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LEENA FINÉR

EFFECT OF FERTILIZATION ON DRY MASS ACCUMULATION AND NUTRIENT CYCLING IN SCOTS PINE ON AN OMBROTROPHIC BOG

LANNOITUKSEN VAIKUTUS MÄNNYN KUIVAMASSAN KERTYMÄÄN JA RAVINTEIDEN KIERTOON OMBROTROFISELLA RÄMEELLÄ

THE SOCIETY OF FORESTRY IN FINLAND
THE FINNISH FOREST RESEARCH INSTITUTE

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ACTA FORESTALIA FENNICA 223

EFFECT OF FERTILIZATION ON DRY MASS ACCUMULATION AND NUTRIENT CYCLING IN SCOTS PINE ON AN OMBROTROPHIC BOG

Lannoituksen vaikutus männyn kuivamassan kertymään ja ravinteiden kiertoon ombrotrofisella rämeellä

Leena Finér

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The first three-year effects of PK(MgB) and NPK(MgB) fertilization on the dry mass accumulation and nutrient cycling were studied in a Scots pine (*Pinus sylvestris* L.) stand growing on a drained low-shrub pine bog in eastern Finland. The total dry mass of the tree stand before fertilization was 78 t/ha, of which the above-ground compartments accounted for 69 %. The annual above-ground dry mass production was 6.3 t/ha, 51 % (3.2 t/ha) of it accumulating in the tree stand.

The study period was too short for detecting any fertilization response in the stems. The total dry mass accumulation was not affected, because the increase in foliar and cone dry masses after both fertilization treatments, and that of the living branches after NPK fertilization, were compensated by the decrease in the dry mass of dead branches.

The nutrients studied accounted for 392 kg/ha (0.49 %) of the total dry mass of the tree stand before fertilization. The amounts were as follows: N 173 kg/ha (44 %), Ca 90 kg/ha (23 %), K 58 kg/ha (15 %). The rest (18 %) consisted of P, Mg, S and micronutrients combined, each 13–22 kg/ha.

The unfertilized trees took up the following amounts of nutrients from the soil: N 15.6, Ca 12.8, K 4.1, P 1.3, Mg 1.7 and S and Mn 1.5 kg/ha/a. The uptake of Fe and Zn was 510 and 130 g/ha and that of B and Cu less than 100 g/ha. More than 50 % of the nutrient uptake, except for that of K and Fe, was released in litterfall. The results indicated very efficient cycling of K, Mn and B between the soil and trees.

The fertilized stands accumulated more N, P, K and B than the unfertilized ones during the three-year study period. The increased accumulation corresponded to 35 % (52 kg/ha) of the N applied on the NPK fertilized plots, 10 % (6 kg/ha) of the P, 25 % (25 kg/ha) of the K and 10 % (0.2 kg/ha) of the B on the PK and NPK fertilized plots. The increased amount of B released in litterfall after fertilization was equivalent to 4 % of the applied B. Fertilization inhibited the uptake of Mn and Ca.

PK(MgB) ja NPK(MgB) -lannoituksen vaikutusta männyn kuivamassan kertymään ja ravinteiden kiertoon tutkittiin kolmen lannoituksen jälkeisen vuoden ajan ojitetulla isovarpuisella rämeellä Pohjois-Karjalassa.

Ennen lannoitusta puuston kuivamassa oli 78 t/ha, josta maanpäällisten osien osuus oli 69 %. Puuston vuotuinen kuivamassan tuotos oli 6,3 t/ha, ja siitä 51 % kerääntyi puustoon.

Lannoitusvaikutus ei näkynyt rungon kuivamassan lisäyksenä tutkimusjaksolla. Lannoitus ei myöskään vaikuttanut kuivamassan kokonaiskertymään. Tosin neulasten ja käpyjen massa lisääntyi sekä PK- että NPK-lannoitetuilla koealoilla ja elävien oksien massa myös NPK-lannoitetuilla koealoilla, mutta samanaikaisesti kuolleiden oksien massa pieneni molempien lannoituskäsittelyjen vaikutuksesta.

Tutkittujen ravinteiden osuus puuston kuivamassasta oli 0,49 % (392 kg/ha) ennen lannoitusta. Tästä typpeä oli 173 kg/ha (44 %), kalsiumia 90 kg/ha (23 %), kaliumia 58 kg/ha (15 %) ja loppu (18 %) jakaantui melko tasaisesti fosforin, magnesiumin, rikin ja hivenravinteiden kesken.

Lannoittamaton puusto otti maasta vuosittain typpeä 15,6, kalsiumia 12,8, kaliumia 4,1, fosforia 1,3, magnesiumia 1,7 sekä rikkiä ja mangaania 1,5 kg/ha. Rautaa ja sinkkiä puusto otti vastaavasti 510 ja 130 g/ha sekä kuparia ja booria alle 100 g/ha. Yli puolet näistä ravinnemääristä, rautaa ja kaliumia lukuunottamatta palasi karikkeiden mukana takaisin maahan. Tulokset antoivat viitteitä kaliumin, mangaanin ja boorin tehokkaasta kierrosta puuston ja maan välillä.

Lannoitetussa puuston kuivamassassa oli enemmän typpeä, fosforia, kaliumia ja booria kuin lannoittamattomassa kolmen vuoden kuluttua lannoituksesta. Lisääntynyt ravinteiden kertymä vastasi 10 % (6 kg/ha) käytetystä lannoitefosforista, 25 % (25 kg/ha) lannoitekaliumista ja 10 % (0.2 kg/ha) lannoiteboorista. Vastaava osuus typen kohdalla oli 35 % (52 kg/ha) NPK-lannoitetuilla koealoilla. Lannoitus vähensi kalsiumin ja mangaanin ottoa.

Keywords: accumulation, biomass, litterfall, nutrient, peatland, *Pinus sylvestris*, production, uptake.
FDC 237 + 114.4 + 174.7 *Pinus sylvestris*

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Contents

Symbols – Merkinnät

Tree – *Puu*

d	over-bark, breast-height diameter – *kuorellinen rinnankorkeusläpimitta*, cm
h	height – *pituus*, dm
cl	crown limit – *latvusraja*, dm
cr	crown ratio – *latvussuhde*, $\frac{h - cl}{h}$
v	over-bark volume – *kuorellinen tilavuus*, l

Branch – *Oksa*

d_b	diameter of branch at 3 cm distance from the stem – *oksan läpimitta 3 cm etäisyydellä rungosta*, mm
h_b	length – *pituus*, cm
pos	relative branch position in the living crown measured from the base of the living crown – *oksan suhteellinen sijainti elävässä latvuksessa, määritettynä elävän latvuksen alarajalta*, %

Equations – *Yhtälöt*

R^2	coefficient of determination – *selitysaste*
S_e	residual standard deviation – *jäännöshajonta*
S_e%	relative standard error – *suhteellinen keskivirhe*, $100 * \sqrt{e^{S_e^2} - 1}$

Other – *Muut*

n	number of observations – *havaintojen lukumäärä*
a	year – *vuosi*
C	current year needles – *uusin neulaskerta*
C + 1	one-year-old needles – *vuoden vanha neulaskerta*
C ≥ 2	two-year-old and older needles – *kaksi vuotta vanha ja vanhempi neulaskerta*

Preface

The present study was financed by the Nordic Forest Research Cooperation Committee, The Finnish Forest Research Institute and the Academy of Finland. Ms. Anki Geddala, Ms. Seija Taskinen, Mr. Markku Tiainen and Mr. Pekka Järviluoto have helped in the collection of material. Ms. Leena Karvinen has given technical help. Professors Finn H. Brække, Seppo Kaunisto, Eero Paavilainen, and Juhani Päivänen and Jussi Saramäki, Lic. For. and Mr. Jaakko Heinonen, M. A. (Statistics) have read the manuscript. The English text was revised by Mr. John Derome, Lic. For. I express my sincere thanks to all those who have contributed to the completion of this study.

Joensuu, November 1991

Leena Finér

1. Introduction

Drained peatland ecosystems in Fennoscandia usually have more organic matter and macronutrients in the root zone than in the vegetation (see e.g. Holmen 1964, Paavilainen 1980, Brække 1988, Kaunisto & Paavilainen 1988, Finér 1989). Potassium is often an exception, because it occurs in almost equal amounts in the vegetation and in the surface peat. Harvesting removes nutrients from the ecosystem, exhausting potassium stores sooner than those of the other nutrients (Kaunisto & Paavilainen 1988, Finér 1989).

Tree growth on ombrotrophic peatlands in Finland is dependent on the pool of available nutrients in the root zone, because nutrient input from the atmosphere is low (see e.g. Järvinen 1986). A shortage of phosphorus, potassium and nitrogen usually limits tree growth on bogs (e.g. Meshechok 1967, Brække 1977a, 1979, Paavilainen 1979). On inland sites, additional boron is also often necessary for balanced growth (Brække 1977a, 1979, 1983, Huikari 1977).

Fertilization has been a common practice in peatland forestry in Finland. The stem height, diameter and volume growth responses of Scots pine to fertilization have been documented in many studies on peat soils. Changes in nutrient concentrations, mostly in the foliage, are also frequently observed. Conclusions about the effect of fertilization on the dry mass and nutrient status in the other tree compartments, however, have to be drawn primarily from the results of only a few studies (see Paavilainen 1967, 1968, 1969, 1980, Vasander 1982, Brække 1986, Finér 1989)

The nutrient doses used in single fertilization treatments are large and not always balanced with the annual uptake of trees. Only relatively small amounts of the fertilizer nutrients usually accumulate in the trees (see e.g. Paavilainen 1973, Ballard 1984, Melin & Nömmik 1988). Most of the added nutrients are fixed in the understorey vegetation and soil or leached out.

The aim of the present study is to determine the effects of fertilization on the dry mass accumulation and nutrient cycling of Scots pine (*Pinus sylvestris* L.) growing on an ombrotrophic pine bog. This study is a part of a Nordic project, the main objectives of which are to study the distribution and cycling of nutrients on drained ombrotrophic pine bogs in different climatic conditions.

2. Material and methods

21. Study site

The experimental field is located in North Karelia (64 km SE of Joensuu 62°14' N; 29°50' E, 81 m a.s.l.). The climatic data are presented in Table 1. The year 1987 was cooler with more precipitation than the others, and the surface peat did not thaw until two weeks after the beginning of the growing season. According to the classification of Heikurainen and Pakarinen (1982), the site type has originally been a low-shrub pine bog. A detailed description of the vegetation is presented by Finér and Brække (1991a). The site was drained in 1967 with a 50 m ditch spacing, and fluctuations in the groundwater table were monitored during 1984-1987 (Table 2).

The peat layer is over one-meter thick and consists of slightly decomposed (vonPost, H3-H5) *Sphagnum* peat with wood in all layers and some *Carex* remnants below a depth of 20 cm (see Brække & Finér 1991). A naturally regenerated 85-year-old Scots pine (*Pinus sylvestris* L.) stand is growing on the site (Table 3) (see also Finér 1991a).

The field experiment was established in 1984 and fertilized in spring 1985. A 3 * 3 Latin-square design with 1500 m^2 plot size was used. The treatments were as follows: 1) unfertilized (0), 2) PK(MgB), and 3) NPK(MgB). The amounts of different elements (kg/ha) applied were: N 150, P 53, K 100, Ca 135, Mg 25, S 28, Cl 95, B 2.4. The fertilizers were given as ammonium nitrate, raw phosphate, potassium chloride, magnesium sulphate and sodium borate.

22. Collection of the material

General

The breast height diameter (mm), height (dm) and length of the living crown (dm) of each tree were measured on the sample plots in 1984 and 1987 (Finér 1991a). The trees were classified into different classes in 1984 as follows: 1) dominant 2) co-dominant, 3) intermediate, 4) suppressed trees. The sampling for dry mass and nutrient determinations was carried out twice, in September-October 1984 and 1987. On both occasions 27 sample trees were chosen, three per sample plot using stratified random sampling based on breast-height diameter. In 1984 the trees were chosen from outside the plots, and in 1987 from inside the plots. The sample tree characteristics are presented in Appendix 1.

Stem measurements

The sample trees were cut as close to the ground as possible and discs were sawn from different relative heights (0, 10, 20, 30, 40, 50, 60, 70, 80, 90 %) and breast height. The over-bark and under-bark diameters (0.01 mm) were measured from the discs in two opposing directions, and the number of annual rings was counted. For the density measurements the fresh volume of the stemwood and stembark was determined by immersing the discs in water.

Branch measurements

The locations of the living branches were defined to 0–30, 30–50, 50–60, 60–70, 70–80, 80–90, 90–100 % of the living crown starting from the lower limit of the living crown. The branch length (cm) and the base diameter (mm) from two opposite directions at a distance of three centimeters from the stem were measured. All dead branches and also all the cones in 1987 were detached and their fresh mass (g) weighed. The branch characteristics are presented in Appendix 2.

Seven living branches were chosen from each sample tree at relative heights of 15, 40, 55, 65, 75, 85, 95 % from the lower limit of the living crown. The branches were divided in the laboratory into cones, current needles (C), one-year-old needles (C + 1), older needles (C ≥ 2) and branchwood with bark. The age of the branches was also determined (Appendix 3). In 1987 the 1000-needle mass was determined in different age classes on one sample tree on every sample plot (Appendix 4). All cones (1987) and ten dead branches were also randomly chosen from each sample tree for dry mass determinations.

Below-ground compartments

Stump and coarse roots (∅ > 10 mm) of every fourth sample tree were excavated in 1984. In 1987 the stump and coarse roots of one sample tree per plot were sampled fot nutrient analyses. The small and fine roots (∅ ≤ 10 mm) were sampled using the core method (see Finér 1991b).

Litterfall

Litterfall was collected on each sample plot with five systematically placed collectors (25 × 25 cm) from September 1984 to September 1987. The collectors were emptied and the nutrient content determined six times per year. The amount of litterfall is presented in Appendix 5. In 1987 the dry mass of 1000 litter needles was determined at each sampling (Appendix 4).

Dry mass and nutrient determinations

All samples were dried at 60 °C to constant weight and weighed. A subsample was dried at 105 °C for dry mass determination.

Nitrogen was analyzed by the Kjeldahl method and K,

Table 1. Length of the growing season, temperature sum (threshold 5 °C) and accumulated precipitation during 1984–1987. The values measured at the synoptic climatic station Tohmajärvi are given in parentheses.
Taulukko 1. Kasvukauden pituus, lämpösumma (kynnysarvo 5°C) ja sademäärä vuosina 1984–1987. Ilmatieteen laitoksen Tohmajärven asemalla mitatut arvot on esitetty suluissa.

Year *Vuosi*	Length of growing season, days *Kasvukauden pituus, vrk*	Temperature sum *Lämpösumma*	Precipitation, mm *Sademäärä, mm* 1.6.–30.9	1.1.–31.12
1984	165 (168)	1107 (1243)	238 (249)	– (618)
1985	141 (169)	1097 (1129)	282 (350)	582 (755)
1986	128 (151)	1026 (1135)	240 (302)	573 (650)
1987	173 (173)	939 (967)	478 (474)	698 (749)

Table 2. Groundwater level during June-September in 1984–1987. The values are average distances to the water table measured from the soil surface, in wells spaced across the plots at right angles to the ditch direction (n = 12).
Taulukko 2. Pohjavesipinnan etäisyys maanpinnasta kesä-syyskuussa vuosina 1984–1987 mitattuna tasaisin välein poikkisaran sijoitetuista kaivoista (n = 12).

Year *Vuosi*	Treatment *Käsittely*	Mean *Keskiarvo*	Max cm	Min
1984	0	48	69	20
	PK	48	70	20
	NPK	48	70	20
1985	0	36	49	27
	PK	33	47	25
	NPK	34	47	27
1986	0	42	58	21
	PK	44	62	23
	NPK	44	60	23
1987	0	25	41	18
	PK	25	40	18
	NPK	25	41	18

Table 3. Tree stand characteristics for trees living in 1987.
Taulukko 3. Puustotunnukset jakson lopussa eläville puille.

