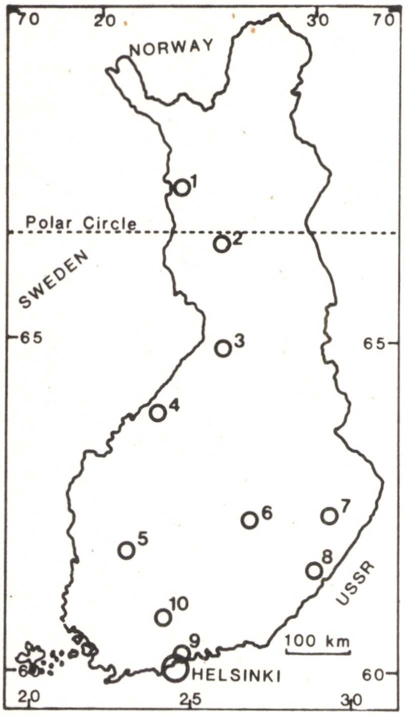
Nutrient *Ravinne*	Layer *Kerros* cm	Group — *Ryhmä* 1 (a) IR [1]	2 (b) Best spruce mires *Parhaat korvet*	3 (c) Others *Muut*
Tot. N	0—10	1157^{bc}	2777^{a}	2998^{a}
	10—20	1650^{bc}	3126^{a}	2934^{a}
Tot. P	0—10	41^{bc}	103^{a}	113^{a}
	10—20	40^{bc}	105^{a}	106^{a}
Tot. K	0—10	20^{b}	36^{ac}	26^{b}
	10—20	11^{b}	20^{ac}	13^{b}
Tot. Ca	0—10	219^{b}	772^{ac}	312^{b}
	10—20	236^{b}	968^{ac}	333^{b}
Tot. Mg	0—10	29^{b}	87^{ac}	25^{b}
	10—20	29^{b}	102^{ac}	21^{b}
Tot. B	0—10	0.11^{b}	0.28^{ac}	0.15^{b}
	10—20	0.09^{b}	0.24^{ac}	0.10^{b}
Tot. Cu	0—10	0.23^{c}	0.57	0.83^{a}
	10—20	0.18^{bc}	0.80^{a}	0.61^{a}
Tot. Zn	0—10	1.92^{bc}	0.60^{a}	0.81^{a}
	10—20	0.59^{bc}	0.38^{a}	0.39^{a}
Tot. Mn	0—10			
	10—20			
Sol. P	0—10	11.1^{c}	9.7^{c}	3.2^{ab}
Liuk. P	10—20	6.2^{c}	4.5^{c}	1.2^{ab}
Exch. K	0—10	22.8^{b}	38.7^{ac}	26.7^{b}
Vaiht. K	10—20	10.7^{b}	17.0^{ac}	9.6^{b}
Exch. Ca	0—10	167^{b}	494^{ac}	214^{b}
Vaiht. Ca	10—20	170^{b}	621^{ac}	243^{b}

[1] IR = Dwarf shrub pine mires

Appendix 2. Correlation coefficients between the amounts of main nutrients in raw humus and peat.
Liite 2. Pääravinteiden määrien väliset korrelaatiokertoimet raakahumuksessa ja turpeessa.

