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The effect of repeated fertilizations on volume growth and needle nutrient concentrations of Scots pine (*Pinus sylvestris* L.) on a drained pine mire.

Jatkolannoitusten vaikutus männyn (*Pinus sylvestris* L.) tilavuuskasvuun ja neulasten ravinnepitoisuuksiin ojitetulla rämeellä

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The nutritional status of Scots pine (*Pinus sylvestris* L.) stands growing on a nitrogen-rich, drained pine mire in western Finland was studied after refertilization using needle analysis and the response of stand volume growth. The main aim was to find out if K-refertilization alone could maintain or increase the volume growth without causing a nutrient imbalance between K and P. The initial fertilization was carried out in 1961–62 using PK fertilizer and refertilized in 1976 and 1989 with different combinations of nitrogen (N), phosphorus (P), potassium (K) and boron (B). Needle samples were taken and the tree stands were measured in 1996 and 2001. Peat samples were taken in 2002. According to the needle analysis results, the concentration of P was above the deficiency level in all the treatments in 1995 and 2000. There was a clear shortage of K in the needles collected from the control treatment, but the concentration of K was still adequate 12 years after the latest K refertilization. The volume growth of the stands clearly responded to the 1976 refertilization with K alone, which was probably due to the fact that trees had been suffering from K deficiency before the first refertilization and 14–15 years thereafter. After the second refertilization, the combination of K and P increased the annual volume growth more than refertilization with K alone. This indicates that about 25 years after the initial fertilization, there was already some shortage of P. The highest stand volume was associated with the combined K (1976) and PK (1989) refertilization treatment. Refertilization with N did not increase stand volumes during the study period.

Keywords: fertilization, refertilization, pine mire, potassium, phosphorus, yield, volume growth

Introduction

The surface peat on pine mires contains only small amounts of native potassium, K (Puustjärvi 1965, Paavilainen 1980, Westman 1981, Kaunisto & Paavilainen 1988, Kaunisto & Moilanen 1998). Potassium deficiency is often the most important reason for the decline of growth on originally open, drained mires or poorly forested wet peatlands with a thick peat layer (Paavilainen 1979, Kaunisto & Tukeva 1984, Moilanen 1984, Kaunisto 1989, Kaunisto 1992, Laiho et al. 2000). The shortage of K may cause sudden leader dieback and even death of trees (Kaunisto & Tukeva 1984). It also reduces the resistance of pines to drought, insect damages and fungal diseases, for example pine canker infection (Ylimartimo 1991, Reinikainen et al. 1998).

The amount of K in the root layer decreases because of the uptake of K by tree stands (Paavilainen 1980, Finér 1992) and the loss of K in tree harvesting (Kaunisto & Paavilainen 1988, Kaunisto & Moilanen 1998). In addition, K is a mobile element which exists freely in soil solution or only weakly bound on the cation exchange sites in peat, and is therefore very susceptible to leaching (Ahti 1983, Malcolm & Cuttle 1983, Wells & Williams 1996).

After drainage, the concentrations and amounts of organically bound N and P in the surface peat increase (Kaunisto & Paavilainen 1988, Kaunisto & Moilanen 1998) as a result of enhanced microbial activity (Kaila 1956) especially on the ombrotrophic sites (Laiho et al. 1999). The amounts of these nutrients in the surface peat increase also because of the compaction of peat. On mesotrophic peatlands, where the N resources are generally sufficient, the shortage of phosphorus (P) in relation to N is a common growth limiting factor (Paarlahti et al. 1971, Kaunisto & Tukeva 1984, Silfverberg & Hartman 1999). Pines suffering from P deficiency may also be exposed to frost damage during the growing season (Reinikainen 1983).

The effect of P fertilization is long lasting (25–30 years) even with modest doses of P (Silfverberg & Hartman 1999), but the duration of K fertilization is only 10–15 years (Kaunisto & Tukeva 1984, Kaunisto 1992, Kaunisto et al. 1999). In order to maintain satisfactory tree growth on potassium-poor peatlands, it is necessary to fertilize stands more often with K than with P. One-sided K fertilization may, however, cause imbalance between P and K if the P nutrition of trees has already weakened. Therefore we should know more about the timing of K refertilization in relation to P fertilization.

Potassium fertilization either alone or together with P increases the foliar K concentrations of tree stands (Kaunisto & Tukeva 1984). The advantage of mere K fertilization instead of combined PK fertilization would be a reduction in fertilization costs. Also the leaching of P, which is one of the reasons for the eutrophication of watercourses, could be reduced because of enhanced stand growth and increased phosphorus uptake by trees.

This study aims at clarifying the growth response of Scots pine stands to refertilization with different combinations of N, P and/or K on a sparsely stocked drained mire of adequate peat nitrogen concentration. The main aim is to compare the effects of K- and PK- fertilization on the volume growth in order to find out if K-fertilization alone could maintain or increase growth on this drained pine mire. Also the nutritional status of trees is studied by using needle analysis.

Material and methods

Sites and treatments

The material was collected from a fertilization experiment at Liesineva in Parkano (61°59'N, 23°15'E). The area had been drained with open ditches (spacing 60–100 m) in 1934–36 and supplemented in 1949–51 with covered ditches (spacing 20–60 m). The ditch cleaning was carried out in 1986. The peatland site type had originally been partly a treeless tall-sedge fen, partly a cotton-grass-sedge pine fen. During the present study the area was a *Vaccinium vitis-idaea* transformed peatland site (Kaunisto 1989). The area is presently stocked mainly by uneven-aged, 50–150-year-old Scots pines *(Pinus sylvestris* L.*)* with an admixture of downy birch *(Betula pubescens* Ehrh.*)* and Norway spruce (*Picea abies* (L.) Karst.*)*.

