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EFFECT OF POTASSIUM FERTILIZATION ON THE GROWTH AND NUTRITION OF SCOTS PINE

Kalilannoituksen vaikutus männyn kasvuun ja ravinnetilaan.

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This paper is based on four experiments established in 1960–1969. There were four sources of potassium: potassium chloride, double salt of potassium and magnesium sulphates, cement potassium and potassium sulphate. The application rates of fertilizer potassium varied from 0 to 664 kg/ha as pure element. Nitrogen and phosphorus or phosphorus alone were also given at the beginning. The experiments were inventoried in 1988. The peat potassium amounts were independent of the application rate. On the other hand, the foliar potassium concentrations were the higher the higher the application rate. Yet, the effect of currently used potassium fertilizer rate, (about 80 kg/ha of K), on the foliar potassium concentrations did not significantly differ from the effect of the double rate. Fertilization increased the basal area growth for 8–22 years, after which the growth started to decline. The reason can at least partly be attributed to the shortage of potassium. The growth response was independent of the potassium source and rate on the potassium fertilized plots.

Key words: Foliar nutrients, peatland, peat nutrients, *Pinus sylvestris*

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INTRODUCTION

Potassium is one of the most abundantly used nutrients by trees. The potassium reserves in Finnish peatlands, however, are usually rather limited (Kivinen 1948, Kaila and Kivekäs 1956, Westman 1981, Kaunisto and Paavilainen 1988). Several investigations have emphasized the significance of potassium for the growth of trees on peatlands (Kaunisto and Tukeva 1984, Kaunisto and Paavilainen 1988, Kaunisto 1989, Zalitis 1990). Potassium shortage is especially typical of originally treeless peatlands (Kaunisto and Tukeva 1984), but trees may suffer from potassium deficiency on originally tree-covered peatlands as well (Kaunisto 1989).

The potassium regime can be improved by fertilization. Potassium chloride, used as a potassium source in present fertilizers, is fully soluble to water. Thus fertilizer potassium is readily available for trees, but on the other hand susceptible to leaching (Lehmusvuori 1981, Ahti 1983, Malcolm and Cuttle 1983), because it is only lightly fixed to the peat cation exchange complex (Kaila and Kivekäs 1956, Pätilä 1990). The duration of the potassium fertilization effect on tree growth remains often rather short, 10–15 years (Kaunisto and Tukeva 1984, Kaunisto 1989).

The Department of Peatland Forestry in the Finnish Forest Research Institute has established several experiments in order to find out whether or not the duration of fertilization effect on tree growth could be prolonged by using higher rates and/or other sources of potassium than potassium chloride. This paper introduces the results from four oldest experiments set up in the 1960s.

MATERIAL AND METHODS

Experimental fields

The material was collected from potassium fertilization experiments set up in South Finland in the 1960s (Table 1). The peat layer was more than 1 m deep in all the experiments (Table 1). The Kivisuo experiment was planted with Scots pine (*Pinus sylvestris*, 2+0) in 1960 and thinned in winter 1984–85. All the other experiments consisted of unevensized naturally regenerated stands. The stands were pine-dominated (*Pinus sylvestris*). Only the Alkkia experiment had some birch (*Betula pubescens)* mixture. Except for the Kaakkosuo experiment the site types were poor (Table 1) and not drainable for forestry according to the present recommendations for practice.

Fertilization design

Different potassium sources and rates were compared in the experiments (Table 2). The Alkkia experiment was a factorial 2 x 3 x 3 (phosphorus fertilization x potassium source x potassium rate, 42, 83, 166 kg/ha) = 18 different K-fertilized treatments. Unfertilized and phosphorus fertilized controls were also included. The number of replicates varied from three to six. In Alkkia the plots were separated from each other by ditches and shallow (20–30 cm) furrows.

In Kaakkosuo there were six plots for six potassium rates (21–664 kg/ha). The plots had been split into two for two different potassium sources. All the K-fertilized plots received also nitrogen and phosphorus. In addition there were an unfertilized and a NP-fertilized control plot. These had also been split into two for measurements. There were no true replicates. Thus the differences could not be statistically tested.