Treatment *Käsittely*	Stem volume o.b. *Rungon kuorellinen tilavuus* m^3/ha 1984	1987	Volume growth o.b. *Rungon kuorellinen tilavuuskasvu* m^3/ha/a	Stems/ha *Runkoluku, kpl/ha*
0	79.7	97.3	5.9	2219
PK	78.8	97.4	6.2	2178
NPK	79.4	99.1	6.6	2072

Ca, Mg, P, S, B, Fe, Mn, Zn and Cu by inductively coupled plasma emission spectrophotometer (ARL 3580) after nitric-perchloric acid digestion (see also Finér 1992).

23. Calculations

231. Equations

Stem, stump and coarse root dry mass

The over-bark and under-bark volumes of the sample trees were calculated by integrating the taper curve smoothed by a cubic spline-function. The volume of bark was obtained as the difference between these volumes. The dry mass of stemwood and stembark (Appendix 6) was calculated by multiplying the volume with the corresponding density obtained as the dry mass-weighted mean of the wood and bark densities of the discs (Appendix 1).

Regression equations based on breast height diameter and tree height were made for stemwood and stembark (Appendix 7). The breast height diameter was used to predict the stump and coarse root dry mass combined (Appendix 7).

Crown dry mass

Formulation of the crown dry mass equations was started from the branch dry mass equations. The dry mass of the foliage was accordingly predicted by branch diameter, length and position in the crown and the dry mass of the branchwood with branch diameter and length only (Appendix 8). The foliar and branchwood dry masses of each sample tree were calculated using these equations (see Appendix 6). The stem diameter at breast height and crown ratio were used to predict the tree foliar and branchwood dry masses, and the breast height diameter only for prediction of the dry mass of dead branches and cones (Appendix 9).

232. Dry mass and dry mass production

The above-ground, stump and coarse root dry masses of the tree stand on each plot in 1984 and 1987 were obtained by summing up the calculated dry masses of each tree (living in 1987) using the equations (see Appendices 7 and 9). The small and fine-root dry mass (∅ ≤ 10 mm) (Finér 1991b) and the litterfall had been measured at the stand level.

The difference between the tree stand dry mass in 1987 and 1984 was regarded as *dry mass accumulation*. The mean above-ground *dry mass production* in the stand during 1984–1987 was estimated by summing up the production in the different tree compartments. The stem, stump and coarse root production was assumed to equal the accumulation. The needle, branch and cone production was calculated from the tree stand dry masses in 1984 and 1987 and litterfall (see Appendix 10). The change in the dry mass by needle age was regarded in the foliage production estimate by assuming no fertilization effect.

233. Nutrient accumulation

The nutrient contents in different tree compartments in the stand before (1984) and three years (1987) after the fertilization treatments were calculated by multiplying the dry masses of the different compartments with the corresponding nutrient concentrations (Finér 1992). The nutrient contents of the litterfall were calculated by multiplying the concentration at each sampling with the corresponding amount of litter. The dry-weight weighted, mean nutrient concentrations are presented in Appendix 11.

The difference between the nutrient contents of the tree stand in 1987 and 1984 was regarded as *nutrient accumulation*. The *nutrient uptake* from the soil to the above-ground compartments was calculated as the sum of the nutrient accumulation in the above-ground compartments and the nutrient content of the above-ground litterfall.

234. Statistical tests

The differences between the results for 1984 and for 1987 were tested with paired t-tests, and the effect of fertilization with analysis of variance and covariance. The differences between the effects of different treatments were tested with the F test after analysis of variance. The tests were done using the T-TEST PAIRS and MANOVA procedures of the SPSS-X statistical package (SPSS-X... 1983).

3. Results

31. Dry mass and its accumulation

Before fertilization in 1984 the average total dry mass of the trees on the sample plots was 77.7 t/ha, of which the above-ground compartments accounted for 69 % (Table 4). The proportion of stemwood was 47 %, and that of the stump and coarse roots 23 %. The dry mass of the living branches and fine roots was almost the same, 8 %, and that of the stembark and foliage, each 5 %. The dead branches accounted for about 3 % of the total dry mass.

64 % of the total above-ground stand dry mass was in the dominant tree class (Fig. 1). The above-ground dry mass was not distributed in the different tree compartments in the same way in all tree classes. The dry mass of stemwood and living branches was proportionally greater in the upper tree classes, and that of stembark, foliage and dead branches in the lower tree classes.

The mean annual dry mass accumulation during 1984–1987 was 3.7 t/ha (4.7 %) on the unfertilized plots (Table 5). Approximately 58 % of this was located in the stemwood, 6 % in the living branches, 12.5 % in the dead branches and 27 % in the stump and coarse roots. The needle dry mass of the oldest age class decreased during the observation period (Tables 5 and 6).

There were statistically significant differences in the stand stembark and foliar dry masses between the treatments before fertilization (Table 6). However, their use as a covariate did not increase the coefficient of determination when the effect of fertilization was tested, and the covariate was omitted from the tests.

Fertilization had no significant effect on the total stand dry mass or dry mass accumulation (Tables 5 and 6). The distribution of dry mass, however, changed in the crowns of the trees. In 1987 the total needle dry mass was 10 % higher on the PK and 7 % higher on the NPK fertilized plots than on the unfertilized ones. In 1984 the corresponding percentages were 2 % and –2 %. The dry mass of the youngest needles increased only on the PK plots due to fertilization (Tables 4, 5 and 6, Fig. 2). The dry mass of needles

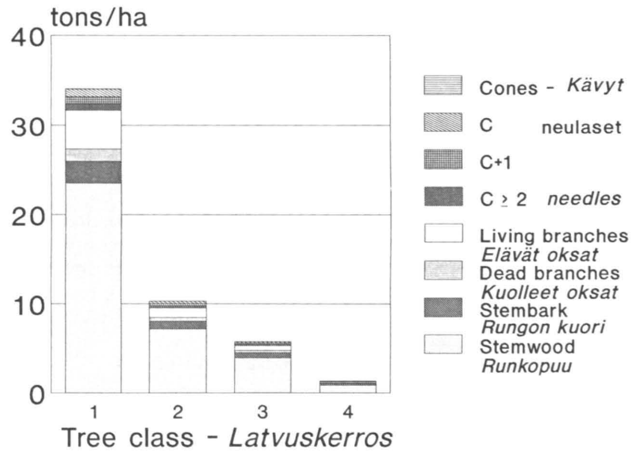

Fig. 1. Distribution of the above-ground dry mass in different tree compartments in different tree classes on the the sample plots in 1984, (1 = dominant, 2 = co-dominant, 3 = intermediate, 4 = suppressed).

Kuva 1. Maanpäällisen kuivamassan jakaantuminen puuston eri osiin eri latvuskerroksissa vuonna 1984, (1 = valtapuut, 2 = lisävaltapuut, 3 = välipuut, 4 = aluspuut).

Table 4. Distribution of dry mass in different tree compartments in 1984 (n = 9) and 1987 (n = 3) on the unfertilized, PK and NPK fertilized plots, (standard deviation in parentheses).
Taulukko 4. Kuivamassan jakaantuminen puuston eri osiin vuonna 1984 (n = 9) ja vuonna 1987 (n = 3) lannoittamattomilla (0), PK- ja NPK-lannoitetuilla koealoilla (keskihajonta suluissa).

	1984	1987 0	1987 PK	1987 NPK
	kg/ha			
Cones – *Kävyt*	38 (1)	49 (7)	77 (7)	229 (28)
Needles – *Neulaset*				
C	1387 (29)	1461 (38)	1550 (40)	1380 (58)
C + 1	1218 (25)	1164 (27)	1610 (66)	1532 (48)
C ≥ 2	1216 (21)	747 (29)	551 (22)	689 (40)
Living branches – *Elävät oksat*	6408 (146)	7001 (328)	7424 (103)	7607 (378)
Dead branches – *Kuolleet oksat*	2122 (10)	3512 (128)	3011 (92)	2984 (234)
Stembark – *Rungon kuori*	4232 (48)	5723 (142)	5664 (295)	5646 (319)
Stemwood – *Runkopuu*	36737 (290)	43471 (1840)	42493 (4760)	42294 (4362)
Above-ground – *Maanpääll.*	53356 (233)	63128 (2840)	62380 (5124)	62361 (5399)
Stump and coarse roots *Kanto ja paksujuuret*	17994 (39)	21001 (784)	21099 (534)	21438 (1518)
Small and fine roots – *Ohutjuuret*	6365 (458)	4423 (1027)	5997 (55)	6510 (2399)
Below-ground – *Maanal.*	24359 (419)	25424 (1700)	27096 (575)	27948 (3872)
Total dry mass *Kokonaiskuivamassa*	77716 (186)	88552 (4179)	89476 (5657)	90309 (9163)

which had been formed in the second year (C + 1) after fertilization was greater in all tree classes as a result of both fertilization treatments. The dry mass of the oldest needles (C ≥ 2) on the dominant trees decreased most clearly after PK fertilization. These needles had mostly been formed in the year of fertilization. The cone dry mass increased in all tree classes, and more after NPK than after PK fertilization.

NPK fertilization increased the living branch dry mass (Tables 5 and 6); in 1987 it was 9 % higher on the NPK plots than on the unfertilized ones (Table 4). The response was measured only in the dominant trees (Fig. 3). The dry mass of dead branches decreased. In 1987 it was 14–15 % smaller on the fertilized plots than on the unfertilized plots. The decrease was relatively smaller in the dominant than in the other tree classes.

Fertilization had no effect on the stemwood or stembark in any of the tree classes. The stump and coarse root dry mass and the small and fine-root dry masses were not affected by fertilization (see also Finér 1991b).

32. Dry mass production

The annual above-ground dry mass production was 6.3 t/ha on the unfertilized plots (Table 7). About 40 % of the above-ground production occurred in the stems, almost the same proportion in the foliage and the remaining 20 % in the branches and cones. 51 % of the above-ground production accumulated in the standing crop, the rest was lost as litter.

Fertilization had no effect on the total above-ground production. However, the branch and cone production increased by 23 % after NPK fertilization.

33. Nutrient content

The studied nutrients accounted for 0.49 % (392 kg/ha) of the dry mass of the trees on the sample plots in 1984 (Table 8). The proportions were N 44 %, Ca 23 % and K 15 %, and the remainder (18 %) was fairly evenly distributed between P, Mg, S and micronutrients combined. Manganese was the dominant micronutrient, followed by Fe, Zn, B and Cu.

Table 5. Mean annual dry mass accumulation during 1984–1987 in different tree compartments on the unfertilized (0), PK and NPK fertilized plots and the F values of the analyses of variance (standard deviation in parentheses).
Taulukko 5. Kuivamassan kertymä vuosina 1984–1987 puuston eri osissa lannoittamattomilla (0), PK- ja NPK-lannoitetuilla koealoilla sekä varianssianalyysien F-arvot (keskihajonta suluissa).

	0	PK	NPK	F value – *F-arvo*
	kg/ha/a			
Cones – *Kävyt*	5 (1)	13 (2)	63 (5)	1421 ***
Needles – *Neulaset*				
C	25 (21)	45 (10)	7 (18)	43.6 *
C + 1	–18 (16)	122 (3)	113 (11)	178 **
C ≥ 2	–157 (13)	–228 (11)	–168 (17)	143 **
Living branches – *Elävät oksat*	225 (114)	282 (29)	429 (82)	9.0
Dead branches – *Kuolleet oksat*	460 (21)	297 (22)	290 (17)	284 ***
Stembark – *Rungon kuori*	487 (29)	469 (91)	490 (30)	0.2
Stemwood – *Runkopuu*	2149 (127)	2017 (569)	1849 (209)	0.6
Above-ground – *Maanpääll.*	3176 (256)	3017 (693)	3073 (71)	0.1
Stump and coarse roots *Kanto– ja paksujuuret*	989 (92)	1037 (99)	1160 (101)	20.1
Small and fine roots – *Ohutjuuret*	–487 (402)	–139 (240)	–96 (914)	0.6
Below-ground – *Maanal.*	502 (328)	898 (212)	1064 (814)	1.2
Total dry mass – *Kokonaiskuivamassa*	3678 (419)	3915 (811)	4137 (824)	1.9

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6. The results of the paired t-tests and the analyses of variance. Different dry mass compartments in 1984 and 1987 as dependent variables in the t-tests, and different dry mass compartments in different treatments in 1984 and 1987 as dependent variables in the variance analyses.
Taulukko 6. Parittaisten t-testien ja varianssianalyysien tulokset. T-testien selitettävinä muuttujina kuivamassat puuston eri osissa vuosina 1984 ja 1987 ja varianssianalyyseissä kuivamassat puuston eri osissa eri käsittelyillä vuosina 1984 ja 1987.

	0	PK	NPK	1984	1987
	t-value – *t-arvo*			F value – *F-arvo*	
Cones – *Kävyt*	–11.2**	–14.3**	23.7***	0.1	140.4**
Needles – *Neulaset*					
C	–2.0	–7.6*	–0.7	82.9**	196.3**
C + 1	1.9	–61.0***	–17.2***	45.4*	287.3***
C ≥ 2	20.3***	35.0***	17.0***	35.5*	272.5***
Living branches – *Elävät oksat*	–3.4	–17.1***	–9.1**	1.3	125.1**
Dead branches – *Kuolleet oksat*	–37.4***	–23.5***	–29.3***	0.1	43.1*
Stembark – *Rungon kuori*	–29.2***	–8.9**	–28.4***	65.2*	0.4
Stemwood – *Runkopuu*	–29.4***	–6.1*	–15.3***	0.2	0.2
Above-ground – *Maanpääll.*	–40.7***	–13.8**	15.3***	0.1	0.1
Stump and coarse roots *Kanto- ja paksujuuret*	–18.6***	–18.2***	–19.9***	0.0	0.6
Small and fine roots – *Ohutjuuret*	2.1	1.0	0.2	1.0	2.6
Below-ground – *Maanal.*	2.7	7.3*	2.3	6.5	2.7
Total dry mass – *Kokonaiskuivamassa*	–15.2***	–8.4**	–8.7***	0.1	0.3

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

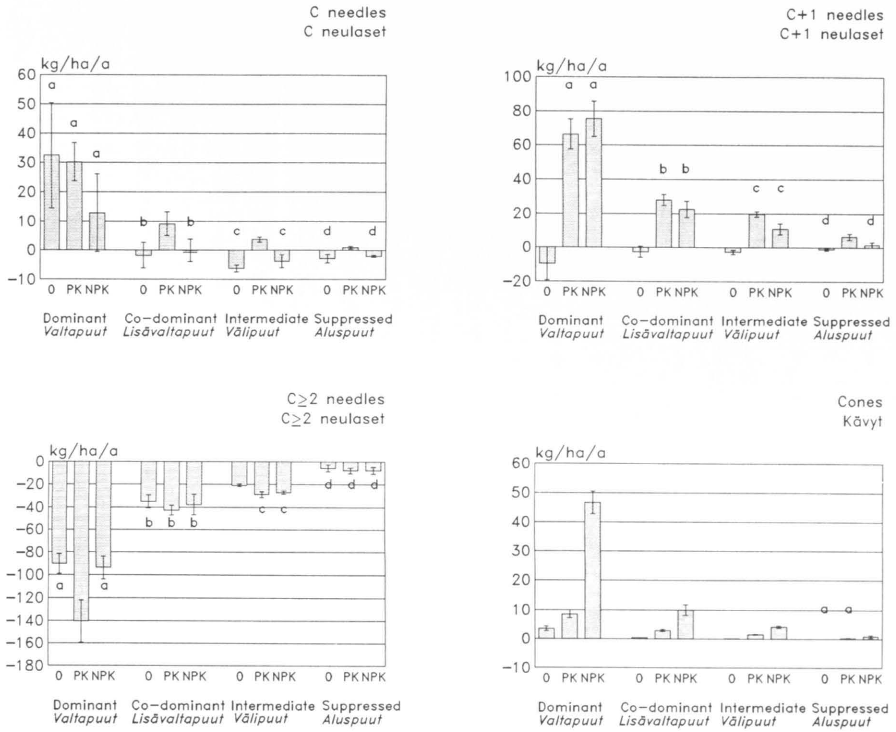

Fig. 2. Annual foliar and cone dry mass accumulation in different tree classes on the control, PK and NPK fertilized plots during 1984–1987. Mean values with the same letter do not differ significantly from each other according to the F test (p > 0.05).

