COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE 140

EFFECT OF REFERTILIZATION ON THE DEVELOPMENT AND FOLIAR NUTRIENT CONTENTS OF YOUNG SCOTS PINE STANDS ON DRAINED MIRES OF DIFFERENT NITROGEN STATUS

SEPPO KAUNISTO

SELOSTE

JATKOLANNOITUKSEN VAIKUTUS MÄNTYTAIMIKOIDEN KEHITYKSEEN JA NEULASTEN RAVINNEPITOISUUKSIIN TYPPITALOUDELTAAN ERILAISILLA OJITETUILLA SOILLA

HELSINKI 1987

COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE

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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 20.2. 1987

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KAUNISTO, S. 1987. Effect of refertilization on the development and foliar nutrient contents of young Scots pine stands on drained mires of different nitrogen status. Seloste: Jatkolannoituksen vaikutus mäntytaimikoiden kehitykseen ja neulasten ravinnepitoisuuksiin typpitaloudeltaan erilaisilla ojitetuilla soilla. Communicationes Instituti Forestalis Fenniae 140. 58 p.

Different combinations of N, P, K and micronutrient fertilizers, lime and wood ash were used for refertilization. The peat nitrogen regime was described by the total peat nitrogen content and humification degree. Both variables explained well the growth variation of trees. The growth of trees on the PK fertilized sample plots increased as the total peat nitrogen content in the 5—10 cm layer rose to 1.6—2.0 %. Refertilization with nitrogen in addition to phosphorus and potassium as compared to mere phosphorus and potassium fertilization increased the growth of trees up to 1.2—1.3 % of the total peat nitrogen content and about 3 of the humification degree. Fertilization with phosphorus, potassium and particularly nitrogen usually lowered the foliar boron contents (the dilution phenomenon) increasing in some cases the occurrence of growth disturbances. In most experiments there was a negative correlation between the proportion of normal seedlings and the foliar nitrogen content as well as the foliar N/B ratio. Nitrogen fertilization also turned needles brown and caused apical damages, the frequency of which had a solid positive correlation with the foliar N/P ratio. Liming increased the shortages of both boron and phosphorus. Good-quality ash raised the foliar nutrient contents and promoted the growth of seedlings, but the effect of poor-quality ash could be even negative.

Jatkolannoituksessa käytettiin erilaisia N-, P-, K- ja hivenainelannoitteiden, kalkin ja puuntuhkan yhdistelmiä. Turpeen typpitaloutta kuvattiin turpeen kokonaistyppipitoisuudella ja maatumisasteella. Molemmat suureet selittivät puiden kasvuvaihtelua hyvin. Puiden kasvu PK-lannoitetuilla koealoilla lisääntyi turpeen kokonaistyppipitoisuuden 5—10 cm:n kerroksessa kohotessa 1,6—2,0 %:iin. Jatkolannoitus typellä fosforin ja kaliumin ohella lisäsi puiden kasvua fosfori-kalilannoitukseen verrattuna turpeen typpipitoisuuden arvoon 1,2—1,3 % ja maatumisasteen arvoon n. 3 saakka. Lannoitus fosforilla, kaliumilla ja erityisesti typellä yleensä alensi neulasten booripitoisuuksia (ohentumisilmiö) lisäten eräissä tapauksissa kasvuhäiriöiden määrää. Useissa kokeissa normaalien taimien osuuden ja neulasten typpipitoisuuden sekä neulasten N/B-suhteen välillä vallitsi negatiivinen korrelaatio. Typpilannoitus aiheutti myös neulasten ruskettumista ja päätesilmun vaurioita, joiden esiintymisfrekvenssi korreloi kiinteästi positiivisesti neulasten N/P-suhteen kanssa. Kalkitus lisäsi sekä boorin että fosforin puutosta. Hyvälaatuinen tuhka kohotti neulasten ravinnepitoisuuksia ja edisti taimien kasvua, mutta huonolaatuisen vaikutus saattoi olla jopa negatiivinen.

Additional keywords: *Pinus sylvestris*, nitrogen, phosphorus, potassium, peatlands
ODC 2-144.444+237.4+174.7 *Pinus sylvestris*

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CONTENTS

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1. INTRODUCTION

Larger amounts of nitrogen than any other nutrient are needed for producing biomass. According to Mälkönen (1974) only about 11 % of phosphorus and about 52 % of potassium in relation to nitrogen were fixed to an advanced pine stand on mineral soil and according to Paavilainen (1980) about 12 % of phosphorus and 36—39 % of potassium to a stand on a pine mire. Nitrogen shortage does not usually lead to bud or shoot disorder, but is usually seen as an overall yellowish colour and a growth decrease in the above ground parts of the plant (Baule & Fricker 1970). As nitrogen application with phosphorus and potassium increase the fertilization costs by 60—80 % in comparison to PK fertilization (Kaunisto 1983, according to 1982 prises), it is economically extremely important to be able to predict the ability of the substrate to provide a stand with nitrogen.

The amount of nitrogen in peat depends primarily on the peat producing plant community and the humification degree of dead plant remnants (Kivinen 1933). The traditional peatland site type classification according to ground vegetation describes fairly well the nitrogen status in the substrate, although the variation is rather large (Vahtera 1955, Westmann 1981). Various forest improvement measures such as drainage and fertilization have a powerful effect on the species composition of plant communities (e.g. Sarasto 1957, Mannerkoski 1970, 1976, Raitio 1976, Kaunisto 1984) thus creating further inaccuracy when using the ground vegetation for estimating nitrogen regime of the substrate. Therefore, instead of an indirect method (ground vegetation), an attempt has been made to estimate the nitrogen regime of peat by using direct methods i.e. chemical analyses, which have shown a solid linear positive correlation between the total nitrogen content of peat and the growth of seedlings during six growing seasons after planting provided that their phosphorus and potassium nutrition has been taken care of (Kaunisto 1982).

Similarly some refertilization experiments have shown a solid positive correlation between height growth and the total nitrogen content of peat (Kaunisto 1985). Owing to the large variation in the cited material, no limit values could be found.

On the other hand abundant nitrogen may cause problems. Schairer & Moosmayer (1958) among others have shown that one-sided nitrogen fertilization may delay the lignification of buds and weaken the resistance against frost, drought and wind. Paavilainen (1976) and Kaunisto & Paavilainen (1977) have shown that one-sided nitrogen fertilization caused severe damages in needles and buds in a young pine stand on an oligotrophic bog, leading to death of pine saplings, multiple leaders and weakened height growth. The results by Kaunisto (1982) led to an interpretation that when the total nitrogen content measured from the 5—10 cm peat layer was over 1.15 % or the humification degree over 2.7 (according to v. Post) in southern Finland enough nitrogen was mineralized to satisfy the needs of pine seedlings in their early stage of development, but above those values the nitrogen fertilization was unnecessary and even harmful. Nitrogen application decreased sapling height growth quite clearly when the total peat nitrogen content was high (> 1.9 %) in the 5—10 cm peat layer.

Commonly occurring, although not covering large areas, growth disturbances of various types have been identified in peatland stands (Veijalainen 1978, 1980). Refertilization with mere main nutrients seems to increase risk of growth disturbances (Veijalainen 1975, 1978, Veijalainen et al. 1984), which are presumably related to the so-called "dilution phenomenon". In other words, as growth is enhanced as a result of the fertilization with the main nutrients, the micronutrient concentrations in needles may drop to deficiency levels (Smith 1962, Wehrmann 1963, Tamm 1964, Veijalainen 1977). Growth disturbances in Finland have usually been diagnosed as a boron deficiency (Huikari 1974, 1977, Veijalainen 1979, 1984 b, Veijalainen et al. 1984, Raitio & Rantala

1977, Raitio 1979). Also other nutrient deficiencies may lead to die-back and multiple-leader trees and after a few years it is difficult to trace the cause. Imbalance between nitrogen and phosphorus (Kaunisto & Paavilainen 1977) as well as scarcity of potassium (Kaunisto & Tukeva 1985) seem to be associated with damages in the leader.

This investigation focuses on the short term effect of refertilization on the development of young pine stands on peatlands. The investigation focuses on the effects of the natural nitrogen regime of peat, fertilizer nitrogen and mineral nutrients applied in different forms (as fertilizers and wood ash) on the survival and height growth of saplings, occurrence of various disturbances and the effect of refertilization with the main nutrients on the micronutrient requirements of saplings.

Experiments for this investigation were established in the Parkano District of the National Board of Forestry, the Kannus research area of the Finnish Forest Research Institute, on land owned by Enso Gutzeit Oy and in several privately owned areas in the Forest Improvement Region of Pori.

Mr Kalle Nevanranta, the special technician, Mr Tauno Suomilammi, Mr Lauri Hirvisaari and Mr Markku Nikola were responsible for the field work. The nutrient analyses were carried out at the Parkano Research Station by Mrs Arja Ylinen and Miss Eeva Pekonen. The material was mainly recorded by Mrs Anneli Nuijanmaa and Mr Markku Nikola. Mr Olli Seppälä, the ADP designer, assisted by Mr Tauno Suomilammi and Mr Lauri Hirvisaari, was responsible for the calculations. The figures were drawn by Mrs Irma Honganpuhto and the typing was performed by Mrs Paula Häkli, Miss Tuire Kilponen, Mrs Tiina Luoto and Miss Pirkko Marjamäki. The text was translated by Mrs Leena Kaunisto, M.A. Prof. Eero Paavilainen, Dr Erkki Lipas and Dr Juhani Päivänen have read the manuscript.

I wish to express my best thanks to all the abovementioned and other persons for their valuable help and cooperation.

2. MATERIAL

21. Experimental areas

The investigation is based on 13 experiments (App. 1, Table 1), eight of which (1—8) were established on privately-owned land in Parkano and Karvia, three experiments (9—11) on land owned by Parkano District of the National Board of Forestry in Parkano and Kuru, one (Experiment 12) in the Experimental Forest of the Forest Research Institute in Kälviä in Central Pohjanmaa and two (13 a and b) on land owned by Enso Gutzeit Oy in eastern Finland. The experiments were set up on 10—12 -year-old practical forest plantations, which is why they differ from each other in regard to the time and mode of establishment, seedling type, ditch spacing and basic fertilization (Table 1). Experiments 1—8, 11 and 13 were spot fertilized and Experiments 9, 10, and 12 broadcast fertilized at the establishment. In NPK fertilizers phosphorus was as superphosphate and in PK fertilizers as rock phosphate. No information on the basic fertilization of Experiment 1 exists. The refertilization experiment was set up 9—11 growing seasons after basic fertilization. The majority of experiments were planted. Experiment 13 was sown and Experiments 9 and 10 were partly sown and partly naturally regenerated. The young pine stands within the experimental areas were fairly homogeneous at the refertilization time, but the stands were different from one experiment to another (Table 1). Experiments 1—6 and 8 were established especially on sites with abundant growth disturbances.

The experimental areas were usually open mires. Only Experiments 9 and 10 were covered with sparcely stocked pine stands before sowing. The original peatland site types ranged from a Sphagnum fuscum bog to a herbrich sedge fen, which was also clearly reflected in the nitrogen content of peat (Table 2). The most interesting experiments in this respect were 12 and 13, as the peat nitrogen content had a wide range within the same experiment. The results of Block 3 in Särkkä are not directly comparable with those of Blocks 1 and 2, because spring floods delayed fertilization partly until the late summer and partly even to the following year.

22. Experimental scheme

A basically similar research scheme applied to all the experiments (Table 3). It was not, however, possible to carry out the complete scheme in each experiment (Table 3). The most complete realization of the basic ideas of the research was possible in the Experiments of Housulampi (9), Jauli (10), Kaunisvesi (12) and Särkkä (13) (Table 3). The sample plots fertilized with phosphorus and potassium either as fertilizers or wood ash will be called PK fertilized plots and those that also obtained nitrogen will be called NPK fertilized or nitrogen fertilized plots. Experiments 1—10 had no replications. Experiment 11 had one or two, Experiment 12 three, Blocks 1 and 2 in Experiment 13 seven in all and Block 3 three replications. The area of a sample plot was 0.15 hectares.

The soil amelioration treatments varied somewhat from one experiment to another. At least one treatment in each experiment included liming. The amount of lime was the same in all experiments (2 000 kg/ha dolomite). Only Experiments 9, 10, 12 and 13 received wood ash. The amounts of ash varied from 0.5 to 5 t/ha (Table 3). Furthermore, the amounts and the quality of wood ash varied from one experiment to another. Ash used for Experiments 9, 10 and 12 was well burnt. As it was possible to collect it dry directly after burning, the nutrient contents were rather high (Table 3). On the other hand, ash used for Experiment 13 was of exceptionally poor quality. Burning had been incomplete and because, in addition, ash had been extinguished in water, the nutrient contents were exceptionally low. The phosphorus and potassium concentrations were less than one third of those used for Experiments 9, 10 and 12 (Table 3). The highest levels of ash (5 000 kg/ha) in the Särkkä Experiment (13) contained only 28 kg/ha of phosphorus while with the commercial phosphorus fertilizers about 40—45 kg/ha of phosphorus was applied. As there was not enough wood ash available in 1981, only half the planned ash was given for ash fertilization plots in Experiment 13. The rest was applied in the spring of 1982. As in Block 3 (Experiment 13 b) flood inhibited the spreading of fertilizers in the spring of 1981, some fertilizers were spread in July 1981 and the rest in the spring of 1982.

Of all the micronutrients the effects of only boron and copper were studied. Boron was applied in connection with PK fertilizer (0-9-17 + 0.2 % B) and copper as $CuSO_4$ except for Experiment 13 which received copper as CuO. Manganese and zinc were applied as sulphates.

Phosphorus and potassium were applied on plots that needed also boron as PK fertilizer (0-9-17 + 0.2 % B) and on other plots separately as rock phosphate (15 % P) and potassium chloride (50 % K) so that the amounts of phosphorus and potassium per hectare were the same as in PK fertilizer. Nitrogen was applied in all experiments as ammonium nitrate with lime (oulusaltpetre).

23. Collection of material and calculation

Five rows of circular sample plots were placed on each 0.15 ha plot stripwise, one on the edge of the strip about 2.5 metres from the ditch on both sides, one in the middle and one on both sides of the strip half-way through the centre and edge. Eight evenly spaced 5 m^2

Table 1. Basic information on the experimental areas.
Taulukko 1. Perustietoja koealueista.

Experiment and code *Koe ja koodi*		Coordinates *Koordinaatit* N ° '	E ° '	Ditch spacing *Sarkalev.* *m*	Afforestation *Viljely* Year *Vuosi*	Seedling type[4]) *Taimilaji*[4])	Basic fertilization *Peruslannoitus* Year *Vuosi*	Fertilizer *Lannoite*	Refertil. year *Jatkol. vuosi*	Area *Pinta-ala* *ha*	No of plots *Koealoja* *kpl*	Height of saplings[8]) *Taimien pituus*[8]) x̄, m	s, m
Ala-Kirjainen	1	62 00	22 40	43	1967	2A	—	—	1979	0.75	5	3.62	0.28
Järvenpää	2	62 00	22 40	40	1970	2A+1A	1970	NPK (15-11-8) 25 g/s[5])	1979	0.75	5	2.39	0.14
Kuusijärvi	3	62 00	22 40	40	1970	2A+1A	1970	NPK (15-11-8) 25 g/s	1979	0.75	5	2.50	0.18
Ellilä	4	62 00	22 40	10[1])	1970	3A	1970	NPK (15-11-8) 20 g/s	1979	1.35	9	1.85	0.18
Hannukainen	5	62 10	22 30	58	1968	2A	1969	PK (0-10-12) 25 g/s	1979	1.35	9	2.14	0.35
Lepola	6	62 10	22 30	53	1968	2A	1969	PK (0-10-12) 40 g/s	1979	1.35	9	2.33	0.21
Penttilä	7	62 10	22 50	10[1])	1970	2A+1A	1970	PK (0-10-12) 25 g/s	1979	1.35	9	1.80	0.27
Viitala	8	62 10	22 30	68	1968	2A	1969	PK (0-10-12) 25 g/s	1979	1.35	9	1.86	0.12
Housulammi	9	61 55	23 30	45	1969	sowing+natural	1969	PK (0-10-12) 500 kg/ha	1979	2.10	14	1.14	0.10
Jauli	10	61 55	23 30	40	1969	*kylvö+luont.*	1971	P=43 kg/ha, K=75 kg/ha	1979	2.10	14	1.04	0.24
Tuuranneva	11	62 20	23 20	40[2])	1969	2A+1A	1969	PK (0-10-12) n. 40 g/s	1979	2.40	16	2.34	0.28
Kaunisvesi	12	63 40	24 05	40[2])	1969	3A	1967	PK (0-7-12) 600 kg/ha	1980	8.10	54	1.10	0.26
Särkkä							1969	PK (0-10-12) 20 g/s					
blocks 1 and 2 / *lohkot 1 ja 2*	13 a	62 45	31 00	40[3])	1970	sown — *kylvö*	1970	NPK (14-8-8) 30 g/s	[6])1981—82	15.68	98	1.75	0.21
block / *lohko 3*	13 b	62 45	31 00	40[3])	1971	sown — *kylvö*	1971	NPK (14-8-8) 30 g/s	[7])1981—82	9.92	45	1.17	0.25

1) Mounding — *Mätästys.*
2) In addition deep furrows 40—60 cm, Kaunisvesi, complementary drainage in 1979. — *Lisäksi syvä vaotus 40—60 cm, Kaunisvesi täydennysojitettu v. 1979.*
3) In addition shallow furrows a. 30 cm. — *Lisäksi matala vaotus n. 30 cm.*
4) 2A = Grown uncovered for 2 years, 2A + 1A = Grown uncovered, transplanted at age of 2 years. — *2A = koulimaton, paljasjuurinen avomaalla kasvatettu taimi, 2A + 1A = kuten edellä, mutta koulittu.*
5) 25 g of fertilizer/seedling — *25 g lannoitetta/taimi.*
6) Half of the ash applied in sring 1981, half in 1982. — *Toinen puoli tuhkasta annettiin vuoden 1982 keväällä.*
7) Some plots not fertilized until 1982. — *Osa koealoista lannoitettiin vasta 1982.*
8) Before refertilization. — *Ennen jatkolannoitusta.*

Table 2. Peatland site type and the total peat nitrogen content in 5—10 and 15—20 cm (Exp. 13) or in 5—10 and 20—25 cm (Exps. 1—12) layers in different experiments.
Taulukko 2. Suotyyppi sekä turpeen kokonaistyppipitoisuus 5—10, 15—20 (kokeet 12 ja 13) tai 20—25 cm (kokeet 1—11) kerroksessa eri kokeissa.

Experiment and code *Koe ja koodi*		Peatland site type[1]) *Suotyyppi*	Peat characteristics — *Turpeen ominaisuuksia* Total N, % — *Kokonais- N, %* 5—10 cm Range *Vaihteluväli*	x̄	15—25 cm Range *Vaihteluväli*	x̄
Ala-Kirjainen	1	RhSN	2.04—2.19	2.15	2.05—2.24	2.15
Järvenpää	2	RhSN	1.87—2.24	2.07	1.61—1.70	1.66
Kuusijärvi	3	RhSN	1.97—2.20	2.15	1.65—1.99	1.79
Ellilä	4	LkN	0.80—1.48	1.17	0.74—1.21	0.92
Hannukainen	5	VSN	1.75—2.40	2.00	0.56—1.72	1.31
Lepola	6	VSN	1.27—1.85	1.35	0.59—2.34	1.45
Penttilä	7	LkN/RN	0.61—0.81	0.71	0.52—1.27	0.72
Viitala	8	VSN	0.58—1.75	1.20	0.17—2.64[2])	0.72[2])
Housulammi	9	TR—LkN—VSN	0.72—1.71	1.21	0.52—1.81	1.58
Jauli	10	TR—LkN—VSN	0.71—1.48	1.02	1.00—1.63	1.34
Tuuranneva	11	LkN	0.78—1.56	1.10	1.02—2.11	1.83
Kaunisvesi	12	LkN/VSN	0.62—2.04	1.17	1.15—2.35	1.99
Särkkä Block *lohko* 1	13 a1	VSN/RhSN	1.94—3.68	2.50	1.87—2.86	2.32
Särkkä Block *lohko* 2	13 a2	VSN/LkN	1.57—3.25	2.00	1.67—2.69	2.20
Särkkä Block *lohko* 3	13 b	LkN/RN	0.58—1.43	0.85	0.66—1.48	1.12

[1]) RhSN = herbrich sedge fen; LkN = small-sedge bog
VSN = ordinary sedge fen; RN = fuscum bog
TR = cotton-grass pine mire
[2]) Contains plenty of mineral soil. — *Sisältää runsaasti kivennäismaata.*

Table 3. Scheme of fertilization and soil amelioration treatments in different experimental groups.
Taulukko 3. Kaavio lannoitus- ja maanparannusainekäsittelyistä eri koeryhmissä.

Soil ameliorants *Maanparannusaineet* *kg/ha*		Micron. fertil. *Hivenlannoitus*	Experiments — *Kokeet* 1—3 O	PK	4—8 O	PK	NPK	9—10 O	PK	NPK	N	11 O	PK	NPK	12 O	PK	NPK	N	13 O	PK	NPK	N
—		O	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x	x	x	
—		B		x		x	x		x	x			x	x		x	x			x	x	
—		B+Cu		x		x	x									x	x			x	x	
—		B+Cu+Zn+Mn							x	x			x	x								
Lime	2000	—														x	x					
Kalkki	2000	B+Cu		x		x	x									x	x			x	x	
	2000	B+Cu+Zn+Mn							x	x			x	x								
Ash	500	—														x	x					
Tuhka	700	—						x	x	x												
	1000	—													x	x	x					
	2000	—																	x	x	x	
	3500	—						x			x											
	5000	—													x			x	x			x

Lime — *Kalkki* = Dolomite — *Dolomiittikalkkia.*
PK = Rock phosphate (14.6 % P) + potassium chloride (49.8 % K) either as PK fertilizer mixture (consists of 0.2 % B) or separately. Phosphorus about 40—45 kg/ha and potassium 78—85 kg/ha depending on site, yet so that the rates within experimental groups were the same. — *Raakafosfaattia (14.6 % P) + kalisuolaa (49.8 % K) joko PK-seoslannoitteena (sis. 0.2 % B) tai erikseen. Fosforia n. 40—45 kg/ha ja kaliumia 78—85 kg/ha paikasta riippuen, kuitenkin siten, että* kokeiden ja koeryhmien sisällä määrät olivat samat.
N = Oulunsalpetre (27.5 % N, ammoniumnitrate with lime) 333—400 kg/ha depending on site. — *Oulunsalpietaria (27.5 % N) 333—400 kg/ha paikasta riippuen.*
B = B 1 kg/ha. With a PK mixture. — *PK-seoslannoitteen yhteydessä.*
Cu = $CuSO_4$ (25 % Cu) 5—10 kg/ha in Experiments — *kokeissa 1—12, CuO (78 % Cu) 8 kg/ha in Exp. — kokeessa 13.*
Zn = $ZnSO_4$ (23 % Zn) 20 kg/ha.
Mn = $MnSO_4$ (26 % Mn) 20 kg/ha.
Wood ash — *Tuhka* = Experiments — *Kokeet* 9—10 & 12 (1.75 % P, 6.58 % K, 37.4 % Ca, 0.16 % B, 0.67 % Zn), lost by ignition — *hehkutushäviö* 2.1 %.
Experiment — *Koe* 13 (0.56 % P, 1.82 % K, 19.7 % Ca, 0.11 % B, 0.34 % Zn), lost by ignition — *hehkutushäviö* 15.0 %.

circular sample plots were placed on each row. Thus 40 circular sample plots were measured on each experimental plot. Each empty circular sample plot was considered as one dead sapling. The characteristics of a sapling closest to the centre point of each circular sample plot were measured. In Experiments 9 and 10 also wildlings were included, which in the other experiments were discarded.

The height of saplings was measured with 1 cm accuracy from 1977 to 1984. Moreover, growth disturbances and various other damages in the crown were observed. Growth disturbances in the crown were classified in the following way:

— healthy-looking tree, normally developed with only one leader
— starting or mild growth disturbance, where the leader is still alive, but not normally developed
— repeated dieback, several dead leaders
— recovering tree with a healthy substitute leader
— several competing leaders at the inventory time.

In the spring of 1982 i.e. the year following the first phase of refertilization, attention was drawn to a remarkable proportion of browned and dead needles in the 1981 leader in the experimental area of Särkkä (13). Damage had occurred during the winter. Blocks 1 and 2 of Experiment 13 a were inventoried in the autumn of 1982 by using the following classification:

— Normal saplings = no foliar damage
— Slightly damaged saplings = less than half the needles of the 1981 leader fallen or brown
— Severely damaged saplings = over half the needles of the 1981 leader fallen and nearly all the rest brown
— The 1981 terminal bud damaged or the leader clearly shorter than the lateral shoots
— Earlier leader change.

The 1984 inventory of all experiments also involved the observation of damages caused by following biotic or abiotic factors:

— insects
— voles or rabbits
— moose
— frost

Needle samples were collected of all the plots in Experiments 12 and 13 in the year preceding refertilization. Needle samples of all the experiments were collected in the second (Experiment 13), third (Experiment 12) or fifth (other experiments) winter after refertilization. The needle samples were taken from the dominant saplings from the youngest needle set of the second uppermost whorl facing the south from ten trees in various parts of the sample plot. The needles were analyzed for N, P, K, Ca, B and Cu.

Peat samples were taken from all the sample plots: from the 5—10 cm layers and 20—25 cm layers in Experiments 1—11, from the 0—25 cm layer as 5 cm partial samples in Experiment 12 and from the 0—20 cm layer also as 5 cm partial samples in Experiment 13. The live moss layer was first removed from the sampling place. Soil samples were taken from an even surface from five systematically placed spots on each 0.15 ha plot and joined in layers to represent the plot. The total nitrogen in peat was determined with the Kjeldahl method and pH in the volume ratio of peat/water 1/5. Furthermore, humification was determined from Experiment 12 and Blocks 2 and 3 of Experiment 13 using the v. Post (1922) method.

Sample plots were combined for calculation into homogeneous groups according to refertilization treatments. Thus groups 1—3, 4—8 and 9—10 were obtained. Experiments 11 and 12 were treated separately. Experiment 13 was usually divided into parts a and b because of the different timing of refertilization. In some cases Experiment 13 a was further divided into two blocks: 13 a 1 and 13 a 2 because of the slightly different nitrogen content of peat (Table 2).

Within the experiments and experimental groups the material was grouped for statistical analyses in two different ways according to different soil amelioration and fertilization treatments:

1. In one-way analyses of variance so that they formed one variable with all the possible combinations as levels. Thus the comparison would also include unrefertilized and those ash fertilization treatments that had no nitrogen fertilized equivalents. The F values for such analyses are mostly presented in the figures.
2. In two-way analyses so that the unrefertilized and those ash fertilized plots without any nitrogen fertilized equivalents were omitted from the calculation. The levels of one variable were different combinations of lime, micronutrients, fertilizer phosphorus and potassium and wood ash (later called ameliorant and/or micronutrient application). Those of the other variable were nitrogen application and no nitrogen application. Thus the plots that received only ash were considered to belong to the same group as the plots that had been fertilized with phosphorus and potassium fertilizers (PK fertilization). The plots that in addition to ash had received nitrogen were considered to belong to the same calculation group as those fertilized with nitrogen, phosphorus and potassium fertilizers (NPK fertilization).

3. RESULTS

31. Peat properties

311. pH value

Liming clearly increased pH in the 5—10 cm peat layer (Fig. 1) except Experiments 1 and 13. The result in Experiment 13 was different probably because the peat samples were taken in the autumn following liming. Thus the influence time had been short compared to the other experiments in which peat samples were taken five (Exp. 12) or six (Exps. 1—11) growing seasons after setting up the experiment.

The effect of ash on peat acidity clearly depended on application rate. The largest amount of ash (5 t/ha) used in the Kaunisvesi experiment (12) raised pH in the 5—10 cm peat layer somewhat more and smaller amounts (0.5 and 1.0 t/ha) less than liming (Fig. 1). In the other experiments differences between the effect of liming and ash were smaller and partly conflicting. The effect of liming and ash fertilization on the acidity of the 20—25 cm peat layer was not significant in any of the cases (Experiments 1—11).

Changes caused by soil ameliorants in peat pH were most prominent in the 0—5 cm surface layer. The difference was as high as 0.7 pH units between the plots fertilized with the largest amounts of ash in the Kaunisvesi Experiment (12) and the control. The wide variation, however, made the result only barely significant, whereas much smaller differences in pH in the 5—10 cm peat layer led to a statistically significant F value. Differences in acidity caused by soil ameliorants were further levelled down in the 10—15 and 15—20 cm peat layers.

312. Total nitrogen content and humification degree of peat

The total peat nitrogen content and its variation in different experiments have already been introduced in Chapter 2 (Table 2). The analyses of variance on each experiment and experimental group showed that the various fertilization and soil amelioration measures have not so far influenced the total nitrogen content of peat statistically significantly.

