Helsinki 1999

ISSN 0039-5471
Suo 50(1): 1–15

Effect of apatite and phlogopite application on the needle nutrient concentrations of *Pinus sylvestris* (L.) on drained pine mires

Apatiitti- ja flogopiittilannoituksen vaikutus männyn neulasten ravinnepitoisuuksiin ojitetuilla rämeillä

Seppo Kaunisto, Mikko Moilanen & Jorma Issakainen

Seppo Kaunisto, The Finnish Forest Research Institute, Parkano Research Station, Kaironiementie 54, FIN-39700 Parkano, Finland (e-mail seppo.kaunisto@metla.fi)
Mikko Moilanen & Jorma Issakainen, The Finnish Forest Research Institute, Muhos Research Station, FIN-91500 Muhos, Finland (e-mail mikko.moilanen@metla.fi, jorma.issakainen@metla.fi)

Pine nutrition was monitored after the application of phosphorus and potassium fertilisers of different solubility in 12 experiments on drained mires in northern Central Finland. Ten experiments involved the following three treatments: (i) control, (ii) fertilisation with rock phosphate and potassium chloride, and (iii) fertilisation with apatite ore or enriched apatite and phlogopite. Two experiments focused on the fertiliser amount. In seven experiments needle samples were collected three times: 3–7, 11–14 and 16–19 years after fertilisation and in the others once or twice (after 10–17 years). The stands suffered from phosphorus and potassium shortage on the unfertilised plots. Rock phosphate had raised the needle phosphorus concentrations slightly more than apatite by 5–7 and 11–14 years after fertilisation. By the last sampling (16–19 years after) apatite had raised the concentrations to about the same or to a higher level than rock phosphate. Potassium chloride raised the concentrations more than phlogopite during the first few years after fertilisation but the situation had reversed by 11–14 years. Five years later the change was even more pronounced. The needle potassium concentrations increased slightly with the increasing application amounts on the nitrogen-rich sites. Fertilisation with PK lowered the needle zinc, manganese, copper and boron concentrations especially on the nitrogen-rich sites.

Keywords: Fertilisation, macronutrient, micronutrient, nutrition, peatland, Scots pine.

INTRODUCTION

About 5.7 million hectares of peatlands and paludified mineral soil forests have been drained for forestry in Finland. In the last national forest inventory (1986–1994) 4.7 million hectares of the drained areas were still classified as peatlands.

Tree growth on drained Finnish mires is often restricted by a shortage of phosphorus (Paarlahti et al. 1971) and often also by a shortage of nitrogen (Kaunisto & Paavilainen 1977, Kaunisto 1982, 1987, Paavilainen 1977, 1979, Moilanen 1992, Moilanen et al. 1996). Moreover, the amounts of potassium and boron may be low in peat soils with respect to the requirements of trees (Kaunisto & Paavilainen 1988, Laiho & Laine 1995). Trees benefit from phosphorus fertilisation on most peatlands (Karsisto 1977, Kaunisto & Paavilainen 1977, Moilanen 1993). Phosphorus was applied as rock phosphate till the late 1980's. Since then, more slowly soluble native apatite has been used as a phosphorus source for peatland forests. Apatite improves the phosphorus nutrition and growth of trees but more slowly than rock phosphate (Karsisto 1977, Vasander & Lindholm 1992, Kaunisto et al. 1993). However, the apatite-fertilised stands reach the same growth level within 5–8 years after fertilisation.

Potassium deficiencies are most common on open mires, Carex-dominated thick-peated pine fens and also on Carex-dominated spruce swamps (Kaunisto & Tukeva 1984, Kaunisto & Paavilainen 1988, Kaunisto 1989, 1992, Moilanen et al. 1996). According to the site type distribution (Keltikangas et al. 1986) more than 1 million hectares of drained peatlands belong to these peatland site types and can be considered as potential potassium deficiency areas in Finland. Potassium has been given mainly as water soluble potassium chloride in practical forest fertilisation. Recently also slowly soluble phlogopite and biotite have been available for fertilisation. These potassium silicate minerals contain no water soluble potassium. Potassium ions are tightly fixed in the interlayer positions of biotite and phlogopite and are only partly released by the cation exchange reactions that are dependent on the amounts of certain cations (K+, Ca++, Mg++, Na+, Al+++, H+) in the soil solution (Black 1968). Phlogopite improves the potassium nutrition of trees more slowly than potassium chloride, but the growth response of trees is similar (Vasander & Lindholm 1992, Kaunisto et al. 1993).

Recent investigations in The Finnish Forest Research Institute show that the effect of phosphorus fertilisation on tree growth may last even for 25–30 years but the effect of potassium fertilisation with potassium chloride only about 15–20 years (Kaunisto 1989, 1992). The experiments with phlogopite are still quite young, the first ones established in the late 1970's. In the study by Kaunisto et al. (1993), involving 9 different experiments, the needle potassium concentrations were generally higher on the phlogopite than on the potassium chloride fertilised sites 11–14 years after the fertiliser application and they were still at a satisfactory level.

This investigation aims at clarifying the nutrition of trees in the above-mentioned nine experiments (Kaunisto et al. 1993) five years later and also at showing the development of especially phosphorus, potassium and boron nutrition of trees after different time periods elapsed from the nutrient application. Three additional experiments (10–12) are included: 10 = Metla, Fiskarhom 3/79; 11 = Metla, Viitasuo 283; 12 = MTTK, Ruukki 2 AB.

MATERIALS AND METHODS

Experimental sites and design

The study material consisted of 12 fertilisation experiments located in northern Central Finland (Fig. 1), mostly in the Muhos Research area of the Finnish Forest Research Institute. Experiments were set up in 12 old drainage areas between the years 1977 and 1985. The oldest drainage was carried out in the 1930's and the most recent one in the 1980's. At the time of fertilisation the sites were at a transforming stage. In most experiments the ditches were cleaned prior to fertilisation. The ditch network was considered satisfactory on all sites.

The sites represented a wide trophic scale, typical of drained peatlands in northern Finland (Table 1). The original mire site types varied from ombrotrophic to minerotrophic and from cotton grass pine bogs (TR) to herb-rich birch-pine fens (RhSR) (according to the classification of Laine & Vasander 1990). Experiment 6 was established on a pine plantation of an open flark fen (VRiN), and the others on pine mires with naturally born stands (mean height between 3–8 m depending on the experiment, Table 1). Differences in site fertility between the experiments were reflected also in the peat total nitrogen concentrations that varied between 0.95–2.58% of dry weight. Experiments 1, 3 and 7 represent poor peat nitrogen status (peat total N concentration < 1.2%, Table 1, Kaunisto 1984). All the others represent adequate or nitrogen-rich conditions (total N > 1.5%, Kaunisto 1984). Average peat thickness varied from 50 to over 150 cm (Table 1) and ditch spacing between 10 and 40 metres. The dominant tree species in all stands was Scots pine (*Pinus sylvestris* L.). The stands were at the young growth or at the young pole stage when the experiments were set up.

One of the experiments (8) had received partly rock phosphate in 1954 before establishing the trial and another experiment (11) PK-fertiliser in 1970. The other experiments were established on unfertilised sites. The experimental designs followed the concept of randomised blocks with two to six replications. The size of the experimental plots varied from 100 to 1600 m^2.

The effect of the potassium dose was studied in two experiments (7 and 8, Table 2, App 1). Experiment 7 involved different phlogopite doses and Experiment 8 also different potassium chloride doses. All the other experiments involved the following treatments: i) control with no fertilisation (0), ii) fertilisation with rock phosphate and potassium chloride (RPc) either given separately or as PK- fertiliser, and iii) fertilisation with apatite ore or enriched apatite + phlogopite (APh, Table 2). Phosphorus and potassium sources and their nutrient amounts are shown in detail in Table 2. The amounts of the main nutrients were mostly in accordance with those given in the forest fertilisation recommendations for practical forestry in Finland. Preliminary results from Experiments 1–9 have been presented earlier by Kaunisto et al. (1993) but are reviewed to some extent also in this paper in order to show the development of the nutrient status of trees in the course of time.