The basic fertilization was carried out in 1961–62 by applying rock phosphate (500–600 kg ha^{-1}) and potassium chloride (150 kg ha^{-1}). In 1976 a 2^3 factorial refertilization experiment was set up in the area as randomised complete blocks using N, P and K fertilizers (Kaunisto 1989), (Table 1). This design was selected because of the high variation in the volume of pine stands (10–78 m^3 ha^{-1}). The experimental area was divided into 11 blocks according to the size of the trees. The experiment consisted of 88 plots with 11 replicates for each treatment. The areas of the plots were 1300 or 1400 m^2. The fertilizers and their amounts were as follows: calcium ammonium nitrate (500 kg ha^{-1}), rock phosphate (500 kg ha^{-1}) and potassium chloride (250 kg ha^{-1}). The thickness of the peat layer is more than 1 meter in the whole area. Before the first refertilization in 1976 the concentrations of N (1.90%) and P (1190 mg kg^{-1}) in the surface peat (0–10 cm) were rather high, but the concentration of K was only 350 mg kg^{-1} on average (Kaunisto 1989).

In 1989 the refertilization was repeated using mere potassium chloride fertiliser (160 kg ha^{-1}) or a combination of potassium chloride fertiliser (160 kg ha^{-1}) and rock phosphate (330 kg ha^{-1}). All the plots, including the controls were fertilized with boron (B) in 1989. Both refertilizations were carried out in the spring. Five different combinations of the two refertilization treatments (control, K_{76}+PK_{89}, NK_{76}+PK_{89}, PK_{76}+K_{89} and NPK_{76}+K_{89}) were selected for the present study. Three of the blocks had been clear-cut and regenerated in the 1980's and are not included in the present investigation. Accordingly, the number of experimental plots is 8x5 = 40 in this study.

In 1979–1980 the experimental area was infected by a severe epidemic of pine canker, *Gremmeniella abietina* (Kaunisto 1989). The total drain in this study consists of the dead and damaged pines that were removed after the epidemic in 1985 (on average 13–19 m^3 ha^{-1} per plot, Kaunisto 1989).

Tree stand measurements

The tree stands were measured in 1996 and again in 2001. The number of live and dead pines, birches and spruces was counted on each plot. Birches and spruces were not included in this study. One tree of each diameter class was chosen as a sample tree as well as two largest and two smallest trees on every plot. The thickness of bark, height and diameter (1.3 m) of the sample trees (11–21 pines on each plot) were measured. The annual diameter increment of the sample trees were determined in 1996 from increment cores. The stem volume with bark, basal area and annual growth were calculated using the KPL-program (Heinonen 1994) of the Finnish Forest Research Institute. Because increment cores were not taken in 2001, the annual growth in 1995–2000 was the mean value of that period.

Table 1. The amounts and combinations of fertilizers in different treatments.
Taulukko 1. Lannoitteiden määrät ja yhdistelmät eri käsittelyissä.

Treatment *Käsittely*	Basic fertilization[a)] *Peruslannoitus* 1961–62 1989	1st refertilization[b)] *1. jatkolannoitus* 1976	2nd refertilization[c)] *2. jatkolannoitus* 1989 1976
1	PK	Control	Control+B
2	PK	K	PK+B
3	PK	NK	PK+B
4	PK	PK	K+B
5	PK	NPK	K+B

a) 72–86 kg P ha^{-1}, 62 kg K ha^{-1}
b) 72 kg P ha^{-1}, 125 kg K ha^{-1}, 137.5 kg N ha ^{1}
c) 49.5 kg P ha^{-1}, 80 kg K ha^{-1}, 1.4 kg B ha ^{1}

Sampling for nutrient analyses

The needle samples of pine were collected in February 1996 and 2001. Current-year needles were sampled from 8 to 10 dominant trees per plot from the sun-exposed upper whorls of tree crowns. No treatments had been carried out in the experimental area between the samplings. The samples were analysed for the N, P, K, Ca, Mg, S, Fe, B, Cu, Zn and Mn concentrations. The dry mass of 100 needles was also measured. The analyses were carried out using the standard methods of the Finnish Forest Research Institute (Halonen et al. 1983). The total N was analysed by the Kjeldahl method at the Parkano Research Station. The concentrations of the other elements were determined with the plasma emission spectrophotometer (ICP) in the laboratory of the Vantaa Research Centre after nitric acid digestion at the Parkano Research Station.

Peat samples were taken from each experimental plot in July 2002. Four subsamples were taken halfway between the plot centre point and the plot corner. One subsample was taken in the plot centre. The samples were taken with an auger having the cutting edge of 60 x 60 mm. The raw humus layer, which consisted of the litter and residues of the bottom layer vegetation was removed from each sample and analysed separately. The peat samples were taken 0–10 and 10–20 cm below the raw humus layer. The thickness of the raw humus layer varied between 3.0–6.8 cm, but there was no clear difference in the thickness between the treatments. The peat and raw humus samples were dried at 105° C for dry mass determination and analysed for total carbon, hydrogen and nitrogen with Leco CHN. The nitric acid digestion was carried out at the Parkano Research Station and the concentrations of P, K, Ca, Mg, S, Fe, B, Cu, Zn, Mn and Al were analysed with the plasma emission spectrophotometer (ICP) in the laboratory of the Vantaa Research Centre. The mean concentrations and total amounts of N, P, K, Fe and Al are presented in Table 2. The amounts of different elements in peat were quite independent of the refertilization treatments.