The Kettula and Kivisuo experimental designs were almost similar to each other. As regards the potassium sources and rates they were factorial experiments for K-fertilized treatments with two potassium sources and five potassium levels. Furthermore, both had unfertilized as well as NP-fertilized controls (Table 2). There were four replicates for potassium treatments. In Kaakkosuo, Kettula and Kivisuo all potassium fertilized plots received also nitrogen and phosphorus (Table 2).

The Kettula, Kaakkosuo and Kivisuo experiments were refertilized in 1976 (Table 1). In Kaakkosuo all the originally fertilized plots, except the NP-fertilized controls, received NP and two of them also micronutrients (Table 1). The Kettula sample plots were divided into two for refertilization. One part remained unrefertilized. The layout of the refertilization in Kettula and Kivisuo consisted of different combinations of rock phosphate, micronutrient mixture and ammonium nitrate with calcium as a form of a 2^3 factorial. The various refertilization treatments in Kettula and Kivisuo were distributed to

Table 1. Basic information on experiments. See the text also.

Taulukko 1. Perustietoja kokeista. Katso myös tekstiä.

Experiment *Koe*	Peat depth *Turve-syvyys* m	Basic drainage *Perusojitus* Year *Vuosi*	Spacing *Sarkalev.* m	Ditch cleaning year *Ojan perkaus-vuosi*	Stand before fertilization *Puusto ennen lannoitusta* Species[1] *Puulaji*[1]	Height, m *Pituus*, m	Location *Sijainti* N	E
Alkkia	1.5+	a.1935	20	1969	P.S./B.Pu	1–5	62°10'	22°48'
Kaakkosuo	1.0 –1.7	1953	45–60	1990	P.S.	1–6	62°04'	24°29'
Kettula	1.5+	1959	35–60	1987	P.S.	0.5	60°24'	23°45'
Kivisuo	2.5+	1945	23	1983	P.S.	0.1	61°53'	25°57'

Experiment *Koe*	Basic fertilization[2] *Peruslannoitus*[2] Year *Vuosi*	Nutrients *Ravinteet*	Refertilization[3] *Jatkolannoitus*[3] Year *Vuosi*	Nutrients *Ravinteet*	Plot size *Koealan koko* m^2	No of plots *Koeal. lukum. kpl*	Site type[4] *Suotyyppi*[4]
Alkkia	1969	P,K	–	–	200	85	LkN
Kaakkosuo	1961	NP,K	1976	NP,micron.	600	16	RaIR-SR
Kettula	1961	NP,K	1976	N,P,micron.	300	21	RaR
Kivisuo	1960	NP,K	1976	N,P,micron.	880	30	LkN

1) P.S. = *Pinus sylvestris*, B.Pu. = *Betula pubescens*

2) N = In Kettula montansaltpetre — *Kettulassa montansalpietaria* 385 kg/ha (N = 26%), in others oulusaltpetre (ammonium nitrate with lime) — *muissa oulunsalpietaria* 400 kg/ha (N = 25%) P = rock phosphate — *raakafosfaattia*. In Alkkia — *Alkkiassa* 300 kg/ha, in the other experiments — *muissa kokeissa* 400 kg/ha (P = 14.3%)

3) In Kaakkosuo all basic-fertilized plots except NP-fertilized controls received NP and two of them micronutrient mixture in addition. In Kettula only plots refertilized with P, NP, P + micronutrients or NP + micronutrients were included in this study. In Kivisuo a plot could receive any one of the combinations of N, P and micronutrient mixture. — *Kaakkosuolla kaikki peruslannoitetut koealat NP-lannoitettuja vertailuja lukuunottamatta saivat NP:n ja kaksi niistä lisäksi hivenseosta. Kettulassa ainoastaan koealat, jotka olivat saaneet P, NP, P + hivenseosta ja NP + hivenseosta otettiin mukaan tutkimukseen. Kivisuolla kaikki N-, P- ja hivenseosyhdistelmät olivat mukana.* Fertilizers used: — *Lannoitteet*: N = 100 kg/ha as oulusaltpetre — *oulunsalpietarina*, P = 58 kg/ha as rock phosphate — *raakafosfaattina*, micronutrient micture — *hivenseosta* 100 kg/ha (B 1.1%, Cu 12.8%, Mn 5.5%, Fe CO_3 9.6%, Zn 5.5%, Mo 1.4%, Na 0.7%)