In Experiment 12 and Blocks 2 and 3 of Experiment 13 (13 a2 and 13 b) the de-

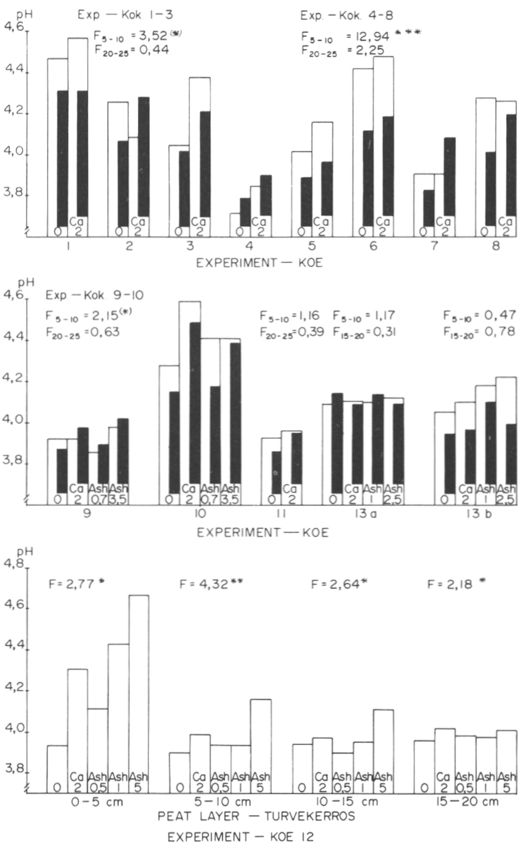

Figure 1. Effect of liming and ash fertilization on peat acidity in the 5—10 (black column) and 20—25 (blank column) cm peat layers in Experiments 1—11 and 13 a and b, as well as in the 0—5, 5—10, 10—15 and 15—20 cm peat layers in Experiment 12. F values for experimental groups.

Kuva 1. Kalkituksen ja tuhkalannoituksen vaikutus turpeen happamuuteen 5-10 (musta pylväs) ja 20-25 (avoin pylväs) cm:n turvekerroksessa kokeissa 1-11 ja 13 a ja b, sekä 0-5, 10-15 ja 15-20 cm:n turvekerroksessa kokeessa 12. F-arvot koeryhmittäin.

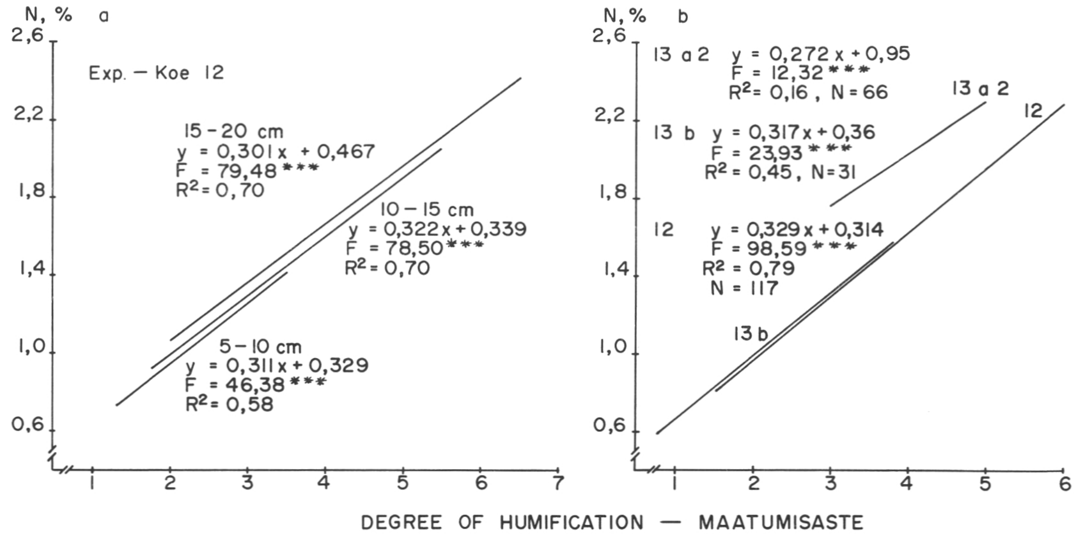

Figure 2. Dependence of the total peat nitrogen content on the humification degree (according to v. Post) in Experiment 12 by peat layers (a) and in Experiments 12, 13 a 2 and 13 b (b) so that different peat layers were combined into the same material.

Kuva 2. Turpeen kokonaistyppipitoisuuden riippuvuus maatumisasteesta (v. Postin mukaan) kokeessa 12 turvekerroksittain (a) sekä kokeissa 12, 13 a 2 ja 13 b (b) siten, että eri turvekerrokset on yhdistetty samaksi aineistoksi.

pendence between the humification degree and total nitrogen content of peat was investigated. Figure 2 a shows the dependence between these variables separately in the 5—10, 10—15 and 15—20 cm peat layers in Experiment 12. The surface layer (0—5 cm) was omitted from the investigation because of vagueness.

A rising line depicted the dependence between humification and total nitrogen content of peat both in the analyses made separately for different peat layers in Experiment 12 (Fig. 2 a) and in the combined materials (Fig. 2 b) of both Kaunisvesi (12) and Särkkä (13 a2 and 13 b). The equations of the lines for Experiments 12 and 13 b were nearly congruent. The peat nitrogen content in Experiment 13 a2 was distinctly higher than in Experiment 13 b in the same humification degree, which is probably due to differences in peat types. Experiment 13 a2 was mainly on a tall-sedge fen and Experiment 13 b on a Sphagnum fuscum and low-sedge bog. Isotalo (1951) and Vahtera (1955) have pointed out that the nitrogen content in sedge peats is higher than in Sphagnum peats even when the humification degree is the same.

32. Foliar nutrients

General

The foliar nutrient levels in Experiments 12 and 13 were investigated both before and after refertilization. In the other experiments the investigation only focused on the post-refertilization state. F values of one-way analyses of variance for combinations of fertilizers and soil ameliorants have been presented in connection with the figures (3—9) and F values of two-way analyses in Appendix 2 (for grouping of the material, see Ch. 23, p. 10).

Nitrogen

The foliar nitrogen contents varied considerably from one experiment to another. The foliar nitrogen contents in Experiments 1—3, 11 and 13 a were clearly higher and in Experiments 9—10, 12 and 13 b somewhat lower than the limit values for nitrogen deficiency in native pine introduced by Paarlahti et al. (1971) and Raitio (1978) (1.30 % and 1.31 % respectively, Fig. 3 a). The

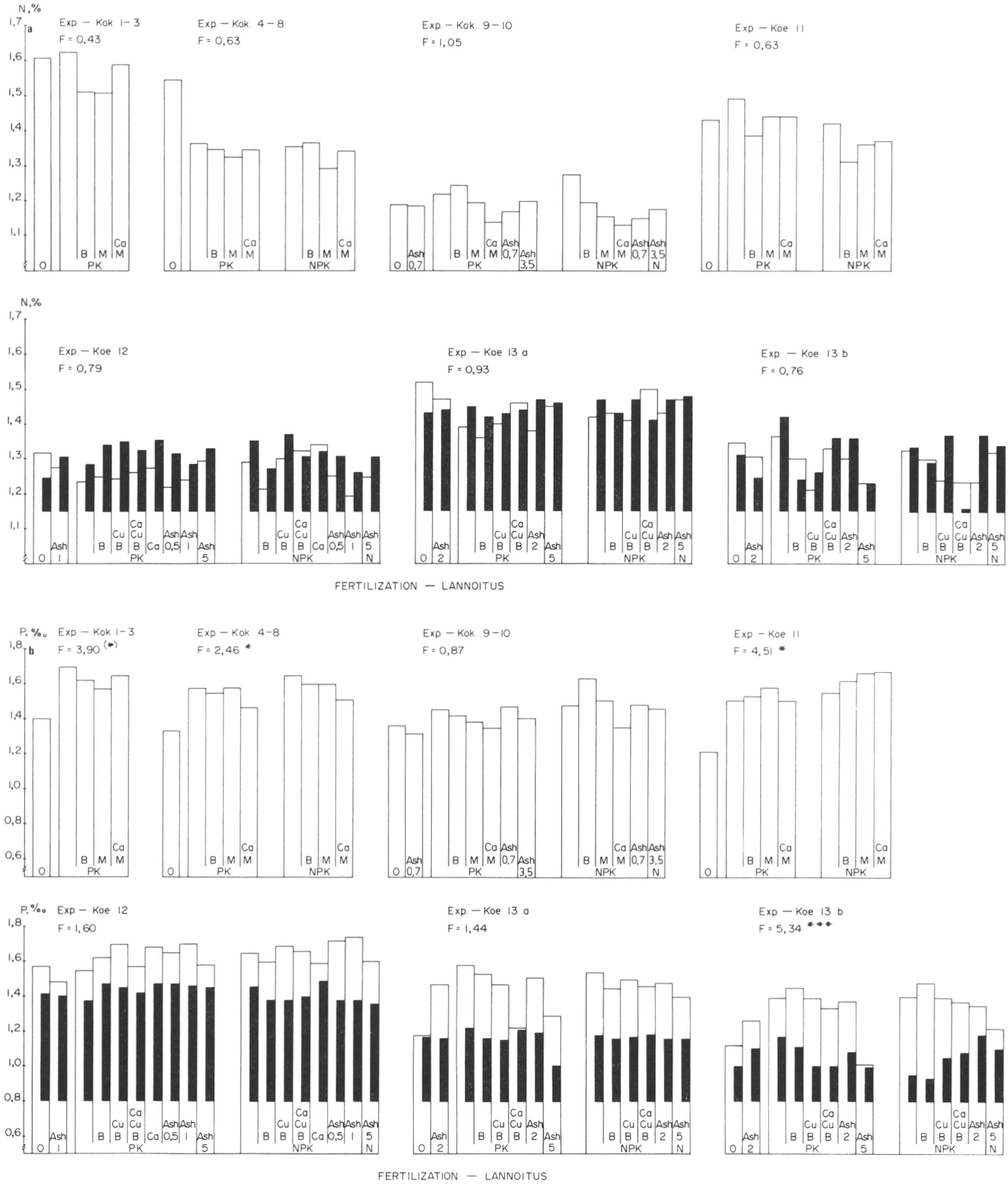

Figure 3. Effect of refertilization on the foliar nitrogen and phosphorus content. Black columns before, blank columns after refertilization. M = micro nutrient mixture B + Cu + Zn + Mn. For nutrient rates see Table 3.

Kuva 3. Jatkolannoituksen vaikutus neulasten typpi- ja fosforipitoisuuteen. Mustat pylväät ennen, avoimet pylväät jälkeen jatkolannoituksen. M = hivenravinneseos B + Cu + Zn + Mn. Ravinnemäärät taulukossa 3.

foliar nitrogen contents corresponded to the peatland site types (Table 2). Experiment 11 was an exception. Although it had been classified as a low-sedge bog, the foliar nitrogen contents were at the same level as in Experiment 13 a. The reason is probably in the fact that it had been ploughed to the depth of 40—50 cm and the seedlings planted on the ridges. The peat nitrogen content was fairly high even in the depth of 20—25 cm (Table 2). Refertilization and soil amelioration did not usually affect the foliar nitrogen contents. The only exception was experiment 13 a, where liming and application of the largest amount of ash as well as nitrogen fertilization increased the foliar nitrogen contents more than the other fertilization treatments (Fig. 3 a, App. 2).

Phosphorus

Except the Kaunisvesi experiment (12) the foliar phosphorus contents on the unfertilized plots were either as high as or lower (Fig. 3 b) than the limit values indicating phosphorus deficiency according to Paarlahti et al. (1971, P = 1.40 ‰) and Raitio (1981, P = 1.45 ‰). Particularly low phosphorus values were found in Experiments 11 and 13. Fertilization with rock phosphate raised the foliar phosphorus contents so that they either reached the abovementioned limit values or surpassed them. The effect was in several cases statistically significant. Liming decreased the foliar phosphorus contents to some extent (see also Kaunisto 1982). The change was greatest on the PK fertilized plots of Experiment 13 a. Nitrogen fertilization had no effect on the foliar phosphorus content (Appendix 1).

The effect of mere wood ash on the foliar phosphorus content varied from one experiment to another. The smallest ash rate, 0.7 t/ha in Experiments 9—10 had no appreciable influence, whereas the application of 3.5 t/ha increased the foliar phosphorus contents to the same level as was found on plots with phosphorus-potassium fertilization. In Experiment 12 ash application alone had no appreciable effect on the foliar phosphorus contents, possibly, because foliar phosphorus levels were fairly high even on control plots. In Experiment 13 a the application of the higher ash rate (5 t/ha) clearly lowered the foliar phosphorus contents as compared to the lower rate (2 t/ha) (Fig. 3 b, App. 2) and in Experiment 13 b even as compared to the control. In Experiment 12 small ash rates (0.5 and 1.0 t/ha) increased the foliar P levels if given with the PK fertilizer, but no such effect was found in Experiment 13 even with 2 t/ha of wood ash.

Potassium

The foliar potassium contents were low on the unrefertilized plots of Experiments 1—8 and 11 (Fig. 4 a), being slightly above the limit value (3.5 ‰) for potassium shortage in average nitrogen and phosphorus conditions and slightly below the limit value (4.0 ‰) for potassium shortage in good nitrogen and potassium conditions as introduced by Paarlahti et al. (1971). The foliar potassium contents in Experiment 12 before refertilization ranged from 3.9 to 4.5 ‰ and were somewhat lower than those on control plots after refertilization and in Experiment 13 a at about the same level as on control plots (4.3 ‰).

Without exception potassium fertilization raised the foliar potassium contents clearly above the above mentioned limit values and in most cases even above the limit value 4.5 ‰ introduced by Raitio (1981). Generally liming seemed to lower the potassium contents to some extent (see also Kaunisto 1982), although there were some exceptions (Exp. 13).

The application of the highest levels of ash (Exps. 12 and 13, 5 t/ha, Exps. 9—10, 3.5 t/ha) raised the foliar potassium contents as compared to unrefertilized plots and in many cases to the same level as with fertilizer potassium application or even above it. Lower rates (1.0 and 2.0 t/ha) had a lesser influence. The application of ash in addition to phosphorus and potassium fertilizers also increased the foliar potassium contents to some extent. Excluding only the NPK fertilized plots of Experiments 11 and 13 a, the application of boron seemed to increase consistently the foliar potassium contents.

N/P ratio

The foliar N/P ratios were high (12—14) on the unrefertilized plots of Experiments 1—8, 11 and 13 a (Fig. 4 b) if compared with the values calculated on the basis of the optimum levels of phosphorus and potassium in the material of Paarlahti et al. (8—9, 1971). The situation was the same in Experiment 13 a also before refertilization. Refertilization with phosphorus lowered the ratio to about 8—11 except in Experiment 13 a, where the foliar N/P ratio was still

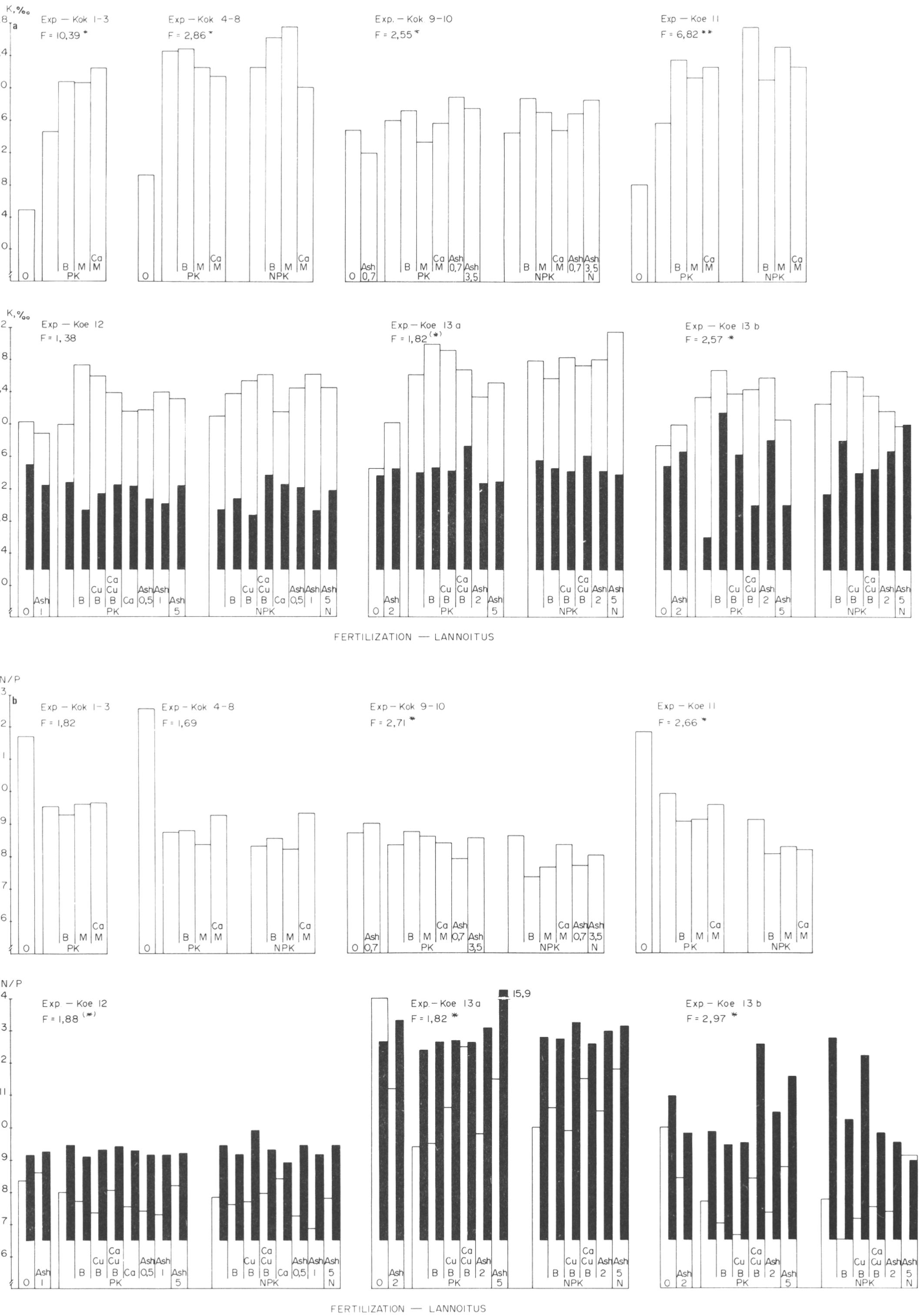

Figure 4. Effect of refertilization on the foliar potassium content and N/P ratio. Key as in Fig. 3 and Table 3.
Kuva 4. Jatkolannoituksen vaikutus neulasten kaliumpitoisuuteen ja N/P-suhteeseen. Selitykset kuten kuvassa 3 ja taulukossa 3.

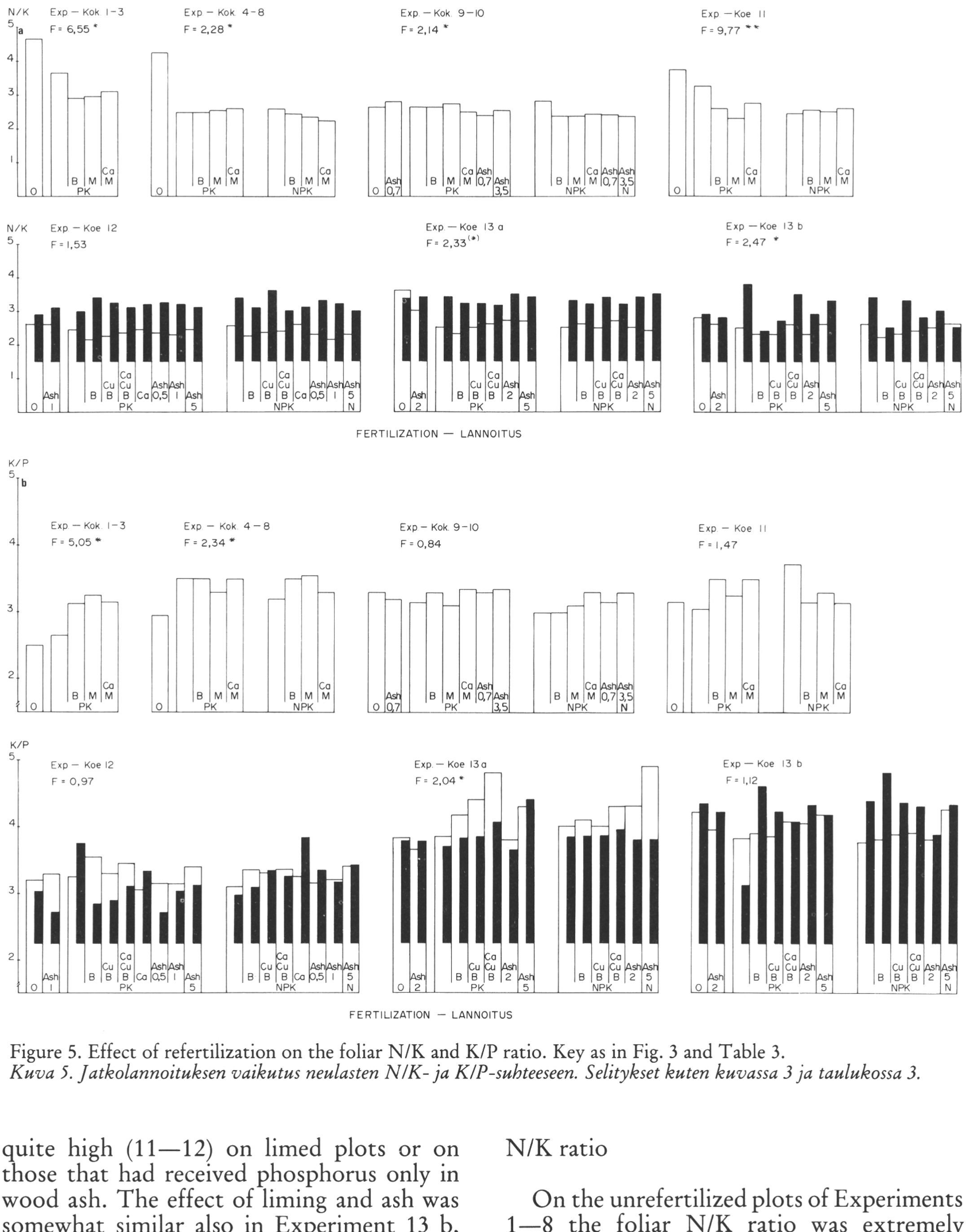

Figure 5. Effect of refertilization on the foliar N/K and K/P ratio. Key as in Fig. 3 and Table 3.
Kuva 5. Jatkolannoituksen vaikutus neulasten N/K- ja K/P-suhteeseen. Selitykset kuten kuvassa 3 ja taulukossa 3.

quite high (11—12) on limed plots or on those that had received phosphorus only in wood ash. The effect of liming and ash was somewhat similar also in Experiment 13 b, although the ratios were much lower. Nitrogen fertilization had no statistically significant effect on the foliar N/P ratio in any of the experiments.

N/K ratio

On the unrefertilized plots of Experiments 1—8 the foliar N/K ratio was extremely high (Fig. 5 a) as compared to the optimum value (3.5) introduced by Puustjärvi (1965). The ratio in Experiments 11 and 13 was near that optimum value and in Experiments 9—10, 12 and 13 b distinctly below it. The application of potassium lowered the ratio down to the cited optimum level, but in most cases below it. Kaunisto & Tukeva

(1984) have obtained similar results in more advanced stands suffering from a potassium deficiency. No statistically significant differences in foliar N/K ratios were found among refertilized plots (App. 2).

K/P ratio

The foliar K/P ratio on the unrefertilized plots in Experiments 1—8 were clearly below the ratio 3.3—3.4 (Fig. 5 b), calculated on the basis of the optimum levels of potassium and phosphorus introduced by Puustjärvi (1965). Fertilization with potassium and phosphorus clearly raised the K/P ratio in these experiments.

The K/P ratio on the unrefertilized plots in Experiments 9—12 was near the cited optimum level and in Experiments 13 a and b above it. Particularly liming and ash fertilization in Experiment 13 a further enlarged the ratio (Fig. 5 b). As mentioned before, liming decreased the foliar phosphorus contents on the PK fertilized sample plots in Experiment 13 a, but did not, to any appreciable extent, affect the foliar potassium contents. Similarly, ash fertilization increased much less the foliar P than K contents. According to the foliar analysis in Experiment 13 trees may have suffered from a phosphorus shortage in relation to potassium, which was further accentuated by liming and ash fertilization in Experiment 13 a. Nitrogen fertilization did not have any significant influence on the K/P ratio (App. 2).

Boron

The foliar boron contents were in all experiments except 9—10 and 13 b close to the boron deficiency limit (7 ppm) suggested by Veijalainen et al. (1984) or below it on the unrefertilized sample plots (Fig. 6 a). Especially in Experiment 11 the foliar boron content was extremely low. In most experiments refertilization with rock phosphate and potassium chloride lowered the foliar boron contents as compared to the unrefertilized plots (Fig. 6 a, App. 2, see also Veijalainen 1977).

Boron application raised the foliar boron content in most cases up to the optimum level, 20—25 ppm, presented by Braekke (1979, see also Veijalainen 1980). The effect of the applied fertilizer borate was statistically significant in all Experiments (Fig. 6 a, App. 2).

Wood ash fertilization raised the foliar boron contents in all cases as compared with those that obtained only rock phosphate and potassium chloride. However, even the highest ash rates did not raise the foliar boron content up to the same level as did fertilizer borate except in Experiments 9—10. It should be pointed out that the application of PK fertilizer enriched with boron provided the sample plot with 1 kg/ha of boron as element, while even the highest application levels of ash gave only about 0.55 kg/ha of boron in Experiment 13 and about 0.8 kg/ha in Experiments 9—10 and 12. Nitrogen fertilization usually decreased the foliar boron contents. The effect was statistically significant in Experiments 4—8, 12 and 13 b (App. 2).

N/B ratio

The foliar N/B ratios were high in all but Experiments 9—10 and 13 b (Fig. 6 b). Fertilization with mere phosphorus and potassium usually increased, but boron application decreased the ratio. Ash fertilization lowered the ratio in Experiments 12 and 13 b to some extent when compared to the trees fertilized with only the main nutrients, although not as much as the fertilizer borate application. Liming affected the N/B ratio only little if also boron was applied, but greatly raised the ratio if boron was not given (Fig. 6, Exp. 12). The N/B ratio was usually between 500—800 when fertilizing with PK and boron.

Calcium

The foliar calcium contents varied very much from one experiment to another. The highest contents were in Experiments 9—10 and 13 b and lowest in Experiment 13 a. The range of calcium contents was about

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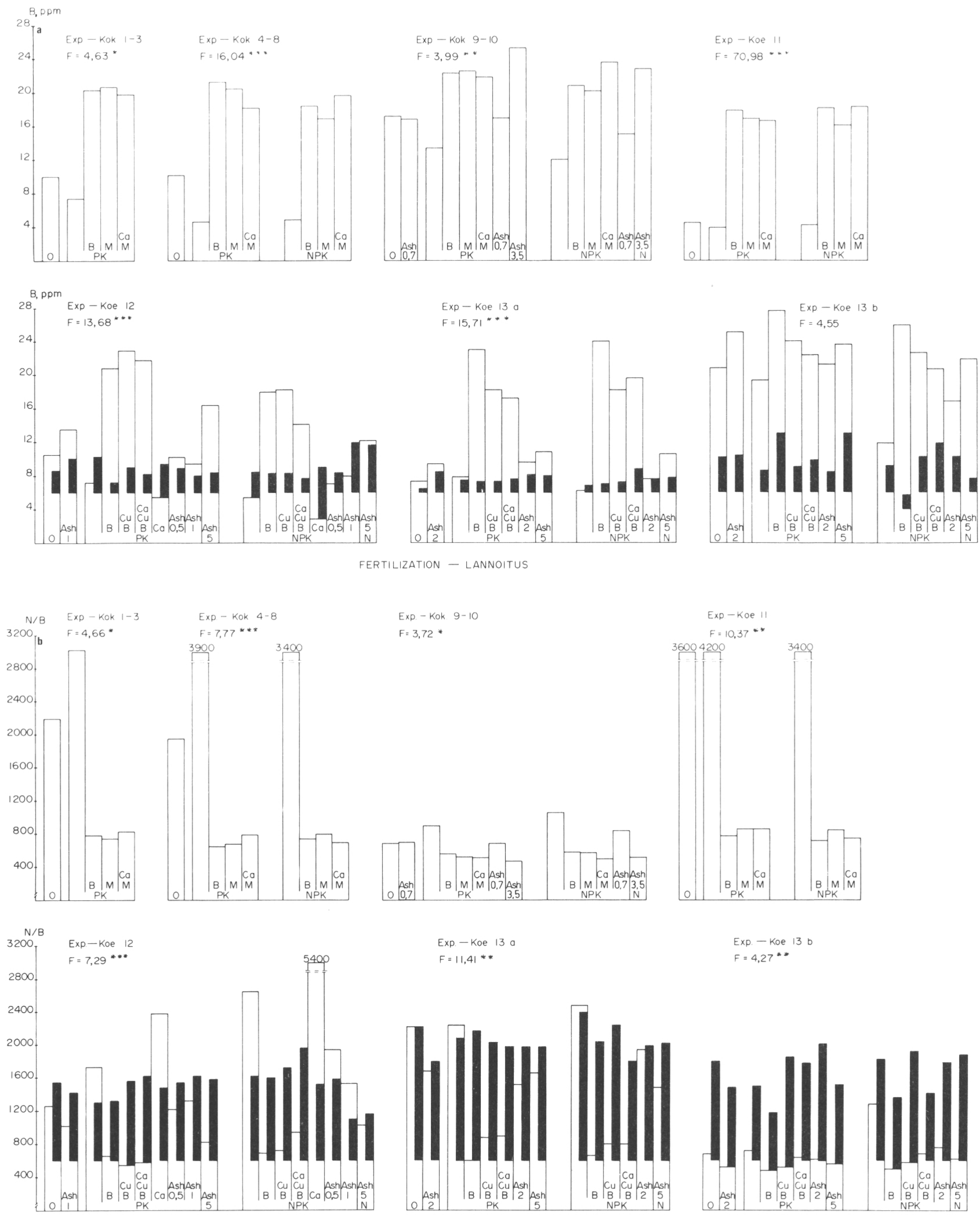

Figure 6. Effect of refertilization on the foliar boron content and N/B ratio. Key as in Fig. 3 and Table 3.
Kuva 6. Jatkolannoituksen vaikutus neulasten booripitoisuuteen ja N/B-suhteeseen. Selitykset kuten kuvassa 3 ja taulukossa 3.