Statistical analyses

SPSS 11 and BMDP 2V programs were used in the statistical analysis. Differences between the fertilization treatments were calculated using the analyses of variance and covariance. The average growth before the first refertilization (1971–74) was used as a covariate for the calculation of differences in the total yield and in stand growth

Table 2. The mean concentrations (mg kg^{-1}) and total amounts (kg ha ^{1}) of nutrients in the 0–20 cm peat layer in 2002. The raw humus layer is included. Standard deviations are shown in brackets.

Taulukko 2. Turpeen keskimääräiset ravinnepitoisuudet (mg kg^{-1}) ja kokonaisravinnemäärät (kg ha^{-1}) vuonna 2002. Mukana raakahumuskerros sekä 0–20 cm:n turvekerros. Suluissa keskihajonnat.

Treatment *Käsittely*	Concentration *Pitoisuus*					Amount *Määrä*				
	N	P	K	Fe	Al	N	P	K	Fe	Al
Control	1.93	989	293	2580	2285	6670	339	74	1003	889
	(0.2)	(140)	(31)	(885)	(656)	(1314)	(69)	(11)	(382)	(308)
K_{76}+PK_{89}	1.88	961	363	2464	1981	6591	332	94	981	787
	(0.2)	(104)	(55)	(754)	(378)	(1425)	(65)	(13)	(368)	(207)
NK_{76}+PK_{89}	1.96	1034	360	2867	2485	6981	370	94	1169	1025
	(0.3)	(138)	(61)	(851)	(766)	(1930)	(93)	(20)	(453)	(431)
PK_{76}+K_{89}	1.95	963	352	2391	2100	6636	325	87	913	802
	(0.2)	(133)	(48)	(429)	(461)	(1476)	(83)	(18)	(252)	(257)
NPK_{76}+K_{89}	1.88	950	357	2535	2016	6471	327	85	1007	796
	(0.3)	(163)	(57)	(528)	(575)	(2001)	(111)	(14)	(378)	(387)
Total	1.92	979	345	2568	2174	6670	338	87	1015	860
	(0.2)	(133)	(55)	(695)	(585)	(1576)	(83)	(17)	(363)	(324)

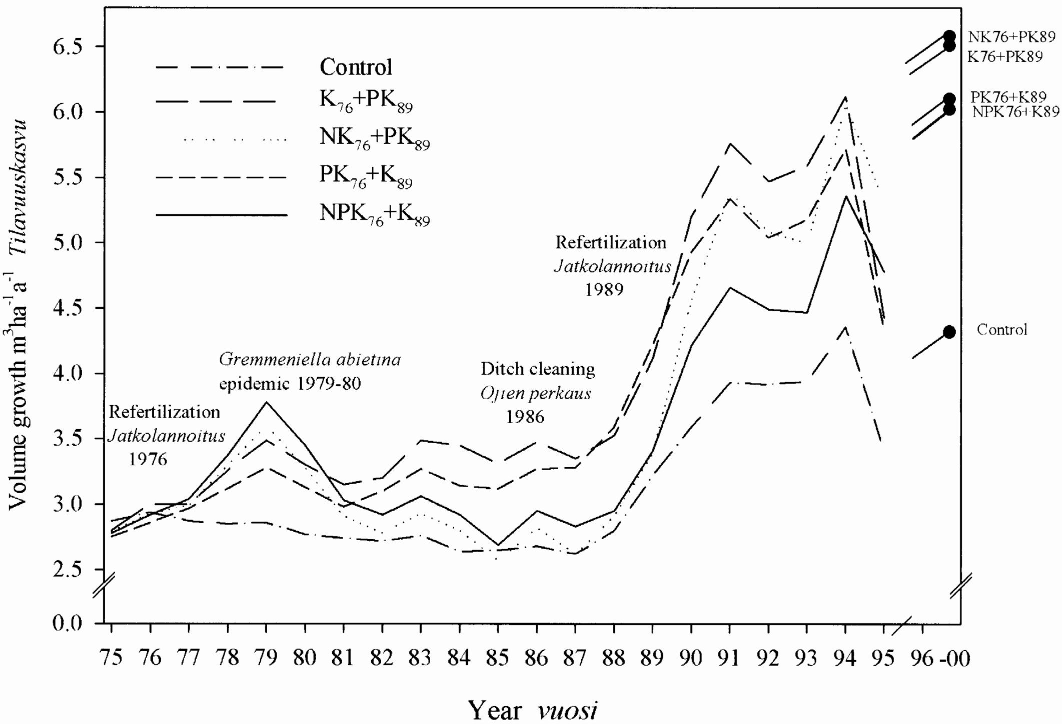

Fig. 1. The volume growth of pine in different refertilization treatments in 1975–2000. The mean volume growth in 1971–74 as a covariate.