Kuva 2. Keskimääräinen vuotuinen neulasten ja käpyjen kuivamassan kertymä eri latvuskerroksissa lannoittamattomilla, PK- ja NPK-lannoitetuilla koealoilla vuosina 1984–1987. Samalla kirjaimella merkityt keskiarvot eivät poikkea merkitsevästi toisistaan F-testin perusteella (p > 0.05).

Table 7. Mean annual above-ground dry mass production after fertilization and the F values of variance analyses (standard deviation in parentheses).

Taulukko 7. Keskimääräinen vuotuinen kuivamassan tuotos lannoituksen jälkeen ja varianssianalyysien F-arvot (keskihajonta suluissa).

Compartment – *Osite*	0	PK	NPK	F value *F-arvo*
		kg/ha/a		
Needles – *Neulaset*	2445 (215)	2303 (351)	2423 (293)	0.35
Branches & Cones – *Oksat & kävyt*	1178 (150)	1022 (155)	1445 (309)	26.0*
Stem with bark – *Runko kuorineen*	2636 (107)	2486 (660)	2339 (210)	0.2
Total – *Koko*	6259 (448)	5810 (980)	6208 (628)	0.27

* p < 0.05

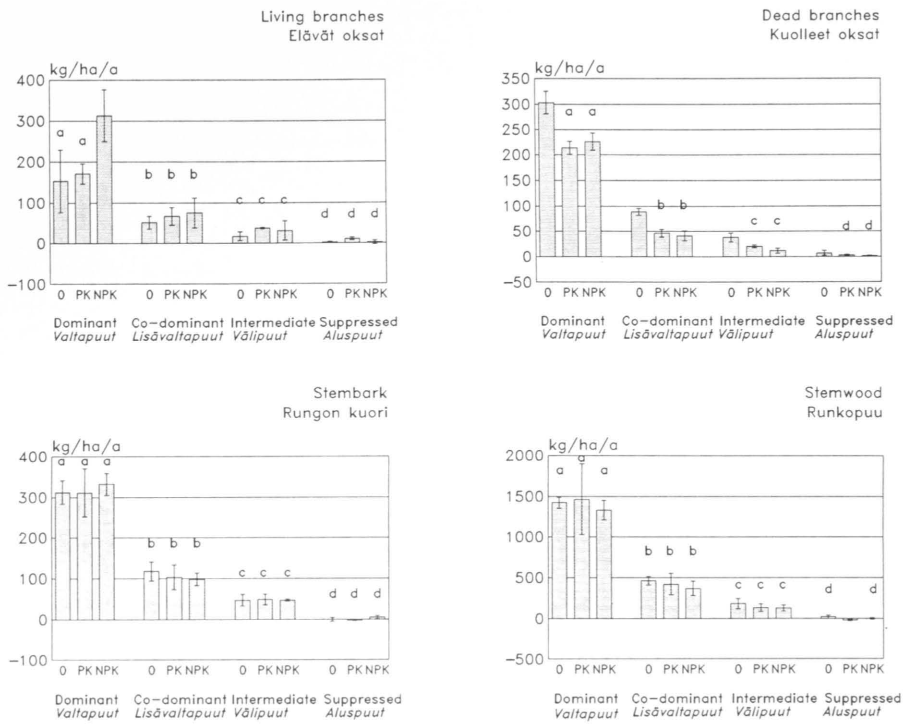

Fig. 3. Annual branch and stem dry mass accumulation in different tree classes on the control, PK and NPK fertilized plots during 1984–1987. Mean values with the same letter do not differ significantly from each other according to the F test (p > 0.05).

Kuva 3. Keskimääräinen vuotuinen oksien ja rungon kuivamassan kertymä eri latvuskerroksissa lannoittamattomilla, PK- ja NPK-lannoitetuilla koealoilla vuosina 1984–1987. Samalla kirjaimella merkityt keskiarvot eivät poikkea merkitsevästi toisistaan F-testin perusteella (p > 0.05).

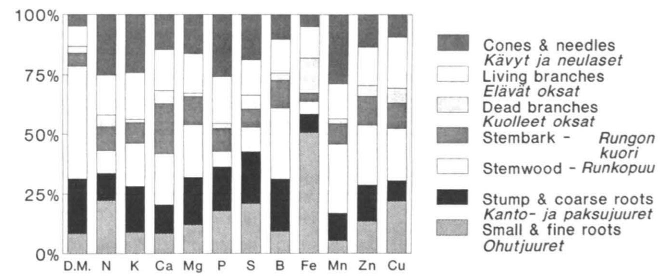

Fig. 4. Average percentual distribution of dry mass and nutrients in the different tree compartments on the sample plots in 1984.

Kuva 4. Kuivamassan ja ravinteiden kesimääräinen prosentuaalinen jakaantuminen puuston eri osiin koealoilla vuonna 1984.

Table 8. Average amounts of nutrients in different tree compartments in 1984 on the sample plots (n = 9), (standard deviation in parentheses).
Taulukko 8. Eri puustonosien keskimääräiset ravinnemäärät koealoilla (n = 9) vuonna 1984, (keskihajonta suluissa).

	N	K	Ca kg/ha	Mg	P
Cones – *Kävyt*	0.12 (0.03)	0.06 (0.01)	0.01 (0.00)	0.02 (0.00)	0.01 (0.00)
Needles – *Neulaset*					
C	15.53 (0.62)	5.48 (0.22)	3.13 (0.12)	1.48 (0.06)	1.75 (0.07)
C + 1	14.13 (0.54)	4.40 (0.17)	4.42 (0.17)	1.15 (0.04)	1.38 (0.05)
C ≥ 2	13.86 (0.52)	4.10 (0.15)	5.53 (0.21)	0.96 (0.04)	1.32 (0.05)
Living branches – *Elävät oksat*	28.90 (0.99)	11.34 (0.39)	15.32 (0.52)	3.66 (0.12)	3.44 (0.12)
Dead branches – *Kuolleet oksat*	8.74 (0.47)	0.84 (0.04)	4.88 (0.26)	0.32 (0.02)	0.39 (0.02)
Stembark – *Rungon kuori*	17.10 (0.63)	4.95 (0.18)	19.00 (0.70)	2.68 (0.10)	1.64 (0.06)
Stemwood – *Runkopuu*	16.75 (1.33)	10.51 (0.83)	19.36 (1.53)	4.89 (0.39)	1.12 (0.09)
Above-ground – *Maanpääll.*	115.13 (4.05)	41.68 (1.57)	71.65 (2.90)	15.15 (0.62)	11.05 (0.37)
Stump and coarse roots *Kanto- ja paksujuuret*	19.61 (1.17)	11.34 (0.67)	10.98 (0.65)	4.50 (0.77)	3.24 (0.19)
Small and fine roots *Ohutjuuret*	38.51 (4.45)	5.03 (0.58)	7.32 (0.85)	2.61 (0.30)	3.05 (0.35)
Below-ground – *Maanal.*	58.12 (4.17)	16.37 (0.71)	18.30 (0.86)	7.11 (0.32)	6.29 (0.33)
Total – *Koko*	173.25 (4.98)	58.05 (1.97)	89.95 (3.22)	22.26 (0.78)	17.34 (0.48)

The nutrient stores in the foliage and branches were greater and that in the stem smaller than their proportion of the dry mass (Fig. 4). The stump and all roots combined accounted for a smaller proportion of the Ca and Mn and a higher proportion of the P, S and Fe stores than their proportion of the dry mass.

The foliage contained almost the same amounts of N, K, Mg, P and S as the living and dead branches combined. Manganese was the only element that was more abundant in the foliage than in the branches. Except for Fe, the living branches had larger nutrient stores than the dead ones. The dry mass of the stembark was small compared to that of the stemwood. However, it contained more P and almost equal amounts of N and Ca as the stemwood. The small and fine roots (∅ ≤ 10 mm) had fixed, except for Fe, also more N and Cu than the stumps and coarse roots.

34. Nutrient accumulation

Annually 5.3 kg/ha of N, 3.7 kg/ha of K, 4.3 kg/ha of Ca and 0.9 kg/ha of P were accumulated in the trees on the unfertilized plots (Table 9). The annual accumulation of Mn, Fe, Mg and S was 317, 244, 213 and 70 g/ha, and that of Zn, B and Cu only 28, 24 and 5 g/ha, respectively. The major part of the nutrients was distributed in the above-ground compartments, especially in the stemwood, stembark and dead branches. The dry mass of the oldest needles was smaller in 1987 than in 1984; this also had an effect on the foliar nutrient stores. However, the foliar P, K and B contents did not decrease. The small and fine root nutrient stores decreased during 1984–1987.

Fertilization had an effect on the total accumulation of all nutrients except Mg, Fe, and Zn (Tables 9 and 10). The fertilized stands accumulated more N, K, P, S, Cu and B and less Ca and Mn. The effect of NPK fertilization was greater on the N, S and Mn contents and smaller on the Ca and Cu contents than that of PK fertilization ($p \leq 0.05$). The nutrient contents of the stump and coarse roots, foliage and living branches were, in relative terms, the most strongly affected by fertilization.

The increased nutrient accumulation corresponded to about 35 % of the N applied on the NPK fertilized plots, and 25 % of the K, 10 % of the P, S and B on the NPK and PK plots within the three-year period. When the increase in N accumulation on the PK fertilized plots was

Table 8 continued.
Taulukko 8 jatkuu.

S	B	Fe	Mn kg/ha	Zn	Cu
0.01 (0.00)	0.000 (0.000)	0.000 (0.000)	0.001 (0.000)	0.001 (0.000)	0.000 (0.000)
1.18 (0.05)	0.019 (0.001)	0.041 (0.002)	0.587 (0.023)	0.059 (0.002)	0.004 (0.000)
1.10 (0.04)	0.016 (0.001)	0.057 (0.002)	0.808 (0.031)	0.061 (0.002)	0.004 (0.000)
1.10 (0.04)	0.013 (0.001)	0.068 (0.003)	0.906 (0.036)	0.064 (0.002)	0.004 (0.000)
2.67 (0.09)	0.065 (0.002)	0.417 (0.014)	1.192 (0.041)	0.219 (0.007)	0.027 (0.001)
1.07 (0.06)	0.014 (0.001)	0.477 (0.026)	0.171 (0.009)	0.062 (0.003)	0.008 (0.000)
1.40 (0.05)	0.054 (0.002)	0.116 (0.004)	0.677 (0.025)	0.170 (0.006)	0.014 (0.001)
1.84 (0.14)	0.140 (0.011)	0.178 (0.014)	2.340 (0.185)	0.344 (0.027)	0.028 (0.002)
10.37 (0.38)	0.321 (0.015)	1.354 (0.056)	6.682 (0.280)	0.980 (0.043)	0.089 (0.004)
3.96 (0.24)	0.103 (0.006)	0.257 (0.015)	0.927 (0.055)	0.214 (0.013)	0.011 (0.001)
3.75 (0.43)	0.042 (0.005)	1.649 (0.190)	0.414 (0.048)	0.180 (0.021)	0.028 (0.003)
7.71 (0.41)	0.145 (0.006)	1.906 (0.185)	1.341 (0.058)	0.394 (0.020)	0.039 (0.003)
18.08 (0.56)	0.466 (0.020)	3.260 (0.172)	8.023 (0.310)	1.374 (0.049)	0.128 (0.004)

taken into account, a maximum of 20 % of the N fertilizer accumulated in the trees on the NPK fertilized plots from 1984 to 1987.

Although fertilization had an effect on the accumulation of most nutrients, it did not have any significant effect on the dry mass accumulation (chapter 31.). Consequently the trees on the fertilized plots used the N, K, P, S, B and Cu less effectively, and the Ca and Mn more effectively than those on the unfertilized plots (see Table 11).

35. Above-ground nutrient uptake and turnover

The annual nutrient uptake of the trees on the unfertilized plots was as follows: N 15.6, Ca 12.8, K 4.1, P 1.3, Mg 1.7 and S and Mn 1.5 kg/ha (Table 10). The annual uptake of Fe and Zn was 510 and 130 g/ha and that of Cu and B less than 100 g/ha. Only part of the uptake accumulated in the standing crop. About 30 % of the K, 40 % of the Fe, 50 % of the P, 60 % of the B, 70 % of the N, Ca, Mg, S, Zn and over 80 % of the amount of Mn and Cu uptake were released to the soil in litterfall (Table 10). The needle litter accounted for 40 % of the Cu, 55 % of the Fe and over 70 % of the release of the other nutrients (Table 12).

Fertilization increased only the B content in the litterfall ($p = 0.07$) (Tables 10 and 12). The increase was equivalent to 4 % of the applied B.

Table 9. Annual nutrient accumulation during 1984–1987 in the different tree compartments on the unfertilized (0), PK and NPK fertilized plots and the results of the analyses of variance. Those with NS do not differ significantly from each other, p > 0.05 (standard deviation in parentheses).

Taulukko 9. Ravinteiden vuotuinen sitoutuminen puuston eri osiin vuosina 1984–1987 lannoittamattomilla (0), PK- ja NPK-lannoitetuilla koealoilla ja varianssianalyysien tulokset. Ne jotka eivät eroa toisistaan merkitsevästi (p > 0.05) on merkitty NS:llä (keskihajonta suluissa).