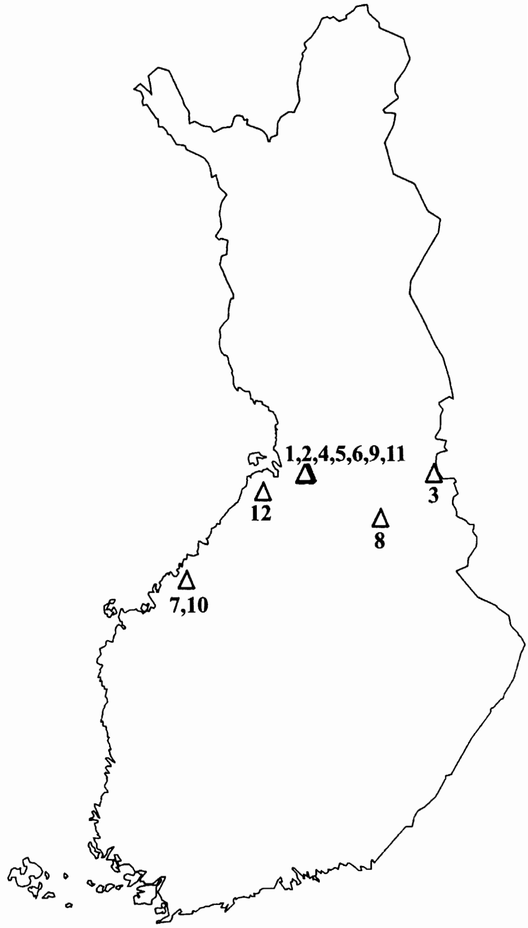

Fig. 1. Location of the experiments.

Kuva 1. Kokeiden sijainti.

Data collection and analyses

Needle samples were collected from all experiments in March 1996. This was the third time for the experiments 1–4 and 7–9 (3–7, 11–14 and 16–19 years after the fertiliser application), the second time for the experiments 5 and 6 (9–11 and 14–16 yrs after, see also Kaunisto *et al.* 1993) and the first time for the experiments 10–12 (17, 14 and 10 years after fertilisation, respectively).

Current needles were sampled from 8 to 10 dominant trees per plot from the sun-exposed upper whorls of tree crowns. The samples were analysed for the N, P, K, Ca, Mg, Fe, Mn, Zn, Cu and B concentrations. Analyses were carried out with the methods routinely used at The Finnish Forest Research Institute and described in detail by Halonen et al. (1983). The total nitrogen was analysed by the Kjeldahl method. Potassium analyses were made by an atomic absorption spectrophotometer (Hitachi 100–40), phosphorus and boron were analysed spectrophotometrically, phosphorus with the vanado-molybdate method.

Calculations

The experiments were combined into different groups according to the time elapsed from the fertilisation, the site type ("adequate nitrogen and nitrogen-rich", peat total N > 1.5% d.w. and "nitrogen-poor" sites, N < 1.2%", see Kaunisto 1984), and according to the "fertiliser" dosage (Experiments 7 and 8). The different groups are presented in the figures and tables. The treatment effects and the interactions between the treatments and experiments within the groups were analysed separately for different sampling times according to the following ANOVA-model:

$$y = F + E + FE + \varepsilon, \qquad (1)$$

where y is the value of response (nutrient concentration), F is the fertilisation treatment, E is experiment, and ε is a random variable (error). In addition, one-way analysis of variance was calculated separately for each experiment (Appendix 1). The statistical calculations followed the general linear models procedure associated with the BMDP statistical software package. The treatment means were compared pairwise within the experiment groups using Bonferron's multiple range tests.

RESULTS

Duration of the fertilisation effect

Phosphorus

The development of the nutrient status of the tree stands after fertilisation was seen best in Experiments 1–4 and 7–9, which had been sampled three times. The results from Experiments 7 and 8 will be presented later in the chapter dealing with the

Table 1. Basic information on the experiments.

Taulukko 1. Koemetsiköiden perustiedot.

Quantity — *Suure*	Experiment — *Koe*											
	1	2	3	4	5	6	7	8	9	10	11	12
Year of drainage/ditch cleaning *Ojitus/ojanperkausvuosi*	1974/83	1975	1976	1932/78	1971/80	1979	1962/77	1950/87	1939/79	1963/77	1969/82	1930/81
Ditch spacing, m — *Sarkaleveys, m*	20	20	25–30	20	20	10	20–30	25–35	20–30	20–30	10–	25–40
Site type[1)] — *Suotyyppi*[1)]	TR	VSR	TR	VSR	VSR	VRiN	TR-PsR	PsR	TR-PsR	TR-VSR	RhSR	VSR
Peat total N in surface 0–10 cm, % *Pintaturpeen N-pitoisuus 0-10 cm, %*	0.95	2.58	1.08	2.05	1.86	2.03	1.14	1.58	2.27	1.50	*n.d.*[2)]	*n.d.*[2)]
Stand height when fertilised, m *Puuston pituus lannoitettaessa, m*	2–6	2–6	1–5	2–4	1–5	0.1[3)]	3–8	3–12	1–5	4–12	2–6	5–10
Peat depth, m *Turpeen syvyys, m*	0.6– > 1.5	> 1.5 1.0	0.5– 0.8	0.6– 1.2	0.6–	> 1.0 1.0	0.7–	> 1.0 0.9	0.7–	> 1.0	> 1.0	> 1.0
Plots/replicates *Koealoja/toistoja*	15/5	9/3	6/2	6/2	9/3	12/4	18/3	21/3	12/4	9/3	6/2	18/6
Year of fertilization *Lannoitusvuosi*	1977	1977	1978	1979	1981	1980	1979	1980[4)]	1979	1979	1982[5)]	1985
Needle samples[6)] *Neulasnäytteet*[6)]	7/14/19	7/14/19	7/14/19	5/12/17	9/14	11/16	3/12/17	3/11/16	5/11/16	17	14	10

[1)] TR = cotton grass pine bog, VRiN = flark fen, PsR = *Carex globularis* pine swamp, VSR = tall-sedge pine fen, LkN = low-sedge fen, RhSR = herb-rich sedge birch-pine fen. See Laine & Vasander (1990). — *Suotyyppien selitykset katso Laine & Vasander (1990).* 2) Not determined. — *Ei analysoitu.* 3) Planted on a mounding site in 1980. Naturally born stands in the other experiments. — *Istutusmännikkö vuodelta 1980. Muilla kohteilla puusto on luontaisesti syntynyttä.* 4) Partially fertilised with rock phosphate (400 kg/ha) in 1954. — *Lannoitettu osittain raakafosfaatilla vuonna 1954.* 5) First fertilisation with PK-fertiliser (500 kg/ha) in 1970. — *Peruslannoitus vuonna 1970 (Suometsien PK-lannos 500 kg/ha).* 6) No. of growing seasons after fertilisation. — *Kasvukausia lannoituksesta, kpl.*

potassium dosage. The needle phosphorus concentrations were below the deficiency level, 1.37 mg g^{-1} (Paarlahti et al. 1971) on the control plots in the nitrogen-rich experiments (Exps 2, 4 and 9) at all sampling times (Fig. 2) but on the nitrogen-poor experiments (1 and 3) only at the last sampling.