Kuva 1. Männyn tilavuuskasvu eri jatkolannoituskäsittelyissä vuosina 1975–2000. Kovariaattina keskimääräinen tilavuuskasvu vuosina 1971–74.

after the first refertilization in order to remove the effect of the annual volume growth before the first refertilization. The pairwise comparisons of means were made with the Bonferroni test and Tukey's test. The correlations between variables were tested using correlation analysis (Pearson) and scatter plots.

Results

Annual volume growth

After the first refertilization in 1976 the annual volume growth of pine increased most on the plots that had received N (Fig. 1). The growth of pine decreased very abruptly especially in the refertilization treatments NK_{76} and NPK_{76} during the pine canker epidemic in 1979–80. After the epidemic, the volume growth on the PK_{76} and K_{76} -fertilized plots was fairly stable or slightly increasing whereas on the N-fertilized plots the volume growth continued to decline for several years. The dead and badly damaged trees were not included in the calculations, so the decline of growth represents the situation of the remaining trees.

According to the pairwise comparison (Bonferroni) differences between the refertilization treatments were statistically significant for the first time in 1979 when the volume growth in treatments NK_{76} and NPK_{76} were higher than in the control. The volume growth in the refertilization treatment K_{76} has been higher than in the control since 1982. This difference was statistically significant throughout the whole study period excluding the last five-year-period 1996–2000. The volume growth in the refertilization treatment PK_{76}+K_{89} has differed from the control since 1986 and NK_{76}+PK_{89} since 1991. The volume growth in treatment K_{76} was significantly

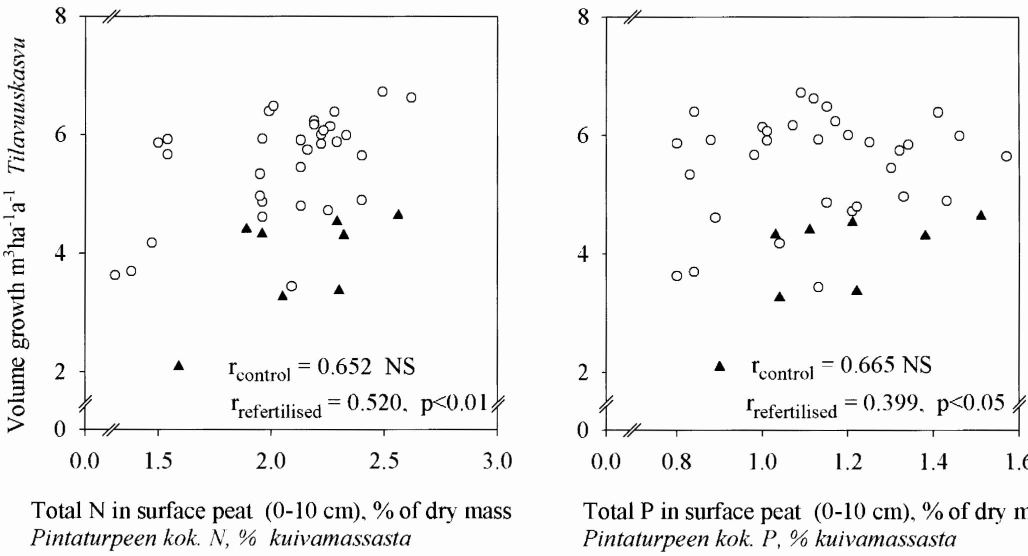

Fig. 2 . The correlation between the nitrogen and phosphorus concentration in peat in 2002 and the mean annual volume growth during period 1995–2000. Control plots are marked with triangles and refertilized plots with circles.

Kuva 2. Turpeen typpi- ja fosforipitoisuuden (vuonna 2002) sekä vuotuisen keskikasvun välinen korrelaatio ajanjaksolla 1995–2000. Kontrollikoealat on merkitty kolmioilla ja jatkolannoitetut koealat ympyröillä.

higher than in treatment NK_{76} during 1983–87. Due to the high variation in the volume growth (range 1.22–7.75 m^3 ha^{-1} a^{-1}) during 1996–2000, the differences between the treatments were not statistically significant even though the volume growth on the control plots was clearly lower than in the other treatments on average.

The combination of P and K increased the annual volume growth after the second refertilization more than K alone (Fig. 1). The differences between PK_{89}-refertilization and K_{89}-refertilization in the annual volume growth were statistically significant during 1991–1994.

The correlations between the N and P concentration in peat in 2002 and the annual volume growth were calculated for the periods 1976–88, 1989–94 and 1995–2000. The N concentration in peat correlated with the volume growth significantly only in the period of 1995–2000 (Fig. 2). The situation was similar with the P concentration in peat (Fig 2.).

Total yield

The effect of the previous volume growth on the total yield was removed by using the mean annual volume growth during 1971–74 as a covariate. According to the total yield, the best growth results were achieved by using K and P together in the second refertilization (Fig. 3). The total yield in the refertilization treatments K_{76}+PK_{89} and K_{76}+PK_{89} was statistically significantly higher than in the control.

Foliar nutrients

Needle samples were taken 7–12 years after the latest refertilization. According to the needle analysis the K-concentration was below the severe deficiency limit (3.5 mg g^{-1}) (Paarlahti et al. 1971, Sarjala & Kaunisto 1993) on the control plots both in 1995 and 2000 (Table 3). The needle P concentrations were highest in the PK_{89}-treatments, but there was no sign of deficiency in the other treatments either. It was, however, surprising that the P concentrations on the control plots were near or within the optimum values (1.6–2.2 mg g^{-1}, Reinikainen et al. 1998) still 39 years after the basic fertilization. The mean Zn concentration in 1995 in all the treatments was close to the deficiency limit of 40 mg kg^{-1} (Reinikainen et al. 1998).