	0	PK	NPK	0	PK kg/ha/a	NPK	0	PK	NPK
		N			K			Ca	
Cones	0.015	0.040	0.255	0.016	0.045	0.175	0.000	0.001	0.008
Kävyt	(0.002)	(0.005)	(0.021)	(0.002)	(0.002)	(0.017)	(0.000)	(0.000)	(0.000)
Needles	–1.793	–0.624	1.098	0.168	2.092	1.982	–0.804	–1.347	–1.031
Neulaset	(0.574)	(0.195)	(0.518)	(0.205)	(0.020)	(0.192)	(0.165)	(0.090)	(0.157)
Living branches	0.873	1.224	4.038	0.561	1.341	2.508	0.654	–0.859	0.213
Elävät oksat	(0.507)	(0.128)	(0.423)	(0.209)	(0.062)	(0.197)	(0.278)	(0.048)	(0.183)
Dead branches	2.106	1.555	1.563	0.275	0.217	0.182	1.631	0.412	0.687
Kuolleet oksat	(0.094)	(0.095)	(0.096)	(0.011)	(0.010)	(0.011)	(0.068)	(0.047)	(0.041)
Stembark	1.586	3.027	3.259	1.218	2.210	1.872	1.195	–1.652	–0.303
Rungon kuori	(0.108)	(0.417)	(0.193)	(0.049)	(0.184)	(0.108)	(0.107)	(0.279)	(0.020)
Stemwood	2.226	3.498	3.113NS	0.455	1.866	1.629	1.495	0.567	1.059NS
Runkopuu	(0.065)	(0.547)	(0.240)	(0.039)	(0.307)	(0.121)	(0.064)	(0.245)	(0.109)
Above-ground	5.013	8.720	13.326	2.693	7.771	8.348	4.171	–2.878	0.633
Maanpäälliset	(1.278)	(1.188)	(1.112)	(0.459)	(0.545)	(0.494)	(0.582)	(0.629)	(0.277)
Stump and coarse roots	3.388	5.209	6.838	1.673	4.943	3.661	0.673	0.843	0.565
Kanto- ja paksujuuret	(0.142)	(0.055)	(0.286)	(0.075)	(0.063)	(0.144)	(0.057)	(0.056)	(0.072)
Small and fine roots	–3.081	–1.059	2.457NS	–0.665	0.090	0.054NS	–0.590	0.000	–0.176NS
Ohutjuuret	(2.406)	(1.448)	(6.600)	(0.261)	(0.191)	(0.768)	(0.457)	(0.277)	(1.028)
Below-ground	0.307	4.150	9.295NS	1.008	5.033	3.715	0.083	0.844	0.389NS
Maanalaiset	(2.358)	(1.486)	(6.884)	(0.229)	(0.254)	(0.912)	(0.411)	(0.258)	(0.957)
Total	5.320	12.870	22.621	3.701	12.804	12.063	4.254	–2.034	1.022
Koko	(3.066)	(2.565)	(7.767)	(0.598)	(0.704)	(1.374)	(0.834)	(0.862)	(0.982)
		Mg			P			S	
Cones	0.002	0.004	0.023	0.004	0.009	0.035	0.002	0.004	0.023
Kävyt	(0.000)	(0.001)	(0.002)	(0.001)	(0.000)	(0.003)	(0.000)	(0.000)	(0.002)
Needles	–0.169	–0.230	–0.178NS	–0.003	0.341	0.372	–0.200	–0.169	–0.047
Neulaset	(0.047)	(0.023)	(0.042)	(0.064)	(0.010)	(0.056)	(0.043)	(0.019)	(0.039)
Living branches	0.075	0.010	0.278	0.090	0.231	0.552	0.012	0.053	0.290
Elävät oksat	(0.063)	(0.014)	(0.047)	(0.060)	(0.016)	(0.053)	(0.044)	(0.011)	(0.037)
Dead branches	0.093	0.059	0.041	0.125	0.083	0.062	0.307	0.188	0.172
Kuolleet oksat	(0.004)	(0.003)	(0.002)	(0.005)	(0.004)	(0.004)	(0.013)	(0.012)	(0.010)
Stembark	0.274	0.234	0.135	0.323	0.497	0.414	0.179	0.265	0.270
Rungon kuori	(0.018)	(0.055)	(0.009)	(0.014)	(0.050)	(0.024)	(0.010)	(0.035)	(0.016)
Stemwood	0.300	0.297	0.373NS	0.069	0.195	0.138	0.068	0.122	0.146NS
Runkopuu	(0.017)	(0.079)	(0.029)	(0.004)	(0.032)	(0.010)	(0.007)	(0.031)	(0.011)
Above-ground	0.575	0.374	0.672NS	0.608	1.356	1.573	0.368	0.463	0.854
Maanpäälliset	(0.127)	(0.159)	(0.068)	(0.138)	(0.101)	(0.120)	(0.104)	(0.088)	(0.079)
Stump and coarse roots	–0.103	0.189	–0.067	0.528	1.382	0.781	0.078	0.439	0.398
Kanto- ja paksujuuret	(0.025)	(0.026)	(0.050)	(0.023)	(0.017)	(0.023)	(0.020)	(0.017)	(0.012)
Small and fine roots	–0.259	–0.077	–0.104NS	–0.263	0.133	0.323NS	–0.376	–0.082	0.030NS
Ohutjuuret	(0.153)	(0.098)	(0.352)	(0.187)	(0.177)	(0.569)	(0.219)	(0.141)	(0.570)
Below-ground	–0.362	0.112	–0.171NS	0.265	1.515	1.104NS	–0.298	0.357	0.428NS
Maanalaiset	(0.128)	(0.088)	(0.302)	(0.179)	(0.134)	(0.591)	(0.200)	(0.137)	(0.558)
Total	0.213	0.486	0.500NS	0.873	2.871	2.677	0.070	0.820	1.282
Koko	(0.200)	(0.228)	(0.334)	(0.269)	(0.221)	(0.686)	(0.247)	(0.217)	(0.608)

Table 9 continued.

Taulukko 9 jatkuu.

	0	PK	NPK	0	PK g/ha/a	NPK	0	PK	NPK
		B			Fe			Mn	
Cones	0.09	0.27	1.00	0.07	0.11	0.62	0.06	0.31	1.26
Kävyt	(0.01)	(0.01)	(0.10)	(0.01)	(0.02)	(0.05)	(0.01)	(0.06)	(0.05)
Needles	1.92	35.93	36.57	–6.99	–17.69	–12.38	–160.23	–257.21	–297.84
Neulaset	(0.74)	(1.09)	(1.72)	(2.17)	(1.21)	(1.95)	(29.26)	(16.86)	(28.68)
Living branches	–0.30	6.57	11.68	0.16	–9.08	25.11	4.46	–43.97	–24.84NS
Elävät oksat	(1.03)	(0.34)	(1.03)	(6.74)	(1.49)	(5.27)	(19.45)	(4.01)	(13.93)
Dead branches	1.69	1.61	2.79	145.62	80.86	81.19	59.64	35.94	15.59
Kuolleet oksat	(0.10)	(0.14)	(0.17)	(6.16)	(5.13)	(4.92)	(2.46)	(1.96)	(0.92)
Stembark	2.04	6.19	3.07	14.82	7.51	7.36	64.57	27.82	–26.99
Rungon kuori	(0.27)	(1.18)	(0.21)	(0.83)	(2.28)	(0.48)	(4.32)	(12.72)	(1.38)
Stemwood	13.57	13.37	13.97NS	138.66	7.52	105.96	286.17	127.05	–11.89
Runkopuu	(0.47)	(2.80)	(0.99)	(5.28)	(2.51)	(9.91)	(8.62)	(36.07)	(20.14)
Above-ground	19.01	63.94	69.08	292.34	69.23	207.86	254.67	–110.06	–344.71
Maanpäälliset	(2.29)	(4.12)	(3.05)	(19.91)	(9.98)	(16.37)	(60.50)	(61.91)	(40.95)
Stump and coarse roots	7.04	25.60	13.04	56.14	21.86	70.90	118.82	20.33	–33.86
Kanto- ja paksujuuret	(0.54)	(0.29)	(0.14)	(2.20)	(5.13)	(2.42)	(5.72)	(5.83)	(11.81)
Small and fine roots	–2.48	7.68	17.59NS	–104.11	32.04	–63.95NS	–56.74	–43.00	–58.32NS
Ohutjuuret	(2.81)	(1.66)	(12.58)	(108.38)	(62.69)	(223.09)	(21.10)	(15.27)	(41.66)
Below-ground	4.56	33.28	30.63NS	–47.96	53.90	6.95NS	62.08	–22.67	–92.18
Maanalaiset	(2.42)	(1.84)	(12.46)	(108.38)	(62.17)	(225.51)	(18.03)	(13.10)	(30.23)
Total	23.57	97.22	99.71	244.38	123.13	214.81NS	316.75	–132.73	–436.89
Koko	(3.92)	(5.21)	(15.51)	(117.52)	(72.15)	(240.02)	(69.52)	(71.71)	(26.39)
		Zn			Cu				
Cones	0.13	0.26	1.38	0.01	0.03	0.02			
Kävyt	(0.02)	(0.02)	(0.12)	(0.00)	(0.01)	(0.00)			
Needles	–11.06	–11.05	–7.87NS	–0.35	–0.27	–0.73			
Neulaset	(2.30)	(1.10)	(2.12)	(0.16)	(0.06)	(0.14)			
Living branches	–2.84	0.48	18.67	0.62	–0.36	1.08			
Elävät oksat	(3.40)	(0.85)	(2.88)	(0.47)	(0.10)	(0.33)			
Dead branches	13.46	13.03	10.40	1.90	1.15	1.31			
Kuolleet oksat	(0.62)	(0.71)	(0.63)	(0.09)	(0.09)	(0.08)			
Stembark	7.51	8.98	7.98NS	1.17	1.25	0.87NS			
Rungon kuori	(0.88)	(3.26)	(0.55)	(0.09)	(0.29)	(0.06)			
Stemwood	29.27	5.72	31.85	2.48	7.29	5.73			
Runkopuu	(1.13)	(3.87)	(2.29)	(0.09)	(1.08)	(0.45)			
Above-ground	36.47	17.42	62.41	5.83	9.09	8.28NS			
Maanpäälliset	(7.26)	(8.74)	(4.28)	(0.80)	(1.48)	(0.60)			
Stump and coarse roots	11.07	11.63	0.23	2.83	10.47	2.13			
Kanto- ja paksujuuret	(1.09)	(1.19)	(2.16)	(0.11)	(0.20)	(0.04)			
Small and fine roots	–19.84	–14.32	–16.61NS	–3.32	–2.21	–3.24NS			
Ohutjuuret	(10.15)	(6.69)	(21.07)	(1.53)	(1.04)	(3.05)			
Below-ground	–8.77	–2.69	–16.38NS	–0.49	8.26	–1.11			
Maanalaiset	(9.19)	(6.20)	(18.95)	(1.51)	(1.23)	(3.10)			
Total	27.70	14.73	46.03NS	5.34	17.35	7.17			
Koko	(12.94)	(14.20)	(21.75)	(1.87)	(2.58)	(3.60)			

Table 10. Amounts of nutrients in the dry mass in 1984 and 1987, nutrient accumulation and uptake between 1984–1987 on the unfertilized (0), PK and NPK fertilized plots and the results of the analyses of variance. Those with NS do not differ significantly from each other, (p > 0.05), (standard deviation in parentheses).

Taulukko 10. Puuston ravinnemäärä vuosina 1984 ja 1987, ravinteiden sitoutuminen ja maastaotto vuosina 1984–1987 lannoittamattomilla (0), PK- ja NPK-lannoitetuilla koealoilla sekä varianssianalyysien tulokset. Ne jotka eivät eroa merkitsevästi toisistaan (p > 0.05) on merkitty NS:llä (keskihajonta suluissa).

	N			K			Ca		
	0	PK	NPK	0	PK	NPK	0	PK	NPK
Above-ground – *Maan päällä*, kg/ha									
In tree stand 1984	115.1	116.7	113.6 NS	41.7	42.2	41.2 NS	71.8	72.3	70.9 NS
Puustossa 1984	(1.23)	(3.0)	(7.0)	(0.6)	(1.1)	(2.7)	(1.4)	(2.1)	(5.1)
In tree stand 1987	130.1	142.8	153.6	49.7	65.5	66.2	84.3	63.6	72.8
Puustossa 1987	(4.5)	(4.9)	(8.9)	(1.7)	(2.5)	(3.9)	(1.6)	(3.2)	(4.9)
Accumulated 1984–1987	15.04	26.16	39.98	8.08	23.31	25.04	12.51	–8.63	1.90
Sitoutunut puustoon 1984–1987	(3.83)	(3.57)	(3.34)	(1.38)	(1.63)	(1.48)	(1.75)	(1.89)	(0.83)
Litterfall 1984–1987	31.81	29.30	38.25NS	4.10	4.89	5.71NS	25.94	24.21	29.11NS
Karikesato 1984–1987	(2.67)	(5.15)	(8.39)	(0.37)	(1.09)	(1.35)	(1.92)	(2.73)	(2.92)
Uptake 1984–1987	46.86	55.45	78.23	12.17	28.21	30.75	38.45	15.58	31.01
Maasta otettu 1984–1987	(5.50)	(6.95)	(10.12)	(1.70)	(2.49)	(2.23)	(2.10)	(2.54)	(3.67)
Below-ground – *Maan alla*, kg/ha									
In tree stand 1984	55.3	55.4	60.7 NS	16.1	16.4	16.7 NS	17.7	18.3	18.8 NS
Puustossa 1984	(3.6)	(3.4)	(4.8)	(0.7)	(0.4)	(1.0)	(0.9)	(0.5)	(1.1)
In tree stand 1987	56.2	70.9	88.6 NS	19.0	31.5	27.8	18.0	20.9	19.9 NS
Puustossa 1987	(7.0)	(1.1)	(20.6)	(1.2)	(0.7)	(3.6)	(1.6)	(0.4)	(3.6)
Accumulated 1984–1987	0.92	12.45	27.9 NS	3.02	15.10	11.15	0.25	2.53	1.17NS
Sitoutunut puustoon 1984–1987	(7.07)	(4.46)	(20.7)	(0.69)	(0.76)	(2.74)	(1.23)	(0.78)	(2.87)
Total – *Koko*, kg/ha									
In tree stand 1984	170.3	175.1	174.3 NS	57.7	58.6	57.9 NS	89.5	90.6	89.7 NS
Puustossa 1984	(3.5)	(5.7)	(6.0)	(1.0)	(1.5)	(3.4)	(2.0)	(2.5)	(5.5)
In tree stand 1987	186.3	213.7	242.2	68.8	97.0	94.0	102.3	84.5	92.8
Puustossa 1987	(11.2)	(5.7)	(29.1)	(2.9)	(3.1)	(7.5)	(4.5)	(3.5)	(8.4)
Accumulated 1984–1987	15.96	38.61	67.90	11.10	38.41	36.19	12.76	–6.10	3.07
Sitoutunut puustoon 1984–1987	(9.20)	(7.70)	(23.30)	(1.79)	(2.22)	(4.12)	(2.50)	(2.59)	(2.95)

Table 10 continued.

Taulukko 10 jatkuu.

	Mg			P			S		
	0	PK	NPK	0	PK	NPK	0	PK	NPK
Above-ground – *Maan päällä*, kg/ha									
In tree stand 1984	15.2	15.3	15.0 NS	11.0	11.2	10.9 NS	10.4	10.5	10.2 NS
Puustossa 1984	(0.3)	(0.5)	(1.1)	(0.9)	(0.3)	(0.6)	(0.1)	(0.3)	(0.7)
In tree stand 1987	16.9	16.4	17.0 NS	12.9	15.3	15.6	11.5	11.9	12.8
Puustossa 1987	(0.6)	(0.8)	(1.1)	(0.4)	(0.4)	(0.8)	(0.4)	(0.4)	(0.8)
Accumulated 1984–1987	1.73	1.13	2.02NS	1.82	4.07	4.72	1.10	1.39	2.56
Sitoutunut puustoon 1984–1987	(0.38)	(0.48)	(0.20)	(0.41)	(0.30)	(0.36)	(0.31)	(0.27)	(0.24)
Litterfall 1984–1987	3.37	3.50	3.84NS	2.12	2.14	2.64NS	3.31	3.10	3.76NS
Karikesato 1984–1987	(0.31)	(0.67)	(0.29)	(0.18)	(0.37)	(0.52)	(0.23)	(0.60)	(0.85)
Uptake 1984–1987	5.08	4.63	5.86NS	3.94	6.20	7.36	4.42	4.49	6.33
Maasta otettu 1984–1987	(0.59)	(1.03)	(0.22)	(0.48)	(0.59)	(0.73)	(0.46)	(0.68)	(0.95)
Below-ground – *Maan alla*, kg/ha									
In tree stand 1984	6.9	7.1	7.3 NS	6.1	6.3	6.5 NS	7.4	7.7	8.0 NS
Puustossa 1984	(0.3)	(0.2)	(0.4)	(0.3)	(0.2)	(0.4)	(0.4)	(0.3)	(0.5)
In tree stand 1987	5.8	7.5	6.8 NS	6.9	10.9	9.8	6.5	8.8	9.2 NS
Puustossa 1987	(0.5)	(0.1)	(1.2)	(0.6)	(0.2)	(1.9)	(0.7)	(0.2)	(1.9)
Accumulated 1984–1987	–1.09	0.34	–0.52NS	0.79	4.55	3.31NS	–0.90	1.07	1.29NS
Sitoutunut puustoon 1984–1987	(0.38)	(0.26)	(0.91)	(0.54)	(0.40)	(1.77)	(0.60)	(0.41)	(1.67)
Total – *Koko, kg/ha*									
In tree stand 1984	22.1	22.4	22.3 NS	17.1	17.5	17.4 NS	17.8	18.2	18.2 NS
Puustossa 1984	(0.5)	(0.4)	(1.3)	(0.3)	(0.5)	(0.7)	(0.4)	(0.5)	(0.8)
In tree stand 1987	22.7	23.9	23.8 NS	19.7	26.2	25.4	18.0	20.7	22.0
Puustossa 1987	(1.1)	(1.0)	(2.3)	(1.0)	(0.6)	(2.7)	(1.1)	(0.5)	(2.6)
Accumulated 1984–1987	0.64	1.46	1.50NS	2.62	8.61	8.03	0.21	2.46	3.85
Sitoutunut puustoon 1984–1987	(0.60)	(0.68)	(1.00)	(0.81)	(0.66)	(2.06)	(0.74)	(0.65)	(1.82)

Table 10 continued.
Taulukko 10 jatkuu.