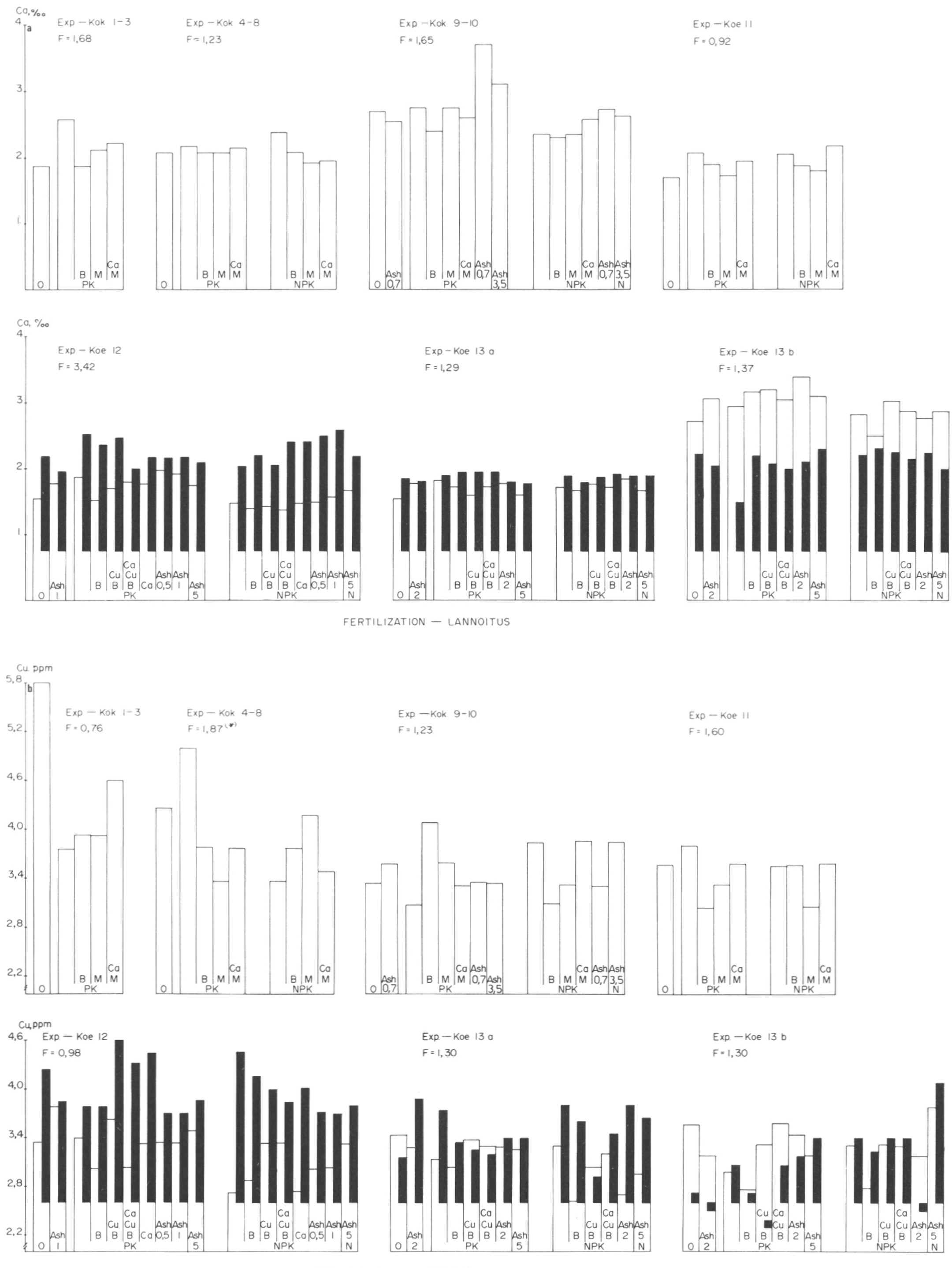

Figure 7. Effect of refertilization on the foliar calcium and copper content. Key as in Fig. 3 and Table 3.
Kuva 7. Jatkolannoituksen vaikutus neulasten kalsium- ja kuparipitoisuuteen. Selitykset kuten kuvassa 3 ja taulukossa 3.

the same as presented by Paarlahti et al. (1971), but somewhat lower than those introducted by Kaunisto (1982) for young pine plantations. Soil amelioration treatments had no appreciable effect on the foliar calcium contents, but nitrogen fertilization decreased it significantly in Experiments 12 and 13 b (Fig. 7 a, App. 2).

Copper

The range of the foliar copper contents was much the same as that reported by Kaunisto (1982) and remained in most cases clearly below 4.0 ppm that Raitio (1978) regards as the optimum content. Soil ameliorant and/or micronutrient application did not have any significant effect on the copper contents. Nitrogen fertilization had only influence in Experiment 13 a, in which the copper contents were lower on the average on NPK than PK fertilized sample plots. The variation, however, was very large.

N/Ca ratio

Refertilization with lime and ash had only little effect on the foliar N/Ca ratio (Fig. 8 a, App. 2). The effect was significant only in Experiments 9—10, in which especially ash fertilization lowered the ratio. Nitrogen fertilization increased the N/Ca ratio significantly only in Experiments 9—10 and 12.

N/Cu ratio

Refertilization did not much influence the foliar N/Cu ratio (Fig. 8 b, App. 2). The effect of soil ameliorant and/or micronutrient application was significant only in Experiment 13 b, where on the plots that had received copper oxide or ash with PK ratios were slightly lower than on the others. Nitrogen fertilization increased the N/Cu ratio significantly only in Experiment 13 a.

P/Ca ratio

Liming and ash fertilization usually lowered the P/Ca ratio to some extent (Fig. 9 a, App. 2). However, the effect was significant only in Experiment 13 b, in which the largest ash amount, in particular, lowered the ratio. Nitrogen refertilization usually increased the ratio, but significantly only in Experiments 9—10, 12 and 13 b.

K/Ca ratio

Soil ameliorant and/or micronutrient application had no significant effect on the foliar K/Ca ratio (Fig. 9 b, App. 2). The effect of nitrogen refertilization was very similar to that of P/Ca ratio.

33. Survival percentage of saplings

331. General

The survival percentage was calculated from the ratio between the number of sapling-growing and the total number of the investigated circular sample plots. The survival percentage in Experiments 1—3 and 4—8 was the lowest on average, about 55 % and 60 %, and in Experiment 11 the highest, about 90 % (Fig. 10) which can be regarded as a very good result. The average survival percentage varied between 70—80 % in the other experiments.

332. Effect of refertilization

It is natural that refertilization had only a slight influence on the survival (Fig. 10, Table 4) because the influencing time was rather short. Nitrogen fertilization in Experiments 4—8 lowered the survival percentage to some extent, but not significantly. A significant interaction existed between nitrogen fertilization and soil ameliorant

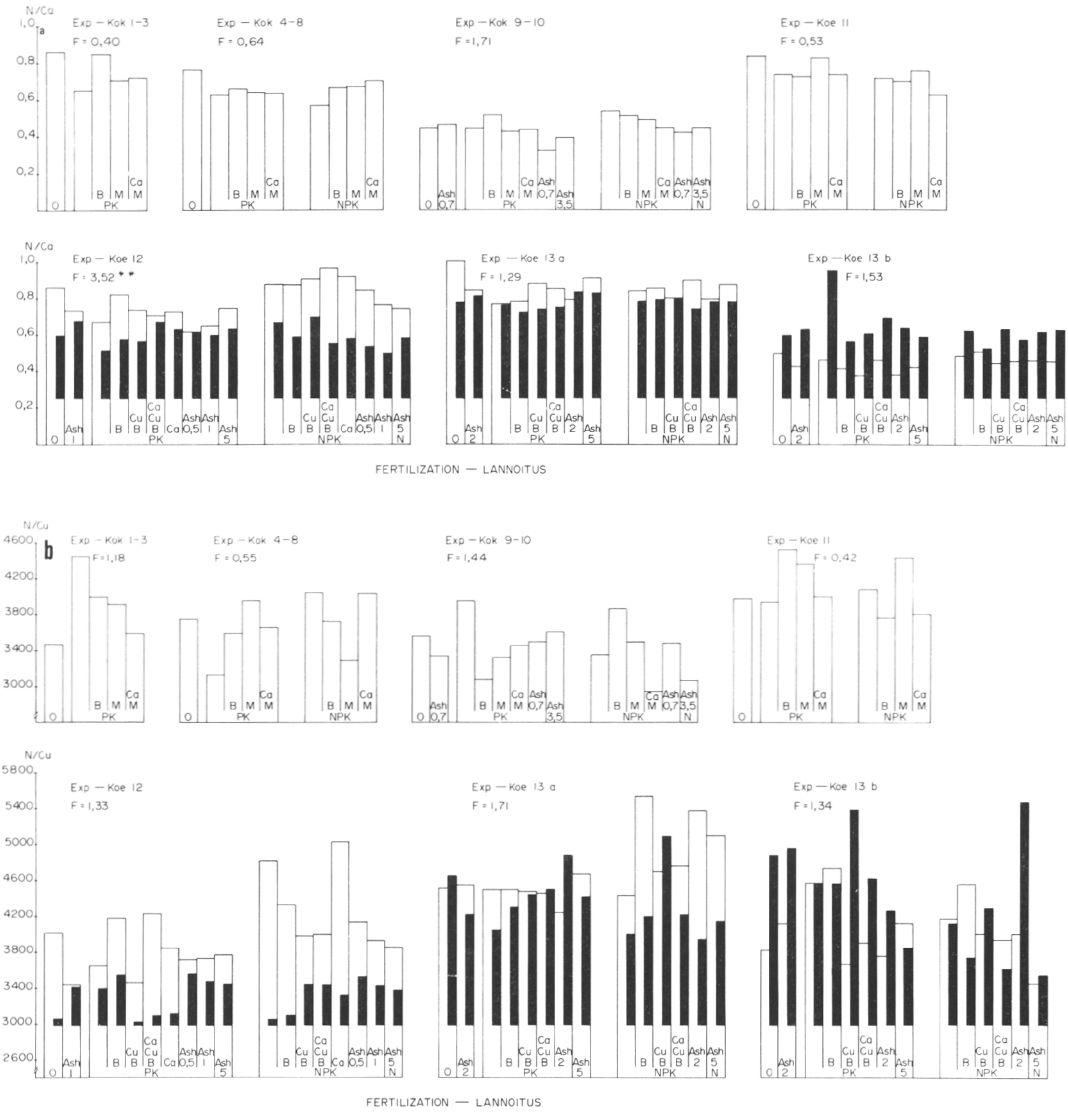

Figure 8. Effect of refertilization on the foliar N/Ca and N/Cu ratio. Key as in Fig. 3 and Table 3.
Kuva 8. Jatkolannoituksen vaikutus neulasten N/Ca- ja N/Cu -suhteeseen. Selitykset kuten kuvassa 3 ja taulukossa 3.

and/or micronutrient application in Experiments 9—10. This was obviously caused by the micronutrient fertilization + liming treatment which lowered the survival percentage on the PK but raised it on NPK fertilized sample plots. A similar situation was seen in the foliar Cu contents (Ch. 32, Fig. 7b) where, however, the interaction was not significant (App. 2). The interaction that existed between the experiment and ameliorant and/or micronutrient application was also caused by liming. Liming + micronutrient fertilization in Experiment 10 raised the survival percentage, but lowered it in Experiment 11. Even a closer inspection did not shed light on the effect of the nutrient status on the phenomenon. Refertilization in Experiments 12 and 13 had no statistically significant effect on the survival percentage.

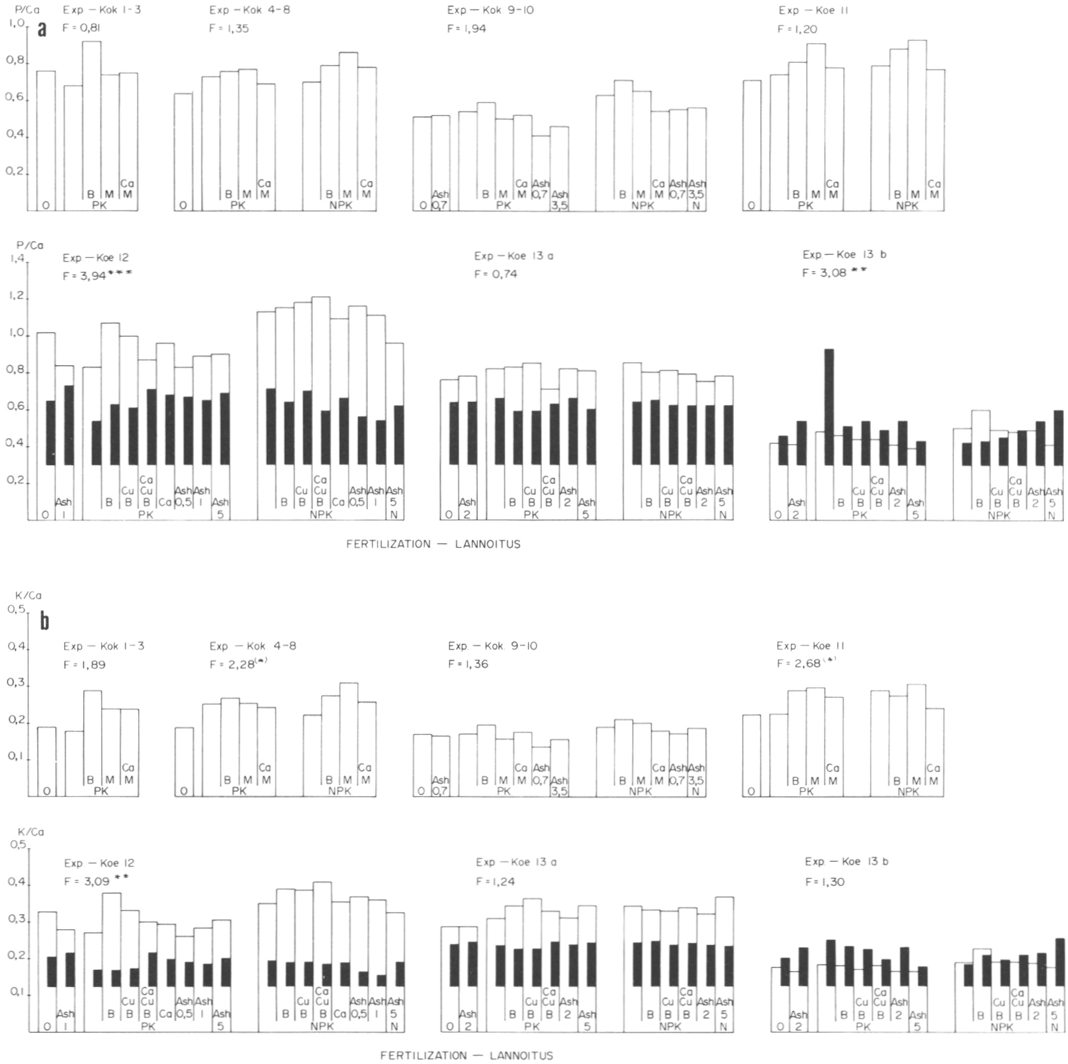

Figure 9. Effect of refertilization on the foliar P/Ca and K/Ca ratio. Key as in Fig. 3 and Table 3.
Kuva 9. Jatkolannoituksen vaikutus neulasten P/Ca- ja K/Ca -suhteeseen. Selitykset kuten kuvassa 3 ja taulukossa 3.

Table 4. F values and significances[1]) in the analyses of variance calculated from the survival percentage of saplings. Soil ameliorant and/or micronutrient application and PK/NPK fertilization as separate class variables.
Taulukko 4. F-arvot ja merkitsevyydet taimien elossaolosadanneksesta lasketuissa varianssianalyyseissä, joissa maanparannus/hivenlannoituskäsittely ja PK/NPK-lannoitus ovat erillisinä luokkamuuttujina.

Indep. var. *Selittäjä*	F value — *F-arvo* Experiment — *Koe*						
	1—3	4—8	9—10	11	12	13a	13b
1 = Exp. — *Koe*	10.92*	3.26*	23.97**				
2 = Amelior./micron. *Maanpar./hivenl.*	1.14	0.94	0.38	0.26	0.42	0.39	0.61
3 = Fertil. — *Lann.*		3.24(*)	5.43(*)	2.44	0.27	0.86	2.44
1 x 2		0.94	10.96*				
1 x 3		0.63	0.05				
2 x 3		0.43	6.25*	2.39	0.86	0.49	0.22

[1]) (*) with 10 % risk — *10 %:n riskillä*

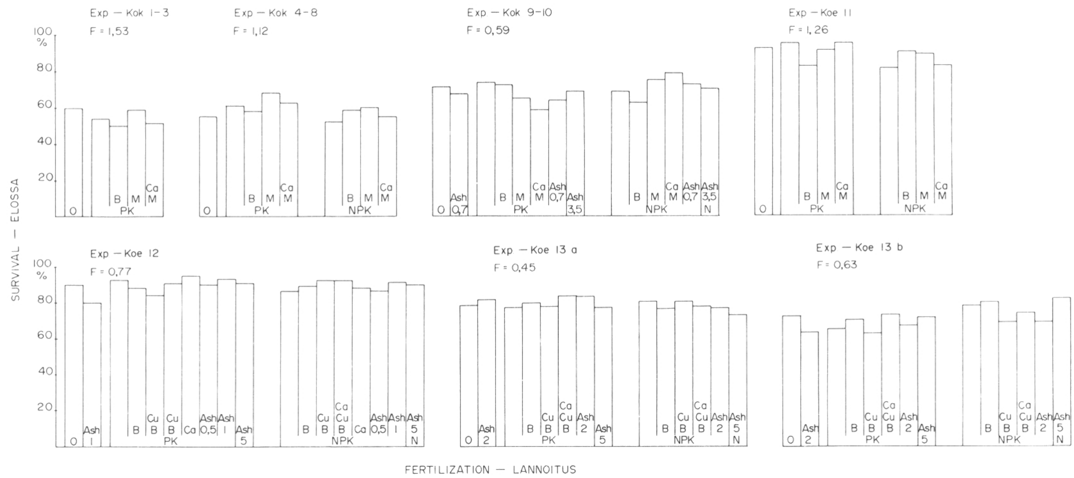

Figure 10. Effect of refertilization on the survival percentage.
Kuva 10. Jatkolannoituksen vaikutus elossaolosadannekseen.

Table 5. Correlation coefficients between the survival percentage of saplings and the foliar nutrient status before and after refertilization in Experiments 12 and 13.
Taulukko 5. Taimien elossaolosadanneksen ja neulasten jatkolannoitusta edeltäneen ja sen jälkeisen neulasten ravinnetilan väliset korrelaatiokertoimet kokeissa 12 ja 13.

Nutrient *Ravinne*	Correlation coefficient — *Korrelaatiokerroin* Experiment — *Koe* 12 Year — *Vuosi* -80	-83	13a Year — *Vuosi* -80	-82	13b Year — *Vuosi* -80	-82
N	—.144	.059	—.281**	—.262*	—.029	—.309
P	—.068	.191	.378***	.207	—.004	—.219
K	—.066	—.037	.243*	.204	.197	.009
Ca	—.163	.113	.087	—.124	.012	—.382*
B	.048	—.046	.106	—.059	.269	.078
Cu	—.306*	.037	—.230*	—.004	.115	—.328
N/P	—.064	—.084	—.348**	—.289**	.020	.000
N/K	—.023	.057	—.305**	—.285**	—.091	—.225
N/Ca	.059	—.020	—.281**	—.062	—.082	.180
N/B	—.091	—.016	—.163	.022	—.256	.061
N/Cu	.291*	—.058	.072	—.145	—.120	.175
P/Ca	.073	.021	.294**	.318**	—.050	.184
P/B	—.081	—.002	.151	.077	—.328	.073
P/Cu	.284	.006	.347**	.121	—.055	.171
K/P	—.015	—.190	—.239*	—.030	.169	.279
K/Ca	.062	—.056	.155	.245*	.114	.330
K/B	—.077	—.028	.087	.088	—.251	.120
K/Cu	.243	—.076	.291**	.122	.042	.298
Ca/B	—.142	—.004	.015	.002	—.239	—.002
Ca/Cu	.079	.016	.257*	—.075	—.055	—.020
B/Cu	.187	—.029	.247*	—.105	.169	.209

333. Relationship between survival percentage and foliar nutrient contents

As the influencing time of refertilization on the survival percentage remained rather short, the following discussion focuses on the correlation between the foliar nutrient status and the survival percentage only in Experiments 12 and 13 where the foliar nutrients were also analyzed before refertilization.

A significant correlation (Table 5) in Experiment 12 existed only between the prerefertilization foliar copper content (–) and N/Cu ratio (+) and the survival percentage.

In Experiment 13 a several significant

Table 6. Percentage of various damages in different experiments and experimental groups.
Taulukko 6. Erilaisten tuhojen osuus eri kokeissa ja koeryhmissä.

Cause of dam. *Tuhon aiheuttaja*	Percentage — *Osuus, %* Experiment — *Koe*						
	1—3	4—8	9—10	11	12	13a	13b
Fungi — *Sienet*	0.0	0.2	4.3	2.1	0.2	0.3	0.5
Insects — *Hyönteiset*	0.0	0.6	3.6	1.3	0.3	1.2	0.3
Voles/hares — *Myyrät/jänikset*	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Moose — *Hirvi*	0.0	1.6	1.3	0.0	1.0	0.0	0.0
Frost — *Halla*	0.0	3.1	9.9	0.9	0.0	0.0	0.0

correlations were found between the prerefertilization foliar nutrient status and survival percentage. The foliar nitrogen and copper contents were negatively and the phosphorus and potassium levels positively correlated with the survival percentage of saplings indicating a phosphorus and potassium shortage in relation to nitrogen. The K/P ratio had a negative correlation with the survival percentage suggesting that the phosphorus shortage was more prominent than that of potassium. The dependences between the above-mentioned variables were still visible in the correlations between the 1982 foliar nutrient status and survival percentage, although not as clearly. The only significant correlation between the foliar nutrient status and survival percentage in Experiment 13 b was that between the 1982 foliar calcium content (−) and survival percentage.

34. Sapling damages

341. Effect of external factors

All the experiments involved the investigation of damages caused by fungi, insects, moose, hares and voles (see Ch. 23). As an exceptionally severe early summer frost in the preinventory summer had damaged pine saplings in western Finland, it was included as one cause of damage. The share of all the above-mentioned causes of damage remained negligible and the treatments had no significant effects. Even the damages by the early summer frost in 1984 remained slight. Therefore only the damage percentages in the experimental groups are presented (Table 6).

342. Effect of nutrient status

3421. Experiments 1—12 and 13 b

In the 1984 inventory only few saplings fell into leader damage classes 2—4. Consequently the proportions of the remaining two classes, Class 5 — multiple-leader saplings — and Class 1 — normal saplings —, had a solid negative correlation. Therefore only the variation in the proportion of normal (= one dominant leader all the time) saplings will be discussed.

Refertilization, the foliar nutrient status and leader damages were so closely related to one another that the effect of refertilization and nutrient status on leader damages will be discussed simultaneously. The main focus in the relations between the foliar nutrient status and damages will be on the correlations between the variables. The calculations are based on the material consisting only of the refertilized sample plots (calculation method 2, Ch. 23), unless otherwise stated.

Only about half in Experiments 1—3 and in Experiments 4—8 a little over half of the saplings were considered normal on average (Fig. 11). In the other experiments the majority of the saplings were normal.

Refertilization did not affect the number of normal saplings statistically significantly in Experiments 1—3 (Fig. 11, Table 7). Table 8, however, indicates that the foliar potassium content had a significant positive correlation with the proportion of normal saplings. The comparison of Figures 4 a and 11 shows that the treatments leading to an increasing foliar potassium content have also had a similar effect on the proportion of normal saplings. Also the correlation between the foliar N/Ca, P/Ca and K/Ca ratios and proportion of normal saplings was positive. It seems that there has been too

Table 7. F values and significances calculated with the analyses of variance calculated from the proportion of normal saplings. Soil ameliorant and/or micronutrient application and PK/NPK fertilization as separate class variables.
Taulukko 7. F-arvot ja merkitsevyydet normaalien ja monilatvaisten taimien osuudesta lasketuissa varianssianalyyseissä, joissa maanparannus/hivenlannoituskäsittely ja PK/NPK-lannoitus ovat erillisinä luokkamuuttujina.

Indep. var. *Selittäjä*	F value — *F-arvo* Experiment — *Koe* 1—3	4—8	9—10	11	12	13a	13b
1 = Exp — *Koe*	1.84	9.21**	168.59***				
2 = Amelior./micron. *Maanpar./hivenl.*	0.24	5.69*	7.44*	1.47	5.24***	2.15	1.83
3 = Fertil. — *Lann.*		1.04	2.89	0.26	8.94**	1.12	0.06
1 x 2		1.71	15.44**				
1 x 3		0.86	0.68				
2 x 3		1.11	13.41**	1.22	3.25*	0.82	0.99

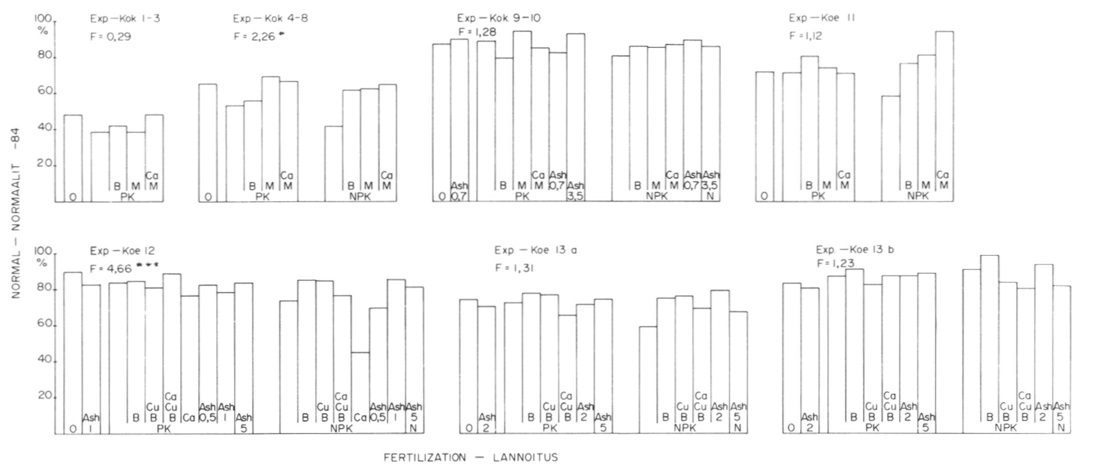

Figure 11. Effect of refertilization on the proportion of normal saplings in 1984.
Kuva 11. Jatkolannoituksen vaikutus normaalien taimien osuuteen v. 1984.

much lime in relation to other main nutrients. On the other hand, by analyzing Figures 8 a, 9 a, b and 11 it seems that liming itself did not raise the values of those ratios or increase the number of abnormal saplings.

Refertilization with only PK or NPK fertilizers in Experiments 4—8 decreased the proportion of normal saplings (Fig. 11). As stated in Chapter 32 (Fig. 6 a) such fertilization treatments lowered the boron contents in particular. Table 8 shows that the foliar boron content indeed had a positive correlation with the proportion of normal saplings. The significance of boron in Experiments 4—8 is also perceptible in the significant correlations between the nutrient ratios including boron and the proportion of normal saplings. Moreover, there was a negative correlation between the foliar calcium content and the proportion of normal saplings and a positive one between K/Ca ratio. Fig. 9 b (Ch. 32) shows that liming had decreased the foliar K/Ca ratio.