4) LkN = Low sedge fen, RaIR = *S. fuscum* rich dwarf-shrub pine bog, RaR = *S. fuscum pine* bog, SR = Poor tall-sedge pine fen. Peatland site types at the time of the basic fertilization. English terms according to Laine and Vasander (1990). — *Suotyypit peruslannoituksen ajankohtana.*

the four original replicates and different levels of basic potassium fertilization according to a certain system. The result was that at one level of potassium fertilization all the following combinations were present: P + micronutrients, micronutrients, N + micronutrients and N + P + micronutrients. The next potassium fertilization level included all the other combinations of the 2^3 factorial etc. In Kettula only the plots that had received P, NP, P + micronutrients or all of those were included in this study, but in Kivisuo all the combinations were included. It was not possible to calculate the effects of different refertilization treatments separately.

Sampling of peat and needles

Peat samples were taken from five points on each sample plot in 1987 or 1988, one about 5 metres from each plot corner in the direction of plot diagonals and one sample from the plot centre. The raw humus layer was separated from peat and analyzed except in the Alkkia experiment. The peat sample itself was taken as a 30-cm-deep profile and divided into 10-cm subsamples. The subsamples of the same layer were combined to represent the whole plot. The samples were stored in the freezer and analyzed at the Parkano Research Station. Except for Kaakkosuo, the samples were taken with fixed volume (250 cm^3) *in situ* for calculating the nutrient amounts per area unit.

Peat was analyzed for the total nitrogen using the Kjeldahl method, for pH (fresh peat/water V/V = 1/5) as well as for the total phosphorus and potassium using the standard methods of the Finnish Forest Research Institute for organic material (Halonen et al. 1983). Average peat properties are presented in Tables 3 and 4.

The needle samples were collected in December 1988 and in February–March 1989. Samples were taken from the southern side of the uppermost whorls (2–3) of about ten trees. The samples were analyzed for nitrogen, phosphorus and potassium.

Measurements of the trees

The breast-height diameter was measured from every tree with a breast-height diameter over 5 cm. The sample trees were taken randomly on the plots. The aim was to have at least one sample tree in each diameter class and an even distribution of the sample trees on each plot. In addition, two trees with the biggest breast-height diameter were selected for a sample tree. The number of the sample trees varied from 10 to 15 per sample plot. The sample trees were measured for the radial growth and height. The radial growth of the sample trees was measured from the increment cores taken at breast height. The annul basal area increment and the total volume of stands were calculated using the KPL-program (a program for calculating stand characteristics in experimental plots) of the Finnish Forest Research Institute.

The analyses of variance and regression were mostly used for the calculations. However, the analysis of covariance was employed when investigating the effect of fertilization on the tree characteristics in Alkkia. The covariate was the basal-area growth during 5 years before fertilization.

RESULTS AND DISCUSSION

Effect of potassium fertilization on peat potassium

There were very small amounts of potassium in peat in all the experiments (Fig. 1), particularly so in the Alkkia experiment when comparing the potassium consumption of trees (e.g. Mälkönen 1974, Paavilainen 1980, Finér 1989). The largest amounts of potassium were found in the surface peat layer (0–10 cm).

The effect of potassium fertilization on the amount of peat potassium was not in any of the experiments statistically significant although in the raw humus layer the amounts somewhat increased along with the increasing application rates (Fig. 1, Table 5). Nor were there statistically significant differences between the various

Table 2. Amount of fertilizer N, P and K as elements and number of experimental plots (= figures inside the Table) in different treatments.

Taulukko 2. Lannoitetypen, -fosforin ja -kaliumin määrät alkuaineina sekä koealojen määrä (luvut taulukon sisällä eri käsittelyissä.