Rock phosphate and apatite raised the needle phosphorus concentrations in both groups at all samplings but significantly only on the nitrogen-rich sites. The phosphorus concentrations were slightly higher on the nitrogen-poor than on the nitrogen-rich sites and lower on the apatite fertilised than on the rock phosphate fertilised plots at the first and second sampling times (Fig. 2). By the third sampling time, 16–19 years after fertilisation, however, the needle phosphorus concentrations had risen to a slightly higher level on the apatite fertilised than on the rock phosphate fertilised nitrogen-poor sites and almost to the same level on the nitrogen-rich sites (Fig. 2, App. 1). However, the differences between the phosphorus sources were not significant in either group. The needle phosphorus concentrations were in most treatments the highest at the second and the lowest at the third sampling time, 16–19 years after fertilisation, being near or below the deficiency limit even on many fertilised sites (Fig. 2, App. 1).

Also in Experiments 12 (10 years after), 5 and 11 (14 years after) and 10 (17 years after fertilisation), rock phosphate and apatite had raised the needle phosphorus concentrations to a satisfactory level and in Experiments 5 and 12 to a significantly higher level on the fertilised sites than on the controls (App. 1). There were only minor differences between the different phosphorus sources. In Experiment 6, fertilised 16 years before sampling, the needle phosphorus concentrations were below the deficiency level in all treatments (App. 1).

Table 2. Phosphorus and potassium sources and the amounts of elemental P, K, Ca, Mg and B (kg ha^{-1}) in the experiments. Treatment combinations are as follows: apatite ore (Exps 1–3) or enriched apatite (A) (Exps 4–6 and 9–12) + phlogopite[1)] (Ph) compared with rockphosphate (R) + potassium chloride[2)] (Pc). 7 and 8 are potassium dose experiments (App. 1).

Taulukko 2. Fosforin ja kaliumin lähteet ja niiden alkuainemäärät (kg ha^{-1}) eri kokeissa. Käsittelyt ovat seuraavat: apatiittimalmi (kokeet 1–3) tai apatiittirikaste (kokeet 4–6 and 9–12) + flogopiitti[1)] verrattuna raakafosfaattiin + kalisuolaan[2)]. Kokeet 7 ja 8 ovat kaliumin määräkokeita (liite 1).

Exp.	Treatment — *Käsittely*											
	Apatite (A) *Apatiitti*				Phlogopite (Ph) *Flogopiitti*				Rockphosphate (R) + KCl (Pc) *Raakafosfaatti + KCl*			
Koe	P	K	Ca	Mg	P	K	Ca	Mg	P	K	Ca	B
1	32	95	105	152	5.4	33	47	43	35	73	87	0.8
2	32	95	105	152	5.4	33	47	43	35	73	87	0.8
3	40	118	129	188	6.8	41	59	53	43	50	106	–
4	31	0.2	70	2.4	9.9	61	86	78	35	73	87	–
5	36	0.2	81	2.8	9.0	55	78	71	44	71	109	–
6	31	0.2	70	2.4	9.9	61	86	78	35	73	87	0.8
7	47	0.3	104	3.6	3–20	21–124	29–176	27–160	–	–	–	–
8	47	0.3	104	3.6	7–27	41–165	59–234	53–213	–	50–200	–	–
9	31	0.2	71	2.4	11	66	94	85	44	83	109	1.0
10	31	0.2	70	2.4	11	64	91	83	44	83	109	1.0
11	31	0.2	70	2.4	10	62	88	80	44	83	109	1.0
12	60	0.4	134	4.6	12	70	100	90	52	100	131	1.2

[1)] HCl extraction K = 4.2%, H_2SO_4 + HNO_3 cooking K = 7.0%, melted material K = 8.1%. Amounts of elemental K calculated on the 5.5% basis. — *HCl-uutos K = 4,2%, H_2SO_4 + HNO_3 keitto K = 7,0%, sulate K = 8,1%. Kaliumin määrät laskettu 5,5%:n mukaan.* 2) Rock phosphate and potassium chloride were added as combined PK fertiliser containing also boron in Experiments 1, 2, 6 and 9–12. — *Raakafosfaatti ja kalisuola annettiin kokeissa 1, 2, 6 ja 9–12 PK-lannoitteena, joka sisältää myös booria.*

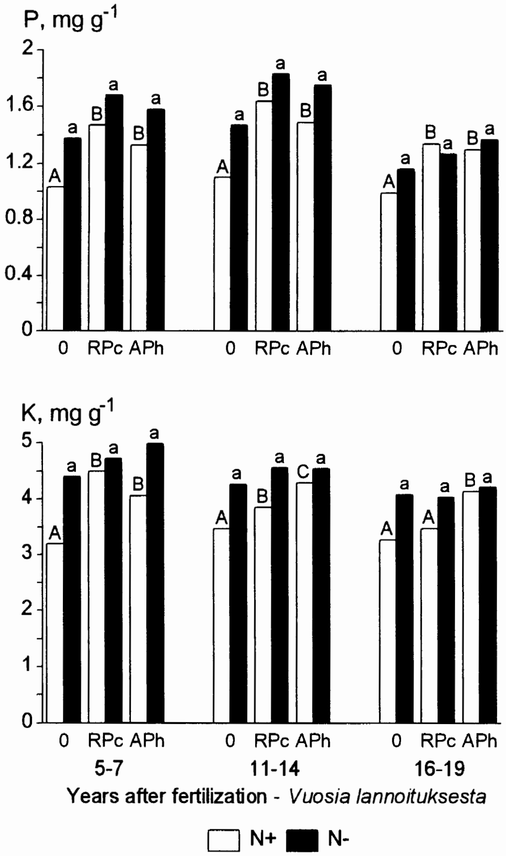

Fig. 2. Phosphorus and potassium concentrations in pine needles by sampling times and fertilization treatments. N+ = nitrogen-rich site types (Exps. 2, 4 and 9; n = 27, peat total N > 1.5%), N– = nitrogen-poor site types (Exps. 1 and 3; n = 21, peat total N < 1.2%). 0 = control, R = rock phosphate, A = apatite, Pc = potassium chloride, Ph = phlogopite. The analyses were calculated separately for different site type and sampling time groups. The columns indicated with the same letter (or letter type) do not differ from each other within the same sampling time (Bonferron, p-value > 0.05).

Kuva 2. Männynneulasten fosfori- ja kaliumpitoisuudet lannoituskäsittelyittäin eri ajankohtina lannoituksen jälkeen. N+ = runsastyppiset kokeet (kokeet 2, 4 ja 9; n = 27, turpeen kokonais-N > 1,5%). N– = niukkatyppiset kokeet (kokeet 1 ja 3; n = 21, turpeen kokonais-N < 1,2%). 0 = kontrolli, R = raakafosfaatti, A = apatiitti, Pc = kaliumkloridi, Ph = flogopiitti. Samalla kirjaimella (kirjaintyypillä) merkittyjen käsittelyjen ravinnepitoisuudet eivät eroa merkitsevästi toisistaan (Bonferron, p-arvo > 0.05). Testaus tehty erikseen kullekin ajankohdalle ja turpeen typpitasolle.

Potassium

On the nitrogen-poor sites (Exps 1 and 3) the needle potassium concentrations were above the severe potassium deficiency level (3.5 mg g^{-1}, Paarlahti et al. 1971, Sarjala & Kaunisto 1993) on the control plots at all sampling times (Fig. 2). There were no significant differences in the needle potassium concentrations between the controls and the two different potassium sources, although fertilisation had slightly raised the concentrations by the first and second samplings.

On the nitrogen-rich sites (Exps 2, 4 and 9) the needle potassium concentrations were below the severe potassium deficiency level on the control plots at all sampling times (Fig. 2). Both potassium sources, phlogopite and potassium chloride, had raised the needle potassium concentrations statistically significantly compared with the controls by the first sampling time, 5–7 years after fertilisation (Fig. 2). The potassium chloride application raised the needle potassium concentrations higher than phlogopite. However, the situation was the opposite at the second sampling. Phlogopite had raised the potassium concentrations statistically significantly higher than potassium chloride, and this difference became even more pronounced at the third sampling time, 16–19 years after the application (Fig 2, App. 1). The potassium concentrations were above the slight potassium deficiency limit 4.0 (Paarlahti et al. 1971, Sarjala & Kaunisto 1993) on the phlogopite fertilised plots at all sampling times but below that on the potassium chloride fertilised plots at the second and third samplings.