In Experiments 9—10 the effect of soil ameliorant and/or micronutrient application on the proportion of normal saplings was rather small on the nitrogen refertilized sample plots (Fig. 11). On the other hand, the application of boron or 0.7 tons of ash to the sample plots in addition to P and K fertilizers without nitrogen, decreased, to some extent, the proportion of normal saplings as compared to other refertilization treatments. The main effect of soil amelio-

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Table 8. Correlation coefficient between the proportion of normal saplings and the foliar nutrient status after refertilization (all the experiments) and before refertilization (Exps. 12 and 13b).

Taulukko 8. Normaalien taimien osuus ja neulasten jatkolannoituksen jälkeisen (kaikki kokeet) sekä jatkolannoitusta edeltäneen (kokeet 12 ja 13b) ravinnetilan väliset korrelaatiokertoimet.

Nutrient *Ravinne*	Correlation coefficients — *Korrelaatiokertoimet*							
	Experiment — *Koe*							
	1—3	4—8	9—10	11	12		13b	
					Before *Ennen*	After *Jälkeen*	Before *Ennen*	After *Jälkeen*
N	.257	—.286	—.243	—.585*	—.055	—.333*	.187	.196
P	.333	—.085	—.307	.148	—.162	—.014	—.205	.239
K	.655**	.075	.031	—.194	—.040	.196	—.023	.029
Ca	—.445	—.389*	.171	.174	—.109	.185	.291	—.176
B	—.286	.540***	.212	.513*	.118	.563***	—.256	—.127
Cu	—.129	.026	—.163	.254	.019	.174	—.012	—.233
N/P	—.020	—.060	.149	—.450	.121	—.222	.212	—.058
N/K	—.389	—.105	—.203	—.226	.006	—.365**	.133	.130
N/Ca	.689**	.155	—.224	—.429	.068	—.295*	—.106	.235
N/B	.027	—.347*	—.246	—.402	—.101	—.779***	.217	.146
N/Cu	.088	—.175	.062	—.477	—.047	—.362*	—.038	.359*
P/Ca	.655**	.287	—.260	—.094	.021	—.168	—.297	.288
P/B	.030	—.383*	—.273	—.348	—.134	—.767***	.208	.155
P/Cu	.115	—.119	—.041	—.157	—.080	—.194	—.217	.329
K/P	.395	.159	.396*	—.276	.065	.200	.136	—.262
K/Ca	.724**	.324*	—.134	—.296	.042	—.062	—.303	.153
K/B	.084	—.358*	—.217	—.404	—.118	—.790***	.194	.119
K/Cu	.299	—.045	.153	—.277	—.043	—.097	—.126	.230
Ca/B	—.051	—.378*	—.084	—.224	—.174	—.747***	.237	.073
Ca/Cu	—.250	—.242	.224	—.048	—.096	.003	.002	.082
B/Cu	—.229	.455**	.279	.435	.095	.551***	—.268	.021

rant and/or micronutrient treatment and the interaction between it and nitrogen fertilization was significant. Absolute differences in the proportions of normal saplings were, however, rather small. Neither the effect of refertilization on the foliar nutrient status nor the correlation between the proportions of normal saplings and the foliar nutrient status seem to shed light on that phenomenon (Ch. 32 and Table 8). An overdosage of boron is probably out of the question, as the foliar boron contents in these treatments did not rise above the other ones, but remained even lower in the case of ash application (see also Braekke 1979).

Refertilization in Experiment 11 had no significant effect on the proportion of normal saplings (Fig. 11, Table 7). The proportion was negatively correlated with the foliar nitrogen and positively with the the foliar boron content referring to an abundance of nitrogen and scarcity of boron (Table 8). The foliar boron content was extremely low in the treatments not refertilized with boron (Fig. 6 a).

In Experiment 12 both soil ameliorant and/or micronutrient application and nitrogen fertilization influenced the number of normal saplings (Fig. 11, Table 7). The main reason was probably the extremely unfavourable effect of liming especially on the NPK fertilized sample plots without micronutrient application. This also caused a significant interaction between the variables. As pointed out previously (Ch. 32, Fig. 6 a) liming had a similar effect on the foliar boron contents.

The relationship between the foliar boron contents and the proportion of normal saplings in Experiment 12 was further shown in correlation analyses. No significant dependences were found between the foliar nutrient status before refertilization and the proportion of normal saplings (Table 8), but after refertilization the foliar boron content had a highly significant positive correlation with the proportion of normal saplings. Similarly, all the nutrient ratios involving boron had a highly significant correlation with the proportion of normal saplings. As the correlations between the foliar nutrient status and the proportion of normal saplings did not appear until the post-refertilization foliar analyses, it is obvious that the change in the nutritional status of saplings induced by refertilization led to growth disturbances. Thus liming led to a drastic increase in

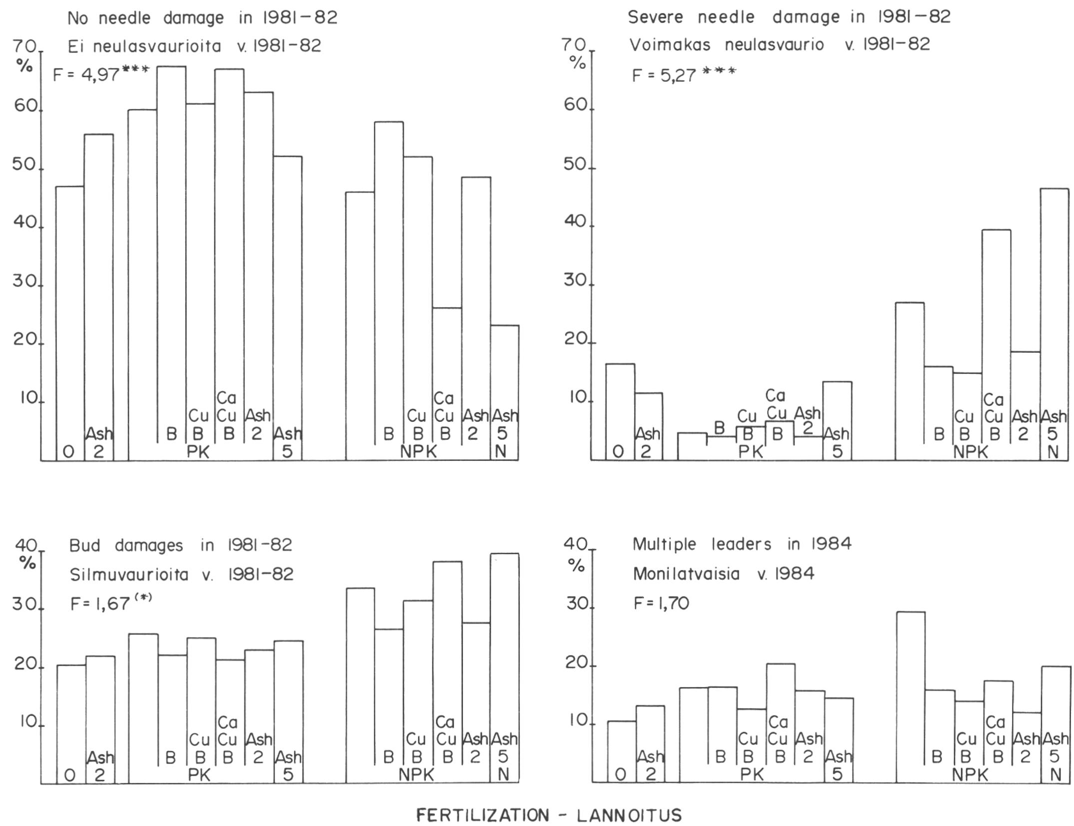

Figure 12. Effect of refertilization on the proportion of needle and bud damages in winter 1981—1982 and that of multipleleader trees in autumn 1984 in Experiment 13 a.

Kuva 12. Jatkolannoituksen vaikutus neulas- ja silmuvaurioiden osuuteen v. 1981 ja monilatvaisten osuuteen v. 1984 kokeessa 13 a.

growth disturbances in spite of the fact that liming did not appreciably affect the foliar Ca contents (see Figs. 7 a and 11, App. 2).

Refertilization in Experiments 13 a and b had no significant effect on the proportion of normal saplings in 1984 (Fig. 11, Table 7). Only one case (N/Cu +, Table 8) in Experiment 13 b showed a significant correlation between the proportion of normal saplings and foliar nutrient status.

3422. Experiment 13 a

Part of the 1981 needles in Experiment 13 a turned brown and died during the winter (1981—82) following refertilization. Refertilization with nitrogen decreased the proportion of undamaged and strongly increased that of damaged saplings as well as those with bud damages (Table 9, Fig. 12). Strikingly few undamaged saplings were on the limed NPK fertilized sample plots and on those ash fertilized plots that had only received nitrogen, but no P and K as fertilizers.

As shown earlier liming and ash fertilization affected quite similarly the foliar P contents and in an opposite way the N/P contents (Ch. 32, Fig. 3 b and 4 b).

No needle samples were collected after refertilization and yet before the injury. Thus there is no direct evidence of the nutritional status of saplings at the time of injuries. In the following the data before refertilization and after injuries will be used for explaining the phenomenon, although it is possible that the phenomenon itself may have affected the foliar nutrient status after the injury.

The needle and bud damages depended greatly on the foliar nutrient status measured

Table 9. F values and significances indicating the effect of refertilization on the proportion of needle and bud damages in the 1982 inventory of Experiment 13a.

Taulukko 9. F-arvot ja merkitsevyydet jatkolannoituksen vaikutuksesta neulas- ja silmuvaurioisten taimien osuuteen v. 1982 inventoinnissa kokeessa 13a.

	Indep. var. — *Selittäjä*		
Dep. var. *Selitettävä*	Amel./Micr. *Maanp./Hivenain.*	N-fertil. *N-lann.*	Inter. *Yhdysv.*
No needle damage *Ei neulasvaurioita*	3.97**	32.81***	2.21(*)
Severe needle damage *Voimakas neulasvaurio*	3.83**	37.74***	1.56
Bud damage *Silmuvaurio*	0.71	10.12**	0.62

Table 10. Correlation coefficients between the foliar nutrient status before (1980) and after refertilization (1982) and the proportion of needle and bud damages in Experiment 13a. All the unrefertilized plots and those fertilized only with the smallest ash amount (2 t) were omitted.

Taulukko 10. Jatkolannoitusta edeltäneen (1980) ja sen jälkeisen (1982, vaurioitumien 1981) neulasten ravinnetilan sekä erilaisten v. 1982 todettujen neulas- ja silmuvaurioiden osuuden väliset korrelaatiokertoimet kokeessa 13a. Aineistosta on poistettu jatkolannoittamattomat sekä pelkästään pienimmän tuhkamäärän (2 t) saaneet koealat.

	Correlation coefficient — *Korrelaatiokerroin*					
Nutrient *Ravinne*	No needle damage *Ei neulasvaurioita*		Severe needle damage *Voimakas neulasvaurio*		Bud damage *Silmuvaurio*	
	Needles of — *Neulaset vuodelta*					
	1980	1982	1980	1982	1980	1982
N	—.444***	—0.540***	.457***	0.578***	.432***	0.534***
P	.428***	0.214*	—.394***	—0.234*	—.331**	—0.132
K	.192	0.134	—.225*	—0.136	—.168	—0.087
Ca	—.215*	0.039	.196	—0.095	.187	0.000
B	—.104	0.104	.158	—0.012	.002	0.004
Cu	—.348***	—0.070	.394***	0.081	.295**	0.070
N/P	—.440***	—0.377***	.402***	0.417***	.370***	0.360***
N/K	—.400***	—0.311**	.416***	0.338**	.360***	0.299**
N/Ca	—.258*	—0.306**	.278**	0.367***	.255*	0.299**
N/B	—.097	—0.007	.047	—0.043	.184	—0.069
N/Cu	.084	—0.120	—.116	0.132	—.015	0.135
P/Ca	.477***	0.165	—.427***	—0.139	—.376***	—0.121
P/B	.268*	0.088	—.294**	—0.144	—.142	—0.126
P/Cu	.432***	0.203	—.437***	—0.215	—.332**	—0.131
K/P	—.317**	—0.111	.230*	0.138	.222*	0.097
K/Ca	.303**	0.078	—.304***	—0.050	—.253*	—0.065
K/B	.171	0.062	—.226*	—0.120	—.070	—0.113
K/Cu	.344**	0.129	—.378***	—0.137	—.271	—0.095
Ca/B	.071	0.047	—.140	—0.108	.021	—0.098
Ca/Cu	.246*	0.107	—.288**	—0.137	—.190	—0.066
B/Cu	.146	0.136	—.120	—0.036	—.184	—0.009

both before and after refertilization (Table 10), although generally less on the values after refertilization. There was a negative correlation between the proportion of undamaged saplings and the foliar copper, calcium and nitrogen contents and N/P and N/K ratios and a positive one with the foliar phosphorus content. The contrary situation was true with the proportion of the severely damaged saplings and those with bud damages. The correlations between the bud damages and the foliar nutrient status were consistently lower than those between the foliar damages and nutrient status, which suggests that needles were more susceptible to damages than buds.

Table 11. Correlation coefficients between the foliar nutrient status in 1980 and the prerefertilization leader changes and between the 1980 and 1982 foliar nutrient status and multiple-leader trees in 1984.

Taulukko 11. Neulasten ravinnetilan v. 1980 ja jatkolannoitusta edeltäneiden pääranganvaihdosten sekä neulasten ravinnetilan vuosina 1980 ja -82 ja v. 1984 havaitun monilatvaisuuden väliset korrelaatiokertoimet.

Nutrient *Ravinne*	Correlation coefficient — *Korrelaatiokerroin*: Earlier leader change — *Aikaisempi päärangan vaihto*	Multiple leaders in 1984 *Monilatvaisia v. 1984*	
	Needles analysis in — *Neulasanalyysi v.* 1980	1980	1982
N	.482***	.294**	.277**
P	—.301**	—.273**	—.159
K	—.136	—.068	—.234*
Ca	.071	—.142	.019
B	.003	—.092	.022
Cu	.217*	.107	.159
N/P	.331**	.228*	.244*
N/K	.384***	.245*	.318**
N/Ca	.360**	.334**	.143
N/B	.197	.182	.041
N/Cu	.085	.034	—.039
P/Ca	—.274**	—.143	—.162
P/B	—.132	—.056	.001
P/Cu	—.297**	—.241*	—.221*
K/P	.157	.156	—.028
K/Ca	—.143	.051	—.180
K/B	—.065	.025	—.021
K/Cu	—.239*	—.140	—.229*
Ca/B	—.024	.003	.023
Ca/Cu	—.198	—.210*	—.130
B/Cu	—.156	—.197	—.019

The foliar copper content in Experiment 13 a was rather low (Ch. 32, Fig. 7 b). Although the correlation between the foliar copper content and the proportion of undamaged saplings was negative as well as that of severely damaged saplings and those with bud damages positive, there is no reason to assume that the situation was caused by toxic amounts of copper, but rather was related to a correlation between copper and some other nutrient. There was in fact a positive and highly significant correlation (r = 0.420***) between nitrogen and copper.

A solid positive dependence of the undamaged saplings on the P/Ca ratio was somewhat surprising. The foliar calcium content had a significant correlation only with the boron content (r = 0.363***), which alone did not seem to affect the number of damages. No statistically significant dependences were found between other nutrients and calcium.

The leader changes before refertilization correlated with the foliar nutrient status before refertilization quite similarly to needle and bud damages (Table 11, see also Table 10), although significant differences were fewer. Also the multiple-leader saplings found in the autumn of 1984 had similar correlations with the 1980 and 1982 foliar nutrient status, although the correlations were still somewhat lower.

The effect of refertilization on the proportion of multiple-leader saplings in the 1984 inventory was similar to its effect on needle and bud damages (Fig. 12). The effect was not, however, significant (Table 7).

The results suggest that the damages in Experiment 13 a were strongly dependent on the nutrient status preceding refertilization so that the imbalance between the N/P ratio (see also Paavilainen 1976 and Paavilainen & Kaunisto 1977) and P/Ca ratio seems to be an important factor. It is interesting that the same quantities were in a solid correlation also with the leader changes that occurred before refertilization. Refertilization, particularly the treatments that enlarged the foliar N/P ratio (N fertilization, liming, largest ash amount + N) led to further damages. However, refertilization did no longer significantly affect the proportion of multiple-leader trees in 1984. Thus saplings were evidently recovering from the damages caused by refertilization.

35. Height growth of saplings

351. Effect of peat properties

3511. Total nitrogen content of peat

The dependence between height growth and the total peat nitrogen content was separately studied on the PK fertilized plots (application of phosphorus and potassium as fertilizers or wood ash) and on the NPK fertilized plots (application of nitrogen and the above-mentioned nutrients). Only the totally unrefertilized plots and those fertilized with ash but without any nitrogen

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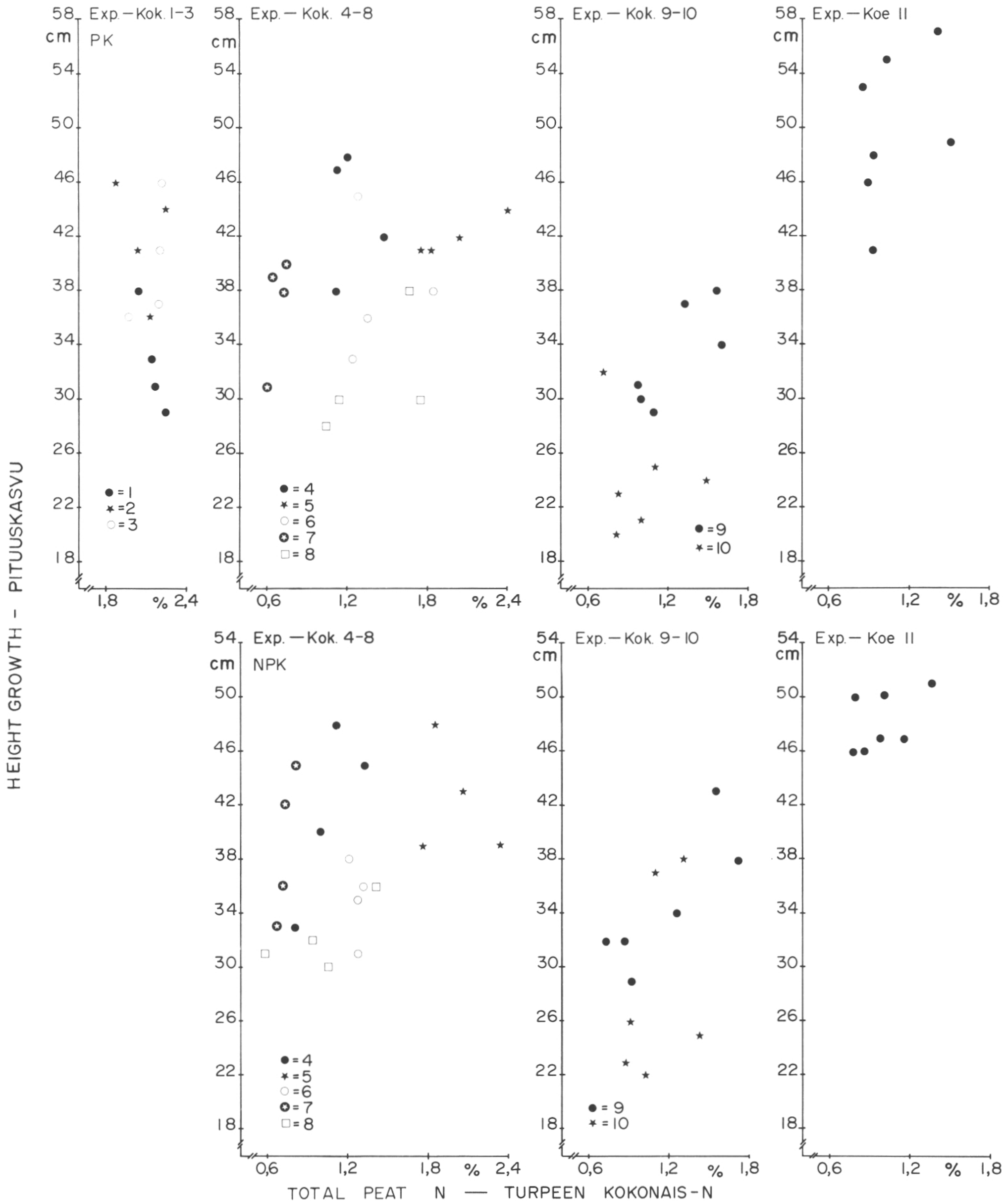

Figure 13. Dependence of the 1984 height growth on the total peat nitrogen content in the 5—10 cm peat layer on the PK and NPK fertilized sample plots of Experiments 1—11.
Kuva 13. Vuoden 1984 pituuskasvun riippuvuus turpeen kokonaistyppipitoisuudesta 5-10 cm:n turvekerroksessa kokeiden 1-11 PK- ja NPK-lannoitetuilla koealoilla.

fertilized equivalent as control were omitted from the investigation.

No significant dependence between the total peat nitrogen content in 5—10 cm peat layer and sapling growth could be detected in the experimental groups of 1—3, 4—8 and 9—10 (Table 12, Fig. 13). By investigating these experiments individually on the basis of Figure 13, a positive correlation between growth and peat nitrogen content seems to exist in Experiments 5—10. Too few observations, however, do not justify the calculation of regression equations for each experiment separately. The combina-

Table 12. The effect of the total peat nitrogen content (%) in the 5—10 cm layer, calculated by the analysis of covariance, on the mean of the postrefertilization height growth of saplings (cm).

Taulukko 12. Kovarianssianalyysillä laskettu turpeen kokonaistyppipitoisuuden (% 5—10 cm:n kerroksessa) vaikutus taimien jatkolannoituksen jälkeisen pituuskasvun (cm) keskiarvoon.

Exp. *Koe*	Fertilization *Lannoitus*	Height growth $\bar{x}$ *Pituuskasvu* $\bar{x}$ Equation *Yhtälö*	F	Height growth 1984 *Pituuskasvu 1984* Equation *Yhtälö*	F
1—3	PK	y=2.93x+26.9	0.07	y=1.18x+27.1	0.02
4—8	PK	y=2.38x+32.8	0.28	y=3.27x+34.0	0.44
	NPK	y=2.61x+33.0	0.25	y=3.64x+33.6	0.44
9—10	PK	y=0.81x+24.6	0.02	y=3.80x+2.44	0.23
	NPK	y=2.39x+27.5	0.23	y=10.17x+20,0	2.74
11	PK	y=12.36x+29.9	45.12*	y=19.62x+28.3	8.02
	NPK	y=7.45x+36.3	2.44	y=7.71x+40.5	1.69
12	PK	y=11.82x+11.26	29.18***	y=12.82x+13.0	34.01***
	NPK	y=0.67x+27.9	0.02	y=0.77x+30.9	0.03
13a$_1$	PK	y=—3.58x+48.6	3.26(*)	y=—3.66x+54.6	1.78
	NPK	y=—4.05x+49.3	8.66**	y=—5.59x+58.9	7.86*
13a$_2$	PK	y=1.34x+33.1	0.69	y=—0.60x+43.6	0.06
	NPK	y=—2.25x+8.3	0.39	y=—5.87x+52.7	1.20
13b	PK	y=7.96x+11.6	3.85(*)	y=10.12x+14.0	7.77*
	NPK	y=15.96x+13.6	4.33(*)	y=25.81x+13.7	8.51*

tion of experiments (1—3, 4—8, 9—10) into calculation entities produces heterogeneous groups where not only the peat nitrogen content and class variables (analysis of covariance) but also some unknown factors may have caused variation in height growth.

The growth of saplings in Experiment 11 increased as the peat nitrogen content rose, but significantly only on the PK fertilized sample plots (Figs. 13 and 14, Table 12).

The dependence between height growth and the total peat nitrogen content (5—10 cm) in Experiments 12 and 13 is seen in Figures 14 and 15 (see also Tables 12 and 13). As the dependence of height growth on the peat nitrogen content in Experiment 13 a was somewhat different in various blocks, the blocks were at first separated for calculation. A straight line explained best the dependence between height growth and the total peat nitrogen content in each separate analysis.

In the areas with a low total peat nitrogen content (Experiments 11, 12 and 13 b, $N_{\bar{x}}$ 0.85—1.17 %) height growth increased both on the PK and NPK refertilized plots as the peat nitrogen content rose. Nitrogen refertilization further increased growth, although in Experiments 11 and 12 only at the lowest total peat nitrogen levels. In these experiments the lines for PK and NPK fertilized plots intersected as the total peat nitrogen reached the values of 1.1—1.3 % (see also Kaunisto 1982). In areas of still higher average levels of total peat nitrogen (Exp. 13 a2, $N_{\bar{x}}$ 2.0 %) height growth increased only little on the PK fertilized and decreased on the NPK fertilized sample plots along with the rising total nitrogen content. In the area of the highest total peat nitrogen level (13 a1, $N_{\bar{x}}$ 2.5 %) the height growth of saplings decreased both on the PK and NPK fertilized sample plots along with the rising total peat nitrogen content, but more abruptly on the NPK than PK fertilized plots.

To get an overall impression on the dependence between the height growth of saplings and total peat nitrogen content, the analyses of covariance were also calculated so that first all the blocks of Experiment 13 were joined and then Experiment 12 was added, although it represented, in many respects, a different situation. In each case the outcome was a downward parabola in which the dependence of growth on the total peat nitrogen content was highly significant (Fig. 14, Table 13). The combined material of Experiments 13 showed a rising growth up to about 2.5—2.6 % total peat nitrogen content. The maximum on the NPK fertilized sample plots was reached with somewhat lower total nitrogen values than on the PK fertilized ones.

The dependence of height growth on the

Table 13. Effect of total peat nitrogen content (% N in the 5—10 cm layer) calculated with the analysis of covariance on the height growth of saplings (cm) in 1984 (I_{h84}) and on mean value ($I_{h\bar{x}}$) of post-refertilization height growth in the joint analysis of Experiments 13a and b as well as 12, 13a and 13b. Soil ameliorant and/or micronutrient treatment as class variable.

Taulukko 13. Kovarianssianalyysillä laskettu turpeen kokonaistyppipitoisuuden (% N 5—10 cm:n kerroksessa) vaikutus taimien pituuskasvuun (cm) v. 1984 (I_{h84}) sekä jatkolannoituksen jälkeisen pituuskasvun keskiarvoon ($I_{h\bar{x}}$) kokeiden 13a ja b sekä 12, 13a ja 13b yhteisanalyysissä. Luokkamuuttujana maanparannus/hivenlannoituskäsittely.

Exper. *Koe*	Fertilization *Lannoitus*	Depend. var. *Selitettävä muutt.*	Regression equation *Regressioyhtälö*	F value — *F-arvo* x^2	Regr. $x+x^2$	Class v. *Luokkam.*	Coeff.det. *Selitysaste %*
13a+b	PK	$I_{h\bar{x}}$	$y = 34.08x - 6.55x^2 - 8.6$	38.45***	98.33***	2.28(*)	80.9
12+13a+b			$y = 29.49x - 5.35x^2 + 4.3$	31.48***	125.37***	3.66**	80.0
13a+b		I_{h84}	$y = 39.16x - 7.76x^2 - 8.2$	38.63***	82.97***	2.86*	78.5
12+13a+b			$y = 33.65x - 6.23x^2 - 3.6$	29.38***	104.65***	3.97**	77.2
13a+b	NPK	$I_{h\bar{x}}$	$y = 20.54x - 4.12x^2 + 10.2$	14.38***	36.63***	3.29*	65.1
12+13a+b			$y = 17.34x - 3.17x^2 + 12.56$	9.52**	41.80***	3.46**	61.1
13a+b		I_{h84}	$y = 23.26x - 5.26x^2 + 15.9$	14.34***	18.67***	2.66*	57.3
12+13a+b			$y = 19.64x - 3.96x^2 + 12.3$	8.91**	23.49***	2.61*	46.9

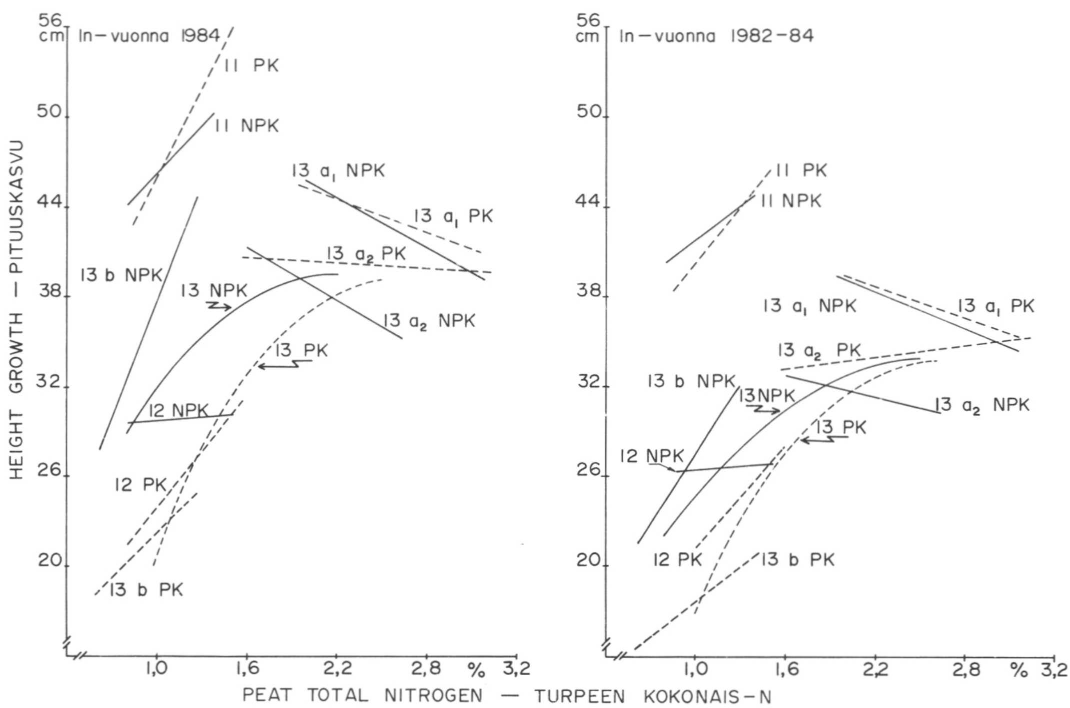

Figure 14. Dependence of the 1984 height growth and the 1982—84 mean annual height growth of saplings on the total peat nitrogen content in the 5—10 cm peat layer in Experiments 11—13. Experiment 13 a was divided into two parts: 13 a1 and 13 a2. Parabola halves drawn on the basis of the entire material of Experiment 13 (= 13 a + 13 b).