	B 0	B PK	B NPK	Fe 0	Fe PK	Fe NPK	Mn 0	Mn PK	Mn NPK
Above-ground – *Maan päällä*, kg/ha									
In tree stand 1984	0.322	0.324	0.319NS	1.35	1.37	1.34NS	6.75	6.80	6.67NS
Puustossa 1984	(0.009)	(0.012)	(0.026)	(0.03)	(0.04)	(0.10)	(0.13)	(0.23)	(0.48)
In tree stand 1987	0.380	0.515	0.526	2.23	1.58	1.97	7.51	6.47	5.63
Puustossa 1987	(0.014)	(0.024)	(0.035)	(0.08)	(0.05)	(0.14)	(0.27)	(0.35)	(0.39)
Accumulated 1984–1987	0.057	0.192	0.207	0.88	0.21	0.62	0.76	–0.33	–1.04
Sitoutunut puustoon 1984–1987	(0.007)	(0.012)	(0.009)	(0.06)	(0.03)	(0.05)	(0.18)	(0.19)	(0.12)
Litterfall 1984–1987	0.091	0.179	0.192NS	0.64	0.58	0.67NS	3.68	3.55	3.95NS
Karikesato 1984–1987	(0.330)	(0.510)	(0.350)	(0.09)	(0.14)	(0.18)	(0.26)	(0.54)	(0.37)
Uptake 1984–1987	0.148	0.371	0.400	1.52	0.79	1.30	4.44	3.22	2.91
Maasta otettu 1984–1987	(0.037)	(0.058)	(0.044)	(0.14)	(0.12)	(0.23)	(0.12)	(0.54)	(0.43)
Below-ground – *Maan alla*, kg/ha									
In tree stand 1984	0.142	0.145	0.147NS	1.78	1.92	2.02NS	1.31	1.34	1.37NS
Puustossa 1984	(0.006)	(0.003)	(0.009)	(0.14)	(0.16)	(0.22)	(0.06)	(0.03)	(0.08)
In tree stand 1987	0.155	0.245	0.239	1.64	2.08	2.04NS	1.50	1.28	1.09
Puustossa 1987	(0.011)	(0.005)	(0.046)	(0.29)	(0.02)	(0.61)	(0.09)	(0.03)	(0.16)
Accumulated 1984–1987	0.014	0.100	0.092NS	–0.14	0.16	0.02NS	0.19	–0.07	–0.28
Sitoutunut puustoon 1984–1987	(0.007)	(0.006)	(0.037)	(0.33)	(0.19)	(0.68)	(0.05)	(0.04)	(0.09)
Total – *Koko*, kg/ha									
In tree stand 1984	0.464	0.468	0.466NS	3.14	3.29	3.36NS	8.06	8.14	8.03NS
Puustossa 1984	(0.013)	(0.015)	(0.033)	(0.15)	(0.16)	(0.18)	(0.16)	(0.25)	(0.53)
In tree stand 1987	0.535	0.760	0.766	3.87	3.66	4.00NS	9.01	7.74	6.72
Puustossa 1987	(0.025)	(0.029)	(0.080)	(0.37)	(0.07)	(0.75)	(0.36)	(0.37)	(0.54)
Accumulated 1984–1987	0.071	0.292	0.299	0.73	0.37	0.64NS	0.95	–0.40	–1.31
Sitoutunut puustoon 1984–1987	(0.012)	(0.016)	(0.047)	(0.35)	(0.22)	(0.72)	(0.21)	(0.22)	(0.08)

Table 10 continued.
Taulukko 10 jatkuu.

	Zn 0	Zn PK	Zn NPK	Cu 0	Cu PK	Cu NPK
Above-ground – *Maan päällä*, kg/ha						
In tree stand 1984	0.98	0.99	0.97NS	0.090	0.090	0.089NS
Puustossa 1984	(0.02)	(0.03)	(0.07)	(0.002)	(0.000)	(0.007)
In tree stand 1987	1.09	1.04	1.16	0.107	0.118	0.114NS
Puustossa 1987	(0.04)	(0.05)	(0.08)	(0.004)	(0.007)	(0.018)
Accumulated 1984–1987	0.11	0.05	0.19	0.018	0.027	0.025NS
Sitoutunut puustoon 1984–1987	(0.02)	(0.03)	(0.01)	(0.002)	(0.004)	(0.002)
Litterfall 1984–1987	0.29	0.30	0.33NS	0.204	0.201	0.225NS
Karikesato 1984–1987	(0.01)	(0.04)	(0.02)	(0.005)	(0.050)	(0.050)
Uptake 1984–1987	0.40	0.35	0.52	0.222	0.228	0.250NS
Maasta otettu 1984–1987	(0.04)	(0.05)	(0.03)	(0.013)	(0.048)	(0.051)
Below-ground – *Maan alla*, kg/ha						
In tree stand 1984	0.38	0.40	0.41NS	0.037	0.041	0.039NS
Puustossa 1984	(0.02)	(0.01)	(0.02)	(0.003)	(0.004)	(0.003)
In tree stand 1987	0.36	0.39	0.36NS	0.035	0.064	0.037NS
Puustossa 1987	(0.03)	(0.01)	(0.07)	(0.004)	(0.001)	(0.009)
Accumulated 1984–1987	–0.03	–0.01	–0.05NS	–0.001	0.025	–0.003
Sitoutunut puustoon 1984–1987	(0.03)	(0.02)	(0.06)	(0.005)	(0.004)	(0.009)
Total – *Koko*, kg/ha						
In tree stand 1984	1.36	1.38	1.38NS	0.126	0.130	0.129NS
Puustossa 1984	(0.03)	(0.04)	(0.02)	(0.003)	(0.006)	(0.003)
In tree stand 1987	1.44	1.43	1.51NS	0.142	0.182	0.151NS
Puustossa 1987	(0.07)	(0.06)	(0.15)	(0.008)	(0.008)	(0.017)
Accumulated 1984–1987	0.08	0.04	0.14NS	0.016	0.052	0.022
Sitoutunut puustoon 1984–1987	(0.04)	(0.04)	(0.07)	(0.006)	(0.008)	(0.011)

Table 11. The total amount of nutrients in the dry mass in 1984 and 1987 per dry mass unit and the amount of nutrients accumulated in the dry mass from 1984 to 1987 per unit of dry mass accumulated during the same period on the unfertilized (0), PK and NPK fertilized plots and the results of the analyses of variance. Those denoted NS do not differ significantly from each other, (p > 0.05), (standard deviation in parentheses).

Taulukko 11. Puuston koko kuivamassaan 1984 ja 1987 ja kuivamassan kertymään vuosina 1984–1987 sitoutuneiden ravinteiden määrät puuston kuivamassa- ja kuivamassan kertymäyksikköä kohti lannoittamattomilla (0), PK- ja NPK-lannoitetuilla koealoilla sekä varianssianalyysien tulokset. Ne jotka eivät eroa merkitsevästi toisistaan (p > 0.05) on merkitty NS:llä (keskihajonta suluissa).

		N	K	Ca g/kg	Mg	P	S
1	0	2.20 (0.06)	0.74 (0.01)	1.16 (0.02)	0.28 (0.00)	0.22 (0.01)	0.23 (0.00)
	PK	2.26 (0.11)	0.75 (0.02)	1.17 (0.03)	0.29 (0.01)	0.23 (0.01)	0.23 (0.01)
	NPK	2.24 (0.12)	0.74 (0.02)	1.15 (0.03)	0.29 (0.01)	0.22 (0.01)	0.23 (0.01)
		NS	NS	NS	NS	NS	NS
2	0	2.10 (0.03)	0.78 (0.01)	1.16 (0.00)	0.26 (0.00)	0.22 (0.00)	0.20 (0.00)
	PK	2.39 (0.09)	1.09 (0.03)	0.95 (0.02)	0.27 (0.01)	0.29 (0.01)	0.23 (0.01)
	NPK	2.68 (0.07)	1.04 (0.02)	1.03 (0.01)	0.26 (0.00)	0.28 (0.00)	0.24 (0.01)
					NS		
3	0	1.40 (0.66)	1.00 (0.05)	1.15 (0.10)	0.06 (0.05)	0.23 (0.05)	0.01 (0.06)
	PK	3.29 (0.15)	3.34 (0.49)	–0.56 (0.33)	0.12 (0.04)	0.75 (0.09)	0.21 (0.02)
	NPK	5.38 (0.79)	2.95 (0.29)	0.23 (0.18)	0.11 (0.05)	0.64 (0.05)	0.30 (0.08)

		B	Fe	Mn mg/kg	Zn	Cu
1	0	6.0 (0.1)	40.5 (1.8)	104.0 (1.9)	17.6 (0.3)	1.6 (0.0)
	PK	6.0 (0.1)	42.3 (3.0)	104.8 (2.4)	17.8 (0.5)	1.7 (0.1)
	NPK	6.0 (0.1)	43.3 (4.2)	103.2 (2.5)	17.7 (0.5)	1.7 (0.1)
		NS	NS		NS	NS
2	0	6.0 (0.0)	43.6 (2.1)	101.8 (0.8)	16.3 (0.0)	1.6 (0.0)
	PK	8.5 (0.2)	40.9 (1.8)	86.6 (1.5)	15.9 (0.3)	2.0 (0.0)
	NPK	8.5 (0.1)	44.1 (3.9)	74.5 (1.5)	16.8 (0.1)	1.7 (0.0)
			NS		NS	
3	0	6.4 (0.3)	65.1 (24.6)	85.5 (10.4)	7.3 (2.6)	1.4 (0.3)
	PK	25.4 (3.9)	30.0 (14.6)	–37.4 (25.6)	3.4 (3.0)	4.5 (0.3)
	NPK	24.3 (1.7)	46.0 (45.0)	–108.4 (20.8)	10.8 (2.9)	1.7 (0.5)
	NS					

1) Fixed in tree stand dry mass in 1984/Dry mass of tree stand in 1984 – *Sitoutunut puuston kuivamassaan 1984/Puuston kuivamassa 1984.*
2) Fixed in tree stand dry mass in 1987/Dry mass of tree stand in 1987 – *Sitoutunut puuston kuivamassaan 1987/Puuston kuivamassa 1987.*
3) Fixed in dry mass accumulation 1984–1987/Dry mass accumulation 1984–1987 – *Sitoutui kuivamassan kertymään 1984–1987/ Kuivamassan kertymä 1984–1987.*

Table 12. The amount of nutrients in the annual litterfall on the unfertilized (0), PK and NPK fertilized plots in 3.9.1984–1.9.1987 (standard deviation in parentheses).

Taulukko 12. Vuotuisen karikesadon sisältämät ravinnemäärät lannoittamattomilla (0), PK- ja NPK-lannoitetuilla koealoilla 3.9.1984–1.9.1987 (keskihajonta suluissa).

		N	K	Ca kg/ha/a	Mg	P	S
Needle	0	7.99 (0.82)	1.04 (0.09)	7.49 (0.60)	0.94 (0.09)	0.51 (0.06)	0.83 (0.06)
Neulas	PK	7.37 (1.06)	1.24 (0.22)	7.11 (0.77)	0.98 (0.16)	0.51 (0.08)	0.79 (0.13)
	NPK	8.99 (1.42)	1.35 (0.31)	8.32 (0.90)	1.01 (0.06)	0.61 (0.08)	0.89 (0.11)
Other	0	2.62 (0.14)	0.33 (0.03)	1.15 (0.23)	0.18 (0.01)	0.19 (0.01)	0.27 (0.01)
Muu	PK	2.40 (0.67)	0.39 (0.15)	0.96 (0.23)	0.18 (0.07)	0.20 (0.04)	0.24 (0.08)
	NPK	3.76 (1.61)	0.56 (0.18)	1.38 (0.73)	0.27 (0.10)	0.27 (0.10)	0.36 (0.18)

		B	Fe	Mn kg/ha/a	Zn	Cu
Needle	0	0.025 (0.011)	0.118 (0.005)	1.184 (0.085)	0.078 (0.003)	0.027 (0.000)
Neulas	PK	0.054 (0.015)	0.110 (0.018)	1.143 (0.168)	0.083 (0.009)	0.025 (0.005)
	NPK	0.055 (0.007)	0.122 (0.005)	1.256 (0.108)	0.089 (0.005)	0.028 (0.002)
Other	0	0.006 (0.000)	0.097 (0.029)	0.041 (0.003)	0.017 (0.002)	0.041 (0.004)
Muu	PK	0.006 (0.002)	0.084 (0.028)	0.041 (0.014)	0.016 (0.005)	0.042 (0.011)
	NPK	0.009 (0.005)	0.102 (0.057)	0.060 (0.031)	0.022 (0.009)	0.047 (0.015)

4. Discussion

41. Dry mass and dry mass production

The dry mass and its distribution between the different tree compartments was within the ranges reported for Scots pine stands growing on drained peatlands (Holmen 1964, Brække 1977b, 1986, Paavilainen 1980, Finér 1989) and mineral soil sites (Mälkönen 1974, Albrektson 1980) in Fennoscandia (Fig. 5, Table 13). The development of the stand was delayed by the poor aeration in the soil before drainage. An equal dry mass is reached at a much younger age on well drained sites. The density and age of the tree stand, as well as the fertility of the site, affect the dry mass distribution. In general, the dry mass of branches, foliage and roots decrease in relation to that of the stem along with an increase in stand age (see e.g. Albrektson 1980, Brække 1986). With increasing site fertility the branch dry mass increases in relation to that of the stem, and an increase in stand density has an opposite effect (Kellomäki and Väisänen 1986).

Stem and branch dry masses have increased and that of needles increased only slightly or remained almost constant in Scots pine stands with the same stem volume as the one studied here (see Brække 1986). However, the foliar dry mass decreased during the observation period on all plots and the decrease was concentrated in the oldest needle class. This can be explained by climatic factors, stand structure and/or diseases. The weather in summer 1987 differed from that during 1984–1986 (see chapter 21.). Summer 1987 was wet and the groundwater table was close to the root zone. Moreover, the frozen soil did not melt until two weeks after the beginning of the growing season. These phenomena may have affected water and nutrient uptake and lead to increased shedding of the oldest needles in 1987. On the other hand, the stand was relatively dense and the poor light conditions in the crown layer may also have increased the mortality of the old needles. However, this is not a probable explanation since Brække (1986) has shown that denser, vigorously growing Scots pine stands have a greater foliage dry mass on ombrotrophic bogs. A light outbreak of *Gremmeniella abietina* (Lagerb.) Morelet, observed

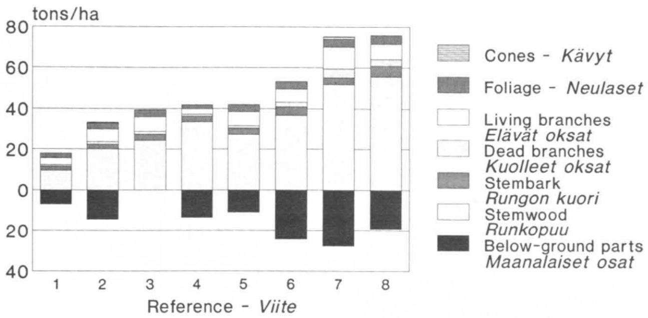

Fig. 5. Distribution of dry mass between the different tree compartments in unfertilized Scots pine stands according to 1) Mälkönen (1974), sample plot no. 1, 2) Finér (1989), VNRmu, 3) Holmen (1964), 4) Finér (1989), RhNRmu, 5) Mälkönen (1974), sample plot no. 2, 6) The present study, 7) Paavilainen (1980), sample plot no. 1, 8) Mälkönen (1974), sample plot no. 3.

Kuva 5. Kuivamassan jakaantuminen puuston eri osiin lannoittamattomissa männiköissä eri tutkimusten mukaan, 1) Mälkönen (1974), koeala no. 1, 2) Finér (1989), VNRmu, 3) Holmen (1964), 4) Finér (1989), RhNRmu, 5) Mälkönen (1974), koeala no. 2, 6) Tämä tutkimus 7) Paavilainen (1980), koeala no. 1, 8) Mälkönen (1974), koeala no. 3.