Nutrient[1)] *Ravinne[1)]*		Total — *Kokonais-*					Easily soluble *Helppoliukoiset*		Exchangeable *Vaihtuvat*	
		N_t	P_t	K_t	Ca_t	Mg_t	N_s	P_s	K_e	Ca_e
		In 0–10 cm — *0–10 cm:n kerroksessa*								
Peat	N_t	1.0000								
Turve	P_t	0.7577***	1.0000							
	K	0.2017	0.5075**	1.0000						
	Ca	0.4500**	0.2431	0.3392	1.0000					
	Mg	0.2496	0.0969	0.3506*	0.9403***	1.0000				
	N_s	0.6744***	0.3796*	−0.0758	0.3796*	0.2252	1.0000			
	P_s	−0.2538	−0.4133*	−0.0597	0.3539*	0.4366**	0.1202	1.0000		
	K_e	0.1189	0.3049	0.8698***	0.3938*	0.4032*	−0.1187	0.0821	1.0000	
	Ca_e	0.4896**	0.3198	0.3406*	0.9203***	0.8277***	0.4626**	0.4149*	0.3330	1.0000
Raw	N_t	0.6809***	0.4815*	−0.1402	0.4719**	0.3184	0.5267**	−0.1966	−0.2183	0.5299**
humus	P_t	−0.0171	0.0289	−0.0607	−0.0476	−0.1089	−0.1133	−0.1592	0.0107	−0.0408
Raaka-	K_t	−0.0460	−0.0025	−0.0550	−0.0480	−0.1046	−0.1254	−0.1361	0.0235	−0.0443
humus	Ca_t	0.3359	0.2187	0.1520	0.6688***	0.5990***	0.3758*	0.1267	0.1459	0.6968***
	Mg_t	0.1598	0.1075	0.2853	0.7028***	0.7091***	0.1589	0.1824	0.3177	0.6722***
		N_t	P_t	K_t	Ca_t	Mg_t	N_s	P_s	K_e	Ca_e
		In 10–20 cm — *10–20 cm:n kerroksessa*								
Peat	N_t	1.0000								
Turve	P_t	0.5948***	1.0000							
	K	0.1152	0.5492**	1.0000						
	Ca	0.5188**	0.2676	0.2011	1.0000					
	Mg	0.3309	0.2382	0.4073*	0.9055***	1.0000				
	N_s	0.5413**	0.2982	0.1664	0.4431*	0.2557	1.0000			
	P_s	−0.3097	−0.5588**	−0.0872	0.1759	0.2573	−0.1224	1.0000		
	K_e	0.2028	0.1709	0.6170***	0.4206*	0.5157**	0.2970	0.4167*	1.0000	
	Ca_e	0.5482**	0.2745	0.2057	0.9867***	0.8758***	0.4434*	0.1540	0.4346*	1.0000
Raw	N_t	0.7680***	0.5348**	0.1196	0.5449**	0.3748*	0.5171**	−0.4551*	0.1122	0.5650**
humus	P_t	−0.2429	−0.2759	−0.2817	−0.1643	−0.1668	−0.1568	−0.2099	−0.2799	−0.1517
Raaka-	K_t	−0.2565	−0.3007	−0.2863	−0.1622	−0.1628	−0.1627	−0.1757	−0.2657	−0.1497
humus	Ca_t	0.5075**	0.3040	0.3501	0.7009***	0.6777***	0.4649*	−0.0543	0.4304*	0.7350***
	Mg_t	0.3708*	0.3103	0.4541*	0.7184***	0.7842***	0.3873*	0.0631	0.5767***	0.7303***
		N_t	P_t	K_t	Ca_t	Mg_t	N_s	P_s	K_e	Ca_e
		In 20–30 cm — *20–30 cm:n kerroksessa*								
Peat	N_t	1.0000								
Turve	P_t	0.6087***	1.0000							
	K	0.3769*	0.8022***	1.0000						
	Ca	0.8908***	0.3308	0.1992	1.0000					
	Mg	0.8373***	0.3629	0.3498	0.9494***	1.0000				
	N_s	0.5407**	0.2472	−0.0260	0.4488*	0.2976	1.0000			
	P_s	0.1695	−0.2038	−0.2489	0.1101	0.1064	0.1012	1.0000		
	K_e	0.7163***	0.4289*	0.4147*	0.6384***	0.7074***	0.1684	0.2770	1.0000	
	Ca_e	0.8907***	0.3466	0.2107	0.9954***	0.9378***	0.4651*	0.0972	0.6236***	1.0000
Raw	N_t	0.5014**	0.4148*	0.2964	0.4634*	0.3418	0.5325**	−0.4406*	0.2848	0.4832**
humus	P_t	−0.2654	−0.1500	−0.1245	−0.1498	−0.1604	−0.1011	−0.1933	−0.2218	−0.1642
Raaka-	K_t	−0.2698	−0.1678	−0.1386	−0.1493	−0.1570	−0.1115	−0.1735	−0.2214	−0.1643
humus	Ca_t	0.5594**	0.2650	0.2626	0.6431***	0.6368***	0.4464*	−0.2090	0.4705*	0.6770***
	Mg	0.5836**	0.2878	0.3395	0.6962***	0.7677***	0.2519	−0.0990	0.6373***	0.7138***

[1)] t = total — *kokonais-*, s = easily soluble — *helppoliukoiset*, e = exchangeable — *vaihtuvat*



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RESEARCH STATIONS

1 Kolari
2 Rovaniemi
3 Muhos
4 Kannus
5 Parkano
6 Suonenjoki
7 Joensuu
8 Punkaharju
9 Ruotsinkylä
10 Ojajoki

FACTS ABOUT FINLAND

Total land area: 304 642 km^2 of which 60—70 per cent is forest land.