Experiment *Koe*	Basic fertil. *Peruslann.* N	P	Potassium source[1)] *Kaliumin lähde*[1)]	Amount of potassium - *Kaliumin määrä* kg/ha 0	21	42	83	166	332	498	664	Σn
Alkkia	0	0	KMg		–	4	4	3	–	–	–	11
	0	0	cK	4	–	4	4	4	–	–	–	4+12
	0	0	KCl		–	4	5	5	–	–	–	14
	0	43	KMg		4	5	4	4	–	–	–	13
	0	43	cK	4	–	4	5	4	–	–	–	4+13
	0	43	KCl	4	–	4	6	4	–	–		4+14
			Σn	8	0	24	29	24	0	0	0	85
Kaakkosuo	0	0	–	2	–	–	–	–	–	–	–	2
	100	57	–	2	–	–	–	–	–	–	–	2
	100	57	KCl	–	1	1	1	1	1	–	1	6
	100	57	K_2SO_4	–	1	1	1	1	1	–	1	6
			Σn	4	2	2	2	2	2	0	2	16
Kettula	0	0	–	1	–	–	–	–	–	–	–	1
	100	57	KCl	–	–	4	4	4	4	–	4	20
	100	57	K_2SO_4	–	–	4	4	4	4	–	4	20
			Σn	1	0	8	8	8	8	0	8	41
Kivisuo	0	0		5	–	–	–	–	–	–	–	5
	100	57	–	4	–	–	–	–	–	–	–	4
	100	57	KCl	–	–	4	4	4	4	4	–	20
	100	57	K_2SO_4	–	–	4	4	4	4	4	–	20
			Σn	9	0	8	8	8	8	8	0	49
			ΣΣn	22	2	42	47	42	18	8	10	191

1) KMg = double salt consisting of sulphates of potassium and magnesium – *Kalium- ja magnesiumsulfaatin kaksoissuola* (K 23.2%, Mg 5.4%). cK = cement potassium, dust from the chimneys of the cement works, – *Sementtitehtaan piipun pölyä,* K 10%, Ca 21%, Mg 1.1%, Al 2.0%, CO_3 18%. K as KCl, K_2SO_4 and K_2CO_3 - *Sisältää* KCl, K_2SO ja K_2CO_3.

potassium sources (Table 6). This is quite understandable, because in all fertilizer materials potassium was in a water soluble form, although in cement potassium part of the potassium was as K_2CO_3. Haveraaen (1978) has found that potassium from K_2CO_3 stays more tightly in cation exchange sites than potassium from KCl.

Table 3. Means and standard deviations of pH and bulk density in the different experiments on fertilized plots.

Taulukko 3. Tiheyden ja pH:n keskiarvot ja standardipoikkeamat kokeiden lannoitetuilla koealoilla.

Quantity *Suure*	Layer *Kerros* cm	Alkkia	Kaakkosuo	Kettula	Kivisuo
pH	Rh [1]	–	4.1±0.1	4.1±0.1	4.1±0.1
	0–10	–	4.0±0.0	3.9±0.1	3.9±0.1
	10–20	–	4.2±0.1	3.9±0.1	4.0±0.0
	20–30	–	4.4±0.2	3.9±0.5	4.0±0.0
Density	Rh	–	–	17±7	33±11
Tiheys	0–10	76±19	–	70±7	111±14
mg/cm³	10–20	75±24	–	65±5	91±27
	20–30	81±29	–	63±4	87±20

1) Rh = Raw humus — *Raakahumus.*

Table 4. Peat nutrient contents in different peat layers as averages of all plots.

Taulukko 4. Turpeen ravinnepitoisuudet kaikkien koealojen keskiarvoina eri syvyyksillä.

Nutrient *Ravinne*	Layer *Kerros* cm	Experiment — *Koe* Alkkia	Kaakkosuo	Kettula	Kivisuo
N, mg/g	Rh 1)	–	15.6±1.5	13.4±1.5	14.7±1.0
	0–10	12.2±3.9	18.3±2.1	8.2±0.8	11.4±1.3
	10–20	11.7±5.4	20.3±1.6	5.8±0.7	8.6±2.0
	20–30	13.2±5.7	20.0±1.7	5.3±0.6	10.0±2.6
P, mg/kg	Rh	–	814±188.9	664±106.4	685±105.0
	0–10	537±180.1	691±214.1	361±67.7	446±80.1
	10–20	361±173.8	537±188.5	169±42.3	217±56.2
	20–30	328±141.4	457±131.4	118±32.5	202±71.5
K, mg/kg	Rh	–	386±113.8	544±118.7	316±74.0
	0–10	187±57.0	147±76.8	298±59.3	182±44.6
	10–20	55±31.0	50±23.8	121±52.9	75±25.5
	20–30	36±14.9	36±12.1	75±31.9	51±20.2