Table 13. Tree stand characteristics of the unfertilized reference stands (see Figs. 5–7).
Taulukko 13. Lannoittamattomien viitemetsiköiden puustotunnukset (ks. kuvat 5–7).

Site type *Kasvupaikkatyyppi*	Volume *Tilavuus* m^3/ha	Volume growth *Tilavuuskasvu* m^3/ha/a	Age *Ikä* a	Above-ground dry mass production *Maanpäällinen kuivamassan tuotos* kg/ha/a	Reference *Viite*
Ledum-pine bog-IR	66	3.6	44	3000	Holmen 1964
Vaccinium-type-VT (mineral soil)	30	2.3	28	2445	Mälkönen 1974 "Sample plot no. 1" *"Koeala no. 1"*
Vaccinium-type-VT (mineral soil)	75	5.0	47	4055	Mälkönen 1974 "Sample plot no. 2" *"Koeala no. 2"*
Myrtillus-type-MT (mineral soil)	149	5.9	45	5095	Mälkönen 1974 "Sample plot no. 3" *"Koeala no. 3"*
Dwarf-shrub pine bog-IR	116	4.5		4690	Paavilainen 1980 "Sample plot no. 1" *"Koeala no. 1"*
Ordinary sedge pine mire-VNR	48	2.7	40–50	3275	Finér 1989
Herbrich sedge pine mire-RhNR	72	2.0	40–60	2320	Finér 1989
Low shrub pine bog-IR	80	5.9	85	6259	The present study *Tämä tutkimus*

on the site in 1987, probably had no effect on the oldest needle class.

The above-ground dry mass production was higher than that reported for other Scots pine stands in Fennoscandia (Table 13). In addition to site and stand factors, this could be explained by methodological differences. In young stands more of the dry mass production takes place in the foliage and branches than in the stem (e.g. Albrektson 1980). In old stands the relationship is the reverse. In the studied stand the production of stemwood was equal to that of foliage. Almost one half of the annual dry mass production was lost as litter. This proportion was greater than in stands on mineral soil studied by Mälkönen (1974), and almost the same as those for peatland stands reported by Paavilainen (1980). One half of the produced needle dry mass senesced before the end of the three-year period (see Appendix 10).

The below-ground production was not measured in this study. In previous studies the production of fine roots has accounted for 5–85 % of the total tree stand production (Harris et al. 1977, Grier et al. 1981, Keyes & Grier 1981, Fogel 1985, Joslin & Henderson 1987, Santantonio & Santantonio 1987).

42. Effect of fertilization on dry mass

In previous studies the needle dry mass has increased already during the first growing season after fertilization (Miller & Miller 1976, Brix 1981). This is mainly caused by the increased size and longevity of the needles (Miller & Miller 1976, Turner 1977). This was probably also true in this study, since litterfall decreased during the year of fertilization (Finér, unpublished data). However, no positive fertilization effect was detected in the dry mass of the oldest needles, which had mostly been formed during the fertilization year. The dry mass of the oldest needles was even lowest on the PK fertilized plots in 1987. This is difficult to explain, but the consequences of the weather in 1987, which probably explained the overall decrease in the dry mass of this needle class, could also have had a negative interaction with PK fertilization, e.g. by inducing N deficiency in poor mineralization conditions. Both fertilization treatments increased the dry mass of the needles that developed in the second year after fertilization due to the increased needle weight (see Appendix 4). Some earlier studies have shown that the needle mass can also increase as a result of the greater number of needles after fertilization (see Brix & Ebell 1969, Miller & Miller 1976, Turner 1977, Brix 1981, Madgwick & Tamm 1987).

NPK fertilization increased the living branch dry mass, most probably due to the decreased mortality of the branches. The branchwood growth and the number of shoots may also have increased (see Brix & Ebell 1969, Saramäki & Silander 1982, Madgwick & Tamm 1987, Nambiar & Fife 1987). PK fertilization did not have any effect on the living branch dry mass, even though the dead branch dry mass decreased. Greater branch litterfall on the PK fertilized plots than on the other plots could be one explanation. It seems also possible that PK fertilization had a negative effect on the branch growth.

Neither the stem dry mass nor the volume increased until the second three-year period after fertilization (Finér 1991a). Stems respond later to fertilization than foliage, often not before the second year (Miller & Miller 1976, Saramäki & Silander 1982). Maximum stem growth usually occurs in the 3rd–4th year after N or NPK fertilization in Scots pine stands (e.g. Viro 1965, Paavilainen 1972, Paavilainen & Simpanen 1975, Saramäki & Silander 1982). The stem dry mass response is relatively smaller than that of the volume, since fertilization decreases the specific gravity of the stemwood (Brix & Ebell 1969, Saikku 1975ab). The total dry mass of the stand was not affected by fertilization. The study period was thus too short for detecting a growth response in the stem, and increases in the foliar and branch dry masses were compensated by the decrease in dead branch dry mass.

43. Nutrient stores

The total above-ground nutrient stores and their distribution between the different tree compartments was inside the ranges reported for the other unfertilized stands studied in Fennoscandia (Figs. 6 and 7). The exceptions were Fe, Cu and B, the reference material for which was rather small.

The total nutrient concentration in the trees was low compared to plant material in general (see e.g. Epstein 1972, Larcher 1980). The composition was also different, the proportions of P and K were low and that of Ca high (see Epstein 1972). However, the concentrations did not

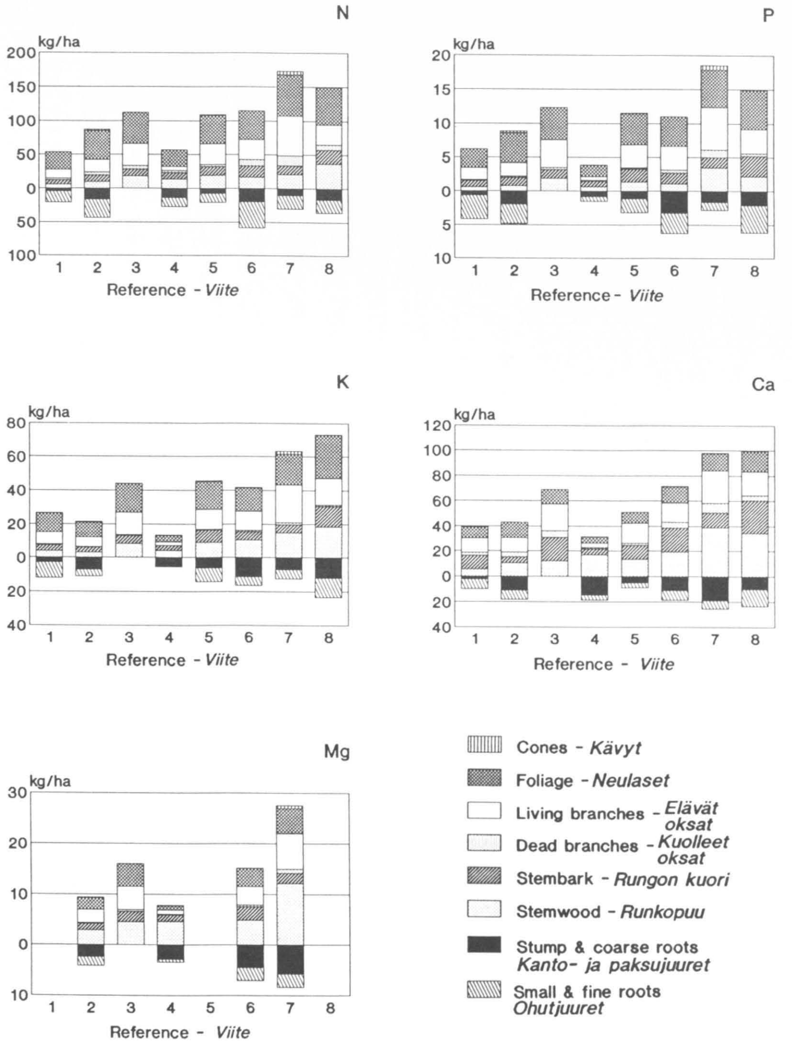

Fig. 6. Distribution of N, K, Ca, Mg and P between the different tree compartments in unfertilized Scots pine stands according to 1) Mälkönen (1974), sample plot no. 1, 2) Finér (1989), VNRmu, 3) Holmen (1964), 4) Finér (1989), RhNRmu, 5) Mälkönen (1974), sample plot no. 2, 6) The present study, 7) Paavilainen (1980), sample plot no. 1, 8) Mälkönen (1974), sample plot no. 3.

Kuva 6. Typen, kaliumin, kalsiumin, magnesiumin ja fosforin jakaantuminen puuston eri osiin lannoittamattomissa männiköissä eri tutkimusten mukaan, 1) Mälkönen (1974), koeala no. 1, 2) Finér (1989), VNRmu, 3) Holmen (1964), 4) Finér (1989), RhNRmu, 5) Mälkönen (1974), koeala no. 2, 6) Tämä tutkimus 7) Paavilainen (1980), koeala no. 1, 8) Mälkönen (1974), koeala no. 3.

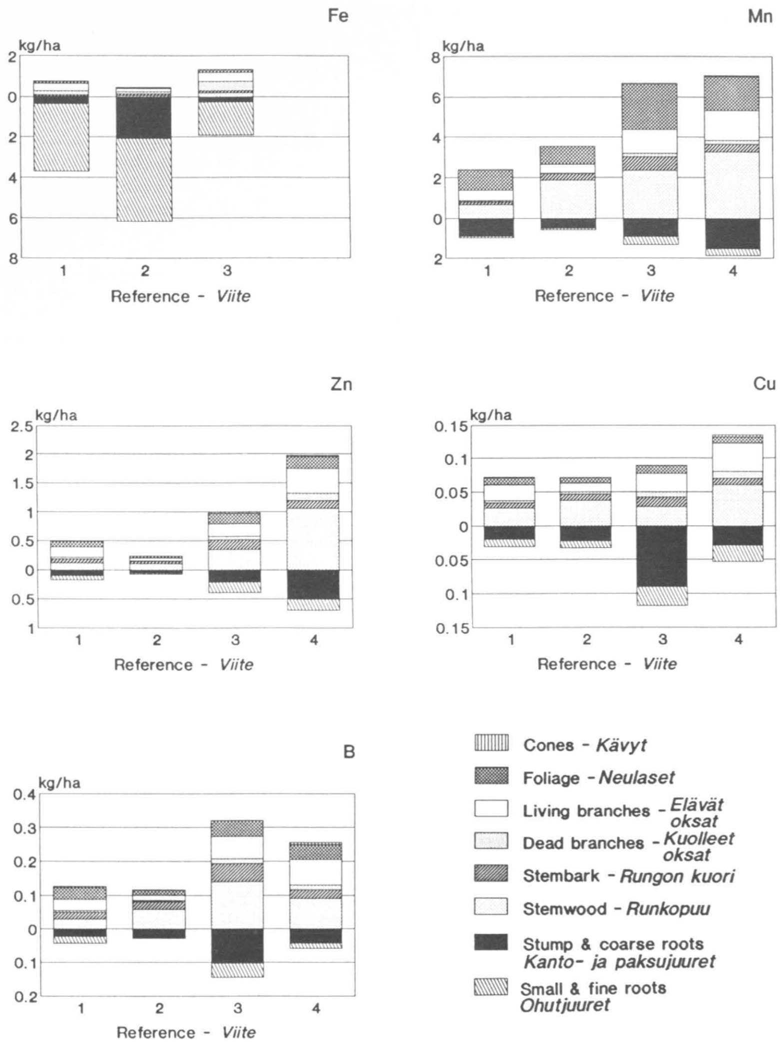

Fig. 7. Distribution of B, Fe, Mn, Zn and Cu between the different tree compartments in unfertilized Scots pine stands according to 1) Finér (1989), VNRmu, 2) Finér (1989), RhNRmu, 3) The present study, 4) Paavilainen (1980), sample plot no. 1.

Kuva 7. Boorin, raudan, mangaanin, sinkin ja kuparin jakaantuminen puuston eri osiin eri tutkimusten mukaan, 1) Finér (1989), VNRmu, 2) Finér (1989), RhNRmu, 3) Tämä tutkimus 4) Paavilainen (1980), koeala no. 1.

Table 14. Nutrient stores in the 0–20 cm peat layer in 1984 (Brække & Finér 1991).
Taulukko 14. Ravinnevarat 0–20 cm turvekerroksessa vuonna 1984 (Brække & Finér 1991).

Nutrient *Ravinne*	kg/ha
N	1912
K	64
Ca	392
Mg	69
P	105
S	258
B	0.36
Fe	213
Mn	10.9
Zn	4.2
Cu	1.1

markedly differ from those observed in other unfertilized Scots pine stands (see Mälkönen 1974, Paavilainen 1980, Finér 1989).

The K, Mn and B pools in the tree stand were close to those in the root zone (Table 14). The other nutrients were more abundant in the surface peat than in the tree stand. The stand was dense and the next silvicultural operation to be carried out on the site would be thinning. It will have a greater effect on the K, Mn and B stores of the site than on the other nutrients (see Kaunisto & Paavilainen 1988, Finér 1989). Stem harvesting, which is the predominant method in Finnish forestry, would remove about one half less of the Ca, Mg, Mn, Zn, B and Cu, one third less of the N, S and K, one fourth less of the P and one fifth less of the Fe from the studied site than whole-tree harvesting. The effect of harvesting methods on the nutritional status of peat soils has been previously emphasized by Kaunisto and Paavilainen (1988) and Finér (1989).

44. Nutrient accumulation and uptake

The relationship between nutrient accumulation and uptake is dependent on the developmental stage of the tree stand (see Miller 1981, 1984). Most of the nutrients taken up from the soil before canopy closure are fixed, but after this stage the proportion of accumulation decreases and a greater part of the nutrients are returned to the soil in litterfall. After crown closure the recycling of nutrients accounts for a large proportion of the annual N, P, K and Mg requirement of the trees (e.g. Lim & Cousens 1986, Helmisaari 1990). Apart from K and Fe, the release of nutrients through litterfall was great compared to the above-ground nutrient uptake on the studied site. Nutrient accumulation mainly took place in the stems, stumps and coarse roots.

The annual nutrient accumulation and uptake from the soil seems to be largely dependent on the dry mass production of the tree stand and its distribution between the different tree compartments (see e.g. Cole & Rapp 1981, Miller 1984, Brække 1990). Marked differences in nutrient accumulation and uptake are observed between tree stands (see Holmen 1964, Mälkönen 1974, Paavilainen 1980, Finér 1989, Brække 1990).

The figures in Table 10 are underestimates for the above-ground K, Ca, Mg and Mn uptake and release, since these nutrients are leached from the pine canopy by precipitation (see Helmisaari & Mälkönen 1989, Hyvärinen 1990). The total nutrient uptake from the soil also includes the below-ground compartments. Annual nutrient uptake by the fine roots may account for an even larger proportion than that of the above-ground compartments, even though the release by fine root turnover probably compensates for the uptake from the soil (see Meier et al. 1985, Vogt et al. 1986).

The annual atmospheric wet deposition of N, Mg and S was 8.4, 0.69 and 7.2 kg/ha on the site during 1984–1987 (Finér & Brække 1991b). The annual accumulation of these nutrients on the unfertilized plots was lower than the deposition. The annual deposition of 1.7 kg of K and 3.1 kg of Ca per ha was smaller than the accumulation in the trees.

Atmospheric wet deposition could satisfy all of the annual uptake of S, and 54 % of N on the unfertilized plots. The proportion for K and Mg was 40 %, and 23 % for Ca. The deposition of P and micronutrients was not measured on the site, but it was most probably of less significance. Phosphorus deposition in eastern Finland has been 0.14 kg/ha/a (Järvinen 1986).