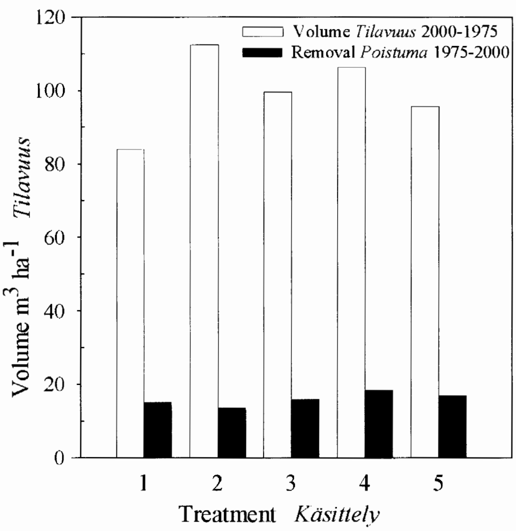

Fig. 3. The total yield of pine in different refertilization treatments (1:control, 2:K_{76}+PK_{89}, 3: NK_{76}+PK_{89}, 4: PK_{76}+K_{89} and 5:NPK_{76}+K_{89}) during 1975–2000. The effect of the previous volume growth on the total yield was removed by using the mean annual volume growth during 1971–74 as a covariate.

Kuva 3. Männyn kokonaistuotos eri jatkolannoituskäsittelyissä (1:Kontrolli, 2:K_{76}+PK_{89}, 3: NK_{76}+PK_{89}, 4: PK_{76}+K_{89} ja 5:NPK_{76}+K_{89}) vuosina 1975–2000. Jatkolannoitusta edeltäneen tilavuuskasvun vaikutus kokonaistuotokseen poistettiin käyttämällä kovariaattina keskimääräistä vuotuista tilavuuskasvua vuosina 1971–74.

The needle nutrient concentrations were higher in 2000 than in 1995 on average, especially the N and P concentrations had clearly increased. The concentration of K and the needle mass were at the same level in both sampling years.

There were statistically significant differences between the control and the refertilization treatments in the mean concentrations of K, Mg, Mn and Fe in the current-year needles both in 1995 and 2000 (Table 3). The concentration of K was significantly lower in the controls than in the refertilized treatments. The concentrations of Mg and Mn were higher on the control plots than on the refertilised ones. The needle Fe concentrations on the control plots were significantly lower than in all the refertilised treatments except in treatment K_{76}+PK_{89} in 1995.

The N/P-ratios in the needles varied between 6.3–10.8 in 1995 and between 6.0–11.3 in 2000, and there were no significant differences between the treatments. According to earlier studies, the optimal N/P ratio is between 8 and 11 (Puustjärvi 1965, Paarlahti et al. 1971, Kaunisto & Tukeva 1984). The N/K-ratio was significantly higher on the control plots (mean 1995: 4.32; mean 2000: 4.91) than in the refertilization treatments (mean 1995: 2.8; mean 2000: 3.5). The optimal value for N/K ratio is 3.0–3.5 (Puustjärvi 1965, Paarlahti et al. 1971). On the refertilized plots the K/P ratios varied between 2.4 and 3.7 in 1995 and between 1.69 and 2.79 in 2000.

Discussion

In this investigation NPK and NK fertilizations in 1976 increased the growth at first, but the increase was followed by a rapid growth reduction due to a *Gremmeniella abietina* epidemic. The reduction in growth after the epidemic correlated positively with the pre-epidemic growth in all the treatments Kaunisto (1989). K application shortened the period of growth reduction, but N fertilization slowed down the recovery of trees (Kaunisto 1989). It was assumed that the remaining trees had recovered from the epidemic by the time of the second refertilization so that the epidemic had no significant effect on the results after the second refertilization. Nitrogen fertilization possibly intensified the negative effect of the pine canker epidemic on growth. On the other hand, the imbalance of foliar N/K and N/Mg ratios has been reported to reduce the resistance of trees to pine canker infection more than the increased availability of N alone (Ylimartimo 1991).

According to Lauhanen & Ahti (2001) the effects of ditch cleaning and complementary ditching on the volume growth were small during the first five-year period after the treatments. The increase in the volume growth was reported to be higher during the post-treatment period of 20 years in comparison with the first ten-year period (Keltikangas et al. 1986, Hökkä 1997). On the other hand, the fast growth reactions at Liesineva after the ditch cleaning were probably due to the fact that there was already an urgent need for ditch network maintenance in the middle of the 1980's. However, the situation was similar in the whole experimental area and differences in the volume growth between the refertilization treatments can be considered as a result of different combinations of fertilizers. This is also supported also by the experimental design, because the different treatments were in quite limited areas inside the blocks and the blocks were evenly distributed over the experimental area.

The concentration of Mn in the needles indicates the drainage condition of a site. If the ditches are in good condition, the Mn concentration is lower than in trees growing on wet soils (Lauhanen & Kaunisto 1999). At Liesineva the Mn concentration in the needles was higher on the control plots than in the other treatments. One reason may be the supposedly higher transpiration from the refertilized than unrefertilized plots because of their bigger stand volume. Fertilization with K also decreases the Mn concentration in the needles especially if there is no simultaneous shortage of P (Veijalainen 1977). A similar "dilution effect" has also been found in the B, Fe and Zn concentrations of needles (Veijalainen 1977, Finér 1992).