1) Rh = Raw humus — *Raakahumus*

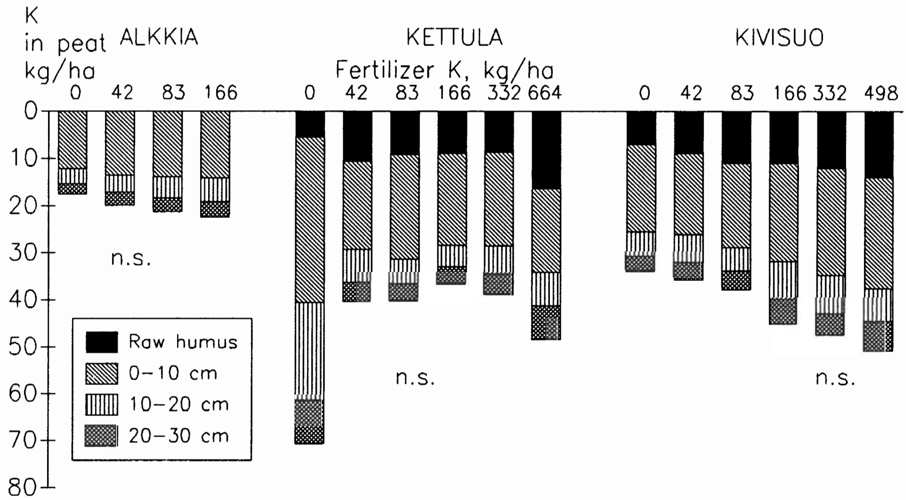


Figure 1. Potassium amounts in different peat layers in Alkkia, Kettula and Kivisuo experiments. n.s. = differences not significant in the analysis of variance.

Kuva 1. Kaliumin määrä turpeessa Alkkian, Kettulan ja Kivisuon kokeissa. n.s. = erot eivät merkitseviä varianssianalyysissä.

Needle nutrients

The needle potassium concentrations 19–29 years after fertilization were higher on the potassium fertilized plots than on the nitrogen-phosphorus of phosphorus fertilized ones (Fig. 2). Generally, the needle potassium concentrations increased

Table 5. Effect of fertilization on the potassium concentrations (mg/kg) of peat and raw humus in the Kaakkosuo experiment.

Taulukko 5. Kalilannoituksen vaikutus turpeen ja raakahumuksen kaliumpitoisuuksiin (mg/kg) Kaakkosuon kokeessa.

Layer *Kerros* cm	Potassium fertilization — *Kalilannoitus*, kg/ha 0	21	42	83	166	332	664	x̄
Rh [1]	402	310	242	375	547	552	562	427
0–10	169	83	77	232	143	220	53	140
10–20	53	30	36	82	44	66	47	51
20–30	28	31	32	51	32	45	37	37

1) Rh = Raw humus — *Raakahumus*

Table 6. Amount of potassium (kg/ha) in 0–30 cm peat layer in connection with different potassium sources. Key as in Table 2. Means of all potassium rates. n.s. = no significant differences in the analysis of variance.

Taulukko 6. Kaliumin määrä (kg/ha) 0–30 cm:n turvekerroksessa käytettäessä erilaisia kaliumin suoloja. Lyhenteet kuten taulukossa 2. Luvut ovat kaikkien lannoitemäärien keskiarvoja. n.s.= ei tilastollisesti merkitseviä eroja varianssianalyysissä.