The needle potassium concentrations in Experiment 12 (10 years after fertilisation) were lower on the phlogopite fertilised than on the potassium chloride fertilised plots but in Experiments 5 and 11 (14 years after) there were only minor differences (App. 1). In Experiments 6 and 10 (16–17 years after fertilisation) phlogopite had raised the needle potassium concentrations higher than potassium chloride (App. 1).

Boron

The needle boron concentrations were adequate or high (Veijalainen et al. 1984) at the first sampling in Experiments 1–4 and Experiment 9 (5–7 years after fertilisation, Table 3). The boron concentrations had decreased on the controls in all experiments by the second and third samplings. The needle boron concentrations were near or below the boron deficiency limit 7 $\mu g\ g^{-1}$ (Veijalainen et al. 1984) in Experiments 3 and 4 both at the second and third sampling time. Fertilisation with phosphorus and potassium lowered the needle boron concentrations if boron was not supplied simultaneously even when using slowly soluble apatite and phlogopite. The trend was similar also in the 1995 needles in Experiments 5, 6 and 10–12 (Table 4).

Table 3. Development of the needle boron concentrations (mg kg^{-1}) in the nitrogen-poor (1 and 3) and nitrogen-rich (2, 4, 9) experiments sampled three times (5–7, 11–14 and 16–19 years after fertilisation). Key as in Fig 2.

Taulukko 3. Neulasten booripitoisuuden (mg kg^{-1}) kehitys niukkatyppisissä (1 ja 3) ja runsas-typpisissä (2, 4, 9) kolmeen kertaan (5–7, 11–14 ja 16–19 vuotta lannoituksesta) analysoiduissa kokeissa. Selitykset kuvassa 2.

Time *Aika*	Fertilisation — *Lannoitus*					
	0	RPc	APh	0	RPc	APh
	Exp. 1			Exps. 2 and 9		
5–7	25	11[1)]	11	19	18[1)]	14
11–14	16	14[1)]	12	13	14[1)]	10
16–19	16	15[1)]	15	11	13[1)]	8
	Exp. 3			Exp. 4		
5–7	20	18	22	19	17	15
11–14	8	7	4	9	6	3
16–19	9	8	3	11	5	4

[1)] Fertilised with boron. — *Saanut boori-lannoituksen.*

Other nutrients

The other nutrients are discussed only on the basis of the 1995 needles. The needle nitrogen concentrations were below the deficiency limit (1.30% according to Paarlahti *et al.* 1971) in the most nitrogen-poor experiments 1 and 3 at the last sampling (Table 5, App. 1). The nitrogen concentrations varied from a slight deficiency to a satisfactory or good level in the experiments with the peat total nitrogen concentration above 1.5% in the 0–10 cm surface peat layer (Table 1 and 5, App. 1). The fertiliser applications lowered the needle nitrogen concentrations on average and in some cases statistically significantly on the nitrogen-rich sites 16–19 years after fertilisation (Table 5, App 1).

The copper concentrations varied in two nitrogen-poor experiments (1 and 3) 19 years after and in two nitrogen-rich experiments (11 and 12) 10–14 years after the fertiliser applications. However, in the other nitrogen-rich experiments (Exp. 5, 14 years after fertilisation and Exps 2, 4, 6, 9 and 10, 16–19 years after, App. 1) fertilisation had decreased the copper concentrations and in the latter group statistically significantly (Table 5). Fertilisation lowered the zinc concentrations quite clearly in most single experiments and in all experiment groups (App 1, Table 5). Rock phos-

Table 4. Boron concentrations (mg kg^{-1}) in Experiments 5, 6 and 10–12 in the 1995 needles.

Taulukko 4. Booripitoisuudet (mg kg^{-1}) kokeissa 5, 6 ja 10–12 vuoden 1995 neulasissa.

Experiment *Koe*	Years since fertilisation *Vuosia lannoituksesta*	Fertilisation *Lannoitus*		
		0	RPc	Aph
11 and 12	10–14	20	22[1)]	17
6 and 10	16–17	15	16[1)]	8
5	14	11	6	7

[1)] Fertilised with boron. — *Saanut boorilannoituksen.*

phate fertilisation lowered the zinc concentrations more than apatite and in most groups statistically significantly. The Ca, Mg, Fe and Mn concentrations were above deficiency limits (Reinikainen *et al.* 1998) in all experiments. Fertilisation decreased the manganese concentrations in almost all experiments (Table 5, App 1).

Effect of the potassium dosage

The effect of the phlogopite dosage was investigated in two experiments (7 and 8) but that of potassium chloride only in Experiment 8. The results of these experiments, as regards phlogopite, are combined in Fig. 3.

The needle potassium concentrations were at a satisfactory level at the first sampling (3 years after fertilisation) in all treatments but already slightly higher on the phlogopite fertilised plots than on the controls (Fig. 3). After 11–12 years the needle potassium concentrations were below the slight potassium deficiency level, 4.0 mg g^{-1} (Paarlahti et al., Sarjala & Kaunisto 1993) on the control plots but above it on the fertilised plots. The difference was statistically significant at the two highest phlogopite doses. The difference between the controls and phlogopite fertilised plots had still increased by the third sampling time, 16–17 years after application, and was significant also at the lowest application rate. The phlogopite dosage did not affect the needle phosphorus concentrations, although 27 kg ha^{-1} more phosphorus than on the controls was applied with the heaviest phlogopite application.

Potassium chloride had raised the needle potassium concentrations considerably more than phlogopite at the two lowest application levels by the first sampling time, whereas there were no differences with the highest dosage (Table 6). The concentrations had risen slightly along the increasing fertiliser amounts by the second sampling (11–12 years after fertilisation) but differences between different potassium sources had disappeared. The situation was quite similar at the third sampling, 16–17 years after fertilisation. The application of phlogopite had resulted in the same kind of potassium concentration levels as the use of potassium chloride.

DISCUSSION

This investigation involves 12 different experiments representing pine mires with different peat total nitrogen status in northern Central Finland.

Table 5. Nutrient concentrations in the 1995 needles by experiment groups according to time since fertilisation, site type and fertilisation treatments. * = statistically significant difference compared with the control (Bonferron $p < 0.05$). 0 = control, RPc = rock phosphate + potassium chloride, APh = apatite + phlogopite.

*Taulukko 5. Ravinnepitoisuuksia vuoden1995 neulasissa koeryhmittäin ja käsittelyittäin. * = ko. käsittely poikkeaa merkitsevästi* (p < 0,05) *lannoittamattomasta. 0 = lannoittamaton, RPc = raakafosfaatti + kalisuola, APh = apatiitti + flogopiitti.*

Nutrient *Ravinne*	Exps 1 and 3 (N-poor, 19 years) *Kokeet 1 ja 3 (Niukkatyppisiä, lannoituksesta 19 v.)*			Exps 2, 4, 6, 9 ja 10 (N-rich, 16–19 years) *Kokeet 2, 4, 6, 9 ja 10 (Runsastyppisiä, lannoituksesta 16–19 v.)*			Exps 5, 11 ja 12 (N-rich, 10–14 years) *Kokeet 5, 11 ja 12 (Runsastyppisiä, lannoituksesta 10–14 v.)*			Exps 7 and 8 (K dosage,16–17 years) *Kokeet 7 ja 8 (Kaliumin määräkokeet, lannoituksesta 16–17 v.)*	
	0	RPc	Aph	0	RPc	Aph	0	RPc	Aph	0	Aph[1)]
N, %	1.14	1.11	1.14	1.63	1.45*	1.45*	1.44	1.39	1.34	1.34	1.49
Ca, mg g^{-1}	2.12	2.07	2.23	1.61	1.63	1.75	1.91	2.05	2.07	1.75	1.94
Mg, mg g^{-1}	1.25	1.30	1.28	1.16	1.22	1.20	1.30	1.09*	1.25	1.36	1.27
Fe, mg g^{-1}	33.6	33.0	34.8	34.7	35.1	38.4	34.7	37.9	37.2	31.7	30.7
Mn, ppm	438	385	381	359	255*	237*	468	346	334	309	249
Zn, ppm	53	46*	51	45	36*	42	45	37*	40	44	40
Cu, ppm	3.6	3.4	3.4	3.9	3.2*	3.2*	3.2	2.9	3.4	3.7	3.3

[1)] The amount of phlogopite = < 750 kg ha^{-1}. — *Flogopiitin käyttömäärä = < 750 kg* ha^{-1}.