There was no need for P application for several years after the first refertilization, because the mere K refertilization in 1976 increased the volume growth slightly more than PK refertilization. The result also implies that one-sided K refertilization 15 years after P fertilization did not cause any severe imbalance in the K and P nutrition of trees. This result is supported also by the fact that stand growth responded quite well also to the mere K refertilization in 1989, 14 years after the first refertilization. On the other hand,

Table 3. Foliar nutrient concentrations and the dry mass (DM) of 100 needles in different refertilization treatments in 1995 and 2000 and the p-values in the analysis of variance. Standard deviations are shown in brackets. Values marked with the same letter did not differ from each other significantly according to pairwise comparison (Tukey).

Taulukko 3. Neulasten ravinnepitoisuus ja 100 neulasen kuivapaino (DM) eri jatkolannoituskäsittelyissä vuosina 1995 ja 2000 sekä varianssianalyysin p-arvot. Suluissa keskihajonnat. Samalla kirjaimella merkityt luvut eivät eronneet merkitsevästi toisistaan pareittaisessa vertailussa (Tukey).

	Control	K_{76} + PK_{89}	NK_{76} + PK_{89}	PK_{76} + K_{89}	NPK_{76} + K_{89}	p
1995						
N mg g^{-1}	13.0 (0.4)	13.5 (0.8)	13.49 (0.8)	13.5 (0.5)	13.3 (0.4)	0.550
P mg g^{-1}	1.55 (0.2)	1.70 (0.1)	1.78 (0.3)	1.67 (0.2)	1.60 (0.2)	0.100
K mg g^{-1}	3.05 (0.4)a	4.78 (0.2)b	4.84 (0.4)b	4.83 (0.3)b	4.55 (0.3)b	**0.000**
Ca mg g^{-1}	1.70 (0.2)	1.65 (0.1)	1.78 (0.2)	1.66 (0.09)	1.63 (0.1)	0.381
Mg mg g^{-1}	1.28 (0.1)a	1.08 (0.07)b	1.13 (0.08)b	1.13 (0.1)b	1.08 (0.09)b	**0.001**
Fe mg kg^{-1}	29 (2.1)a	33 (4.1)ab	34 (4.7)b	34 (4.6)b	34 (4.0)b	**0.004**
B mg kg^{-1}	23 (3.8)	23 (3.8)	23 (2.8)	24 (2.3)	24 (2.5)	0.726
Mn mg kg^{-1}	205 (66)a	121 (23)b	141 (38)b	140 (30)b	142 (47)b	**0.000**
Cu mg kg^{-1}	2.9 (0.3)	2.9 (0.4)	2.9 (0.6)	3.0 (0.4)	2.8 (0.5)	0.896
Zn mg kg^{-1}	38 (4.6)	38 (3.5)	41 (6.1)	41 (2.3)	39 (7.2)	0.362
DM g	2.22 (0.2)	2.37 (0.4)	2.30 (0.3)	2.40 (0.2)	2.32 (0.4)	0.678
2000						
N	16.3 (1.0)	16.3 (1.8)	16.4 (1.7)	15.7 (1.5)	15.1 (1.0)	0.232
P	2.09 (0.3)	2.05 (0.2)	2.12 (0.3)	1.89 (0.2)	1.95 (0.2)	0.094
K	3.35 (0.3)a	4.69 (0.3)b	4.45 (0.4)b	4.70 (0.2)b	4.40 (0.6)b	**0.000**
Ca	2.25 (0.3)	2.38 (0.2)	2.39 (0.3)	2.28 (0.2)	2.23 (0.2)	0.425
Mg	1.72 (0.2)a	1.33 (0.2)b	1.44 (0.2) b	1.33 (0.2)b	1.45 (0.2)b	**0.000**
Fe	40 (3.5)a	43 (4.6)ab	44 (5.8)ab	44 (4.8)ab	46 (6.6) b	**0.033**
B	24 (3.3)	24 (3.9)	24 (3.0)	24 (2.9)	25 (3.9)	0.873
Mn	271 (82) b	150 (38)a	207 (40)ab	191 (35)a	211 (49)ab	**0.002**
Cu	3.0 (0.3)	2.5 (0.6)	2.9 (0.7)	3.2 (0.4)	3.0 (0.4)	0.119
Zn	50 (7.1)	46 (7.9)	50 (12.9)	53 (7.3)	52 (11.1)	0.368
DM	1.77 (0.2)a	2.32 (0.4)bc	2.17 (0.4)ac	2.06 (0.4)ac	2.19(0.4)bc	**0.008**

after the second refertilization the volume growth on the plots that were fertilized with PK in 1989 was higher than on the plots that had received only K. The result indicates that about 25 years after the basic fertilization there was already some shortage of P. This agrees well with the results reported by Silfverberg and Hartman (1999), who suggested that the effect of P fertilization could continue for 25–30 years.