Kuva 14. Taimien pituuskasvun v. 1984 sekä keskimääräisen vuotuisen pituuskasvun vuosina 1982-84 riippuvuus turpeen kokonaistyppipitoisuudesta 5-10 cm:n turvekerroksessa kokeissa 11-13. Koe 13 a jaettu kahteen osaan 13 a1 ja 13 a2. Parabelin puolikkaat piirretty koko kokeen 13 (= 13 a + 13 b) aineiston perusteella.

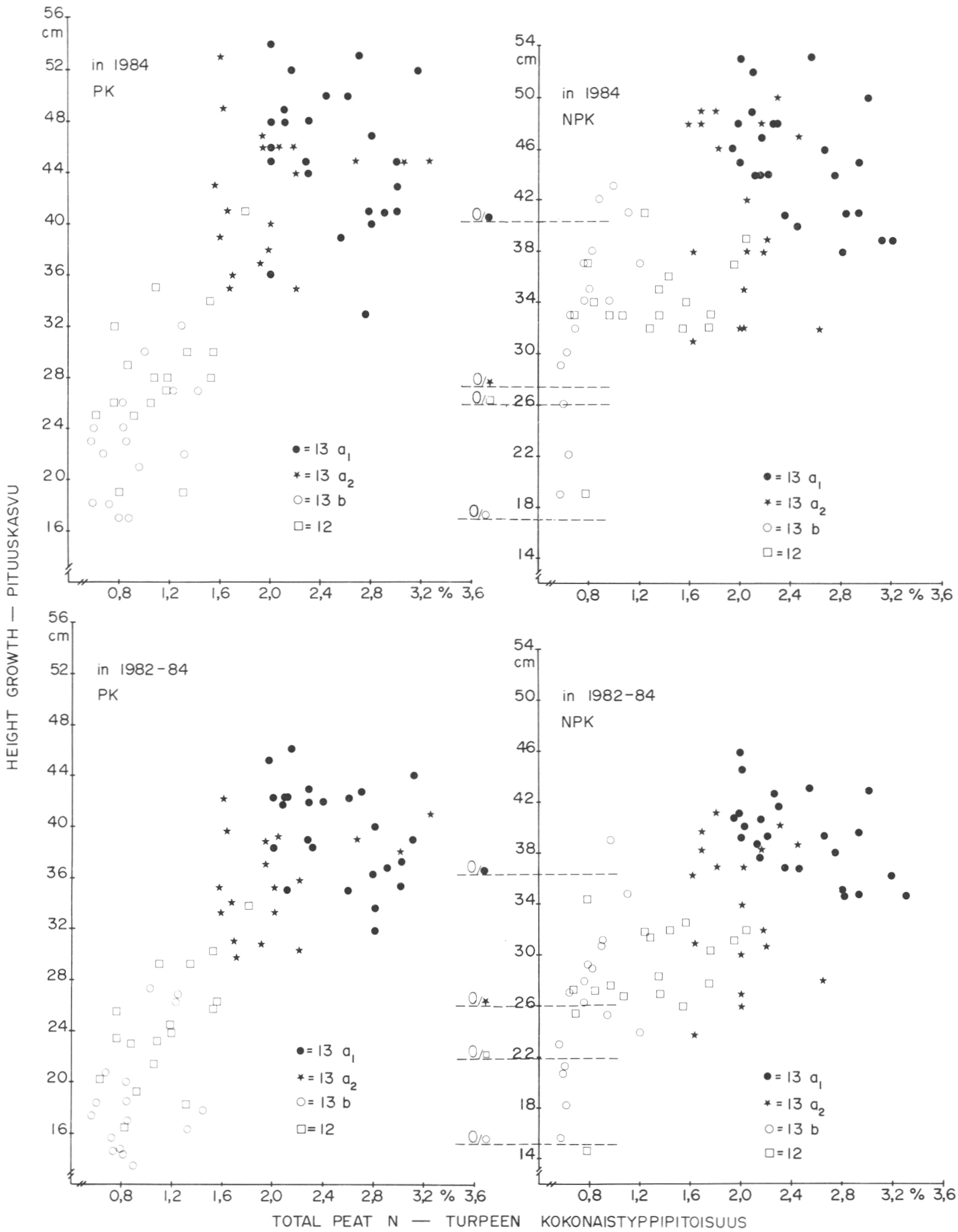

Figure 15. Dependence of the 1984 and the 1982—84 mean annual height growth on the total peat nitrogen content in the 5—10 cm peat layer on the PK and NPK fertilized sample plots of Experiments 12 and 13.
Kuva 15. Vuoden 1984 ja vuosien 1982-84 keskimääräisen vuotuisen pituuskasvun riippuvuus turpeen kokonaistyppipitoisuudesta 5-10 cm:n turvekerroksessa kokeiden 12 ja 13 PK- ja NPK-jatkolannoitetuilla koealoilla.

Table 14. Coefficients of determination in the regression analyses between the peat nitrogen content analyzed from different peat layers and the postrefertilization height growth in Experiments 12 and 13.

Taulukko 14. Selitysasteet eri turvekerroksista määritetyn turpeen typpipitoisuuden ja jatkolannoituksen jälkeisen pituuskasvun välisissä regressioanalyyseissä kokeissa 12 ja 13.

Experiment *Koe*	Fertilization *Lannoitus*	Coeff. det. — *Selitysaste, %* Peat layer — *Turvekerros, cm* 0—5	5—10	10—15	15—20	0—10	0—15	5—15
12	PK	47.9	51.8	27.8	17.7	52.5	54.1	47.3
13 a 1		17.1	21.5	27.6	33.7	18.2	20.7	24.8
13 a 2		5.6	17.3	13.8	7.8	8.2	10.2	15.3
13 b		32.2	21.1	9.0	18.3	25.8	23.5	18.2
$\bar{x}$		25.7	28.2	19.6	19.4	26.2	27.1	26.4
12	NPK	17.8	21.3	30.3	32.5	20.5	23.3	25.9
13 a 1		34.2	29.4	8.0	1.1	34.1	30.2	23.1
13 a 2		7.0	1.2	6.0	3.0	6.5	4.8	1.2
13 b		41.9	66.3	42.3	26.7	59.3	66.8	64.2
$\bar{x}$		25.2	29.6	21.7	15.8	30.1	31.3	28.6

total nitrogen content is shown also as a scatter diagram in Figure 15. It shows that the height growth of saplings on the PK fertilized sample plots increased up to 1.6—2.0 % of total peat nitrogen content, after which the height growth levelled down and at higher values started to decline. The situation is similar on the NPK fertilized plots. The values of the total peat nitrogen content that marked the maximum growth are somewhat lower than the calculated ones, which is natural as the material concentrates on the rising part of the parabola. The results of the Kaunisvesi experiment (12) on the plots fertilized with phosphorus and potassium agree with the results of the Särkkä experiments (13 a and b). On the NPK fertilized plots, however, the height growth of saplings in Kaunisvesi seems to have been less affected by the total peat nitrogen content than the corresponding plots of the Särkkä experiment.

The total peat nitrogen content from the 5—10 cm layer was chosen to represent the peat nitrogen status and height growth in the whole material on the basis of the earlier investigations (Kaunisto 1982, Kaunisto & Tukeva 1984). The dependence between height growth and peat nitrogen status was investigated more thoroughly in Experiments 12 and 13 where, in addition to the total nitrogen content in the 5—10 cm peat layer, the height growth of saplings was also explained by the total nitrogen content in the 0—5, 10—15, 15—20, 0—10, 0—15 and 5—15 cm peat layers. For this purpose Experiment 13 was divided into three parts in regard to the total nitrogen content, namely 13 a1, 13 a2 and 13 b.

Among the 5 cm peat layers the values measured from the 5—10 cm layer explained best the height growth of saplings after refertilization (Table 14). This was particularly true in the cases where the nitrogen content in general was a good indicator of height growth, such as the PK fertilized plots of Experiment 12 and the NPK fertilized ones in Experiment 13 b. The coefficient of determination was very similar when using as explaining variables the total nitrogen contents of the combinations of peat layers 0—10, 0—15 and 5—15 cm. Growth could not nearly as well be explained by the total nitrogen content in the 0—5, 10—15 and 15—20 cm peat layers.

3512. Peat humification degree

The dependence of height growth on the peat humification degree was only studied in Experiment 12, because in Experiments 13 a2 and 13 b too few humification determinations and none in the others were made (see also Ch. 312). The humification degree in Experiment 12 was determined on all the fertilized sample plots and all peat layers. Thus it is possible to study the relationship as accurately as that between the nitrogen content and growth.

Table 15. Dependence of the mean postrefertilization height growth of saplings, calculated with the analysis of covariance, on the peat humification degree as well as coefficients of determination of the models. In addition coefficents of determination when using the total peat nitrogen content as a covariate variable. Soil ameliorant and/or micronutrient application as class variable.

Taulukko 15. Kovarianssianalyysillä laskettu taimien jatkolannoituksen jälkeisen keskimääräisen pituuskasvun riippuvuus turpeen maatuneisuudesta sekä mallien selitysasteista. Lisäksi selitysasteet käytettäessä turpeen kokonaistyppipitoisuutta kovariaattina. Luokkamuuttujana maanparannus/hivenlannoituskäsittely.

Peat layer *Turvekerros* *cm*	Fertilization *Lannoitus*	Equation *Yhtälö*	F value — *F-arvo* Regr.	 Class var. *Luokka-muuttuja*	Coeff. det., % when... as cov. — *Selitysaste, %, kun kovariaattina* Humific. *Maatun.*	 Tot. N *Kok. N*
0—5	PK	y = 3.70x + 17.3	0.71	1.15	44.7	68.6
	NPK	y = 1.98x + 24.6	0.34	1.01	42.3	45.4
5—10	PK	y = 5.49x + 11.7	16.78**	2.41	78.5	75.8
	NPK	y =—0.29x + 29.1	0.02	1.04	40.8	41.2
10—15	PK	y = 2.98x + 14.3	17.53**	3.03 (*)	79.2	76.4
	NPK	y = 0.90x + 25.3	0.28	1.04	42.3	49.4
15—20	PK	y = 2.39x + 14.7	10.22**	1.46	71.3	62.6
	NPK	y = 2.70x + 15.7	1.95	1.31	50.3	57.4

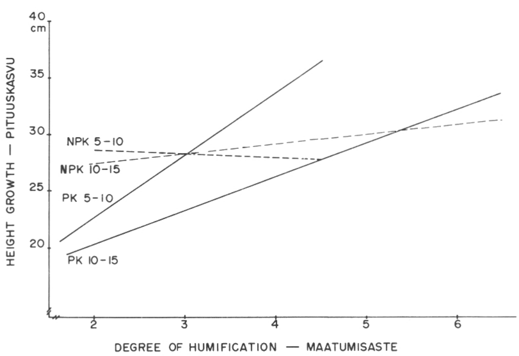

Figure 16. Dependence of the 1982—84 mean annual height growth on saplings on peat humification degree (acc. v. Post) in the 5—10 and 10—15 cm peat layer in Experiment 12. Equations in Table 15.

Kuva 16. Taimien jatkolannoituksen jälkeisen keskimääräisen pituuskasvun riippuvuus turpeen maatuneisuudesta 5-10 ja 10-15 cm:n turvekerroksessa kokeessa 12. Yhtälöt taulukossa 15.

The height growth of saplings on the PK fertilized sample plots increased statistically significantly as humification increased in the 5—10, 10—15 and 15—20 cm layer (Table 15, Fig. 16). The dependence was linear and best explained by humification in the 5—10 and 10—15 cm peat layer. No statistically significant relationship between height growth and the humification degree was found among the NPK fertilized plots. The lines indicating the dependence of height growth on the humification degree in 5—10 cm peat layer for PK and NPK fertilized sample plots intersected at humification degree 3.

352. Effect of refertilization

Height growth

Saplings in Experiments 1—3 grew somewhat better on the refertilized than unrefertilized plots, but the effect was not significant (Fig. 17, Table 16). The result was surprising because on the basis of the foliar nutrient contents rather small amounts of phosphorus and potassium in relation to nitrogen were available to the saplings (see Chapter 32, Figs. 4 b and 5 a). In Experiments 4—8 refertilization increased the growth of saplings significantly in several cases. The most obvious exception was NPK fertilization without micronutrients, which did not, to any remarkable degree, increase the growth of saplings as compared to the unrefertilized plots. Nitrogen fertilization did not influence the height growth of saplings significantly (Table 16).

Refertilization in Experiments 9—10 increased to some degree the height growth of saplings, but in none of the cases significantly (Fig. 17, Table 16). Rather poor drainage may have impaired the fertilization influence. Nitrogen fertilization slightly increased height growth but not significantly.

Refertilization in Experiment 11 strongly increased the height growth of saplings (Fig. 17). The smallest growth increase as compared to the unrefertilized plots was on the plots that had received only phosphorus and potassium as fertilizers. Even on these plots height growth differed significantly from the

Table 16. F values and significances in the analyses of variance and covariance[1]) calculated from the mean postrefertilization[2]) height growth of saplings. Soil ameliorant and/or micronutrient application and nitrogen fertilization as separate class variables.

Taulukko 16. F-arvot ja merkitsevyydet taimien jatkolannoituksen jälkeisestä[2]) keskimääräisestä pituuskasvusta lasketuissa varianssi- ja kovarianssianalyyseissä[1]), joissa maanparannus/hivenlannoituskäsittely ja typpilannoitus ovat erillisinä luokkamuuttujina.

Independent variable *Selittävä muuttuja*	F values in experiments — *F-arvot kokeissa*						
	1—3	4—8	9—10	11	12	13a	13b
1 = Exp. — *Koe*	5.88*	9.94***	14.28*	—	—	—	—
2 = Amelior./micron. *Maanpar./hivenl.*	0.78	3.12(*)	0.39	13.67**	3.68**	16.16***	1.43
3 = N-fertil. — *N-lann.*	—	0.02	5.04(*)	0.93	57.77***	8.02**	31.06***
1 x 2	—	1.29	0.20	—	—	—	—
1 x 3	—	0.82	0.60	—	—	—	—
2 x 3	—	1.55	0.50	6.07(*)	1.99(*)	0.40	0.38

[1]) The analysis of covariance in Experiments 11—13, the height of saplings before refertilization as covariate in Experiments 12 and 13, the total peat nitrogen content in the 5—10 cm layer in Experiment 11.
[2]) In Experiments 4—12 years 80—84, in Experiment 13 years 82—84.
[1]) *Kovarianssianalyysi kokeissa 11—13, kovariaattina taimien pituus ennen jatkolannoitusta kokeissa 12 ja 13, turpeen kokonaistyppipitoisuus 5—10 cm:n kerroksessa kokeessa 11.*
[2]) *Kokeissa 4—12 vuodet 80—84, kokeessa 13 vuodet 82—84.*

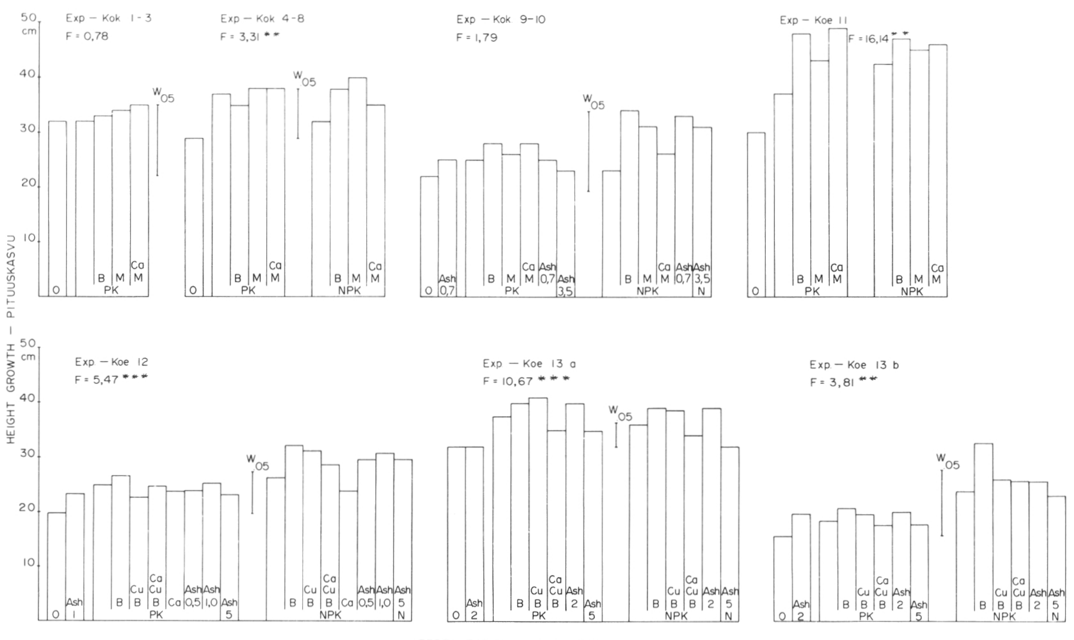

Figure 17. Effect of refertilization on the mean annual postrefertilization height growth in different experiments. $W_{.05}$ is the significant difference with 5 % risk calculated by means of the Tukey's test for all the treatments.
Kuva 17. Jatkolannoituksen vaikutus jatkolannoituksen jälkeiseen keskimääräiseen vuotuiseen pituuskasvuun eri kokeissa. $W_{.05}$ on Tukeyn testin avulla laskettu merkitsevä ero 5 %:n riskillä.

unrefertilized ones. In this case the differences in mean values were investigated with a modified Student-Newman-Keuls test, as the number of replications varied (see e.g. Mäkinen 1978). There were significant differences also between the refertilization treatments (Table 16). Height growth on the plots refertilized merely with the main nutrients (PK or NPK) was smaller than that on the plots that had in addition to PK and NPK received boron or boron, copper and lime.

Refertilization also increased the height of saplings in Experiment 12 in comparison to the unrefertilized plots (Fig. 17, Table 16). The growth increase was not significant in any of the cases unless refertilization involved also nitrogen. The analysis of the mere refertilized treatments showed that the effect of nitrogen fertilization was highly significant (Table 16). As stated before (Chapter 21 and 3511) the peat nitrogen content in Experiment 12 was rather low and there was a positive correlation between the total peat nitrogen content and growth on the PK fertilized sample plots. An interesting observation was the clearly negative effect of lime on growth on the nitrogen-fertilized sample plots. In comparison to the values of the foliar analysis (Ch. 32) liming strongly lowered the foliar boron content (Fig. 6 a) and increased the foliar N/B ratio (Fig. 6 b) if no boron had been applied. The height growth of saplings on the plots that had received only Ca, N, P and K differed significantly from that on the plots fertilized in addition with boron, boron + copper or wood ash (1 t/ha).

Refertilization increased the growth of saplings in Experiment 13 a. In comparison to the control, however, the growth increase had no statistical significance on the plots that had been limed or received the largest amount of ash (5 t/ha, Fig. 17). Similarly on the plots that had received only nitrogen, potassium and phosphorus as fertilizers, height growth did not differ significantly from that of the control.

When only the PK or NPK refertilized plots were compared, height growth on the plots with the highest ash rate in Experiment 13 a differed from the other treatments, except liming significantly (Fig. 17). Growth on the limed plots differed significantly from those fertilized with micronutrients. As stated before in Chapter 32, both liming and the largest ash amount strongly raised the foliar N/P ratio in Experiment 13 a.

Nitrogen refertilization weakened the height growth of saplings significantly in Experiment 13 a (Table 16). The result was foreseeable since the total nitrogen content in the area was fairly high (x = 2.29 %) and since growth had remained steady or declined even on the PK fertilized plots along with the rising total nitrogen content and the straight line depicting the dependence was at a higher level on PK than NPK fertilized plots (see Chapter 3511).

Refertilization did not increase growth much in Experiment 13 b (Fig. 17). Saplings grew better on the plots fertilized with nitrogen, phosphorus, potassium and boron than on the control plots or those without nitrogen fertilization. Other significant differences in comparison to the unrefertilized plots were not found.

The comparison between the refertilized sample plots showed that nitrogen fertilization increased the height growth of saplings highly significantly on the average. The result could be anticipated, since the total peat nitrogen content was low in the experiment ($N_{\bar{x}}$ = 0.85 %) and the growth of saplings had a positive correlation with the total peat nitrogen content even on the NPK fertilized sample plots (see Ch. 3511).

The effect of refertilization in Experiments 1—3 and 9—10 was not significant when investigating the average height growth after refertilization. The situation in Experiments 1—3 was the same in each successive year. The effect of refertilization in Experiments 9—10, however, was significant in three successive growing seasons after refertilization (Table 17). In the other experiments the effect of refertilization on the height growth of saplings could by statistically shown even in the last investigation year.

Height

The effect of refertilization on the total height growth of saplings was very much the same as above, although the differences were smaller (Fig. 18).

353. Relationship between height growth and foliar nutrient contents

The dependence between height growth and foliar nutrient levels and ratios were studied with regression analyses and analyses of covariance. As no distinct parabolical dependences with which the optimum values for foliar nutrients and ratios could be investigated was found, the dependence will be only studied by correlation matrices

Table 17. F values and significance in the analyses of variance and covariance[1]) calculated from the mean postrefertilization[2]) height growth of saplings. The soil amelioration and fertilization treatments combined into one variable. Then mean height of sapling in the refertilization spring as covariate.

Taulukko 17. F-arvot ja merkitsevyydet jatkolannoituksen jälkeisestä[2]) taimien pituuskehityksestä lasketuissa varianssi- ja kovarianssianalyyseissä[1]), joissa eri maanparannus- ja lannoituskäsittelyt on yhdistetty yhdeksi muuttujaksi. Kovariaattina taimien keskipituus jatkolannoitusvuoden keväänä.

Experiments *Kokeet*	Height growth — *Pituuskasvu* -84	-83	-82	-81	-80	-79	x[1])	Height — *Pituus* -84
1—3	1.80	1.57	0.84	0.34	0.03	1.28	0.78	0.77
4—8	4.00**	3.31**	2.54*	2.71*	2.09(*)	1.21	3.31**	2.08(*)
9—10	0.79	1.01	2.43(*)	3.90*	1.78	0.89	1.79	0.92
11	5.35*	8.99*	5.96*	8.41*	6.82*	1.96	16.14**	0.72
12	7.62***	4.41***	3.60***	4.83***	2.43*	1.43	5.47***	7.62***
13a	8.36***	11.63***	6.91**	1.56	0.14	—	10.67***	3.31***
13b	4.63**	3.43**	1.34	0.84	0.29	—	3.81**	3.11**

[1]) The analysis of covariance in Experiments 11—13, the height of saplings before refertilization as covariate in Experiments 12 and 13 and the total peat nitrogen content in Experiment 11.
[2]) In Experiments 1—12 years 79—84, in Experiment 13 years 81—84.
[1]) *Kovarianssianalyysi kokeissa 11—13, kovariaattina taimien pituus ennen jatkolannoitusta kokeissa 12 ja 13 ja turpeen kokonaistyppipitoisuus kokeessa 11.*
[2]) *Kokeissa 1—12 vuodet 79—84, kokeessa 13 vuodet 81—84.*

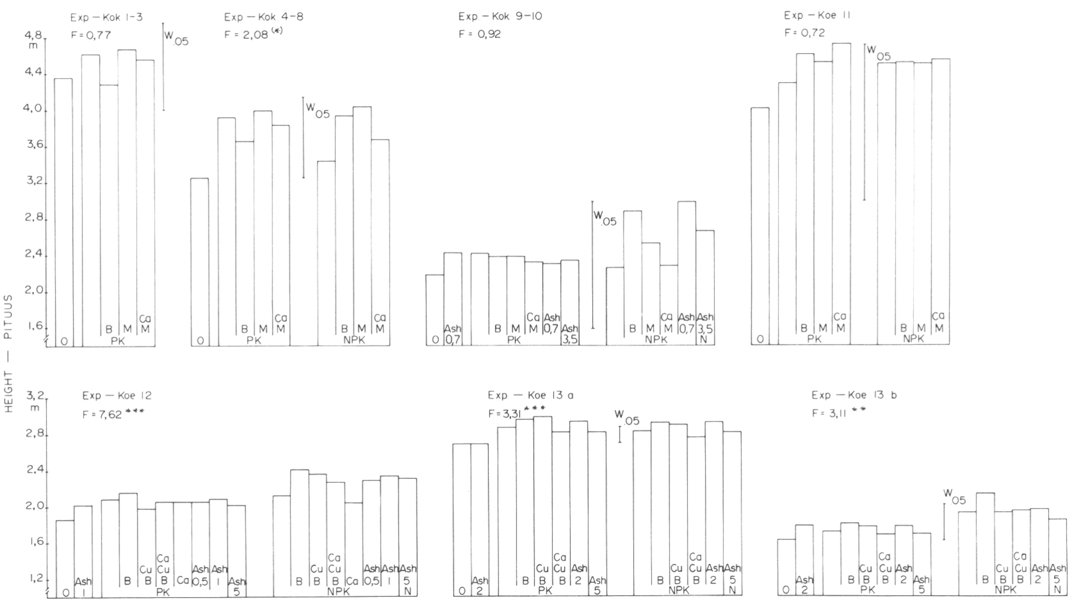

Figure 18. Effect of refertilization on the height of saplings in 1984.
Kuva 18. Jatkolannoituksen vaikutus taimien pituuteen v. 1984.

(Tables 18—24). The totally unrefertilized and those plots that had received ash but had no nitrogen fertilized equivalents were omitted from the material of all the experiments.

The 1983 height growth in Experiments 1—3 correlated positively with the foliar potassium content (Table 18), which would suggest that even after refertilization the area suffered from a potassium deficiency. This assumption seems surprising, since refertilization with PK hardly increased growth (Chapter 352), although the foliar potassium contents rose considerably (Chapter 32).

The height growth of saplings in Experiments 4—8 neither in 1983 nor 1984 had any significant correlations with the foliar po-

Table 18. Correlation coefficients between foliar nutrient contents and ratios in winter 1983—84 and the height growth of saplings (in 1983 and 1984) in Experiments 1—12.
Taulukko 18. Neulasten ravinnepitoisuuksien ja -suhteiden talvella 1983—84 ja taimien pituuskasvun (vuosina 1983 ja 1984) väliset korrelaatiokertoimet kokeissa 1—12.