Experiment *Koe*	Potassium source — *Kaliumin lähde*				
	KCl	K_2SO_4	KMg	cK	Significance *Merkitsevyys*
Alkkia	21	–	20	22	n.s.
Kettula	33	34	–	–	n.s.
Kivisuo	31	30	–	–	n.s.

with increasing potassium rates given in fertilization. However, even a double rate, compared to the present forestry practice (about 80 kg/ha), caused no statistically significant differences in the needle potassium concentrations at the time of the inventory. Except for the largest potassium fertilizer amounts, the needle potassium concentrations were usually around the shortage limit (4.0 mg/g) given

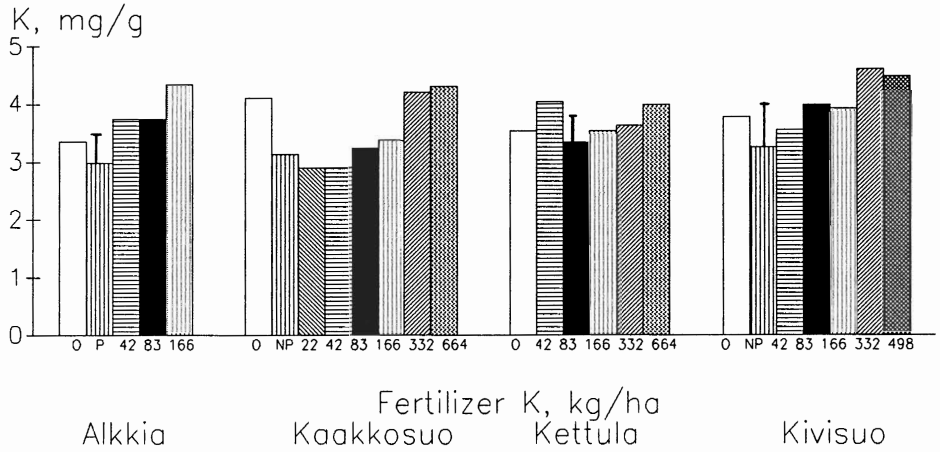


Figure 2. Foliar potassium concentrations 19 (Alkkia), 28 (Kaakkosuo and Kettula) and 29 (Kivisuo) years after fertilization. Vertical line indicates the significant difference at the 5% risk level.

Kuva 2. Neulasten kaliumpitoisuudet 19 (Alkkia), 28 (Kaakkosuo ja Kettula) ja 29 (Kivisuo) vuoden kuluttua lannoituksesta. Pystysuora viiva osoittaa tilastollisesti merkitsevän eron 5%:n riskitasolla.

Table 7. Effect of potassium source on the needle potassium concentrations (mg/g). Key as in Table 2. Means of all potassium rates. n.s. = no significant differences.

Taulukko 7. Kaliumin lähteen vaikutus neulasten kaliumpitoisuuksiin (mg/g). Lyhenteet kuten taulukossa 2. Luvut ovat kaikkien lannoitemäärien keskiarvoja. n.s. = ei tilastollisesti merkitseviä eroja.

Experiment *Koe*	Potassium source — *Kaliumin lähde*				
	KCl	K_2SO_4	KMg	cK	Significance *Merkitsevyys*
Alkkia	4.03	–	3.84	3.94	n.s.
Kaakkosuo	3.48	3.54	–	–	–
Kettula	3.80	3.63	–	–	n.s.
Kivisuo	4.11	4.02	–	–	n.s.

by Paarlahti et al. (1971). The needle potassium concentrations in Kivisuo were fairly high in connection with the two heaviest fertilization treatments. Potassium source did not affect the needle potassium concentrations (Table 7).

Stand volume

The stand volume varied considerably both within and between the experiments (Table 8). On the P and NP fertilized plots the stand volume was higher than on the unfertilized ones. Generally the highest volumes were achieved on plots where also potassium had been applied. However, only in Kivisuo and Kettula the difference in stand volume between the NPK-fertilized plots and the unfertilized controls was statistically significant. Potassium fertilization in addition to P or NP increased the stand volume, but statistically significantly only in Kivisuo.

Basal area growth

The response of the basal area growth to fertilization was quite rapid and clear in all the experiments (Fig. 3). However, the duration of the growth response varied considerably between the experiments.

In the **Alkkia** experiment the maximum annual basal area increment was attained 7–8 years after fertilization, after which growth declined. The decline was more pronounced on the plots fertilized with phosphorus only than on those with potassium or phosphorus and potassium. The differences in the basal area increment between the fertilized and unfertilized plots were statistically significant only in the years of the highest growth (1973–75). No significant differences were found between the fertilized plots.