The needle nitrogen concentrations were satisfactory in most experiments with an adequate or high peat total nitrogen concentration (N > 1.5%), but they were below the deficiency limit in the two most nitrogen-poor experiments (Exps 1 and 3) at the final sampling. This agrees fairly well with the results obtained by Kaunisto (1984, 1987) from areas in western and eastern Finland with somewhat higher temperature sum than in the experiments of this investigation. However, according to Moilanen (1993) the peat total nitrogen concentration should be about 2.2–2.4 % in the climatic region of this investigation in order to have satisfactory nitrogen nutrition of pine. The needle nitrogen concentrations are a consequence of annual variation in the nitrogen mineralization rate influenced by annually varying climatic conditions. The annual variation in the needle nutrient status has also been noted in other investigations (Helmisaari 1990, Moilanen et al. 1996).

Phosphorus shortage was quite evident in almost all unfertilised treatments. Phosphorus fertilisation had raised the needle phosphorus concentrations to an adequate or good level in most experiments by 11–14 years after fertilisation but they were surprisingly near or under the deficiency

Table 6. Effect of the amount (kg ha^{-1}) of potassium chloride (Pc) and phlogopite (Ph) on the potassium concentrations (mg g^{-1})of pine needles by sampling times (exp. 8; n = 21). Basic fertilisation treatment on all plots (excluding control) was enriched apatite (A) 300 kg ha^{-1}. The figures indicated with the same letter do not differ from each other within the same sampling time (Bonferron, p value > 0.05).

Taulukko 6. Kalisuolan (Pc) ja flogopiitin (Ph) määrän (kg ha^{-1}) vaikutus neulasten kaliumpitoisuuksiin (mg g^{-1}) *kolmena ajankohtana lannoituksen jälkeen (koe 8, n = 21). Pohjalannoituksena kaikilla käsittelyillä (paitsi kontrollilla) apatiittirikaste (A) 300 kg ha^{-1}. Samalla kirjaimella merkityt luvut eivät eroa merkitsevästi toisistaan tietyn keruuajankohdan sisällä (Bonferron, p-arvo > 0,05).*

Fertilisation *Lannoitus*	Years since fertilisation *Vuosia lannoituksesta*		
	3	11–12	16–17
0	4.2 a	3.7 a	3.4 a
A + Pc 100	5.8 b	4.3 ab	4.3 b
A + Ph 750	4.9 ab	4.4 ab	4.1 ab
A + Pc 200	6.5 b	4.6 ab	4.4 b
A + Ph 1500	4.8 ab	4.5 ab	4.5 b
A + Pc 400	4.9 ab	4.9 b	4.6 b
A + Ph 3000	5.0 ab	4.9 b	4.8 b

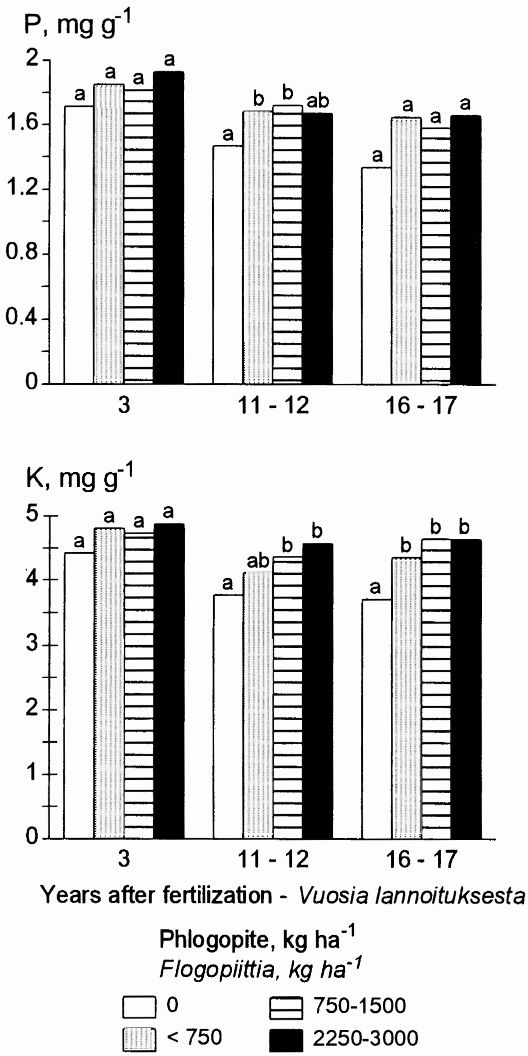

Fig. 3. Potassium and phosphorus concentrations in pine needles at three different sampling times when using different phlogopite amounts (Exps. 7 and 8; n = 39). All plots (excluding control) had also received enriched apatite 300 kg ha^{-1}. The columns indicated with the same letter do not differ from each other within the same sampling time (Bonferron, p-value > 0.05).

Kuva 3. Flogopiitin määrän vaikutus männynneulasten kalium- ja fosforipitoisuuksiin kolmena ajankohtana lannoituksen jälkeen (kokeet 7 ja 8; n = 39). Pohjalannoituksena kaikilla käsittelyillä (paitsi kontrollilla) apatiittirikaste 300 kg ha^{-1}. Samalla kirjaimella merkityt käsittelyt eivät eroa merkitsevästi toisistaan (Bonferron, p-arvo > 0.05). Kukin ajankohta testattu erikseen.

limit on many fertilised plots after 16–19 years.

In Experiment 3 the phosphorus amounts applied as apatite were 5–9 kg ha^{-1} and in Experiments 7 and 8 as much as 15–16 kg ha^{-1} higher than in the other "old experiments". In these experiments the needle phosphorus concentrations were higher than in the experiments on average. The results imply that the amount of phosphorus applied in apatite possibly influenced the duration of the fertilisation effect. In recent unpublished investigations in The Finnish Forest Research Institute similar findings have also been made showing that 44 and 66 kg ha^{-1} of apatite may maintain the phosphorus nutrition of Scots pine at an adequate level for at least 25 years, while 22 kg ha^{-1} cannot.

Also phlogopite contains some phosphorus. The amounts of phosphorus applied in phlogopite varied from 3 to 27 kg ha^{-1}. It is not known how long it takes for this phosphorus to become available to plants. However, the results of this study imply that phosphorus in phlogopite is fixed very tightly, because the needle phosphorus concentrations had not risen along with the increased application amounts even by the last sampling 16–17 years after fertilisation.

The earlier results by Kaunisto *et al.* (1993), concerning partly the same material as in this study, showed quite unanimously that for trees phosphorus in rock phosphate is more readily usable than in apatite. In this study, however, 16–19 years after fertilisation differences in the needle phosphorus concentrations were quite small and on average even higher on the apatite than on the rock phosphate fertilised plots, although the amounts of applied phosphorus in apatite were 3–13 kg ha^{-1} smaller than in rock phosphate (Exps 1–6, 9–11). The results imply that the fertilisation effect of apatite may last longer than that of rock phosphate (see also Karsisto 1977).