Nutrient *Ravinne*	Correlation coefficient — *Korrelaatiokerroin*									
	Experiment — *Koe*									
	1—3 Year — *Vuosi*		4—8 Year — *Vuosi*		9—10 Year — *Vuosi*		11 Year — *Vuosi*		12 Year — *Vuosi*	
	-83	-84	-83	-84	-83	-84	-83	-84	-83	-84
N	.439	.481	—.106	.066	.040	.118	.489	.571*	—.125	—.217
P	—.024	—.262	.216	.131	—.107	—.043	.299	.323	.080	.045
K	.548*	.667**	.135	—.007	.284	.315	.408	.372	.070	.179
Ca	—.371	—.333	—.532***	—.410**	—.243	—.123	—.406	—.262	—.293*	—.267
B	—.074	.153	—.080	—.188	.412*	.357	.033	—.150	—.016	.153
Cu	—.271	—.345	.204	.213	.078	.084	—.577*	—.479	—.286	—.095
N/P	—.271	—.068	—.101	—.016	.144	.090	—.443	—.421	—.143	—.189
N/K	—.208	—.257	—.038	.102	—.165	—.128	—.041	.026	—.120	—.270
N/Ca	.572*	.557*	.370*	.363*	.281	.191	.504*	.442	.173	.105
N/B	.548*	.390	.034	.157	—.421*	—.296	.298	.435	.023	—.271
N/Cu	.310	.332	—.261	—.222	—.026	—.001	.657*	.628**	.245	.005
P/Ca	.071	—.107	.355*	.242	.074	.069	.262	.289	.291*	.240
P/B	—.037	—.289	.224	.162	—.174	—.102	.319	.369	.031	—.261
P/Cu	.192	—.054	.081	—.025	—.111	—.056	.336	.361	.310*	.112
K/P	—.243	—.023	—.097	—.037	.194	.130	—.436	—.413	—.005	.129
K/Ca	.517	.540*	.481**	.292	.368	.256	.583*	.442	.248	.263
K/B	.536*	.517	.257	.188	—.250	—.159	.353	.449	.024	—.267
K/Cu	.477	.517	—.208	—.302	.071	.065	.586*	.497*	.312*	.179
Ca/B	—.364	—.412	—.397*	—.224	—.356	—.222	—.360	—.165	—.020	—.312
Ca/Cu	—.117	—.063	—.426**	—.394*	—.247	—.148	.165	.192	—.001	—.143
B/Cu	.178	.263	—.275	—.338*	.194	.150	.459	.293	.058	.196

tassium or phosphorus contents (Table 18). The results would indicate that thanks to refertilization the phosphorus-potassium nutrition of saplings had reached such a level that no shortages of these nutrients exist any longer. This is also indicated by the great increase in the foliar phosphorus and potassium contents after fertilization (Ch. 32). Similarly, there seems to be enough boron and copper also on the sample plots without boron and copper application. The result is surprising in the case of boron, as refertilization with the main nutrients lowered the foliar boron content down to 4—5 ppm, which is clearly below the deficiency limits according to literature (see Kolari 1979, Veijalainen et al. 1934, Braekke 1977, 1979). There was a negative correlation between the foliar calcium content and height growth which is possibly due to different cell sizes of needles growing at different speed.

The 1983 height growth of saplings in Experiments 9—10 had a positive correlation with the foliar boron content and a negative one with the N/B ratio (Table 18). Although there was no statistically significant correlation between the 1984 height growth and foliar boron content, it seems that despite the high foliar boron content on average some saplings had suffered from a boron shortage after refertilization. As stated in Chapter 32 the foliar boron levels lowered drastically especially on the plots which received only N, P and K as fertilizers. Yet, the foliar boron contents were over 10 ppm i.e. above the deficiency limit introduced by Kolari (1979). In this respect the result conflicts with the results of Experiments 4—8.

The 1983 height growth of saplings in Experiment 11 correlated negatively with the foliar Cu contents and positively with the N/Cu, K/Ca and K/Cu ratios (Tables 18). The 1984 height growth had a positive correlation with the foliar nitrogen content. It seems that the area suffered from scarcity of potassium. Excess of copper hardly is the reason, since the foliar copper contents were not higher than in the other experiments (Ch. 32, Fig. 7 b).

Experiments 12 and 13 include the investigation of the dependence between the height growth of saplings and the nutritional state of needles sampled both before and after refertilization. The 1980 foliar nutrient contents in Experiment 12 had no statistical-

Table 19. Correlation coefficients between the height growth of saplings and the 1980 foliar nutrient content in Experiment 13a. All the refertilized sample plots were included.

Taulukko 19. Taimien pituuskasvun ja neulasten ravinnetilan v. 1980 väliset korrelaatiokertoimet kokeessa 13a. Mukana kaikki jatkolannoitetut koealat.

Nutrient *Ravinne*	Correlation coefficient — *Korrelaatiokerroin* Height growth in — *Pituuskasvu vuonna* -80	-81	-82	-83	-84
N	—.570***	—.634***	—.601***	—.422***	—.209
P	.639***	.677***	.659***	.403***	.260*
K	.491***	.487***	.434***	.269*	.132
Ca	—.227*	—.168	—.246*	—.298**	—.296**
B	—.311**	—.303**	—.329**	—.249*	—.212*
Cu	—.412***	—.443***	—.390***	—.415***	—.264*
N/P	—.591***	—.627***	—.619***	—.411***	—.242*
N/K	—.588***	—.633***	—.589***	—.395***	—.190
N/Ca	—.365***	—.456***	—.375***	—.194	—.010
N/B	.055	.002	.047	.046	.110
N/Cu	.034	.021	.016	.158	.167
P/Ca	.664***	.671***	.689***	.491***	.365***
P/B	.553***	.545***	.550***	.372***	.287**
P/Cu	.606***	.637***	.591***	.497***	.330**
K/P	—.331**	—.347**	—.390***	—.255*	—.202
K/Ca	.544***	.507***	.503***	.401***	.286**
K/B	.473***	.450***	.447***	.313**	.239*
K/Cu	.548***	.561***	.501***	.463***	.296**
Ca/B	.318**	.309**	.315**	.202	.161
Ca/Cu	.292**	.339**	.279**	.288**	.170
B/Cu	.004	.033	—.008	.079	.026

ly significant correlation with the height growth of saplings, which is why the results have not been introduced. Only few significant dependences even between the 1983 foliar analyses and height growth were found in this experiment (Table 18). The 1983 height growth had a positive correlation with the foliar K/Cu, P/Cu and P/Ca ratios and a negative one with the foliar calcium content.

The most interesting experiments in regard to the foliar nutrient content and the height growth of saplings are 13 a and b. Before refertilization there was a highly significant positive correlation between the foliar phosphorus and potassium contents and height growth in Experiment 13 a, but a highly significant negative one between the foliar nitrogen and copper content and height growth (Table 19). Similarly the foliar calcium and boron content had a negative correlation with height growth, although milder. All the nutrient ratios in which phosphorus or potassium content was as a dividend and Ca, B or Cu as a divider had a highly significant positive correlation with height growth, while the correlation between the N/P and N/K ratio and height growth was negative. The result clearly indicates that before refertilization the trees suffered from an intensive phosphorus and potassium shortage in relation to other nutrients. As the correlation between the phosphorus content and height growth was somewhat higher than that between the potassium content and height growth and as the correlation between the K/P ratio and growth was significantly negative, it is obvious that the trees suffered even more from phosphorus than potassium shortage. This is also implied by the very low phosphorus contents in 1980 (Ch. 32, Fig. 3 b).

The 1980 foliar nutrient contents and ratios had significant correlations with the height growth of saplings also in the years following refertilization so that even in the third growing season after refertilization (1983) all the above-mentioned correlation coefficients were significant (Table 19). The calculation of the correlation coefficients between the foliar nutrient contents in 1980 and 1982 showed that the foliar nitrogen, phosphorus and potassium contents in different years correlated significantly as can be seen from the following figures:

Table 20. Correlation coefficients between the height growth of saplings and the 1980 foliar nutrient status in Experiment 13a. Included were all the plots treated with phosphorus and potassium fertilizers excluding limed plots.

Taulukko 20. Taimien pituuskasvun ja neulasten ravinnetilan v. 1980 väliset korrelaatiokertoimet kokeessa 13a. Mukana fosforia ja kaliumia lannoitteina saaneet koealat kalkittuja lukuunottamatta.

Nutrient *Ravinne*	Correlation coefficient — *Korrelaatiokerroin* Height growth in — *Pituuskasvu vuonna* -80	-81	-82	-83	-84
N	—.527***	—.644***	—.568***	—.260	—.058
P	.628***	.728***	.661***	.280*	.177
K	.561***	.586***	.475***	.277*	.041
Ca	—.159	—.082	—.232	—.349**	—.330*
B	—.368**	—.356**	—.349**	—.364**	—.194
Cu	—.294*	—.321*	—.307*	—.405**	—.218
N/P	—.585***	—.703***	—.618***	—.266*	—.091
N/K	—.565***	—.668***	—.563***	—.265*	—.027
N/Ca	—.347**	—.489***	—.344**	—.033	.127
N/B	.123	.047	.078	.190	.138
N/Cu	—.030	—.071	—.027	.229	.206
P/Ca	.612***	.659***	.672***	.412**	.313*
P/B	.575***	.579***	.535***	.370**	.217
P/Cu	.519***	.568***	.519***	.432***	.260
K/P	—.323*	—.426**	—.441***	—.127	—.206
K/Ca	.554***	.523***	.528***	.449***	.247
K/B	.523***	.501***	.458***	.367**	.185
K/Cu	.474***	.493***	.433***	.445***	.223
Ca/B	.388**	.380**	.333*	.261	.113
Ca/Cu	.222	.269*	.215	.251	.120
B/Cu	—.083	—.053	—.042	.020	.040

	N	P	K	Ca	B	Cu
r	0.686***	0.363***	0.300**	−0.083	0.016	0.024

Thus the nutritional status of saplings before refertilization influenced the height growth of saplings even four years after refertilization and the foliar nutrient contents at least two years after refertilization.

Previous discussions on foliar nutrient contents and growth of saplings in Chapters 32 and 352 showed that some refertilization treatments had had only little effect on the foliar nutrient contents and height growth of saplings. In cases like these it is possible that the nutrient status of saplings at the time of refertilization has a long-term effect on the future development of saplings. Therefore a correlation matrix including only the plots that had received phosphorus and potassium (or P, K and N) as fertilizers was separately calculated. The limed plots were omitted, because liming was known to affect the foliar phosphorus contents (Ch. 32) and growth of saplings (Ch. 352). When using this part material the correlation between height growth and foliar phosphorus and potassium content was weaker (Table 20). The correlation between the 1983

Table 21. Correlation coefficients between the height growth of saplings and the 1982 foliar nutrient status in Experiment 13a. All the refertilized sample plots were included.

Taulukko 21. Taimien pituuskasvun ja neulasten ravinnetilan v. 1982 väliset korrelaatiokertoimet kokeessa 13a. Mukana kaikki jatkolannoitetut koealat.

Nutrient *Ravinne*	Correlation coefficient — *Korrelaatiokerroin* Height growth in — *Pituuskasvu vuonna* -82	-83	-84
N	—.525***	—.448***	—.308**
P	.330**	.328**	.301**
K	.198	.210*	.221*
Ca	—.037	.097	.124
B	—.000	.111	.116
Cu	—.172	—.172	—.118
N/P	—.484***	—.470***	—.389***
N/K	—.374***	—.345**	—.298**
N/Ca	—.252*	—.308**	—.263*
N/B	.075	—.022	—.047
N/Cu	—.057	.008	.014
P/Ca	.356**	.232*	.192
P/B	.166	.059	.012
P/Cu	.337**	.356**	.306**
K/P	—.169	—.177	—.117
K/Ca	.187	.106	.113
K/B	.147	.049	.004
K/Cu	.225*	.245*	.220*
Ca/B	.089	.017	—.032
Ca/Cu	.119	.218*	.188
B/Cu	.043	.155	.137

Table 22. Correlation coefficients between the height growth of saplings and the 1980 foliar nutrient status in Experiment 13b. All the refertilized sample plots were included.

Taulukko 22. Taimien pituuskasvun ja neulasten ravinnetilan v. 1980 väliset korrelaatiokertoimet kokeessa 13b. Mukana kaikki jatkolannoitetut koealat.

Nutrient *Ravinne*	Correlation coefficient — *Korrelaatiokerroin* Height growth in — *Pituuskasvu vuonna* -80	-81	-82	-83	-84
N	—.452**	—.469**	—.349*	—.269	—.260
P	.822***	.832***	.674***	.292	.091
K	.466**	.474**	.526**	.445*	.350*
Ca	—.397*	—.395*	—.216	—.016	.027
B	.828***	.823***	.576***	.284	.184
Cu	—.496**	—.393*	—.345	—.218	—.167
N/P	—.692***	—.715***	—.574***	—.334	—.216
N/K	—.451**	—.473**	—.460**	—.395*	—.347
N/Ca	.073	.066	.000	—.150	—.210
N/B	—.606***	—.597***	—.398*	—.204	—.176
N/Cu	.352*	.253	.245	.147	.091
P/Ca	.656***	.669***	.507**	.165	.012
P/B	—.511**	—.489**	—.295	—.119	—.107
P/Cu	.858***	.780***	.644***	.345	.200
K/P	—.291	—.282	—.082	.170	.256
K/Ca	.780***	.791***	.673***	.388*	.245
K/B	—.542**	—.516**	—.281	—.057	—.028
K/Cu	.717***	.633***	.582***	.413*	.315
Ca/B	—.653***	—.632***	—.377*	—.124	—.083
Ca/Cu	.380*	.293	.299	.268	.238
B/Cu	.928***	.856***	.643***	.333	.208

Table 23. Correlation coefficients between the height growth of saplings and the 1980 foliar nutrient status in Experiment 13b. Included were all the sample plots treated with phosphorus and potassium fertilizers excluding limed plots.

Taulukko 23. Taimien pituuskasvun ja neulasten ravinnetilan v. 1980 väliset korrelaatiokertoimet kokeessa 13b. Mukana fosforia ja kaliumia lannoitteina saaneet koealat (kalkittuja lukuunottamatta).

Nutrient *Ravinne*	Correlation coefficient — *Korrelaatiokerroin* Height growth in — *Pituuskasvu vuonna* -80	-81	-82	-83	-84
N	—.666**	—.698***	—.492*	—.283	—.218
P	.868***	.864***	.657**	.176	—.070
K	.429*	.373	.416	.326	.244
Ca	—.455*	—.450*	—.264	.034	.129
B	.930***	.926***	.676***	.280	.137
Cu	—.699***	—.678**	—.559**	—.340	—.244
N/P	—.837***	—.851***	—.630**	—.254	—.071
N/K	—.506*	—.486*	—.436*	—.314	—.248
N/Ca	.067	.071	.023	—.154	—.227
N/B	—.762***	—.783***	—.566**	—.264	—.190
N/Cu	.420	.362	.346	.232	.159
P/Ca	.662**	.681***	.508*	.091	—.097
P/B	—.670**	—.683***	—.503*	—.237	—.191
P/Cu	.888***	.854***	.670**	.306	.132
K/P	—.351	—.386	—.160	.154	.289
K/Ca	.853***	.809***	.675**	.274	.085
K/B	—.731***	—.754***	—.508*	—.175	—.097
K/Cu	.733***	.668**	.580***	.374	.266
Ca/B	—.814***	—.824***	—.557**	—.188	—.100
Ca/Cu	.434*	.391	.358	.325	.294
B/Cu	.954***	.923***	.699***	.321	.170

Table 24. Correlation coefficients between the height growth of saplings and the 1982 foliar nutrient status in Experiment 13b. All the refertilized sample plots were included.

Taulukko 24. Taimien pituuskasvun ja neulasten ravinnetilan v. 1982 väliset korrelaatiokertoimet kokeessa 13b. Mukana kaikki jatkolannoitetut koealat.

Nutrient *Ravinne*	Correlation coefficient — *Korrelaatiokerroin* Height growth in — *Pituuskasvu vuonna* -82	-83	-84
N	—.537**	—.409*	—.319
P	.393*	.343	.295
K	.089	.106	.144
Ca	—.168	—.454**	—.550**
B	.054	—.089	—.085
Cu	—.286	—.299	—.275
N/P	—.626***	—.497**	—.400*
N/K	—.446*	—.360*	—.320
N/Ca	—.109	.207	.351*
N/B	—.093	.079	.084
N/Cu	—.019	.066	.097
P/Ca	.374*	.594***	.658
P/B	.060	.201	.177
P/Cu	.436*	.428*	.388*
K/P	—.411*	—.325	—.226
K/Ca	.189	.457**	.571***
K/B	—.002	.157	.153
K/Cu	.275	.304	.305
Ca/B	—.054	.019	—.025
Ca/Cu	.113	—.145	—.259
B/Cu	.174	.067	.053

height growth and the 1980 foliar phosphorus and potassium content, was however, still significant with 5 % risk (Table 20). Even in this part material the foliar phosphorus contents measured before and after refertilization showed a significant correlation (r = 0.265*).

The correlation between the 1982 foliar nutrient status (after refertilization) and height growth was not quite as solid as that between growth and nutrient contents of the 1980 needles (Table 21). However, there still existed a highly significant negative correlation between height growth and the foliar nitrogen content, N/P and N/K ratio, and a highly significant positive correlation between the foliar phosphorus content and growth indicating that some saplings even after refertilization suffered particularly from a phosphorus shortage, but also from a potassium shortage to some extent, especially in relation to nitrogen. The foliar phosphorus contents and the height growth of saplings remained at lower levels on the plots that received lime or the largest amount of ash (Ch. 32, Fig. 3 b, Ch. 352, Fig. 17).

In Experiment 13 b height growth correlated with the foliar phosphorus and potassium contents quite similarly as in Experiment 13 a (Table 22). Unlike in Experiment 13 a there was a solid positive correlation between the foliar boron content before refertilization and growth. The ratios between all the main nutrients and boron correlated negatively with height growth. It is evident that there existed not only a phosphorus and potassium but also an acute boron shortage, which is also indicated by low foliar boron contents in 1980 (Ch. 32, Fig. 6 a).

Also in Experiment 13 b the 1980 foliar nutrient contents correlated with the height growth of saplings even in subsequent years (Table 22). The correlations were not, however, as solid as in Experiment 13 a either in the whole material of the refertilized sample plots (Table 22) or in the part material where phosphorus and potassium (or P, K and N) were given as fertilizers (Table 23). The comparison between the 1980 and 1982 foliar analyses showed that only the foliar nitrogen contents in various years correlated significantly, as shown by the following figures:

	N	P	K	Ca	B	Cu
r	0.380*	0.115	0.052	0.051	0.288	0.200

The foliar phosphorus content analyzed after refertilization still correlated positively with height growth, but only barely significantly (Table 24). On the other hand, the correlation coefficient of the N/P ratio was highly significant still implying an imbalance between nitrogen and phosphorus. The K/P ratio was negative. The correlation coefficients were higher than before refertilization, thus the availability of phosphorus in relation to potassium had weakened as a result of refertilization.

4. DISCUSSION AND CONCLUSIONS

41. General

Owing to the diverse correlations and in order to avoid unnecessary repetition, some of the results have already been discussed in previous chapters. The following discussion will focus only on certain main points.

42. Reliability

The investigation is based on a fairly large material with also some geographical variation. Experiments 1—10 had no replications and Experiment 11 only one. Thus the experiments 1—10 were too small for individual analyses, which was why they were grouped according to refertilization treatments (Exps. 1—3, 4—8 and 9—10). Then the error variance included the first (Exps. 1—3) or second (4—10) order interactions and it was impossible to fully eliminate the variation between the experimental fields.

Because of the lack of replications, the use of the analyses of covariance was not expedient in Experiments 1—10 as the values could not be corrected to regression and thus the information on the possibly statistical significant differences would have remained unreliable. It is possible that the effects of refertilization in Experiments 1—10 were hidden behind the differences in the starting situation both inside and between the experimental areas. Thus the main focus is on Experiments 12 and 13.

The reliability of the results in Experiment 13 b was disturbed by the late application of fertilizers in 1981 and the fact that part of fertilization was not carried out until the next year. For Experiment 13 a half the ash was spread in 1981 and the other half in 1982. This hardly affects the trend of the main results, although it may have influenced the intensity of the responses.

43. Fertilization and foliar nutrients

Phosphorus, potassium and boron applied as fertilizers raised the corresponding foliar nutrient contents generally also in the cases where the nutrient contents were above the deficiency limits according to literature (see Ch. 32). Nitrogen and calcium fertilization had no effect on the foliar nitrogen and calcium contents. The variation in copper was rather large in the experiments where it had been given as copper sulphate, but in Experiments 13 a and b where copper was applied as oxide, the copper contents rose to some degree (not significantly) after copper fertilization (see also Veijalainen 1980).

The effect of wood ash on the foliar nutrient contents was unexpectedly slight. Even the largest ash doses affected the foliar phosphorus contents rather little and in Experiments 13 a and b in fact negatively as compared to the smaller (2 t) ash amount. As already pointed out that particular ash was poor in phosphorus (0.56 %) so that only 28 kg per hectare of phosphorus as element was received even with the highest application rate. Evidently part of the phosphorus was fixed in incompletely burnt ash fractions. Moreover, it is possible that part of the phosphorus was in a form not available to plants, as there was more calcium in relation to phosphorus than in normal ash (see also Kaunisto 1982). The rather weak effect of ash fertilization on the foliar phosphorus contents in Experiments 9—10 and 12 was, on the other hand, somewhat surprising, since ash provided about 61 kg/ha of phosphorus in Experiments 9—10 and 88 kg/ha in Experiment 12 i.e. clearly more than in fertilizers (45 kg/ha). It seems that the phosphorus in ash has an even slower effect on the foliar phosphorus contents than the phosphorus applied as rock phosphate.

In most cases the largest ash amounts, 3.5 t (Exps. 9—10) and 5 t (Exps. 12 and 13), raised the foliar potassium contents, to about the same level as fertilizer potassium or a little above it. Yet with the highest rate of wood ash a. 330 kg/ha in Experiment 12 and a. 230 kg/ha in Experiments 9—10 as compared to 83 kg/ha of potassium in the fertilizer was applied on the experimental plots. On the other hand, the result was about the same in Experiment 13 a where even with the highest ash application rate only a. 91 kg/ha of potassium was given. The results suggest that rather low concentrations of potassium in wood ash may provide young trees with that element, at least temporarily. However, in the most nitrogen-poor wood ash fertilized Experiment (13 b) wood ash application had only a very slight effect (see also Silvferberg and Huikari 1985).

The results of this investigation give reason to emphasize the significance of ash quality particularly for phosphorus, but there is reason to believe that low potassium concentrations in wood ash may also lead problems in the future, because both phosphorus and potassium shortages have appeared in old wood ash fertilization experiments (Silfverberg and Huikari 1985) where the quality of wood ash was presumably much better than that in Experiment 13 of this investigation.

High ash amounts increased the foliar boron contents to some extent, but less than the boron applied as fertilizer. One has to keep in mind though that even the largest doses (Exp. 12) of ash provided boron somewhat less per hectare (0.8 kg/ha) than when applied as fertilizer (1 kg/ha).

The mutual dependences between certain nutrients regarding the nutrient status of trees are interesting. The application of phosphorus and potassium strongly decreased the boron concentration in needles, which was further accentuated by nitrogen fertilization along with phosphorus and potassium. This so-called dilution phenomenon in connection with macronutrient fertilization has been verified in several previous studies (Smith 1962, Vehrmann 1963, Tamm 1964, Veijalainen 1977). In most cases (Exps. 1—8 and 12) the foliar boron contents fell down to the deficiency limit ($<$ 7 ppm, introduced by Reinikainen & Veijalainen 1983, see also Veijalainen 1977, Braekke 1979). Similarly, liming with the other main nutrients (Exp. 12) lowered the foliar boron contents (see also Kaunisto 1982), which was presumably caused by weakened solubility of boron (Black 1968) because pH rose as a result of liming.

44. Nutrient status and damages

It has been proved in different contexts that deficiency or imbalance of certain nutrients in relation to other nutrients causes abnormal growth in peatland pine stands, the most visible signs of which are multiple-leader trees and bushiness or even death. The problem has in most cases been diagnosed as a micronutrient, particularly boron, deficiency (Huikari 1974, 1977, Veijalainen 1979, 1984b, Raitio & Rantala 1977, Reinikainen and Veijalainen 1983, Veijalainen et al. 1984). The shortage of boron may cause damage in the apex or its death (Raitio & Rantala 1977) leading to multiple-leader trees. In fact in Finland growth disturbance has generally come to mean abnormal growth caused by a boron deficiency. Indeed, boron fertilization has helped decrease the occurrence of this growth disturbance (e.g. Veijalainen 1981, Veijalainen et al. 1984). Also this investigation confirmed that boron fertilization raised the foliar boron contents and increased the number of normal (= one leader) trees in some experiments (4—8 and 12). Furthermore, a positive correlation existed between the foliar boron content and the proportion of normal saplings. In these experiments fertilization with the main nutrients increased the height growth of saplings, which led to the drastic decline in the foliar boron content (to a. 4 ppm) in the treatments without boron application, boron deficiency and consequently damages in the apex (see Ch. 34). In both cases the foliar boron contents of the unrefertilized saplings were about 10 ppm, which, for example, Kolari (1979) has set as the upper limit of a boron deficiency. On the other hand, it is somewhat surprising that in Experiments 11 and 13 a where the foliar boron contents were even lower than the cited values on the unrefertilized sample plots, and macronutrient fertilization also increased growth, no dilution phenomenon of boron was seen in needle analyses and no significant effect on the proportion of normal saplings could be seen in the comparisons between the refertilized treatments. There was, however, a slightly positive correlation between the proportion of normal saplings and the foliar boron content in Experiment 11.

It seems that the foliar boron concentration as such is not the only indicator of possible apical damages after macronutrient fertilization. Yet, it is obvious that growth disturbances may be anticipated as a result of refertilization when the foliar boron content is 10 ppm or less, and then in addition to the level of the foliar boron content especially reduction in the foliar boron content induced by refertilization is important.

The application of boron in Experiments 9—10 somewhat decreased the proportion of normal saplings. This was not, however, related to the foliar boron contents. Thus there is no reason to suspect an overdosage of boron. As boron, however, moves easily from the fertilizer to needles, as proved by this investigation (see also Braekke 1979, Veijalainen 1979) and the effect is of long duration (Veijalainen 1984b), the amount of boron could perhaps be lower than the 1 kg/ha used in this investigation.

The destruction of tree apexes also takes place when there are shortages of main nutrients. Kaunisto & Tukeva (1984) found severe shoot damages caused by a potassium shortage in advanced pine stands. Paavilainen (1976) and Kaunisto & Paavilainen (1977) found that one-sided nitrogen fertilization caused browning of needles, damages in terminal buds and increased mortality of saplings. In such cases the foliar N/P ratio best explained the amount of damages. However, boron was not included in that investigation.

Similar browning of needles and dieback during the winter following nitrogen refertilization was found in Experiment 13 a as compared to the above-mentioned investigations. Application of boron at refertilization seemed to decrease the occurrence of foliar and bud damages to some extent (see also Kaunisto 1983), but the foliar boron content or the ratios between boron and the other nutrients did not explain the damages. Instead, the foliar nitrogen (−) and phosphorus content (+) and the relationship between these two as well as the ratios between the above-mentioned and several other nutrients well explained the needle and bud damages. The refertilization treatments where the foliar N/P ratio rose in relation to PK or PK + B fertilization strongly increased damages. Particularly harmful in this respect were liming and high ash amounts (5 t/ha). As pointed out previously the ash used for this experiment contained exceptionally low amounts of phosphorus. The dependence between the foliar N/P ratio and occurrence of damages was linear, but the severest damages seemed to appear when the N/P ratio was larger than 11 (see also Paavilainen 1976, Kaunisto & Paavilainen 1977). According to this and the cited previous investigations it seems that the measures which raise the foliar nitrogen content in relation to the other main nutrients, particularly phosphorus, may weaken the winter resistance of needles and buds leading to foliar and bud damages and ultimately to multiple-leader trees and growth decline.

45. Significance of the nutrient status before refertilization

The earlier investigations have pointed out that vigorous trees respond more readily to forest amelioration measures than stunted trees. Heikurainen and Kuusela (1962) found a positive correlation between the postdrainage recovery of trees and the predrainage growth. Ipatiev and Paavilainen (1975) reported that a stand responded to fertilization the more the better the prefertilization growth.

Also in this investigation the growth of saplings before and after refertilization were in a solid correlation, which is the reason for choosing prerefertilization growth as a covariate. Moreover, growth variation both before and after refertilization was explained also by means of the foliar nutrient status before refertilization in Experiments 12 and 13. Solid correlations were found between the foliar nutrient contents measured before refertilization and height growth of that same year in Experiment 13 a and b. Interestingly enough these nutrient contents explained growth as late as 1984 i.e. 3—4 years after refertilization. Although the material was confined to only the treatments where refertilization had no statistically significant influence on damages or growth of saplings, still significant dependences were found between the foliar nutrient contents measured before refertilization and postrefertilization growth. Similarly needle and bud damages in the winter of 1981—1982 in Experiment 13 a had a solid correlation with the foliar nutrient contents analyzed before refertilization. When comparing individual nutrients the foliar phosphorus and potassium contents a year before and two years after refertilization had positive correlations.

The results suggest that refertilization with rock phosphate affects rather slowly the foliar phosphorus contents and that the foliar nutrient status before refertilization is still perceptible a few years after refertilization both in the foliar nutrient contents, possible damages and growth. This would emphasize the significance of a sufficiently early refertilization to avoid growth decline due to nutrient shortages. In this case the saplings had been spot fertilized 12 years before refertilization, which was obviously a few years too late even for a tall sedge fen (Exp. 13 a) (see also Huikari & Paarlahti 1973, Kaunisto 1977, 1979, Laine & Mannerkoski 1980).