The results of the needle P analyses support fairly well the growth results. The effect of P fertilization continued still 25 years after the first refertilization in PK_{76}+K_{89} and NPK_{76}+K_{89} treatments. It was somewhat surprising that the needle P concentrations on the control plots were optimal still 39 years after the basic P-fertilization. A shortage of P reduces the size of needles and may therefore increase the concentration (Reinikainen et al. 1998). At Liesineva the dry mass of 100 needles was in the control treatment about the same as in the refertilized treatments in 1995 but clearly smaller in 2000 (Table 3). It is possible that trees on the control plots suffered from P deficiency in 2000 despite the high concentration of P in the needles. The doses of P-fertiliser used in the basic fertilization and in the first refertilization were about double (86 and 72 kg P ha^{-1}, respectively) compared with the present recommendations (40–45 kg P ha^{-1}), which may also have affected the result. However, no differences were found in the peat P amounts between the control plots and the refertilized ones in 2002.

When calculated according to the values used by Kaunisto & Paavilainen (1988) for the phosphorus contents of pine stands the refertilized stands in the present study contained on average 25 kg ha^{-1} of P including the standing crop in 2000 and the drain during 1975–2000. On the control plots the mean P content was 21 kg ha^{-1}. The amount of total P in peat (0–20 cm including raw humus) on the refertilized plots varied between 195–555 kg ha^{-1} and about 14% was in a soluble form. The control plots contained 236–437 kg P ha^{-1}. It is not known how much of the fertilizer P has penetrated into the deeper peat layers or leached out of the area.

According to Kaunisto & Paavilainen (1988), large doses of P fertilizer led to a substantial leaching of P from the site. The risk of the enhanced leaching of applied P has been observed especially on the nutrient-poor acid peatlands, where the P adsorption capacity is related to the low content of Fe and aluminium in peat (Nieminen & Jarva 1996). A strong correlation between the amounts of P and Fe in peat was observed by Silfverberg & Hartman (1999). In this investigation a clear positive correlation was found between the amount of P and Fe ($r_{refertilized} = 0.755$, $p<0.01$) in peat as well as between the amount of P and Al ($r_{refertilized} = 0.916$, $p<0.01$) in peat.

The concentration and amount of nutrients in peat indicate rather well the wood production capacity of a site (Kaunisto & Paavilainen 1988). Especially, peat N (Kaunisto 1982, Kaunisto 1987, Kaunisto & Paavilainen 1988, but also peat P (Kaunisto & Paavilainen 1988, Silfverberg & Hartman 1999) and peat Fe correlate positively with tree growth. The correlations between the N and P concentration in peat in this study corresponded fairly well to the results in the previous studies.

Apparently the trees suffered from K shortage already at the time of the first refertilization because the volume growth responded to mere K refertilization. The earlier results by Kaunisto (1992) showed that the first fertilization with potassium chloride increased tree growth for 8–22 years depending on the site. According to the results by Kaunisto et al. (1999) the needle K concentration indicated deficiency of K on nitrogen rich sites 16–19 years after the first potassium chloride fertilization. At Liesineva the needle K concentrations in 2000 i.e. 12 years after the latest K refertilization were still adequate.

N-fertilization may decrease the growth of pine seedlings on nitrogen-rich peatlands (Kaunisto 1982). Kaunisto (1987) reported that fertilization with N even in connection with the other main nutrients caused needle and bud damage, and he found a negative correlation between the needle N concentration and the proportion of normal pine seedlings. A short-term effect of N fertilization has been reported by Moilanen (1984), Paavilainen (1984), Silfverberg (1984) and Finér (1991).

It is difficult to explain the strong but short-term decrease in the volume growth in 1995. According to the needle nutrient analysis, trees did not suffer from any acute nutrient deficiency even if the N concentrations in the needles were below the optimum levels (15.0–16.0 mg g^{-1}, Paarlahti et al. 1971, Kaunisto 1982) in all the treatments in 1995. Tree growth is dependent on the temperature sum of two previous years especially on nitrogen poor peatlands (Kaunisto 1985). According to Moilanen 1993, the correlation between the temperature sum and tree growth was, however, not significant. In Parkano the temperature sum in 1994 was close to the long-term average (1172 d.d.), but in 1993 the end of the growing season was rather cold and the temperature sum was only 1048 d.d. The low needle N concentrations in 1995 may be connected with the low temperature sum in 1993 and may be, at least partly, the reason for the reduction in tree growth.

Conclusions

As regards the growth of tree stands, it seems quite safe and beneficial to repeat potassium fertilization at the intervals of about 15 years and phosphorus fertilization at the intervals of 25–30 years on peatlands poor in phosphorus and potassium but adequate nitrogen concentration. Nitrogen fertilization should, however, be avoided.

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Tiivistelmä — Jatkolannoitusten vaikutus männyn (*Pinus sylvestris* L.) tilavuuskasvuun ja neulasten ravinnepitoisuuksiin ojitetulla rämeellä

Kaliumin (K) määrä pintaturpeessa on vähäinen alun perin avoimilla tai vähäpuustoisilla, ojitetuilla turvemailla. Erityisesti typpirikkailla soilla kaliumin puute voi vähentää puuston kasvua sekä aiheuttaa äkillisen latvakasvaimen tai koko puun kuoleman. Fosforin (P) puutos puolestaan vähentää puiden talvenkestävyyttä ja vaikuttaa siten puuston elinvoimaisuuteen. Pelkän kaliumin käyttö lannoitteena vähentäisi paitsi lannoituskustannuksia, myös vesistöjen rehevöitymistä aiheuttavaa fosforin huuhtoutumista. Fosforilannoituksen vaikutuksen on aikaisemmissa tutkimuksissa todettu olevan noin 25–30 vuotta, mutta kaliumlannoituksen vain noin 10–15 vuotta, joten riittävän kasvun aikaansaamiseksi kaliumlannoitus olisi tehtävä useammin kuin fosforilannoitus. Lannoitusten ajoituksesta ei ole vielä riittävästi tutkimustietoa

Mäntypuuston (*Pinus sylvestris* L.) ravinnetilaa ja kasvureaktioita eri lannoituskäsittelyihin tutkittiin ojitetulla rämeellä Länsi-Suomessa. Tärkeimpänä tavoitteena oli selvittää, onko kaliumjatkolannoitus yksistään riittävä ylläpitämään tai lisäämään tilavuuskasvua aiheuttamatta samalla fosforin puutosta. Puuston ravinnetila selvitettiin neulasanalyysien avulla.