Except for S, the supply of other nutrients was thus largely dependent on mineralization from the peat on the unfertilized plots. The total pools of N and P were large in the peat compared to uptake by the trees, but the slow rate of mineralization limits their availability (see e.g. Kaunisto & Paavilainen 1988, Brække & Finér 1991). Although a large proportion of the total Ca, Mg, K, Mn and Zn in the surface peat was rather easily extractable (Brække & Finér 1991), the total amounts of Mn and K in the root zone on the unfertilized plots corresponded to only 7 and 16 years' uptake respectively. The B content in the upper 20 cm peat layer was also only seven times larger than the annual uptake, but most of the B was tightly bound to the peat matrix (see Brække & Finér 1991). It would appear that the B, Mn and K supply is closely dependent on efficient cycling between the soil and the trees if fertilizers are not applied. This also means that the system is easily disturbed. Boron deficiency is probably one of the main reasons for nutritional growth disturbances on peatlands in Finland (Veijalainen et al. 1984), and K deficiency has even caused the death of trees on some sites exceptionally poor in K (Kaunisto & Tukeva 1984).

45. Effect of fertilization on nutrient contents

The foliar nutrient concentrations indicated a restricted supply of N, P, K and B before fertilization (see Finér 1992), and the uptake of these nutrients was promoted by fertilization. One third of the increased B uptake was already released in the litterfall at the end of the three-year study period. The extra elements accumulated primarily in the canopy, where the dry mass and nutrient concentrations (see Finér 1992) also increased the most (see also Melin & al. 1983, Melin & Nömmik 1988, Nömmik & Larsson 1989).

Compared to the annual above-ground uptake on unfertilized plots, the amount of B applied was about 50, P 40 and that of N, Ca, Mg, S and K, 10 to 25 times greater. Fertilization approximately doubled the annual uptake of N, P, K and B, while the total accumulation of these nutrients was three to four times greater after fertilization. However, the uptake of Mg was not affected and that of Ca and Mn was inhibited. Fertilization has also been observed to decrease Mn uptake in previous studies (Finér 1989). The lower uptake of Mn and also Ca could be explained by the inhibitory effect of the other fertilizer cations or chemical reactions in the peat.

The amount of applied N was lower and that of P, K, Ca, Mg, S and especially B higher than the stores in the tree layer before fertilization. The increased nutrient accumulation was low compared to the applied amounts of fertilizers. However, these observations are in accordance with earlier ones in which the increased accumulation in the tree stand has been less than one half of the applied N, P, K within 0.5–15 years after fertilization (see e.g. Paavilainen 1973, Ballard 1984, Melin & Nömmik 1988, Finér 1989, Nömmik & Larsson 1989). The proportions have also decreased along with increasing fertilizer doses (Miller et al. 1976). The ability of the studied stand to exploit the applied fertilizers was largely dependent on the capacity of the canopy to enlarge its dry mass after fertilization.

The greater amounts of K and B in the surface peat of the fertilized plots could indicate that some of the fertilizers were still left in the peat (Brække & Finér 1991). The remainder was probably taken up by the understorey vegetation (e.g. Päivänen 1970, Paavilainen 1980) or leached out (e.g. Ahti 1983).

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Seloste

Lannoituksen vaikutus männyn kuivamassan kertymään ja ravinteiden kiertoon ombrotrofisella rämeellä

Johdanto

Ojitettujen soiden ravinnevarat ovat sitoutuneet elävään ja kuolleeseen orgaaniseen aineeseen, kasvillisuuteen ja turpeeseen. Kaliumia ja joitakin hivenravinteita lukuunottamatta ravinteita on enemmän juuristokerroksessa kuin kasvillisuudessa (esim. Holmen 1964, Paavilainen 1980, Brække 1988, Kaunisto ja Paavilainen 1988, Finér 1989). Orgaanista ainetta ja ravinteita poistuu soilta huuhtoutumalla ja puunkorjuussa.

Ombrotrofisten soiden puusto kasvaa turpeesta mineralisotuvien ravinteiden varassa, sillä laskeuman mukana tuleva käyttökelpoinen ravinnelisä on pieni. Useimmilla turvemailla fosforin, kaliumin ja boorin niukkuus rajoittaa puuston kasvua, ja karuimmilla turvemailla on puutetta myös typestä (esim. Meshechok 1967, Brække 1977a, 1979, 1983, Paavilainen 1979).

Lannoitus on ollut yleistä ojitetuilla soilla maassamme. Lannoituksen vaikutuksia selvittävät tutkimukset ovat kuitenkin keskittyneet suurimmalta osin vain rungon kasvussa ja neulasten ravinnepitoisuuksissa tapahtuvien muutosten tarkasteluun. Puuston muut osat ovat jääneet vähälle huomiolle.

Puuston kuivamassan tuotosta ja ravinteiden kiertoa koskevat tutkimustulokset ovat tarpeen mm. selvitettäessä soiden merkitystä orgaanisen aineen ja ravinteiden varastoina, tutkittaessa mahdollisuuksia jatkuvaan kestävään puuntuotantoon turvemailla sekä tarkasteltaessa lannoiteravinteiden kulkeutumista suoekosysteemissä. Tämän tutkimuksen tarkoituksena on selvittää lannoituksen vaikutusta puuston kuivamassan kertymään ja ravinteiden kiertoon ombrotrofisella rämeellä kasvavassa männikössä.

Aineisto ja menetelmät

Tutkimuksen aineisto kerättiin Pohjois-Karjalasta isovarpuiselta rämeeltä, joka oli ojitettu 20 vuotta ennen kokeen perustamista. Tutkimusalueella kasvoi noin 85-vuotias männikkö (taulukko 3). Mittaukset aloitettiin vuonna 1984 ja koe lannoitettiin keväällä 1985. Koe toteutettiin latinalaisen neliön periaatteen mukaan (3 * 3). Lannoituskäsittelyt olivat 1) lannoittamaton (0), 2) PK (MgB) ja 3) NPK (MgB) ja käytetyt lannoitemäärät (kg/ha): N 150, P 53, K 100, Ca 135, Mg 25, S 28, Cl 95 ja B 2,4.

Tutkimuksessa kerättiin vuosina 1984 ja 1987 aineisto, jonka perusteella laadittiin puukohtaiset rungon, latvuksen ja kanto- ja paksujuurten kuivamassayhtälöt (liitteet 7, 9). Yhtälöillä laskettiin metsikkötason kuivamassa vastaaville ositteille. Ohutjuurten ja karikesadon kuivamassa mitattiin metsikkötasolla. Tämän lisäksi analysoitiin eri ositteiden ravinnepitoisuudet (Finér 1992, liite 11) ravinnemäärien laskemista varten.

Tulokset ja tarkastelu

Kuivamassa ja kuivamassan tuotos

Puuston kuivamassa oli ennen lannoitusta 77,7 t/ha (taulukko 4, kuvat 1 ja 4), josta maanalaisten osien osuus oli 69 %. Runkopuun osuus metsikön kuivamassasta oli 47 % ja elävien sekä kuolleiden oksien yhteensä 11 %. Rungon kuoren ja neulasten osuus kuivamassasta oli 5 %. Kolmen vuoden tarkastelujaksolla puuston vuotuinen kuivamassan kertymä oli 3,7 t/ha (taulukko 5), josta suurin osa kohdistui runkoon. Puuston maanpäällisten osien vuotuinen kokonaistuotos oli 6,3 t/ha, ja siitä 51 % kerääntyi puuston (taulukko 7, liite 10).

Lannoitus ei vaikuttanut kuivamassan kokonaiskertymään, mutta muutti sen jakaantumista latvuksessa (taulukot 4 ja 5). Lannoitus lisäsi neulasmassaa 7–10 % (taulukko 4). Neulasmassa oli kuitenkin kaikilla koealoilla pienempi tarkastelujakson lopussa kuin alussa, minkä tulkittiin johtuneen pääasiassa kylmän kevään 1987 ja koko kesän 1987 korkealla olleen pohjavesipinnan (taulukko 2) vaikutuksesta puiden veden ja ravinteiden ottoon. NPK lannoitus lisäsi myös elävien oksien kuivamassaa n. 9 %:lla (taulukko 4). Molemmat lannoituskäsittelyt vähensivät kuolleiden oksien kuivamassaa 14–15 % ja lisäsivät käpyjen massaa. Runkoon ja maanalaisiin osiin lannoitus ei vaikuttanut. Myöskään rungon tilavuuskasvu ei lisääntynyt ennen toista kolmivuotisjaksoa lannoituksen jälkeen (Finér 1991a). Lannoitusvaikutusta koskevat tulokset olivat sopusoinnussa aikaisempien tutkimustulosten kanssa, joiden mukaan männyllä lannoitusvaikutus ilmenee ensimmäisenä latvuksessa ja vasta myöhemmin rungossa (ks. Miller & Miller 1976, Saramäki & Silander 1982).

Ravinteiden kierto

Tutkittujen ravinteiden osuus lannoittamattomien puiden kuivamassasta oli 392 kg/ha (0,49 %) (taulukko 8). Tästä typpeä oli keskimäärin 173 kg/ha (44 %), kalsiumia 90 kg/ha (23 %), kaliumia 58 kg/ha (15 %) ja loppu (18 %) jakaantui melko tasaisesti fosforin, magnesiumin, rikin ja hivenravinteiden kesken. Puiden kokonaisravinnepitoisuus (% k.a.) oli pieni ja fosforin sekä kaliumin osuus alempi ja kalsiumin korkeampi kuin kasveissa keskimäärin (Epstein 1972, Larcher 1980). Puiden kokonaisravinnepitoisuus oli kuitenkin lähes saman suuruinen kuin aikaisemminkin tutkituissa männiköissä (ks. Mälkönen 1974, Paavilainen 1980, Finér 1989).

Puustossa oli kaliumia, mangaania ja booria lähes yhtä paljon kuin juuristokerroksessa (taulukot 8 ja 14). Muiden ravinteiden varastot olivat suuremmat ylimmässä 20 cm turvekerroksessa kuin puustossa. Juuriston osuus puuston kuivamassasta oli n. 30 % samoin kuin sen osuus puuston sitomasta typen, kaliumin, magnesiumin, fosforin, kuparin, sinkin ja boorin määrästä (kuva 4). Vastaavasti kalsiumia ja mangaania juuristossa oli vähemmän ja rikkiä ja erityisesti rautaa enemmän. Latvuksen kuivamassa oli selvästi pienempi kuin rungon, mutta ravinnevarastona se oli merkityksellisempi. Edellisen perusteella oli pääteltävissä, että puunkorjuulla on vaikutusta erityisesti tutkitun suon kaliumin, mangaanin ja boorin varastoihin, ja kokopuukorjuun vaikutus on voimakkaampi kuin runkopuukorjuun.

Puusto otti maasta vuosittain keskimäärin typpeä 15,6, kalsiumia 12,8, kaliumia 4,1, fosforia 1,3, magnesiumia 1,7 sekä rikkiä ja mangaania 1,5 kg/ha maanpäällisiin osiinsa (taulukko 10). Rautaa ja sinkkiä puusto otti vastaavasti 510 ja 130 g/ha sekä kuparia ja booria alle 100 g/ha. Karikkeiden mukana palasi maahan ravinteita, rautaa ja kaliumia lukuunottamatta määrä, joka oli yli puolet puuston maasta ottamasta ravinnemäärästä. Rikkiä lukuunottamatta kasvien ravinteiden saanti riippui lannoittamattomilla koealoilla suuresti ravinteiden mineralisaatiosta maassa, sillä laskeuman mukana tuleva ravinnelisä oli vähäinen (Finér & Brække 1991b). Tulokset antoivat viitteitä kaliumin, mangaanin ja boorin tehokkaasta kierrosta puuston ja maan välillä, ja samalla näiden ravinteiden kierron herkästä järkkymisestä.

Neulasanalyysien mukaan kasvupaikalla oli ennen lannoitusta tarjolla niukasti typpeä, fosforia, kaliumia ja booria (Finér 1992). Lannoitus vaikutti magnesiumia, rautaa ja sinkkiä lukuunottamatta kaikkien muiden ravinteiden kertymään (taulukot 9, 10). Lannoitetun puuston kuivamassassa oli enemmän typpeä, fosforia, kaliumia, rikkiä, kuparia ja booria kuin lannoittamattomassa puustossa kolmen vuoden kuluttua lannoituksesta. Lisääntynyt ravinteiden kertymä vastasi 25 % (25 kg/ha) käytetystä lannoitekaliumista, 10 % (6 kg/ha) lannoitefosforista ja 10 % (0.2 kg/ha) lannoiteboorista. Vastaava osuus typen kohdalla oli 35 % (52 kg/ha) NPK-lannoituksen jälkeen, mutta mikäli myös PK lannoituksesta johtuva typen lisääntynyt kertymä otettiin huomioon, osuus oli vain n. 20 % (30 kg/ha). Noin kolmasosa puuston ottamasta lisäboorista oli jo palannut karikkeiden mukana takaisin maahan.

Lannoitettu puusto otti maasta vähemmän kalsiumia ja mangaania kuin lannoittamaton. Lannoituksen on aikaisemminkin todettu pienentäneen puiden Mn ottoa (Finér 1989), ja sen samoin kuin Ca oton pienemiseen vaikuttivat todennäköisesti toiset lannoitekationit tai maassa tapahtuneet kemialliset reaktiot.

Puuston kertynyt lisäravinnemäärä (N, P, K) on myös muissa tutkimuksissa ollut yleensä alle puolet lannoiteravinnemäärästä (Paavilainen 1973, Ballard 1984, Melin & Nömmik 1988, Finér 1989, Nömmik & Larsson 1989). Osa lannoiteravinteista on todennäköisesti sitoutunut pintakasvillisuuteen (esim. Päivänen 1970, Paavilainen 1980), osa turpeeseen (ks. Brække & Finér 1991) ja osa on kulkeutunut pois kasvupaikalta (esim. Ahti 1983).

Appendix 1. Sample tree characteristics in 1984 and 1987 on the unfertilized (0), PK and NPK fertilized plots.

Liite 1. Koepuutunnuksia vuonna 1984 ja 1987 lannoittamattomilla (0) sekä PK- ja NPK- lannoitetuilla koealoilla.

Characteristic *Tunnus*		1984 all-*kaikki*	1987 0	1987 PK	1987 NPK
d, cm	$\bar{x}$	11.5	12.6	12.5	12.9
	min	4.9	6.0	7.0	6.4
	max	22.0	19.1	18.9	23.6
h, dm	$\bar{x}$	104	116	115	115
	min	64	84	89	84
	max	133	134	147	145
cl, dm	$\bar{x}$	47	63	57	62
	min	26	52	42	42
	max	64	70	69	78
cr	$\bar{x}$	0.54	0.45	0.51	0.46
	min	0.40	0.36	0.42	0.37
	max	0.69	0.54	0.60	0.52
v, l	$\bar{x}$	75	91	88	104
	min	8	13	22	16
	max	269	181	211	281
Age - *Ikä*, a	$\bar{x}$	85	89	87	91
	min	63	74	75	71
	max	114	98	96	110
Stemwood density *Runkopuun tiheys*, kg/l	$\bar{x}$	0.44	0.42	0.41	0.42
	min	0.38	0.38	0.39	0.38
	max	0.52	0.48	0.45	0.47
Stembark density *Rungon kuoren tiheys*, kg/l	$\bar{x}$	0.33	0.29	0.28	0.29
	min	0.29	0.28	0.25	0.27
	max	0.39	0.32	0.31	0.33
n		27	9	9	9

Appendix 2. Branch characteristics of sample trees in 1984 and 1987 on the unfertilized (0), PK and NPK fertilized plots.

Liite 2. Lukuoksatunnuksia vuonna 1984 ja 1987 lannoittamattomilla (0) sekä PK- ja NPK- lannoitetuilla koealoilla.