46. Peat nitrogen status and growth

The peat nitrogen regime was mainly described by the total peat nitrogen content and to some extent also by the humification degree of peat (the entire Exp. 12, partly Exps. 13 a2 and 13 b). There was a solid correlation between peat humification degree and the total nitrogen content (see also Kivinen 1933, Isotalo 1951, Vahtera 1955). The correlation between humification degree and the total peat nitrogen content was very similar to that in the material introduced earlier by Kaunisto (1982). In both cases humification degree 2 corresponds to the total nitrogen content of about 1.0 %. The nitrogen content rose about 0.2—0.3 % units per one humification unit.

The usefulness of the humification degree as an indicator of the total peat nitrogen content is decreased by the fact that the same humification degree in Carex peats corresponds to a somewhat higher total peat nitrogen contents than in Sphagnum peats (Isotalo 1951, Vahtera 1955), which is also seen in this investigation (Ch. 312). Both in this investigation and the previous one by Kaunisto (1982) the material consisted of both Sphagnum and Carex peats, which means that along with the increase in the humification degree the total nitrogen content rises more abruptly than when studying Sphagnum and Carex peats separately. As a result the nitrogen contents of Sphagnum peats may have been overestimated while those of Carex peats underestimated as regards the total nitrogen content in the range of peat nitrogen regime which is important for pine. Even so determination of humification degree may be regarded as a fairly good means of estimating the total peat nitrogen content in field conditions.

Clear correlations were found between tree growth and peat nitrogen status as estimated by both the total nitrogen content and humification degree. The results indicate that as the total peat nitrogen content in the 5—10 cm layer is 1.6—2.0 % the height growth in a young pine stand does not much increase along with the rising nitrogen content, although the nutrient status had been taken care of according to present fertilization recommendations as regards to phosphorus and potassium or using even more diverse fertilization including also micronutrients. The results also indicate that at even considerably lower levels of nitrogen content (1.2—1.3 % or humification degree according to v. Post a. 3) nitrogen fertilization in addition to phosphorus and potassium was useless and at higher levels even harmful to the height growth of saplings by causing needle and bud damages. The result agrees with that introduced by Kaunisto (1982) for somewhat younger stands in southern Finland (total N 1.15 % and humification 2.7). The difference may be related to differences in temperature sums and the effect of this on nitrogen mobilization.

Thus special attention should be paid to the nitrogen status of a young pine stand to be refertilized and unnecessary nitrogen fertilization should be avoided. The results also show that the nitrogen-richest peatlands cannot be recommended for growing pine, but if possible more nitrogen demanding tree species should be used.

The total nitrogen content in Experiments 12 and 13 was measured from the 20 cm peat layer at 5 cm intervals. These results as well as those introduced by Kaunisto (1982) and Kaunisto and Tukeva (1984) show that the total nitrogen content measured from the 5—10 cm peat best explains the variation in height growth.

Growth was equally well explained by the peat nitrogen content in the 0—10, 5—15 and 0—15 cm layers. As the control material for the ratio between the total peat nitrogen content in the 5—10 cm peat layer and growth is most abundant (Kaunisto 1982, 1985, Kaunisto & Tukeva 1984) it would be sensible to take peat samples for determinations of the nitrogen status from that particular layer. Although the total peat nitrogen values from the 15—20 cm or deeper layers have been rather poor indicators of growth variation, they can provide information for the estimation of the future nitrogen regime on the site for the growth of trees. Therefore samples should be taken from the 5—10 cm layers indicating present growth and deeper for estimating the long-term nitrogen regime of a site.

5. SUMMARY

The aim of the investigation was to find out the effects of natural nitrogen conditions of peat, fertilizer nitrogen and mineral nutrients applied in different ways (as fertilizers and wood ash) on the survival of saplings, occurrence of various disturbances and height growth of saplings as well as the effect of refertilization with the main nutrients on the micronutrient requirements of saplings. The investigation is based on 13 experiments, mainly on open peatlands, with a total of 293 sample plots (Tables 1 and 2).

The peat nitrogen regime was described by the total nitrogen content of peat and humification degree defined according to v. Post. There was a solid correlation between these characteristics (Fig. 2). The total nitrogen content of peat was 1 % in fuscum-rich peats at humification degree 2. The nitrogen content rose about 0.2—0.3 % units per one humification degree. In sedge-rich areas the nitrogen content was 0.3—0.4 % units higher at the corresponding humification degree. The humification degree seems to be quite a practicable means of estimating the nitrogen content in field conditions.

The growth of trees on PK fertilized sample plots increased as the total peat nitrogen content rose to 1.6—2.0 % in the 5—10 cm layer (Fig. 15). At higher nitrogen levels growth declined along with rising total peat nitrogen content. Refertilization with nitrogen along with phosphorus and potassium increased the growth of trees up to the peat (5—10 cm layer) nitrogen content of 1.2—1.3 % (Fig. 14, Tables 12 and 13) and humification degree of about 3 (Fig. 16, Table 15), above which values nitrogen fertilization reduced growth.

Fertilization with phosphorus and potassium usually raised the foliar phosphorus and potassium contents (Figs. 3 b and 4 a), but lowered those of boron (Fig. 6 a, dilution phenomenon) increasing the frequency of growth disturbances in some cases (Fig. 11). Nitrogen fertilization and especially liming along with phosphorus and potassium fertilization lowered the foliar boron contents (Fig. 6 a) and increased the occurrence of growth disturbances (Fig. 11). Several experiments revealed a negative correlation between the proportion of normal seedlings and the foliar nitrogen content as well as the foliar N/B ratio (Table 8).

On some naturally nitrogen-rich sites nitrogen fertilization caused browning of needles and damages in terminal buds, which had a positive correlation with the foliar N content and N/P ratio (Table 10). Liming accentuated this problem by lowering the foliar phosphorus contents (Fig. 3 b). Damages in terminal buds and needles caused by unbalanced N/P ratios slowed down height growth.

Special attention should be paid to the nitrogen conditions of the substrate when growing young pine stands on peatland, in order to avoid expensive, unnecessary nitrogen application which may even cause growth losses.

The foliar phosphorus and potassium contents before refertilization explained the postrefertilization growth for many years (Tables 19, 20, 22 and 23). Thus it seems that the prerefertilization nutrient status of saplings affects the postrefertilization growth for a long time. Therefore refertilization should be carried out early enough to prevent growth losses.

Fertilization with good-quality wood ash (1.7 % P and 6.58 % K, 3500—5000 kg/ha) promoted the growth of saplings, but only in few cases more than PK or NPK fertilization alone and in all cases less if boron had been applied in addition to PK or NPK (Figs. 17 and 18). Poor-quality wood ash (0.56 % P and 1.82 % K) even reduced the growth of saplings as compared to PK or NPK fertilized plots. The result emphasizes the significance of the quality of ash used for fertilizing peatlands.

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SELOSTE

Jatkolannoituksen vaikutus mäntytaimikoiden kehitykseen ja neulasten ravinnepitoisuuksiin typpitaloudeltaan erilaisilla ojitetuilla soilla

1. Johdanto

Biomassan tuotannossa tarvitaan typpeä suurempia määriä kuin mitään muuta yksittäistä ravinnetta. Kun lannoitetypen lisäys kohottaa lannoituskustannuksia 60—70 % PK-lannoitukseen verrattuna, on taloudellisesti erittäin tärkeätä kyetä ennakoimaan kasvualustan kyky tuottaa riittävästi typpeä puuston käyttöön. Perinteinen turvemaiden kasvupaikkaluokitus pintakasvillisuuden mukaan kuvaa kohtalaisesti kasvualustan typpitaloutta luonnontilassa, joskin vaihtelu on varsin suurta. Erilaisten metsänparannustoimenpiteiden, kuten ojituksen ja lannoituksen vaikutuksen vuoksi turpeen typpitalouden arviointi pintakasvillisuuden perusteella on kuitenkin jossain määrin epävarmaa muuttuma- ja turvekangasvaiheessa. Onkin tärkeätä löytää menetelmiä, joilla pintakasvillisuuden sijasta turpeen typpitaloutta puiden kasvun kannalta voitaisiin kuvata suoraan turpeesta mitattavilla ominaisuuksilla. Aikaisemmin onkin jo jossain määrin kuvattu turpeen kokonaistyppipitoisuuden ja maatuneisuuden sekä männyntaimien varhaiskehityksen välistä riippuvuutta.

Turvemaiden puustoissa on todettu verrattain yleisesti erilaisia kasvuhäiriöitä. Jatkolannoitus pelkillä pääravinteilla näyttää lisäävän kasvuhäiriöiden riskiä. Suomessa näiden on todettu aiheutuvan yleisimmin boorinpuutoksesta, mutta myös typen ja fosforin epätasapaino samoin kuin kaliumin niukkuuskin saattavat aiheuttaa latvusvaurioita.

Tässä tutkimuksessa tarkastellaan jatkolannoituksen vaikutusta lähinnä avosuotaimikoiden jatkokehitykseen. Erityisesti pyritään selvittämään turpeen luontaisen typpitalouden ja lannoitetypen sekä eri muodoissa (lannoitteina ja puun tuhkassa) annettujen kivennäisravinteiden vaikutusta taimien elossapysymiseen, erilaisten häiriöiden esiintymiseen ja taimien pituuskasvuun sekä pääravinnelannoituksen vaikutusta taimien hivenaineiden tarpeeseen.

2. Aineisto

21. Koealueet

Aineisto perustuu 13 kokeeseen, joista kahdeksan koetta (1—8) on perustettu yksityismaille Parkanoon ja Karviaan, kolme koetta (9—11) Metsähallinnon Parkanon hoitoalueen maalle Parkanoon ja Kuruun, yksi (koe 12) Keski-Pohjanmaalle Metsäntutkimuslaitoksen Kannuksen tutkimusalueeseen ja yksi (koe 13) Itä-Suomeen Enso Gutzeit Oy:n maalle (taulukko 1, liite 1). Kokeet on perustettu 10—12 vuotta vanhoille käytännön metsänviljelyaloille, jonka vuoksi koealueet poikkeavat jossain määrin toisistaan viljelyajankohdan, viljelytavan, taimilajin, sarkaleveyden ja peruslannoituksen suhteen (taulukko 1). Valtaosalla koealueista on metsikön perustamisvaiheessa tehty laikkulannoitus, mutta kokeet 9 ja 10 sekä koe 12 on hajalannoitettu. Koealueesta 1 ei ole peruslannoitustietoja. Jatkolannoituskoe perustettiin 9—11 kasvukautta peruslannoituksen jälkeen. Pääosa kokeista on istutettu. Koe 13 on kylvetty ja kokeet 9 ja 10 sekä kylvetty että osittain metsittyneet myös luontaisesti. Taimikot koealueiden sisällä olivat jatkolannoitushetkellä verraten tasaisia, joskin koealueiden välillä oli verrattain suuriakin eroja (taulukko 1).

Koealueet olivat yleensä avosoita. Vain kokeissa 9 ja 10 on nähtävästi ollut harvakseltaan mäntypuustoa ennen kylvöä. Alkuperäinen suotyyppi vaihteli rahkanevasta ruohoiseen saranevaan, mikä näkyi myös selvästi turpeen typpipitoisuuksissa (taulukko 2). Mielenkiintoisimpia tässä suhteessa ovat kokeet 12 ja 13, joissa kummassakin turpeen typpipitoisuudella on laaja vaihteluväli saman kokeen alueella. Särkän lohkon 3 tuloksia ei voida suoraan vertailla lohkojen 1 ja 2 tulosten kanssa, koska lohkolla 3 kevättulvat viivästyttivät lannoitusta myöhään kesälle ja osittain jopa seuraavaan vuoteen.

22. Koesuunnitelmat

Tutkimussuunnitelman runko oli kaikissa kokeissa periaatteessa samanlainen. Jokaisessa kokeessa ei kuitenkaan ollut mahdollista toteuttaa suunnitelmaa täydellisenä. Osittain oli syynä tilanpuute, osittain vaikeudet puuntuhkan hankinnassa. Monipuolisimmin tutkimuksen perusajatukset voitiin toteuttaa Housulammin (9), Jaulin (10), Kaunisveden (12) ja Särkän (13) kokeissa (taulukko 3). Näissä vertailtiin erilaisten maanparannus- ja hivenaineiden sekä PK- ja NPK-lannoituksen yhdistelmiä siten, että annettiin joko pelkkää booria, booria ja kuparia (kokeet 9 ja 10 lisäksi Zn ja Mn), booria, kuparia ja kalkkia tai pieniä määriä puuntuhkaa joko PK- tai NPK-lannoituksen yhteydessä. Lisäksi tutkittiin pelkän puuntuhkan ja puuntuhkan + typpilannoituksen vaikutusta taimien kehitykseen. Koealoja, jotka ovat saaneet fosforia ja kaliumia joko lannoitteina tai tuhkana, kutsutaan jatkossa PK-lannoitetuiksi ja koealoja, jotka ovat saaneet lisäksi typpeä NPK-lannoitetuiksi tai typpilannoitetuiksi koealoiksi. Kokeissa 1—8 ja 11 ei ollut puuntuhkakäsittelyjä ja kokeissa 1—3 puuttuivat lisäksi typpilannoitukset. Kaikissa kokeissa oli lisäksi jatkolannoittamaton vertailu. Kokeissa 1—10 käsittelyt oli toteutettu vain kertaalleen. Kokeessa 11 yhteen—kahteen, kokeessa 12 kolmeen, kokeen 13 lohkoissa 1 ja 2 yhteensä seitsemään ja lohkossa 3 kolmeen kertaan.

Maanparannusainekäsittelyt vaihtelivat jonkin verran kokeittain. Kalkitus (2000 kg/ha dolomiittikalkkia) oli mukana vähintään yhdessä käsittelyssä kaikissa kokeissa. Tuhkaa saatiin vain kokeisiin 9, 10, 12 ja 13. Tuhkalannoituksessa annettiin samankin kokeen sisällä erilaisia määriä. Lisäksi tuhkan määrät vaihtelivat jonkin verran kokeittain. Myös tuhkan laatu vaihteli. Kokeisiin 9, 10 ja 12 tuhka kerättiin parkanolaiselta Aureskosken sahalta. Tuhka oli hyvin palanutta. Kun se vielä voitiin kerätä talteen kuivana suoraan polton jälkeen, olivat sen ravinnepitoisuudet verrattain korkeita (taulukko 3). Sen sijaan kokeessa 13 käytetty Enso Gutzeit Oy:n Uimaharjun sahalta kerätty tuhka oli poikkeuksellisen huonolaatuista. Palaminen oli ollut epätäydellistä ja kun tuhka vielä oli sammutettu veteen, olivat tuhkan ravinnepitoisuudet poikkeuksellisen alhaisia. Esim. fosforia ja kaliumia oli vain vajaa 1/3 Aureskosken tuhkan fosfori- ja kaliumpitoisuuksiin verrattuna (taulukko 3). Suurimmalla Särkän kokeessa käytetyllä tuhkamäärällä tuli fosforia vain 28 kg/ha, kun yleensä metsän lannoituksessa käytetään fosforia 40—45 kg/ha. Koska tuhkaa ei ollut riittävästi saatavissa v. 1981, annettiin kokeen 13 tuhkalannoituskoealoille tuhkaa ensin vain puolet suunnitellusta määrästä. Loppuosa annettiin keväällä 1982. Lohkossa 3 (koe 13b) tulva esti lannoitteiden levityksen keväällä 1981. Lannoitteet levitettiin kokeelle osittain heinäkuussa 1981, osittain keväällä 1982.

Hivenaineiden osalta vertailtiin lähinnä boorin ja kuparin vaikutusta. Boori annettiin PK-lannoksen (0-9-17 + 0,2 % B) yhteydessä ja kupari $CuSO_4$:na koetta 13 lukuunottamatta, jossa se annettiin CuO:na. Mangaani ja sinkki annettiin sulfaattina.

Fosfori ja kalium annettiin koealoilla, joissa tarvittiin myös booria PK-lannoksena (0-9-17 + 0,2 % B) ja muilla koealoilla raakafosfaattina ja kalisuolana siten, että fosforin ja kaliumin määrät hehtaaria kohden laskettuna olivat samat kuin PK-lannoksella lannoitettaessa. Typpi annettiin kaikissa kokeissa oulunsalpietarina.

23. *Aineiston keräys ja laskenta*

Jokaiselle koealalle sijoitettiin 40 kpl 5 m^2:n suuruisia ympyräkoealoja, joilta mitattiin lähimpänä koealan keskipistettä olevan viljelytaimen tunnukset. Kokeissa 9 ja 10 hyväksyttiin myös luonnontaimet. Muissa kokeissa luonnontaimet hylättiin. Jokaiselle koealalle sijoitettiin viisi ympyräkoealariviä saran suunnassa, yksi kumpaankin reunaan n. 2,5 m:n päähän sarkaojasta, yksi keskelle ja yksi kummallekin saran puoliskolle keskustan ja reunan puoliväliin. Jokaiselta riviltä otettiin kahdeksan ympyräkoealaa tasavälein. Jokainen tyhjä ympyräkoeala laskettiin yhdeksi kuolleeksi taimeksi.

Puista mitattiin pituus vuodesta 1977 vuoteen 1984 1 cm:n tarkkuudella. Lisäksi tarkkailtiin latvuksen kehityshäiriöitä ja erilaisia muita vaurioita. Latvuksen häiriöt luokiteltiin seuraavasti:

1 = terveennäköinen puu, puu kehittynyt normaalisti, koko ajan yksi pääverso
2 = alkava tai lievä häiriö, jossa puun latva on vielä elossa, mutta ei normaalisti kehittynyt
3 = toistunut latvakato, useita kuolleita latvoja
4 = elpyvä puu, ohituskasvain terve
5 = useita kilpailevia latvoja inventointihetkellä

Särkän koealueella havaittiin vuoden 1982 keväällä, siis jatkolannoituksen ensimmäistä vaihetta seuraavana vuotena, että vuoden 1981 pääverson neulasista huomattava osa oli muuttunut ruskeiksi ja kuollut. Koealueen 13 a toistot 1 ja 2 inventoitiin vuoden 1982 syksyllä käyttäen seuraavaa luokitusta:

1. normaalit taimet = ei neulasvaurioita
2. lievästi vaurioituneet taimet = vajaa puolet vuoden 1981 pääverson neulasista pudonnut tai ruskeita
3. voimakkaasti vaurioituneet taimet = yli puolet v. 1981 pääverson neulasista pudonnut, lähes kaikki loput ruskeita
4. vuoden 1981 päätesilmu tuhoutunut tai pääverso jäänyt selvästi sivuversoja lyhyemmäksi.

Lisäksi tarkasteltiin vuoden 1984 inventoinnin yhteydessä kaikissa kokeissa muita vaurioita seuraavan luokituksen mukaisesti:

2 = tuhohyönteiset
3 = myyrä ja jänis
4 = hirvi
5 = halla

Kokeista 12 ja 13 kerättiin neulasnäytteet kaikilta koealoilta jatkolannoitusta edeltäneenä vuotena. Kaikilta kokeilta kerättiin neulasnäytteet talvella kolmannen (koe 12) tai toisen (muut kokeet) kasvukauden neulasista jatkolannoituksen jälkeen. Neulasnäytteet kerättiin talvella kymmenestä valtataimesta eri puolilta koealaa toiseksi ylimmän oksakiehkuran nuorimmasta neulaskerrasta etelän puolelta. Neulasista määritettiin N, P, K, Ca, B ja Cu.

Jokaiselta koealalta otettiin turvenäytteet: kokeista 1—11 5—10 ja 20—25 cm:n kerroksista, kokeesta 12 0—25 cm:n kerroksesta 5 cm:n osanäytteinä sekä kokeesta 13 0—20 cm:n kerroksesta samoin 5 cm:n osanäytteinä. Jokaiselta koealalta otettiin näyte viidestä eri puolille koealaa systemaattisesti sijoitetusta kohdasta tasapinnasta. Osanäytteet yhdistettiin kerroksittain koealaa edustavaksi koosteeksi. Turpeesta määritettiin kokonaistyppi Kjeldahl-menetelmällä ja pH tilavuussuhteessa maa/vesi 1/5. Lisäksi kokeesta 12 ja kokeen 13 lohkoilta 2 ja 3 osalta koealoja määritettiin turpeen maatuneisuus v. Postin (1922) menetelmällä.

Tulosten laskentaa varten koealueita yhdisteltiin lannoitus- ja maanparannuskäsittelyjen mukaisesti yhdenmukaisiin ryhmiin. Tällä tavoin muodostuivat koeryhmät 1—3, 4—8 ja 9—10. Kokeet 11 ja 12 käsiteltiin erillisinä. Koe 13 jaettiin yleensä kahteen osaan: lohkot 1 ja 2 = koe 13 a ja lohko 3 = koe 13 b. Syynä oli jatkolannoituksen eriaikaisuus. Joissakin tapauksissa koe 13 a jaettiin vielä kahteen turpeen kokonaistyppipitoisuuden suhteen lievästi erilaiseen lohkoon, 13 a1 ja 13 a2 (taulukko 2).

Kokeiden ja koeryhmien sisällä aineistot ryhmiteltiin laskentaa varten erilaisten maanparannus- ja lannoituskäsittelyjen suhteen kahdella eri tavalla:

1. yksisuuntaisena siten, että nämä muodostivat yhden muuttujan, jossa tasoina oli näiden kaikki mahdolliset yhdistelmät. Tällöin vertailuun voitiin sisällyttää myös jatkolannoittamattomat sekä eräät pelkän tuhkalannoituksen saaneet käsittelyt, joilla ei ollut typpilannoitettua vastinparia. Näiden analyysien F-arvot on yleensä esitetty kuvissa.

2. kaksisuuntaisina siten, että laskennasta jätettiin pois kokonaan jatkolannoittamattomat sekä ne tuhkalannoitetut koealat, joilla ei ollut typpilannoitettua vastinparia. Tällöin toisen muuttujan tasoina olivat erilaiset maanparannus- ja hivenaineiden, lannoitefosforin ja -kaliumin sekä puuntuhkan yhdistelmät (jatkossa maanparannus/hivenlannoituskäsittely) ja toisena muuttujana typpilannoitus, jolloin tasoina olivat toisaalta fosforia ja kaliumia ja toisaalta typpeä, fosforia ja kaliumia jossakin muodossa saaneet koealat. Tällöin siis pelkän tuhkalannoituksen katsottiin kuuluvan samaan ryhmään kuin fosforia ja kaliumia lannoitteina saaneet koealat (PK-lannoitus). Koealojen, joille tuhkan lisäksi oli annettu typpeä, katsottiin kuuluvan laskennassa samaan ryhmään kuin typpeä, fosforia ja kaliumia lannoitteina saaneet koealat (NPK-lannoitus).

3. Tulokset

31. Turpeen ominaisuudet

311. Happamuus

Kalkitus ja tuhkalannoitus kohottivat turpeen pH:ta 5—10 cm:n kerroksessa yleensä verrattain selvästi (kuva 1). Poikkeuksena oli koe 13, jossa kalkki levitettiin näytteenottoa edeltäneenä talvena. Maanparannusaineiden vaikutus turpeen pH:hon 20—25 cm:n turvekerroksessa ei ollut ainoassakaan tapauksessa merkitsevä. Kokeen 12 perusteella 5 t:n tuhkamäärän vaikutus ulottui vielä 15—20 cm:n kerrokseen saakka merkitsevänä ja pH oli selvästi korkeampi kuin kalkituilla (2 t/ha) tai 1 t:n tuhkaerän saaneilla koealoilla.

312. Turpeen kokonaistyppipitoisuus ja maatuneisuus

Turpeen kokonaistyppipitoisuuden ja maatuneisuuden välistä riippuvuutta selviteltiin kokeessa 12 sekä jossain määrin myös kokeen 13 lohkoissa 2 (13 a2) ja 3 (13 b). Maatuneisuuden ja kokonaistyppipitoisuuden välistä riippuvuutta eri turvekerroksissa kuvasivat lähes yhdensuuntaiset suorat (kuva 2 a). Suorien kulmakertoimet olivat hyvin edellisten kaltaisia silloinkin, kun turvekerrokset yhdistettiin samaksi aineistoksi (kuva 2 b). Kokeissa 12 ja 13 b maatumisastetta 2 vastasi turpeen typpipitoisuus 1,0 %. Typpipitoisuus kohosi yhtä maatumisasteen yksikköä kohden 0,2—0,3 %-yksikköä. Kokeessa 13 a2 turpeen typpipitoisuus oli 0,3—0,4 %-yksikköä korkeampi kuin kokeissa 12 ja 13 b, mikä ilmeisesti johtui siitä, että alue oli pääosiltaan sarainen. Todennäköisesti myös maatumisasteen ja turpeen typpipitoisuuden välistä vuorosuhdetta kuvaavien suorien kulmakertoimien arvot ovat suurempia kuin puhtailla sara- tai rahkaturpeilla, koska koealueihin yleensä sisältyi jossain määrin molempia. Käytettäessä tämän tutkimuksen tuloksia turpeen typpipitoisuuden määrittämisessä maatumisasteen avulla tuleekin ottaa huomioon, että saraturpeilla saattaa tapahtua turpeen typpipitoisuuden aliarvioimista ja rahkaturpeilla sen yliarvioimista männyn kasvatuksen kannalta tärkeimmällä turpeen typpipitoisuuden alueella.

32. Neulasten ravinteet

Lannoituksen vaikutusta neulasten ravinnepitoisuuksiin on esitelty kuvissa 3—9 ja liitteessä 2. Lannoitteissa annetut fosfori, kalium ja boori kohottivat yleensä selvästi vastaavia neulasten ravinnepitoisuuksia (kuvat 3 b, 4 a ja 6 a). Erityisesti lannoiteboraatin vaikutus oli voimakas. Kuparilannoitus ei vaikuttanut tilastollisesti merkitsevästi neulasten kuparipitoisuuksiin ainoassakaan tapauksessa (kuva 7 b, liite 2).

Kalkitus alensi jonkin verran neulasten fosfori-, kalium- ja booripitoisuuksia, mutta kohotti typpipitoisuutta (kuvat 3 a ja b, 4 a, 6 a). Tuhkalannoitus suurimmilla määrillä (3,5 ja 5 t/ha) kohotti neulasten fosforipitoisuuksia suunnilleen samalle tasolle kuin näitä ravinteita lannoitteina annettaessa paitsi kokeessa 13, jossa suurimmalla tuhkamäärällä neulasten fosforipitoisuudet olivat selvästi alempia kuin fosforia lannoitteina saaneilla koealoilla. Tässä kokeessa tuhka oli erittäin huonolaatuista (vähän fosforia, 0,56 % ja huonosti palanutta). Tuhkalannoitus kohotti neulasten kaliumpitoisuuksia lannoittamattomaan verrattuna ja eräissä tapauksissa jopa korkeammiksi kuin kaliumia lannoitteina saaneilla koealoilla (kuva 4 a). Vaihtelu oli kuitenkin suuri ja vaikutus verrattain vähäinen, kun ottaa huomioon, että joissakin tapauksissa kaliumia tuli tuhkassa kolminkertainen (kokeet 9—10) tai jopa yli nelinkertainen (koe 12) määrä kalilannoitukseen verrattuna. Tuhkalannoitus kohotti myös neulasten booripitoisuuksia (kuva 6 a), mutta yleensä vähemmän kuin lannoiteboraatin lisäys. Tulokset korostavat tuhkan laadun merkitystä turvemaiden lannoituksessa.

33. Taimien elossaolosadannes

Taimien elossaolosadannes on laskettu inventointihetkellä taimellisten ympyräkoealojen suhteena kaikkien tarkastettujen ympyräkoealojen lukumäärään, joten jatkolannoituksen vaikutusaika elossaolosadannekseen on jäänyt vain muutamaksi vuodeksi. Näin ollen on luonnollista, että jatkolannoitus vaikutti elossaolosadannekseen varsin vähän (kuva 10, taulukko 4).

Kokeissa 12 ja 13 tarkasteltiin lisäksi neulasten jatkolannoitusta edeltäneen ravinnetilan ja taimien elossaolosadanneksen välistä riippuvuutta. Kokeessa 12 ainoastaan neulasten kuparipitoisuuden (−) sekä N/Cu-suhteen (+) ja elossaolosadanneksen välillä vallitsi tilastollisesti merkitsevä riippuvuus (taulukko 5). Kokeessa 13 a neulasten typpi- ja kuparipitoisuus sekä K/P-suhde korreloivat negatiivisesti ja fosfori- ja kaliumpitoisuus positiivisesti taimien elossaolosadanneksen kanssa.

34. Taimien vauriot

Kaikissa kokeissa tarkasteltiin sienten, hyönteisten, hirvien, jäniksien, myyrien ja hallan aiheuttamia vaurioita. Vaurioita esiintyi erittäin vähän eikä jatkolannoitus yhdessäkään tapauksessa vaikuttanut vaurioiden määrään tilastollisesti merkitsevästi, joten vaurioista on esitetty vain koeryhmäkohtaiset keskiarvot (taulukko 6).

Kokeissa tarkasteltiin myös pääverson kehityksen eriasteisia häiriöitä. Tuloksissa on esitetty vain normaalien taimien (= yksi johtava pääverso koko ajan) osuus

v. 1984 (kuva 11, taulukot 7 ja 8). Kokeen 13 a tulokset on esitetty erikseen, koska koe inventoitiin myös aikaisemmin (1982) talvella 1981—82 syntyneiden neulas- ja silmuvaurioiden vuoksi (kuva 12, taulukot 9—11).