Lannoituskoealue sijaitsee Parkanon Liesinevalla, joka on ojitushetkellä (1934–36) ollut suotyypiltään osittain saranevaa ja osittain sara- ja tupasvillarämettä. Täydennysojitus tehtiin vuosina 1949–51 ja ojien perkaus vuonna 1986. Vuosina 1979–81 koealueella oli vakava versosurmaepidemia (*Gremmeniella abietina*), jonka vaurioittamat puut poistettiin kunnostushakkuussa vuonna 1985. Peruslannoituksessa vuosina 1961–62 käytettiin PK-lannoitetta ja jatkolannoituksissa vuosina 1976 ja 1989 erilaisia typen, fosforin ja kaliumin yhdistelmiä (Taulukko 1). Vuonna 1976 perustetun 2^3 faktorikokeen koealoista oli tässä tutkimuksessa mukana 40 koealaa, joiden koko oli 1300–1400 m^2. Neulasnäytteiden otto ja puuston mittaus tehtiin vuosina 1996 ja 2001. Turvenäytteet otettiin vuonna 2002 (Taulukko 2).

Typpilannoituksen vaikutus oli lyhytaikainen ja on saattanut voimistaa puuston tilavuuskasvun nopeaa taantumista versosurmaepidemian jälkeen. Tutkimuksessa oletettiin kunnostushakkuun jälkeen jäljelle jääneen puuston toipuneen epidemiasta toiseen jatkolannoitukseen mennessä. Vuonna 1986 tehdyn ojien perkauksen jälkeen kasvu kääntyi nousuun, mikä viittaa huonontuneeseen vesitalouteen. Vaikutus kohdistui kuitenkin tasaisesti koko alueelle, joten tilavuuskasvun erot eri käsittelyiden välillä ilmaisevat eri lannoitusyhdistelmien vaikutusta.

Pelkkä kaliumjatkolannoitus vuonna 1976 lisäsi puuston tilavuuskasvua selvästi, mikä viittaa siihen, että kaliumin puute oli vaikuttanut kasvuun jo ennen jatkolannoitusta. Fosforin ja kaliumin yhdistelmä toisessa jatkolannoituksessa lisäsi vuotuista tilavuuskasvua enemmän kuin pelkkä kalium eli 25 vuotta peruslannoituksen jälkeen fosforista alkoi olla jo puutetta (Kuva 1). PK-lannoitteen käyttö toisessa jatkolannoituksessa antoi myös korkeimman kokonaistuotoksen tutkimusjakson aikana (Kuva 3).

Nuorimpien neulasten kaliumpitoisuus oli riittävä vielä 12 vuotta viimeisimmän kaliumlannoituksen jälkeen (Taulukko 4). Kontrollikoealoilla näytepuiden neulasten kaliumpitoisuus oli selkeästi puutosrajan alapuolella ja poikkesi tilastollisesti merkitsevästi jatkolannoituskäsittelyjen näytepuiden pitoisuuksista. Fosforilannoituksen vaikutus jatkui vielä 25 vuotta ensimmäisen jatkolannoituksen jälkeen käsittelyissä $PK_{76}+K_{89}$ ja $NPK_{76}K_{89}$. Kontrollikoealoilla neulasten fosforipitoisuus oli optimaalinen 39 vuotta peruslannoituksen jälkeen, mutta vuoden 2000 näyteneulasten kuivamassa oli merkitsevästi pienempi kuin muissa käsittelyissä, mikä viittaa heikentyneeseen fosforitilanteeseen kontrollikoealoilla.

Turpeen kokonaistyppi- ja fosforipitoisuuksien sekä puuston tilavuuskasvun välillä oli tilastollisesti merkitsevä korrelaatio (Kuva 2). Maaperältään kohtalaisen runsastyppisellä koealueella typpilannoituksella ei saatu aikaan puuston kokonaistuotoksen kasvua. Tämä vahvistaa aikaisemmin saatuja tutkimustuloksia, joiden mukaan pintaturpeen typpipitoisuuden avulla voidaan arvioida typpilannoituksen tarvetta. Puuston kokonaistuotos oli korkein käsittelyssä $K_{76}+PK_{89}$, kun tutkimusjaksoa edeltäneen tilavuuskasvun vaikutus oli poistettu kovarianssianalyysin avulla (Kuva 3).

Tulosten perusteella ojitetuilla rämeillä kaliumlannoitus kannattaa toistaa noin 15 vuoden välein ja fosforilannoitus noin 25–30 vuoden välein, mikäli pintaturpeessa on niukasti kaliumia ja fosforia, mutta typpipitoisuus on riittävä. Typpilannoitusta olisi vastaavilla kohteilla kuitenkin vältettävä.