Characteristic *Tunnus*		1984 all *kaikki*	1984 /tree */puu*	1987 0 all *kaikki*	1987 0 /tree */puu*	1987 PK all *kaikki*	1987 PK /tree */puu*	1987 NPK all *kaikki*	1987 NPK /tree */puu*
Living branches - *Elävät oksat*									
d_b, mm	$\bar{x}$	13	11	13	12	14	13	14	12
	min	2	6	2	7	2	9	2	7
	max	47	19	37	17	41	18	54	19
h_b, cm	$\bar{x}$	89	77	98	87	98	89	93	83
	min	4	40	4	63	3	66	2	56
	max	341	127	288	112	310	128	322	133
n	$\bar{x}$	2120	151	673	75	691	77	707	79
	min		102		44		53		49
	max		226		94		117		112
Dead branches - *Kuolleet oksat*									
Fresh mass *Tuoremassa*, g	$\bar{x}$	49	51	60	63	56	55	64	65
	min	1	6	1	11	1	14	1	5
	max	2176	241	1361	250	1177	149	2810	199
n	$\bar{x}$	1909	72	873	97	765	85	780	87
	min		44		76		55		48
	max		104		122		104		136

Appendix 3. Characteristics of sample branches in 1984 and 1987 on the unfertilized (0), PK and NPK fertilized plots

Liite 3. Koeoksatunnuksia vuonna 1984 ja 1987 lannoittamattomilla (0) sekä PK- ja NPK- lannoitetuilla koealoilla.

Characteristic *Tunnus*		1984 all-*kaikki*	1987 0	PK	NPK
d_b, mm	$\bar{x}$	13	13	14	14
	min	3	3	6	4
	max	47	32	34	49
h_b, cm	$\bar{x}$	89	90	93	90
	min	13	9	19	16
	max	341	226	243	320
Needle dry mass *Neulaskuivamassa*, g					
C	$\bar{x}$	17.1	19.8	22.0	25.7
	min	0.5	0.8	3.6	0.9
	max	165.6	150.9	99.8	254.1
C+1	$\bar{x}$	14.4	17.6	22.9	28.0
	min	0.0	0.0	0.0	0.0
	max	139.7	160.5	124.9	306.0
C≥2	$\bar{x}$	12.2	12.0	9.6	15.0
	min	0.0	0.0	0.0	0.0
	max	121.5	90.2	42.6	248.4
Branch dry mass *Oksakuivamassa*, g	$\bar{x}$	85.4	75.1	85.1	105.6
	min	0.4	0.2	1.8	0.7
	max	2212.5	596.5	693.9	2005.0
Age - *Ikä*, a	$\bar{x}$	8	7	7	8
	min	1	1	1	1
	max	38	24	28	38
n		186	63	63	63

Appendix 4. 1000-needle dry mass in different age-classes and litter in 1987 on the unfertilized (0), PK and NPK fertilized plots, (standard deviation in parentheses).

Liite 4. Tuhannen eri-ikäisen elävän ja karikeneulasen painotettu kuivamassa vuonna 1987 lannoittamattomilla (0) sekä PK- ja NPK- lannoitetuilla koealoilla, (keskihajonta suluissa).

	0	PK g	NPK
Living needles - *Elävät neulaset*			
C	11 (3.9)	13 (0.5)	11 (0.3)
C+1	16 (5.9)	22 (4.3)	24 (6.2)
C≥2	13 (3.7)	15 (1.6)	13 (1.8)
Needle litter *Neulaskarike*	7.1 (0.9)	7.7 (1.3)	9.0 (1.8)

Appendix 5. Litterfall in 3.9.1984-1.9.1987 on the unfertilized (0), PK and NPK fertilized plots, (standard deviation in parentheses).

Liite 5. Karikesato 3.9.1984-1.9.1987 lannoittamattomilla (0) sekä PK- ja NPK- lannoitetuilla koealoilla, (keskihajonta suluissa).

	0	PK kg/ha	NPK
Needles - *Neulaset*	3752 (247)	3450 (494)	3582 (423)
Other - *Muu*	1465 (96)	1289 (508)	1989 (884)

Appendix 6. Dry mass characteristics of the sample trees in 1984 and 1987 on the unfertilized (0), PK and NPK fertilized plots.

Liite 6. Koepuiden kuivamassatunnuksia vuonna 1984 ja 1987 lannoittamattomilla (0) sekä PK- ja NPK-lannoitetuilla koealoilla.

Characteristic *Tunnus*		1984 all-*kaikki*	1987 0	 PK	 NPK
Cone dry mass *Käpykuivamassa*, g	$\bar{x}$		165	120	308
	min		0	8	0
	max		928	383	1034
Needle dry mass *Neulaskuivamassa*, g					
C	$\bar{x}$	1198	1279	1338	1284
	min	134	158	331	203
	max	3613	2620	3565	3915
C+1	$\bar{x}$	1065	950	1335	1332
	min	113	155	373	253
	max	3220	1803	3309	4057
C≥2	$\bar{x}$	1005	628	420	740
	min	136	88	125	72
	max	2876	1216	954	2167
Live branch dry mass *Elävien oksien kuivamassa*, g	$\bar{x}$	7106	6937	7633	8262
	min	357	628	1100	694
	max	29215	16360	21739	29389
Dead branch dry mass *Kuolleiden oksien kuivamassa*, g	$\bar{x}$	1835	3330	2712	3191
	min	216	652	486	276
	max	5838	10910	6953	9848
Stembark dry mass *Rungon kuoren kuivamassa*, g	$\bar{x}$	3.2	4.4	4.3	4.9
	min	0.6	1.2	1.4	1.2
	max	11.2	8.4	7.8	12.3
Stemwood dry mass *Runkopuun kuivamassa*, kg	$\bar{x}$	32	37	37	42
	min	4	7	9	7
	max	112	77	86	110
Stump and coarse root dry mass *Kannon ja paksujuurten kuivamassa*, kg					
	$\bar{x}$	20			
	min	1.6			
	max	63			

Appendix 7. Stem, stump and coarse root dry mass equations in 1984 and 1987 on the unfertilized (0), PK and NPK fertilized plots.

Liite 7. Runko- sekä kanto- ja paksujuurikuivamassayhtälöt vuonna 1984 ja 1987 lannoittamattomilla (0), sekä PK- ja NPK- lannoitetuilla koealoilla.

Independent variable *Selittävä muuttuja*	1984 all-*kaikki*	1987 0	 PK	 NPK
	Coefficients-*Kertoimet*			
	ln (Stembark) - *ln (Rungon kuori)*, kg			
Constant-*Vakio*	-0.7220	-5.7367	-5.3095	-3.4382
ln(d)	2.1274	1.4480	1.5413	1.7949
ln(h)	-0.7392	0.7304	0.5915	0.0582
n	27	9	9	9
R^2	0.97	0.98	0.98	0.99
S_e	0.1328	0.1000	0.0963	0.1144
S_e%	13.3	10.0	9.6	11.4
	ln (Stemwood) - *ln (Runkopuu)*, kg			
Constant-*Vakio*	-5.7103	-5.9689	-8.1559	-6.6539
ln(d)	1.7256	1.7123	1.4666	1.6551
ln(h)	1.0241	1.0778	1.6665	1.2442
n	27	9	9	9
R^2	0.99	0.99	0.99	0.99
S_e	0.0643	0.0228	0.0622	0.0813
S_e%	6.4	2.3	6.2	8.1
	ln (Stump and coarse roots)- *ln (Kanto- ja paksujuuret)*, g			
Constant-*Vakio*	-3.3420			
ln(d)	2.4142			
n	7			
R^2	0.99			
S_e	0.1176			
S_e%	11.8			

Appendix 8. Branch dry mass equations in 1984 and 1987 on the unfertilized (0), PK and NPK fertilized plots.

Liite 8. Oksien kuivamassayhtälöt vuonna 1984 ja 1987 lannoittamattomilla (0) sekä PK- ja NPK- lannoitetuilla koealoilla.

Independent variable *Selittävä muuttuja*	1984 all-*kaikki*	1987 0	 PK	 NPK
	Coefficients - *Kertoimet*			
	ln (C- needles) - *ln (C- neulaset)*, g			
Constant - *Vakio*	-5.2650	-5.0515	-4.2297	-4.2770
ln(d_b)	1.3751	1.9573	1.9317	2.4161
ln(h_b)	0.6310	0.3657	0.1700	-0.1950
pos	0.0426	0.0302	0.0400	0.0524
pos^2*10^{-4}	-2.112	-1.453	-2.591	-3.298
n	186	63	63	63
R^2	0.81	0.95	0.91	0.89
S_e	0.4640	0.2469	0.2628	0.3970
S_e%	49.0	25.1	26.7	41.3
	ln {(C+1- needles)+1} - *ln {(C+1- neulaset)+1 }*, g			
Constant - *Vakio*	-4.8294	-3.8305	-6.8975	-5.4542
ln(d_b)	1.1403	1.2915	0.2036	1.1634
ln(h_b)	0.7132	0.4893	1.7692	0.8987
pos	0.0506	0.0523	0.0519	0.0633
pos^2*10^{-4}	-4.247	-5.018	-4.246	-5.817
n	186	63	63	63
R^2	0.90	0.90	0.94	0.93
S_e	0.3598	0.4013	0.3189	0.3700
S_e%	37.6	42.3	33.1	38.8
	ln {(C≥2- needles)+1} - *ln {(C≥2- neulaset)+1 }*, g			
Constant - *Vakio*	-1.7197	-1.0720	-0.5395	-1.7860
ln(d_b)	1.7754	1.9294	1.8829	2.8341
ln(h_b)	-0.2267	-0.4460	-0.6405	-0.8600
pos	0.0520	0.0538	0.0607	0.0419
pos^2*10^{-4}	-6.544	-6.797	-8.5688	-5.524
n	186	63	63	63
R^2	0.86	0.88	0.87	0.81
S_e	0.4991	0.4354	0.4432	0.3040
S_e%	53.6	46.2	47.1	71.2
	ln (Living branches) - *ln (Elävät oksat)*, g			
Constant - *Vakio*	-5.8400	-6.4365	-6.6572	-6.1496
ln(d_b)	1.8800	1.5882	1.7390	1.9250
ln(h_b)	1.0716	1.3576	1.3057	1.092
n	186	63	63	63
R^2	0.97	0.99	0.99	0.99
S_e	0.2628	0.1794	0.1601	0.1932
S_e%	26.7	18.1	16.1	19.5

Appendix 9. Dry mass equations of different crown compartments in 1984 and 1987 on the unfertilized (0), PK and NPK fertilized plots.

Liite 9. Latvuksen eri osien kuivamassayhtälöt vuonna 1984 ja 1987 lannoittamattomilla (0) sekä PK- ja NPK-lannoitetuilla koealoilla.

Independent variable *Selittävä muuttuja*	1984 all-*kaikki*	1987 0	 PK	 NPK
	Coefficients - *Kertoimet*			
	ln (Cones+1)* - *ln (Kävyt+1)**, g			
Constant - *Vakio*		9.7570	-4.1570	-3.3124
ln(d)		5.2788	3.2730	3.3491
n				
R^2		0.74	0.65	0.54
S_e		1.3140	0.9240	1.5430
S_e%		215.0	116.1	313.3
	ln (C- needles) - *ln (C- neulaset)*, g			
Constant - *Vakio*	2.8966	1.8004	2.5858	2.4000
ln(d)	1.9320	2.2770	1.9820	2.1108
ln(cr)	1.1458	0.7551	0.7917	1.1190
n	27	9	9	9
R^2	0.98	0.99	0.96	0.98
S_e	0.1322	0.1011	0.1777	0.1640
S_e%	13.3	10.1	17.9	16.5
	ln (C+1- needles) - *ln (C+1- neulaset)*, g			
Constant - *Vakio*	2.6514	1.7072	3.2199	3.1822
ln(d)	1.9828	2.0529	1.7782	1.9598
ln(cr)	1.1520	0.2108	0.9352	1.5340
n	27	9	9	9
R^2	0.98	0.99	0.95	0.98
S_e	0.1430	0.1111	0.1991	0.1607
S_e%	14.4	11.1	20.1	16.2
	ln (C≥2- needles) - *ln (C≥2- neulaset)*, g			
Constant - *Vakio*	2.6905	0.1588	1.8429	0.8310
ln(d)	1.8779	2.2563	1.7245	2.5454
ln(cr)	0.8357	-0.5938	0.3424	1.3964
n	27	9	9	9
R^2	0.98	0.97	0.94	0.99
S_e	0.1350	0.1631	0.1892	0.1332
S_e%	13.6	16.4	19.1	13.4
	ln (Living branches) - *ln (Elävät oksat)*, g			
Constant - *Vakio*	2.7932	1.8239	2.9424	3.7943
ln(d)	2.6708	2.7347	2.5359	2.6129
ln(cr)	1.3568	0.1899	0.9977	2.4262
n				
R^2	0.97	0.99	0.94	0.99
S_e	0.2239	0.1518	0.2866	0.1469
S_e%	22.7	15.3	29.2	14.8
	ln (Dead branches) - *ln (Kuolleet oksat)*, g			
Constant - *Vakio*	1.8943	1.8330	1.3496	1.1418
ln(d)	2.2181	2.3913	2.5237	2.5966
n	27	9	9	9
R^2	0.87	0.88	0.93	0.89
S_e	0.3649	0.3732	0.2712	0.4584
S_e%	37.7	38.6	27.6	48.3

* Values below 0=0 - *arvot alle 0=0.*

Appendix 10. Calculation of the needle dry mass production in 1985-1987. Adjusted for the dry weight changes on the unfertilized plots, (standard deviation in parentheses).

Liite 10. Neulaskuivamassan tuotoksen (kg/ha) laskenta vuosille 1985-1987. Kuivamassan muutokset huomioitu lannoittamattoman aineiston mukaisesti, (keskihajonta suluissa).

	0	PK kg/ha	NPK
Needle dry mass 1984 - *Neulaskuivamassa 1984*	4481 (68)	4565 (205)	4392 (214)
Litterfall 1984-1987 - *Karikesato 1984-1987*	8444 (557)	7763 (1113)	8060 (954)
1985-1987 formed needles in litterfall *1985-1987 syntyneitä neulasia karikesadossa*	3963 (602)	3197 (945)	3668 (748)
Needle dry mass 1987 - *Neulaskuivamassa 1987*	3372 (93)	3711 (128)	3601 (142)
Needle dry mass production 1985-1987 *Neulaskuivamassan tuotos 1985-1987*	7335 (645)	6908 (1053)	7269 (878)

Appendix 11. The mean nutrient concentrations of the litterfall on the unfertilized (0), PK and NPK fertilized plots during 3.9.1984 - 1.9.1987, (standard deviation in parentheses).

Liite 11. Neulas- ja muun karikkeen keskimääräiset ravinnepitoisuudet lannoittamattomilla (0) sekä PK- ja NPK-lannoitetuilla koealoilla ajalla 3.9.1984-1.9.1987, (keskihajonta suluissa).

	Needles - *Neulaset*			Other - *Muu*		
	0	PK	NPK	0	PK	NPK
N %	0.598	0.601	0.703	0.503	0.546	0.540
	(0.023)	(0.009)	(0.034)	(0.032)	(0.090)	(0.057)
K %	0.078	0.101	0.105	0.063	0.087	0.082
	(0.004)	(0.005)	(0.014)	(0.004)	(0.010)	(0.010)
Ca %	0.561	0.583	0.665	0.223	0.222	0.193
	(0.019)	(0.044)	(0.154)	(0.050)	(0.051)	(0.027)
Mg %	0.070	0.080	0.080	0.035	0.040	0.039
	(0.002)	(0.007)	(0.012)	(0.001)	(0.004)	(0.005)
P %	0.038	0.042	0.048	0.037	0.047	0.039
	(0.002)	(0.002)	(0.001)	(0.002)	(0.013)	(0.004)
S %	0.062	0.064	0.070	0.052	0.054	0.051
	(0.001)	(0.001)	(0.001)	(0.001)	(0.006)	(0.005)
B ppm	20	46	46	11	13	14
	(7)	(7)	(3)	(1)	(1)	(1)
Fe ppm	88.4	89.3	96.9	187	189	145
	(2.3)	(3.9)	(13.3)	(63)	(22)	(29)
Mn ppm	892	932	998	80	92	84
	(113)	(15)	(179)	(9)	(10)	(11)
Zn ppm	59	68	71	33	35	32
	(4)	(4)	(13)	(4)	(4)	(2)
Cu ppm	20	20	22	79	98	71
	(1)	(1)	(3)	(11)	(20)	(23)

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