The earlier results by Kaunisto *et al.* (1993) showed that trees take up potassium more readily from potassium chloride than from phlogopite. Similar results were obtained also by Sarjala and Kaunisto (1993, 1996), who showed that potassium chloride raised the needle potassium concentrations faster than biotite. However, 11–14 years after the fertiliser application differences between the potassium sources had levelled out and in most cases reversed in the present study. The same trend was even more consistent after 16–19 years. Consequently, the results suggest that phlogopite has a longer-lasting effect than potassium chloride on the potassium nutrition of pine trees.

The amounts of applied potassium partly explain the different results between the potassium sources. The effect of the phlogopite amount on the potassium concentrations in needles was quite well shown in Experiments 7 and 8 where the needle potassium concentrations steadily increased along with the increased amount especially at the samplings 11–12 and 16–17 years after fertilisation. The importance of the fertiliser dosage was quite obvious also in Experiments 1–3. The sites had received two-threefold rates of elemental potassium in phlogopite and apatite ore compared with potassium chloride, resulting in higher potassium concentrations already 5–7 years after fertilisation. On the other hand, in Experiment 12 potassium chloride contained 30 kg ha^{-1} more elemental potassium than phlogopite resulting in higher needle potassium concentrations still 11 years later. The results agree also with the results by Kaunisto (1992) and Moilanen (1993) where the needle potassium concentrations rose along with the application rate of potassium chloride.

Although the potassium concentrations rose with the increasing application amounts, also quite low rates (375–750 kg ha^{-1}) of phlogopite in Experiments 7 and 8 and still quite reasonable rates (1100–1200 kg ha^{-1}) of phlogopite in Experiments 4, 9 and 10 resulted in adequate or even good potassium nutrition of pines for at least 16–17 years. In these experiments HCl extractable amounts (about 4.2% K) of potassium were lower but the total potassium amounts (about 8.5% K) analysed from melted material higher than in potassium chloride. It is not known if any part of this extremely tightly fixed 4.3 % of potassium is available to plants. However, the results confirm the earlier findings by Kaunisto et al. (1993) on the usability of phlogopite as a reasonable potassium source for trees on pine mires.

Both the needle phosphorus and potassium concentrations were lower on the nitrogen-rich than nitrogen-poor sites. Also the effect of fertilisation was more pronounced on the nitrogen-rich sites. On the nitrogen-rich sites the more easily soluble phosphorus and potassium fertilizers (rock phosphate and potassium chloride) quite unanimously raised the corresponding needle nutrient concentrations more than the more slowly soluble ones, whereas the situation varied on the nitrogen-poor sites.

Tree growth is highly dependent on the peat nitrogen status (Paavilainen 1977, 1979, Kaunisto 1984, 1987). The results indicate that trees on the nitrogen-rich sites had been able to use phosphorus and potassium more efficiently than these nutrients were released from apatite and phlogopite at the beginning. On the other hand, the release was sufficient on the nitrogen poor-sites from the very beginning because of the slower growth rate (Kaunisto et al. 1993). Kaunisto et al. (1993) showed that tree growth was lower on the apatite than on the rock phosphate fertilised plots for a couple of years after fertilisation but there was no difference in the response of tree growth to phlogopite and potassium chloride.

In addition to phosphorus and potassium, boron was applied in the PK fertiliser for peatland forests except in Experiment 4. Fertilisation with mere phosphorus and potassium decreased the needle boron concentrations and quite frequently near or below the deficiency limit, 7 µg/g (Veijalainen et al.1984) indicating a typical dilution effect when fertilising with the main nutrients (Veijalainen 1977). This occurred even in connection with slowly soluble apatite and phlogopite.

Out of the micronutrients also copper, manganese but especially zinc concentrations behaved quite similarly to boron and mainly decreased in connection with fertilisation and also with time. It is quite obvious that at least boron but possibly also zinc is needed in apatite and phlogopite based fertilizers, because zinc is involved in many physiological processes (Brown et al. 1993) in plants and it is very scarce in Finnish peats (Kaunisto & Paavilainen 1988, Kaunisto & Moilanen 1998).

CONCLUSIONS

Phosphorus is more readily usable for trees in rock phosphate than in apatite. Apatite and phlogopite are fairly good phosphorus and potassium sources for pine on drained peatlands and they seem to affect tree nutrition longer than the more soluble rock phosphate and potassium chloride. The amount of apatite and phlogopite influence the duration of the fertilisation effect but even quite low rates (375–750 kg ha^{-1}) and still quite reasonable rates (1100–1200 kg ha^{-1}) of phlogopite may result in adequate or even good potassium nutrition of pines for at least 16–19 years. Out of micronutrients at least boron but possibly also zinc should be added to phosphorus and potassium fertilizers.

ACKNOWLEDGEMENTS

We sincerely thank Dr Leena Finér and Mr Timo Penttilä for many fertile suggestions in completing the manuscript and Mrs Leena Kaunisto for revising the English language of the manuscript. Ms Tuire Kilponen helped in completing the tables and figures.

REFERENCES

Black, A 1968. Plant and soil relationships. Wiley & Sons. 792 pp.

Brown, P. H., Cakmak, I. & Zhang, Q. 1993. Form and function of zinc in plants. In: Robson, A. D. (ed.). Zinc in soils and plants. Proceedings of the international symposium on "Zinc in soils and plants" at the University of Western Australia, pp. 93–106. Kluver Academic Publishers, Dordrecht.

Halonen, O., Tulkki, H. & Derome, J. 1983. Nutrient analysis methods. Metsäntutkimuslaitoksen tiedonantoja 121. 28 pp.

Helmisaari, H.-S. 1990. Temporal variation in nutrient concentrations of Pinus sylvestris needles. Scandinavian Journal of Forest Research 5: 177–193.

Karsisto, K. 1977. Kotimaisten fosforirikasteiden käyttökelpoisuus suometsien lannoituksessa (Summary: Possibilities of native phosphate concentrates in fertilizing peatland forests). Suo 28(2): 43–46.

Kaunisto, S. 1982. Development of pine plantations on drained bogs as affected by some peat properties, fertilization, soil preparation and liming (Seloste: Männyn istutustaimien kehityksen riippuvuus eräistä turpeen ominaisuuksista sekä lannoituksesta, muokkauksesta ja kalkituksesta ojitetuilla avosoilla). Communicationes Instituti Forestalis Fenniae 109. 56 pp.

Kaunisto, S. 1984. Peat properties in estimating need for nitrogen fertilization on pine plantations on bogs. In: Proceedings of the 7th International Peat Congress in Dublin, June 18–23, 1984, Vol. 3, pp. 327–341. IPS, Dublin.

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

Kaunisto, S. 1989. Jatkolannoituksen vaikutus puuston kasvuun vanhalla ojitusalueella (Summary: Effect of refertilization on tree growth in an old drainage area). Folia Forestalia 724. 15 pp.

Kaunisto, S. 1992. Effect of potassium fertilization on the growth and nutrition of Scots pine (Tiivistelmä: Kalilannoituksen vaikutus männyn kasvuun ja ravinnetilaan). Suo 43(2): 45–62.

Kaunisto, S. & Moilanen, M. 1998. Kasvualustan, puuston ja harvennuspoistuman sisältämät ravinnemäärät neljällä vanhalla ojitusalueella. Metsätieteen aikakauskirja - Folia Forestalia 3/1998: 393–410.

Kaunisto, S., Moilanen, M. & Issakainen, J. 1993. Apatiitti ja flogopiitti fosfori- ja kaliumlannoitteina suomänniköissä (Summary: Apatite and phlogopite as phosphorus and potassium fertilizers in peatland pine forests). Folia Forestalia 810. 30 pp.