At the inventory the average needle nitrogen and phosphorus concentrations in the Alkkia experiment were satisfactory (on fertilized plots N = 14.5 mg/g, P = 1.67 mg/g on average, see also Table 9), but there were also concentrations near or below the deficiency limits, N = 13.0 and P = 1.40 mg/g (Table 9) given by Paarlahti et al. (1971). However, when considering that the foliar potassium concentrations were in most cases near the shortage limit (e.g. Paarlahti et al. 1971, Raitio 1978, Kaunisto and Tukeva 1984), that there were exceptionally low amounts of potassium in peat and that in the last 7 years

Table 8. Stand volume (m^3/ha) on differently fertilized sample plots in all experiments and percentage of birch ( ) in Alkkia.

Taulukko 8. Puuston tilavuus (m^3/ha) eri tavoin lannoitetuilla koealoilla ja koivun prosenttinen osuus ( ) Alkkiassa.

Fertilization *Lannoitus*	Alkkia	Kaakkosuo	Kettula	Kivisuo
0	47 (20)	54	9	11
K	73 (30)	–	–	–
(N)P [1]	67 (38)	65	–	32
NP + K21	–	104	–	–
NP + K42	73 (29)	74	49	79
NP + K83	85 (30)	68	60	93
NP + K166	74 (36)	152	53	93
NP + K332	–	105	45	82
NP + K498	–	–	–	90
NP + K664	–	145	43	–
Sign. [2] + 0	n.s.	–	*	**
Sign. [2] + K	n.s.	–	n.s.	*

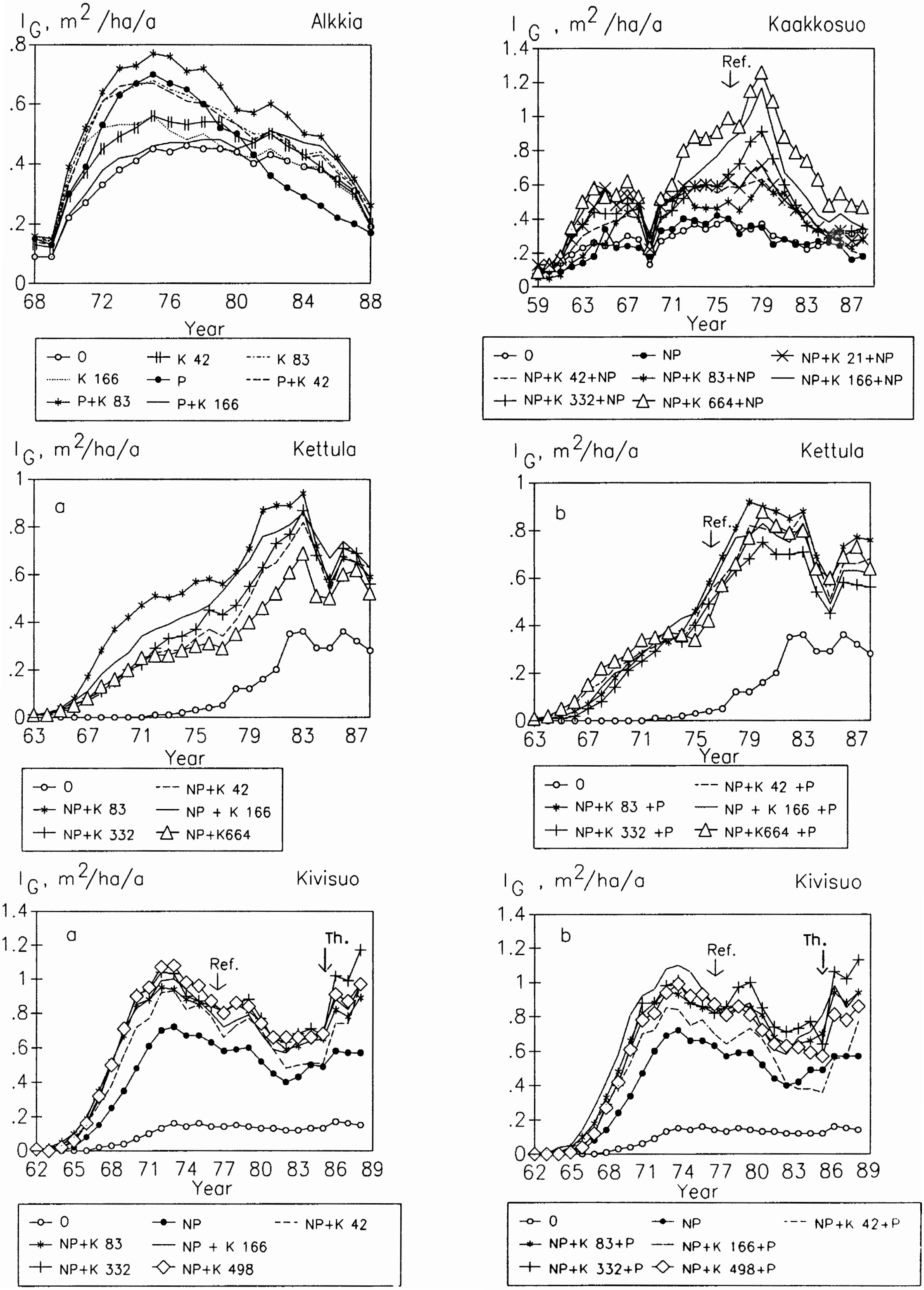
1) In Alkkia only P was given in basic fertilization. — *Alkkiassa peruslannoituksessa annettiin vain fosforia.*
2) Significance + K includes fertilized treatments only. Significance + 0 includes also the controls. n.s. = not significant, * and ** = significant at 5 and 1% risk respectively — *Sign. + K sisältää vain lannoitetut koealat. Sign. + 0 sisältää myös vertailukoealat. n.s. = ei tilastollisesti merkitsevä, * = merkitsevä 5:n ja ** = merkitsevä 1%:n riskillä.*