Mean temperature, °C:	Helsinki	Joensuu	Rovaniemi
January	-6,8	-10,2	-11,0
July	17,1	17,1	15,3
annual	4,4	2,9	0,8
Thermal winter (*mean temp.* < 0°C):	20.11.—4.4.	5.11.—10.4.	18.10.—21.4.

Most common tree species: Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens

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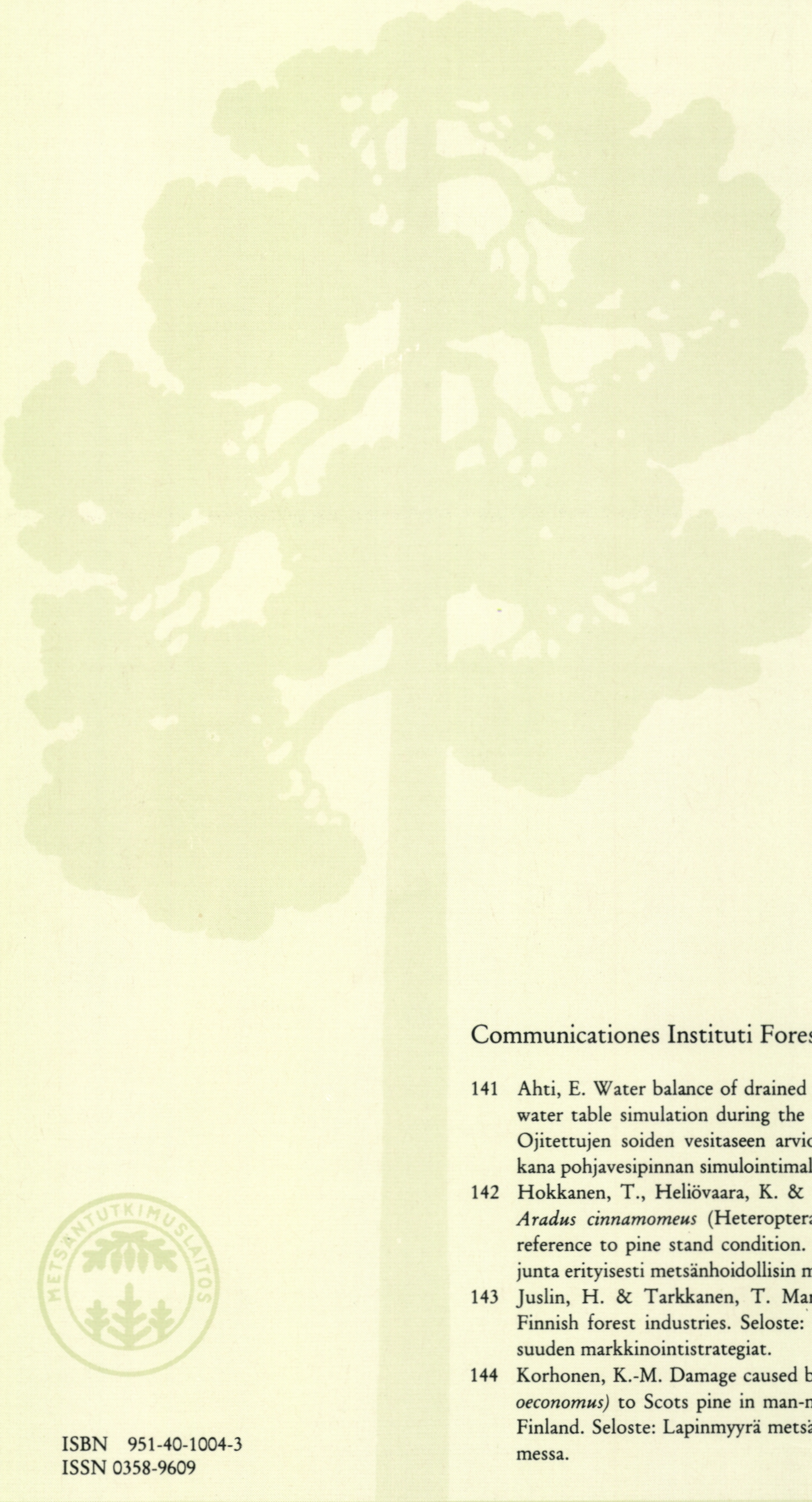

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