Kaunisto, S. & Paavilainen, E. 1977. Response of Scots pine plants to nitrogen refertilization on oligotrophic peat (Seloste: Typpijatkolannoituksen vaikutus männyn taimien kehitykseen karulla turvealustalla). Communicationes Instituti Forestalis Fenniae 92(1). 54 pp.

Kaunisto, S. & Paavilainen, E. 1988. Nutrient stores in old drainage areas and growth of stands (Seloste: Turpeen ravinnevarat vanhoilla ojitusalueilla ja puuston kasvu). Communicationes Instituti Forestalis Fenniae 145. 39 pp.

Kaunisto, S. & Tukeva, J. 1984. Kalilannoituksen tarve avosoille perustetuissa riukuasteen männiköissä (Summary: Need for potassium fertilization in pole stage pine stands established on bogs). Folia Forestalia 585. 40 pp.

Keltikangas, M., Laine, J., Puttonen, P. & Seppälä, K. 1986. Vuosina 1930–1978 metsäojitetut suot: ojitusalueiden inventoinnin tuloksia (Summary: Peatlands drained for forestry during 1930–1978: results from field surveys of drained areas). Acta Forestalia Fennica 193. 94 pp.

Laiho, R. & Laine, J. 1995. Changes in mineral element concentrations in peat soils drained for forestry in Finland. Scandinavian Journal of Forest Research 10: 218–224.

Laine, J. & Vasander, H. 1990. Suotyypit. Kirjayhtymä, Helsinki. 80 pp.

Moilanen, M. 1992. Suopuustojen ravinnetila Pohjois-Suomen vanhoilla ojitusalueilla. In: Valtanen, J., Murtovaara, I. & Moilanen, M. (eds.). Metsäntutkimuspäivä Taivalkoskella 1991. Metsäntutkimuslaitoksen tiedonantoja 419: 58–65.

Moilanen, M. 1993. Lannoituksen vaikutus männyn ravinnetilaan ja kasvuun Pohjois-Pohjanmaan ja Kainuun ojitetuilla soilla (Summary: Effect of fertilization on the nutrient status and growth of Scots pine on drained peatlands in northern Ostrobothnia and Kainuu). Folia Forestalia 820. 37 pp.

Moilanen, M., Piiroinen, M.-L & Karjalainen, J. 1996. Turpeen ravinnevarat metsähallituksen vanhoilla ojitusalueilla. In: Piiroinen, M.-L. & Väärä, T. (eds). Metsäntutkimuspäivä Kajaanissa 1995. Metsäntutkimuslaitoksen tiedonantoja 598: 35–54.

Paarlahti, K., Reinikainen, A. & Veijalainen, H. 1971. Nutritional diagnosis of Scots pine by needle and peat analysis (Seloste: Maa- ja neulasanalyysi turvemaiden männiköiden ravitsemustilan määrityksessä). Communicationes Instituti Forestalis Fenniae 74(5). 58 pp.

Paavilainen, E. 1977. Jatkolannoitus vähäravinteisilla rämeillä. Ennakkotuloksia (Abstract: Refertilization on oligotrophic pine swamps. Preliminary results). Folia Forestalia 327. 32 pp.

Paavilainen, E. 1979. Jatkolannoitus runsastyppisillä rämeillä. Ennakkotuloksia (Abstract: Refertilization on nitrogen-rich pine swamps. Preliminary results). Folia Forestalia 414. 23 pp.

Reinikainen, A., Veijalainen, H., Nousiainen, H. 1998. Puiden ravinnepuutokset — Metsänkasvattajan ravinneopas. Metsäntutkimuslaitoksen tiedonantoja 688. 44 pp.

Sarjala, T. & Kaunisto, S. 1993. Needle polyamine concentrations and potassium nutrition in Scots pine. Tree Physiology 13: 87–96.

Sarjala, T. & Kaunisto, S. 1996. Effect of different potassium sources on the seasonal variation of potassium and free polyamines in Scots pine needles. Silva Fennica 30(4): 387–398.

Vasander, H. & Lindholm, T. 1992. Effect of readily and slowly soluble fertilizers on the growth and needle nutrient contents of Scots pine in Southern Finland. Proceedings of the 9th International Peat Congress June 22–26, 1992. Vol. 2: 342–351.

Veijalainen, H. 1977. Use of needle analysis for diagnosing micronutrient deficiencies of Scots pine on drained peatland (Seloste: Neulasanalyysi männyn mikroravinnetilanteen määrityksessä turvemailla). Communicationes Instituti Forestalis Fenniae 92(4). 32 pp.

Veijalainen, H., Reinikainen, A. & Kolari, K. K. 1984. Metsäpuiden ravinneperäinen kasvuhäiriö Suomessa. Kasvuhäiriöprojektin väliraportti (Summary: Nutritional growth disturbances of forest trees in Finland. Interim report). Folia Forestalia 601. 41 pp.

TIIVISTELMÄ:

Apatiitti- ja flogopiittilannoituksen vaikutus männyn neulasten ravinnepitoisuuksiin ojitetuilla rämeillä.

Tutkimuksen tarkoituksena oli selvittää flogopiitin käyttökelpoisuutta rämepuustojen kaliumlannoitteena ja apatiitin käyttökelpoisuutta puiden fosforin lähteenä. Aikaisemmissa tutkimuksissa flogopiitti (apatiitin rikastusprosessissa jäljelle jäävä silikaattimineraali) on osoittautunut varsin lupaavaksi kaliumlannoitteeksi (Kaunisto et al. 1993) ja apatiitti hyväksi fosforin lähteeksi (Karsisto 1977). Tässä tutkimuksessa tarkastellaan puuston ravinnetilaa Kauniston ym. (1993) esittelemissä kokeissa, kun lannoituksesta oli kulunut 14–19 vuotta (kokeet 1–9, taulukot 1 ja 2). Aikaisemmin esiteltyjen kokeiden lisäksi mukana on kolme uutta koetta (kokeet 10–12). Kaikki kokeet on perustettu Metsäntutkimuslaitoksen Muhoksen tutkimusaseman toimesta Keski- ja Pohjois-Pohjanmaalle ja Kainuuseen (Kuva 1). Kokeiden alkuperäinen ojitusta edeltänyt suotyyppi vaihtelee varsinaisesta rimpinevasta ja tupasvillarämeestä ruohoiseen sararämeeseen (Taulukko 1). Pääpuulajina kaikissa metsiköissä on mänty. Käsittelyt kokeissa 1–6 ja 9–12 ovat seuraavat: (i) lannoittamaton vertailu, (ii) lannoitettu raakafosfaatilla ja kalisuolalla, (iii) lannoitettu apatiittimalmilla tai apatiittirikasteella ja flogopiitilla (Taulukko 2). Raakafosfaatti ja kalisuola oli useissa tapauksissa annettu suometsien PK-lannoitteena, joka sisältää myös booria (Taulukko 2). Kokeissa 7 ja 8 tutkittiin flogopiitin ja kokeessa 8 myös kalisuolan määrän vaikutusta neulasten ravinnepitoisuuksiin (Taulukko 2).

Ensimmäisten neulasanalyysien perusteella (5–7 vuotta kokeiden perustamisen jälkeen) lannoittamattomilla puilla esiintyi fosforin ja kaliumin puutosta (Kuva 2). Lannoitus sekä raakafosfaatilla että apatiitilla kohottivat neulasten fosforipitoisuudet tyydyttävälle tasolle. Kumpikin lannoite kohotti neulasten fosforipitoisuuksia lannoittamattomaan verrattuna vielä 16-19 vuotta lannoituksen jälkeen (Kuva 2). Tällöin neulasten fosforipitoisuudet olivat apatiitilla lannoitetuilla koealoilla vähän korkeampia kuin raakafosfaateilla lannoitetuilla koealoilla.