Kokeissa 1—3 keskimäärin vajaa puolet ja kokeissa 4—8 keskimäärin hiukan yli puolet taimista olivat normaaleja v. 1984 (kuva 11). Sen sijaan muissa kokeissa normaaleja taimia oli valtaosa. Kokeissa 1—3 jatkolannoitus ei vaikuttanut normaalien taimien osuuteen (kuva 11, taulukko 7), mutta normaalien taimien osuus korreloi positiivisesti neulasten kaliumpitoisuuden kanssa (taulukko 8). Kokeissa 4—8 jatkolannoitus pelkällä PK- tai NPK-lannoitteilla vähensi normaalien taimien osuutta (taulukko 7, kuva 11). Kysymys oli ilmeisesti pääravinnelannoituksen aiheuttamasta boorin puutoksesta, koska neulasten booripitoisuus korreloi positiivisesti normaalien taimien osuuden kanssa (taulukko 8).

Myös kokeissa 11 ja 12 todettiin neulasten booripitoisuuden ja normaalien taimien osuuden välillä positiivinen korrelaatio. PK- ja NPK-lannoituksen ohella kalkitus alensi neulasten booripitoisuuksia (ks. luku 32) ja pienensi normaalien taimien osuutta. Yleensä neulasten typpipitoisuus korreloi negatiivisesti normaalien taimien osuuden kanssa. Kokeissa 9—10 neulasten booripitoisuuden ja normaalien taimien osuuden välillä vallitsi negatiivinen korrelaatio (taulukko 8). Syy ei tutkimuksessa selvinnyt.

Kokeen 13 a taimissa v. 1982 todetut neulas- ja silmuvauriot korreloivat neulasten jatkolannoitusta edeltäneiden ravinnepitoisuuksien kanssa (taulukko 9). Tärkeimmät olivat positiivinen korrelaatio neulasvaurioiden ja neulasten N-, Cu- ja Ca-pitoisuuksien sekä N/P-, N/K- ja K/P-suhteiden kanssa ja negatiivinen korrelaatio vaurioiden ja neulasten P-pitoisuuden kanssa. Typpijatkolannoitus, kalkitus ja suurin tuhka-annos lisäsivät neulasvaurioiden määrää. Samanlaisia korrelaatioita, joskaan ei yhtä voimakkaina havaittiin myös aikaisempien pääranganvaihtojen ja v. 1980 analysoitujen neulasten ravinnepitoisuuksien sekä v. 1984 todetun monilatvaisten osuuden ja v. 1982 analysoitujen neulasten ravinnepitoisuuksien välillä (taulukko 11).

Tulosten perusteella näyttää siltä, että yksipuolinen jatkolannoitus pelkillä pääravinteilla voi aiheuttaa taimissa boorin puutosta, mikä johtaa kärkikasvupisteen häiriöihin ja edelleen monilatvaisuuteen. Erityisesti typpilannoitus ja kalkitus ovat olleet tässä suhteessa ongelmallisia. Boorin lisäys on kuitenkin yleensä vähentänyt näitä häiriöitä.

Kalkitus ja typpilannoitus fosforilannoituksen ohellakin saattavat aiheuttaa hetkellisen N/P-suhteen häiriintymisen, jolloin seurauksena on neulas- ja silmuvaurioita sekä tästä johtuvaa monilatvaisuutta. Ongelmien välttämiseksi mäntytaimikoiden typpijatkolannoitustarve tulisikin arvioida erityisen huolellisesti.

35. Taimien pituuskasvu

351. Turpeen ominaisuuksien vaikutus

3511. Turpeen kokonaistyppipitoisuus

Tutkittaessa taimien pituuskasvun ja turpeen kokonaistyppipitoisuuden keskinäistä riippuvuutta kiinnitettiin päähuomio 5—10 cm:n turvekerroksesta tehtyihin analyyseihin. Kokeissa 12 ja 13 tarkasteltiin myös 0—5, 10—15, 15—20, 0—10, 5—15 ja 0—15 cm:n turvekerrosten kokonaistyppipitoisuuden ja pituuskasvun välistä riippuvuutta.

Kokeissa 1—10 taimien pituuskasvu oli turpeen kokonaistyppipitoisuudesta riippumaton (kuva 13, taulukko 12). Kokeissa 11 ja 12 taimien pituuskasvu PK-lannoitetuilla koealoilla lisääntyi tilastollisesti merkitsevästi kokonaistyppipitoisuuden kohotessa (kuvat 13 ja 14, taulukko 12). NPK-lannoitetuillakin koealoilla riippuvuus oli positiivinen, mutta ei merkitsevä. Kokeen 13 runsastyppisimmässä osassa, lohkossa 1 (13 a1) taimien pituuskasvu väheni turpeen kokonaistyppipitoisuuden lisääntyessä sekä PK- että NPK-lannoitetuilla koealoilla. Kokonaistyppipitoisuudeltaan keskimmäisessä lohkossa (13 a2) ei muuttujien välillä ollut tilastollisesti merkitsevää riippuvuutta ja vähätyppisimmässä lohkossa (13 b) riippuvuus oli positiivinen sekä PK- että NPK-lannoitetuilla koealoilla.

Tarkasteltaessa kokeen 13 tuloksia yhtenä kokonaisuutena ja lisättäessä tähän vielä kokeen 12 tulokset todettiin, että taimien pituuskasvu turpeen kokonaistyppipitoisuuden funktiona oli kohoava 1,6—2,0 %:n turpeen kokonaistyppipitoisuuteen saakka, jolloin kasvu ensin tasaantui ja kääntyi sitten alenevaksi sekä PK- että NPK-lannoitetuilla koealoilla (kuvat 14 ja 15, taulukko 13). Pituuskasvun maksimi oli jonkin verran alemmalla kokonaistyppipitoisuuden tasolla NPK- kuin PK-lannoitetuilla koealoilla. PK-lannoitukseen verrattuna NPK-lannoitus lisäsi taimien kasvua turpeen kokonaistyppipitoisuuden ollessa alle 1,2—1,3 % (kokeet 11 ja 12, kasvu 82—84) ja pienensi kasvua typpipitoisuuden ollessa tätä korkeampi.

Pituuskasvua selittivät suunnilleen yhtä hyvin turpeen kokonaistyppipitoisuudet 5—10, 0—10, 0—15 ja 5—15 cm:n turvekerroksissa (taulukko 14).

Tulosten perusteella näyttää siltä, että turpeen kokonaistyppipitoisuuden avulla voidaan arvioida verrattain hyvin kasvualustan typpitaloutta ja mäntytaimikoiden typpilannoituksen tarvetta ja että mäntytaimikoiden jatkolannoituksessa tulisi kiinnittää erityistä huomiota turpeen typpitalouteen ja pyrittävä välttämään tarpeetonta typpilannoitusta. Kaikkein runsastyppisimpiä soita tulisi ehkä välttää männyn kasvatuksessa ja pyrkiä uudistamaan ne mahdollisuuksien mukaan enemmän typpeä vaativille puulajeille: kuuselle ja koivulle.

3512. Turpeen maatuneisuus

Turpeen maatuneisuuden ja kasvun välistä riippuvuutta analysoitiin vain kokeessa 12. PK-lannoitetuilla koealoilla pituuskasvu lisääntyi suoraviivaisesti maatumisasteen kohotessa (kuva 16, taulukko 15). NPK-lannoitetuilla koealoilla riippuvuus oli vähäisempi eikä tilastollisesti merkitsevä. NPK-lannoitus lisäsi taimien pituuskasvua maatumisasteen kohotessa maatumisasteeseen 3 saakka. Parhaiten pituuskasvun ja maatumisasteen välistä riippuvuutta selittivät 5—10 ja 10—15 cm:n turvekerroksesta määritetyt arvot. Selitysaste oli hieman korkeampi kuin kokonaistyppipitoisuuden ollessa selittäjänä (taulukko 15).

Tulosten perusteella näyttää siltä, että maatumisasteen määritys on verrattain käyttökelpoinen keino arvioida turpeen typpitaloutta maasto-olosuhteissa, joskin käyttökelpoisuutta vähentää se, että saraturpeilla samaa maatumisastetta vastaa korkeampi typpipitoisuus kuin rahkaturpeilla.

352. Jatkolannoituksen vaikutus

Kokeita 1—3 ja 9—10 lukuunottamatta jokin jatkolannoituskäsittelyistä lisäsi pituuskasvua tilastollisesti merkitsevästi (kuva 17, taulukko 16). Kokeissa 4—8, 10—11 ja 13 a PK-lannoitus lisäsi kasvua. Kokeissa 12 ja 13 b tarvittiin fosforin ja kaliumin ohella typpeä kasvun parantamiseksi. Typpilannoitus sen sijaan alensi kasvua kokeessa 13 a, jossa turpeen kokonaistyppipitoisuus oli korkea. Kalkitus heikensi kasvua useissa tapauksissa. Kokeissa 9—10, 12 ja 13 b vaikutus näytti liittyvän taimien booritalouteen sekä liian korkeaan N/B-suhteeseen (kuvat 6 a, 6 b ja liite 2). Kokeessa 13 a kalkituksen negatiivinen vaikutus liittyi taimien fosforitalouteen sekä liian korkeaan N/P-suhteeseen (kuvat 3 b, 4 b ja liite 2).

Tuhkalannoitus lisäsi yleensä taimien kasvua, mutta ei enempää kuin lannoitteetkaan. Poikkeuksena oli koe 13, jossa tuhkalannoitus ei lisännyt kasvua edes jatkolannoittamattomaan verrattuna. Syynä oli ilmeisesti tuhkan huono laatu. Tuhka oli huonosti palanutta ja siinä oli fosforia erittäin vähän (0,56 %).

Kokeissa 4—8, 11, 12 ja 13 jatkolannoituksen vaikutus jatkui vielä inventointivuotena, 3—6 vuotta jatkolannoituksen jälkeen (taulukko 17). Jatkolannoituksen vaikutus taimien pituuteen oli hyvin samanlainen kuin pituuskasvuunkin, joskin erot olivat vähäisempiä (kuva 18).

Tulosten perusteella näyttää siltä, että ojitetuille avosoille perustettujen taimikoiden jatkolannoituksessa on syytä käyttää fosforin ja kaliumin ohella myös booria. Typpilannoituksen tarve tulisi selvittää erittäin tarkoin, koska se useissa tapauksissa on tarpeeton ja runsastyppisillä suotyypeillä jopa vahingollinen (ks. myös luku 351). Tuhkalannoituksessa tulisi kiinnittää entistä suurempaa huomiota tuhkan laatuun ja erityisesti sen fosforipitoisuuteen.

353. Neulasten ravinteet pituuskasvun selittäjinä

Neulasten ravinnetilan ja pituuskasvun välistä riippuvuutta tarkasteltiin pelkästään korrelaatiokertoimien avulla (taulukot 18—24). Kaikissa kokeissa neulasten ravinneanalyysejä tehtiin jatkolannoituksen jälkeen, mutta kokeissa 12 ja 13 myös ennen jatkolannoitusta. Kokeissa 1—12 neulasten ravinnetilan ja kasvun väliset riippuvuudet olivat verraten vähäisiä. Kokeessa 13 a neulasten fosfori- ja kaliumpitoisuus ennen jatkolannoitusta korreloivat positiivisesti sekä typpi- ja kuparipitoisuus negatiivisesti niin jatkolannoitusta edeltäneen kuin sen jälkeisenkin pituuskasvun kanssa vielä 3—4 vuotta jatkolannoituksesta (taulukko 19). Kokeessa 13 b pituuskasvu korreloi fosforin ja kaliumin lisäksi positiivisesti myös neulasten booripitoisuuden kanssa (taulukko 22). Kummassakin kokeessa tilanne säilyi samantapaisena, joskin korrelaatiot olivat pienempiä, myös aineiston osassa, jossa oli mukana vain ne jatkolannoituskäsittelyt, joiden kesken ei todettu olevan tilastollisesti merkitseviä vaikutuseroja (= fosforia ja kaliumia tai näiden lisäksi typpeä lannoitteina saaneet koealat kalkittuja lukuunottamatta, taulukot 20 ja 23). Myös jatkolannoituksen jälkeinen ravinnetila korreloi edellä esitetyn kaltaisesti taimien kasvun kanssa (taulukot 21 ja 24), mutta kokeessa 13 b korrelaatiot eivät olleet tilastollisesti merkitseviä (taulukko 24). Kokeessa 13 a todettiin lisäksi neulasten fosfori- ja kaliumpitoisuuksien v. 1980 korreloivan positiivisesti vastaavien pitoisuuksien kanssa v. 1982.

Tulosten perusteella näyttää siltä, että lannoitus raakafosfaatilla vaikuttaa verrattain hitaasti taimien kasvuun ja että jatkolannoitusta edeltävä ravinnetila heijastuu puiden kasvussa varsin pitkään jatkolannoituksen jälkeenkin. Tulos korostaa riittävän aikaisen jatkolannoituksen merkitystä, jolloin vältytään ravinnepuutosten aiheuttamilta kasvutappioilta.

4. Yhteenveto

Tutkimuksessa pyrittiin selvittelemään turpeen luontaisen typpitalouden ja lannoitetypen sekä eri muodoissa (lannoitteina ja puuntuhkassa) annettujen kivennäisravinteiden vaikutusta taimien elossapysymiseen, erilaisten häiriöiden esiintymiseen ja taimien pituuskasvuun sekä pääravinnelannoituksen vaikutusta taimien hivenaineiden tarpeeseen. Tutkimus perustuu 13 pääasiassa avosoille perustettuun kokeeseen, joissa koealoja oli yhteensä 293 kpl (taulukot 1 ja 2).

Turpeen typpitaloutta kuvattiin turpeen kokonaistyppipitoisuudella ja v. Postin mukaan määritetyllä maatumisasteella. Em. suureiden välillä vallitsi kiinteä positiivinen riippuvuus (kuva 2). Maatumisasteella 2 oli rahkavaltaisissa turpeissa turpeen kokonaistyppipitoisuus 1 %. Typpipitoisuus kohosi n. 0,2—0,3 %-yksikköä yhtä maatumisasteen luokkaa kohden. Saravaltaisella alueella typpipitoisuus oli 0,3—0,4 %-yksikköä korkeampi vastaavassa maatumisasteessa. *Maatumisaste onkin varsin käyttökelpoinen maastomenetelmä turpeen typpitalouden arvioimiseksi.*

Puiden kasvu PK-lannoitetuilla koealoilla lisääntyi turpeen kokonaistyppipitoisuuden 5—10 cm:n kerroksessa kohotessa n. 1,6—2,0 %:iin, jolloin kasvu ensin tasoittui ja kääntyi sitten alenevaksi typpipitoisuuden edelleen kohotessa (kuva 15). Jatkolannoitus typellä fosforin ja kaliumin ohella lisäsi puiden kasvua turpeen typpipitoisuuden arvoon 1,2—1,3 % (kuva 14, taulukot 12 ja 13) ja maatumisasteen arvoon n. 3 saakka (kuva 16, taulukko 15), joita suuremmilla arvoilla typpilannoitus alensi kasvua.

Lannoitus fosforilla ja kaliumilla yleensä kohotti neulasten fosfori- ja kaliumpitoisuuksia (kuvat 3 b ja 4 a), mutta alensi niiden booripitoisuuksia (kuva 6 a, ohentumisilmiö) lisäten eräissä tapauksissa kasvuhäiriöiden määrää (kuva 11). Typpilannoitus, ja erityisesti kalkitus, fosforin ja kaliumin ohella alensivat neulasten booripitoisuuksia (kuva 6 a) ja lisäsivät kasvuhäiriöiden määrää edelleen (kuva 11). Eräissä kokeissa todettiin normaalien taimien osuuden ja neulasten typpipitoisuuden sekä neulasten N/B-suhteen välillä negatiivinen korrelaatio (taulukko 8).

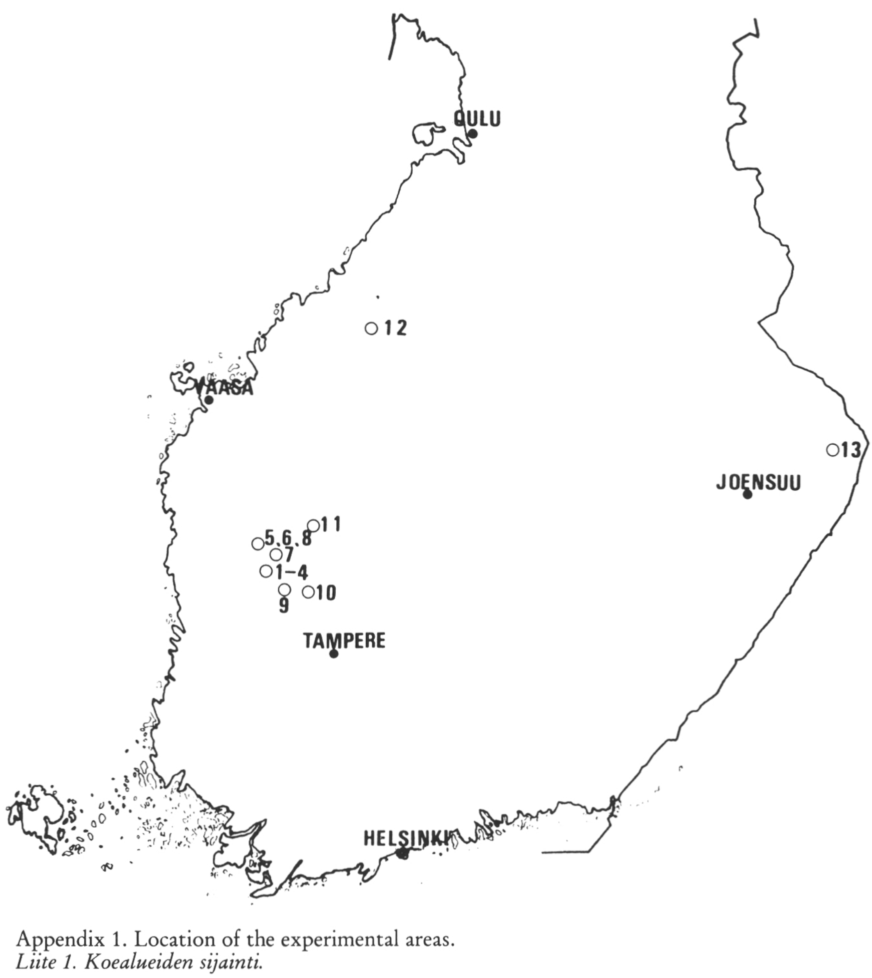
Luontaisesti runsastyppisellä alueella typpilannoitus aiheutti neulasten ruskettumista ja päätesilmujen vaurioita (kuva 12), jotka korreloivat kiinteästi positiivisesti neulasten typpipitoisuuden ja N/P-suhteen kanssa (taulukko 10). N/P-suhteen epätasapainon aiheuttamat päätesilmujen ja neulasten vauriot aiheuttivat pituuskehityksen hidastumista. *Mäntytaimikoiden kasvatuksessa turvemailla tuleekin kiinnittää erityistä huomiota kasvualustan typpitalouteen, jotta kallista typpilannoitetta ei lisättäisi tarpeettomasti tai aiheutettaisi typen lisäyksellä jopa kasvutappioita.*

Kalkitus lisäsi sekä fosforin että boorin puutoksen aiheuttamia ongelmia alentamalla näiden ravinteiden määriä neulasissa (kuvat 3 b ja 6 a).

Jatkolannoitusta edeltäneet neulasten fosfori- ja kaliumpitoisuudet selittivät jatkolannoituksen jälkeistä kasvua useiden vuosien ajan (taulukot 19, 20, 22 ja 23). *Näyttääkin siltä, että taimien jatkolannoitusta edeltänyt ravinnetila vaikuttaa pitkään jatkolannoituksen jälkeiseenkin kasvuun. Jatkolannoitus tulisikin suorittaa riittävän ajoissa kasvutappioiden välttämiseksi.*

Lannoitus hyvälaatuisella puuntuhkalla (1,75 % P ja 6,58 % K, 3500—5000 kg/ha) kohotti taimien kasvua, mutta vain harvoissa tapauksissa enemmän kuin pelkkä PK- tai NPK-lannoitus ja jokaisessa tapauksessa vähemmän, jos PK:n tai NPK:n lisäksi oli annettu vielä booria (kuvat 17 ja 18). Huonolaatuinen tuhka (0,56 % P ja 1,82 % K) jopa heikensi taimien kasvua PK- tai NPK-lannoitettuihin verrattuna. *Tulos korostaa turvemaiden lannoituksessa käytettävän tuhkan laadun merkitystä.*

KAUNISTO, S. 1987. Effect of refertilization on the development and foliar nutrient contents of young Scots pine stands on drained mires of different nitrogen status. Seloste: Jatkolannoituksen vaikutus mäntytaimikoiden kehitykseen ja neulasten ravinnepitoisuuksiin typpitaloudeltaan erilaisilla ojitetuilla soilla. Communicationes Instituti Forestalis Fenniae 140. 58 p.

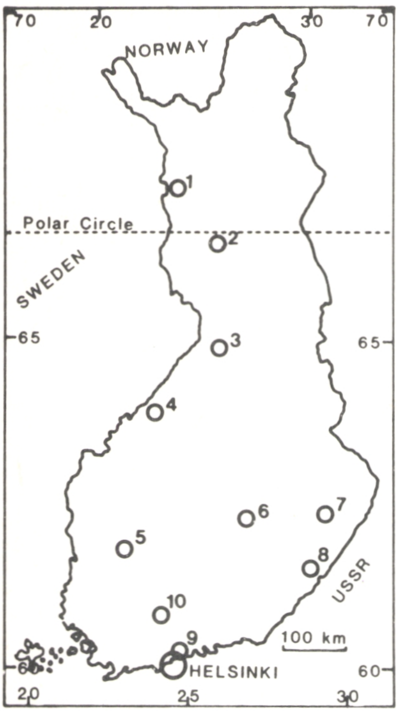


Appendix 1. Location of the experimental areas.
Liite 1. Koealueiden sijainti.

Appendix 2. Effect of soil ameliorant and/or micronutrient application and nitrogen fertilization on the foliar nutrient contents and there ratios. F values and significances.[1)]
Liite 2. Maanparannus/hivenainelisäyksen sekä typpilannoituksen vaikutus neulasten ravinnepitoisuuksiin ja ravinnesuhteisiin. Varianssianalyysin F-arvot ja merkitsevyydet.

Experiment *Koe*	Independ. var. *Selitt. muutt.*	Nutrient and nutrient ratio — *Ravinne ja ravinnesuhde* N	P	K	B	Ca	Cu	N/P	N/K	N/B	N/Ca	N/Cu	K/P	P/B	P/Ca	P/Cu	K/B	K/Ca	K/Cu
4—8	1 = Exp. — *Koe*	16.00***	9.73**	3.70*	12.54***	2.60(*)	1.84	26.52***	24,25***	19.35***	8.14**	6.12**	0.57	10.82***	3.50*	3.45*	11.40***	2.04	3.80*
	2 = Amel./micron. *Maanp./hiv.*	0.74	1.86	0.97	246.99***	2.00	0.58	2.57	1.84	206.02***	1.68	0.23	0.89	168.65***	1.36	0.01	170.88***	1.35	0.29
	3 = N Fertil. — *N-lann.*	0.45	1.99	0.26	7.38*	0.03	1.02	0.70	0.01	0.79	0.23	0.61	0.77	0.00	1.37	1.01	0.73	0.44	0.63
	1 × 2	1.54	0.61	0.60	7.25**	0.65	0.51	1.80	1.74	17.83***	1.57	0.89	2.53(*)	11.73***	0.45	0.50	12.94***	0.55	0.54
	1 × 3	0.34	1.09	0.45	3.30(*)	0.31	0.39	0.94	0.77	1.38	0.40	0.66	1.32	1.73	1.15	0.30	1.58	0.56	0.21
	2 × 3	0.47	0.15	0.48	4.87*	1.15	2.47	0.13	0.70	1.81	1.06	2.04	2.35	0.45	0.63	2.00	2.49	1.06	1.04
9—10	1 = Exp. — *Koe*	0.92	1.45	1.48	1.06	0.00	0.08	0.27	4.80(*)	0.83	0.08	0.00	5.42(*)	1.12	0.36	0.13	0.41	0.41	0.73
	2 = Amel./micron. *Maanp./hiv.*	1.27	1.01	5.43*	14.96***	2.12	0.21	0.99	4.60(*)	7.55*	8.47*	0.55	1.76	6.34*	4.81(*)	1.17	9.07*	2.86	0.57
	3 = N Fertil. — *N-lann.*	0.26	2.20	0.31	2.36	5.38(*)	0.16	6.24(*)	1.10	1.41	13.30*	0.48	3.16	2.94	19.87**	0.46	2.29	9.97*	0.07
	1 × 2	0.44	0.82	3.50(*)	2.32	1.63	0.35	0.61	1.67	0.91	5.22*	0.51	1.02	1.04	3.41	1.56	1.38	3.04	0.95
	1 × 3	0.08	0.00	0.81	4.61(*)	0.10	0.18	0.00	0.02	1.11	0.57	0.28	0.07	1.31	0.52	0.18	0.76	0.12	0.41
	2 × 3	0.26	0.50	2.81	0.45	0.68	2.01	1.63	2.67	0.26	1.35	1.70	0.38	0.20	0.66	4.56(*)	0.21	0.67	3.44
11	1 = Amel./micron. *Maanp./hiv.*	0.51	0.42	0.09	113.62***	0.78	0.92	0.55	0.83	20.84**	0.31	0.23	0.09	9.75*	1.00	1.14	15.86**	1.24	0.85
	2 = N Fertil. — *N-lann.*	1.14	2.10	1.86	0.23	0.16	0.00	2.30	4.31(*)	0.47	0.85	0.18	0.01	0.07	0.18	0.61	0.01	0.20	0.47
	1 × 2	0.00	0.12	2.02	0.45	0.11	0.62	0.03	1.47	0.34	0.06	0.26	2.22	0.16	0.06	0.44	0.02	1.01	1.52
12	2 = Amel./micron. *Maanp./hiv.*	0.98	1.64	1.42	26.89***	2.24(*)	1.60	2.11(*)	1.69	12.81***	1.85	1.00	1.86	14.08***	1.55	0.60	18.58***	2.24(*)	0.76
	3 = N Fertil. — *N-lann.*	0.07	0.57	0.58	16.03***	31.68***	1.11	0.04	0.00	10.25**	28.94***	5.84*	0.06	11.36**	36.55***	5.23*	16.14***	24.92***	4.76*
	1 × 2	0.78	0.78	0.41	0.70	1.13	0.65	0.77	0.42	2.60*	1.31	0.94	0.41	2.16(*)	1.31	0.47	3.21*	1.01	0.59
13 a	2 = Amel./micron *Maanp./hiv.*	3.34*	2.75*	0.15	29.31***	1.55	1.38	2.73*	0.36	23.61***	1.27	1.08	2.46*	20.10***	1.03	1.93(*)	18.11***	0.78	0.76
	3 = N Fertil. — *N-lann.*	4.35*	0.13	0.:49	0.27	0.30	4.04*	0.02	0.03	0.20	0.09	8.87**	0.26	0.01	0.05	4.25*	0.33	0.12	4.87*
	1 × 2	0.52	1.02	0.53	1.64	0.41	1.08	0.48	0.79	0.70	0.93	1.36	1.46	0.38	0.80	0.57	0.67	0.60	0.70
13 b	2 = Amel./micron. *Maanp./hiv.*	1.57	7.02***	2.79*	7.97***	0.53	2.06	4.67**	2.39(*)	5.40**	1.19	3.04*	2.26(*)	4.53**	3.59*	10.45***	3.58*	1.10	4.38**
	3 = N Fertil. — *N-lann.*	0.00	0.14	0.57	8.63**	7.82*	0.38	0.06	0.03	4.22(*)	7.54*	0.22	0.33	5.32*	11.72**	0.06	4.03(*)	5.22*	0.46
	1 × 2	1.44	0.34	0.79	0.63	0.67	1.71	0.57	0.42	1.61	0.46	1.17	0.35	1.56	0.93	1.64	1.36	0.46	0.78

1) (*) = with 10 % risk — *10 %:n riskillä*



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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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139 Kellomäki, S. & Väisänen, H. Kasvatustiheyden ja kasvupaikan viljavuuden vaikutus puiden oksikkuuteen taimikko- ja riukuvaiheen männiköissä. Malleihin perustuva tarkastelu. Summary: Effect of stand density and site fertility on the branchiness of Scots pines at pole stage. A study based on models.

140 Kaunisto, S. Effect of refertilization on the development and foliar nutrient contents of young Scots pine stands on drained mires of different nitrogen status. Seloste: Jatkolannoituksen vaikutus mäntytaimikoiden kehitykseen ja neulasten ravinnepitoisuuksiin typpitaloudeltaan erilaisilla ojitetuilla soilla.

141 Ahti, E. Water balance of drained peatlands on the basis of water table simulation during the snowless period. Seloste: Ojitettujen soiden vesitaseen arvioiminen lumettomana aikana pohjavesipinnan simulointimallin avulla.

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