Sekä vesiliukoinen kaliumkloridi (kalisuola) että flogopiitti kohottivat neulasten kaliumpitoisuuksia, mutta kalisuola flogopiittia enemmän, kun lannoituksesta oli kulunut 5–7 vuotta (Kuva 2). Myöhemmin, 10–14 vuotta lannoituksen jälkeen, neulasten kaliumpitoisuudet suunnilleen yhtä korkeita tai korkeampia flogopiitilla kuin kalisuolalla lannoitetuilla koealoilla niissä kokeissa, joissa turpeen typpipitoisuus oli yli 1,5% kuiva-aineesta (Kuva 2, Liite 1, Taulukko 1). Ero flogopiitin hyväksi oli yleensä vielä suurempi kokeissa, joissa lannoituksesta oli kulunut 16–19 vuotta (Kuva 2, Liite 1).

Flogopiitin annostuksen lisääntyessä neulasten kaliumpitoisuudet kohosivat, mutta jo suhteellisen pienilläkin flogopiitin määrillä (375–750 kg ha^{-1} kuivana) puuston kaliumin tarve tuli tyydytetyksi ainakin 16–17 vuodeksi (Kuva 3, Taulukko 6, Liite 1). Lannoitus fosforilla ja kaliumilla alensi neulasten sinkki-, mangaani-, kupari- ja booripitoisuuksia erityisesti runsastyppisillä kasvupaikoilla (Liite 1, Taulukot 3–5).

Tulosten mukaan apatiitti on puille kohtalainen fosforin ja flogopiitti hyvä kaliumin lähde rämemänniköissä ainakin 15–20 vuotta. Jatkotutkimuksin tulee selvittää, turvaako flogopiitin kalium puiden kaliumin tarpeen yhtä pitkään (25–30 vuotta) kuin apatiitin fosfori puiden fosforiravitsemuksen. Rämemetsien lannoituksessa tulee tämänkin tutkimuksen tulosten perusteella käyttää fosforin ja kaliumin ohella ainakin booria. Myös sinkkiä saattaisi olla tarpeen lisätä turvemaiden lannoitteisiin, vaikka varsinaisia visuaalisia sinkin puutoksia ei olekaan havaittu.

Received 4.5.1998, accepted 12.11.1998

Appendix 1. Nutrient concentrations in the 1995 needles by experiments and fertilisation treatments. (N, P, K, Ca and Mg as mg g^{-1} and others as mg kg^{-1}) 7 and 8 also the amounts of potassium fertilisers presented as kg ha^{-1}. * = statistical difference compared with the control (Bonferron. $p < 0.05$). 0 = control, RPc = rock phosphate+potassium chloride, APh = apatite + phlogopite.

Liite 1. Ravinnepitoisuudet kokeittain ja käsittelyittäin vuoden 1995 neulasissa. (N, P, K, Ca ja Mg mg g^{-1} ja muut mg kg^{-1}). Kokeissa 7 ja 8 esitetty kaliumlannoitteiden määrät kg ha^{-1}. **= ko. käsittelyllä merkitsevä ero lannoittamattomaan verrattuna (Bonferron p < 0,05). 0 = lannoittamaton, RPc = raakafosfaatti + kalisuola, APh = apatiitti+flogopiitti.*

	N	P	K	Ca	Mg	Mn	Zn	Cu	B
Exp. — *Koe* 1.									
0	1.12	1.16	4.14	2.18	1.28	493	54	3.6	16.2
RPc	1.10	1.24	3.99	2.01	1.36	415	46*	3.3	14.6
APh	1.11	1.21	4.27	2.27	1.30	401	51	3.4	14.7
Exp — *Koe* 2.									
0	1.58	0.86	3.16	1.46	1.24	373	59	3.5	12.4
RPc	1.36	1.29*	3.24	1.46	1.22	250	37*	2.9	12.3
APh	1.57	1.19*	4.21*	1.74	1.22	275	59	3.2	9.2
Exp — *Koe* 3.									
0	1.21	1.17	3.92	1.98	1.18	300	52	3.6	8.6
RPc	1.16	1.35	4.12	2.22	1.17	311	47	3.7	8.0
APh	1.20	1.75*	4.06	2.15	1.23	332	49	3.3	3.2
Exp. — *Koe* 4.									
0	1.45	1.26	3.41	1.61	1.29	533	44	4.5	11.4
RPc	1.21*	1.57	3.54	1.58	1.21	365	35	3.0*	5.3
APh	1.43	1.77*	4.63	1.86	1.22	261	37	3.1*	3.5*
Exp — *Koe* 5.									
0	1.52	0.98	3.30	1.78	1.24	219	48	3.7	11.0
RPc	1.29	1.53*	4.15*	2.03	1.15	181	33*	3.0	5.8
APh	1.32	1.45*	4.12*	2.07	1.30	198	40	3.2	6.6
Exp. — *Koe* 6.									
0	2.08	0.82	2.57	1.27	0.91	287	34	3.7	14.0
RPc	1.77	0.86	2.84	1.51	1.22*	151*	35	3.2	11.2
APh	1.60*	0.98*	3.39*	1.73*	1.21*	152*	36	3.1	4.6*
Exp. — *Koe* 7.									
0	1.31	1.26	4.00	1.96	1.17	423	41	3.7	16.4
A + Ph375	1.45	1.56	4.23	2.07	1.23	386	33	3.1	12.1
A + Ph750	1.48	1.57	4.79	2.04	1.15	331	37	3.3	10.4
A + Ph1125	1.46	1.52	4.73	1.87	1.14	339	38	3.4	10.8
A + Ph1500	1.43	1.47	4.74	1.93	0.97	289	33	2.8	10.5
A + Ph2250	1.39	1.47	4.52	2.14	1.14	313	37	2.9	9.6
Exp — *Koe* 8.									
0	1.37	1.41	3.41	1.54	1.56	195	48	3.7	5.9
A+Ph750	1.51	1.83	4.05	1.85	1.39	166	43	3.4	3.7
A+Pc100	1.21	1.89	4.33*	1.75	1.43	219	44	3.6	6.2
A+Ph1500	1.32	1.76	4.46*	1.99	1.38	223	51	3.8	4.2
A+Pc200	1.30	1.82	4.40*	1.98	1.42	225	50	4.0	6.7
A+Ph3000	1.35	1.85	4.75*	2.04	1.32	211	52	3.3	4.6
A+Pc400	1.30	1.75	4.60*	1.85	1.34	219	47	3.7	5.8
Exp — *Koe* 9.									
0	1.50	0.96	3.29	1.83	1.27	310	49	4.3	10.2
RPc	1.29*	1.26*	3.61	1.63	1.31	289	42	3.7*	13.1
APh	1.27*	1.14	3.83	1.76	1.27	264	41	3.3*	7.4

Appendix 1. Continued. — *Liite 1. Jatkuu.*

	N	P	K	Ca	Mg	Mn	Zn	Cu	B
Exp — *Koe* 10.									
0	1.41	1.33	4.40	1.92	1.21	390	40	3.9	15.8
RPc	1.49	1.57	4.79	2.03	1.14	280	30	2.9	21.2
APh	1.40	1.60	4.99	1.69	1.04	260	35	3.4	12.0
Exp — *Koe* 11.									
0	1.55	1.30	3.05	1.74	1.35	517	42	3.0	14.0
RPc	1.48	1.54	4.00	1.93	1.23	476	45	3.2	17.7
APh	1.32	1.54	4.05	2.09	1.43	351	46	4.5	11.9
Exp — *Koe* 12.									
0	1.36	1.23	3.01	2.03	1.31	576	45	3.1	26.3
RPc	1.41	1.64*	4.34*	2.11	1.01*	384*	35*	2.8	27.1
APh	1.35	1.55*	3.86*	2.06	1.17	396*	38	3.1	22.8*