growth was poorer on P-fertilized than on K- or PK-fertilized plots, it is probable that the growth decline was also, at least partly, caused by a potassium shortage. Another reason may be the deterioration of ditches and partly also a nitrogen shortage.

In **Kaakkosuo** the growth of trees increased for 19 years, after which it declined very suddenly despite the refertilization

Figure 3. (Right) Effect of the fertilizer rate on the annual basal area increment in the experiments. The fertilization year was 1969 in Alkkia, 1961 in Kettula and Kaakkosuo and 1960 in Kivisuo. Refertilization (Ref.) in 1976 in Kaakkosuo, Kettula and Kivisuo. In Kettula Fig. a includes the unrefertilized and b the refertilized parts of the plots. In Kivisuo Figure a includes all the plots, but Fig. b only the plots that have received P at refertilization. In Kettula and Kivisuo refertilized plots may have also N or micronutrients or both. Th. = thinning in winter 1984–85. See also Table 2 and Chapter "Material and methods".

Kuva 3. (Oikealla) Lannoituksen vaikutus vuotuiseen pohjapinta-alan kasvuun. Lannoitusvuosi oli Alkkiassa 1969, Kettulassa ja Kaakkosuolla 1961 ja Kivisuolla 1960. Kaakkosuo, Kettula ja Kivisuo jatkolannoitettiin (ref.) v. 1976. Kettulassa osakuvassa a ovat jatkolannoittamattomat ja osakuvassa b jatkolannoitetut koealojen puoliskot. Kivisuolla osakuva a sisältää kaikki koealat, mutta osakuva b vain jatkolannoituksessa fosforia saaneet koealat. Kettulassa ja Kivisuolla jatkolannoitetut koealat ovat voineet saada myös typpeä tai hivenaineita tai molempia. Th = harvennus talvella 1984–85. Katso myös taulukko 2 ja luku "Material and methods".



I_G, m²/ha/a
Alkkia
Year
0
K 166
P+K 83
K 42
P
P+K 166
K 83
P+K 42
I_G, m²/ha/a
Kaakkosuo
Ref.
Year
0
NP+K 42+NP
NP+K 332+NP
NP
NP+K 83+NP
NP+K 664+NP
NP+K 21+NP
NP+K 166+NP
I_G, m²/ha/a
Kettula
a
Year
0
NP+K 83
NP+K 332
NP+K 42
NP + K 166
NP+K664
I_G, m²/ha/a
Kettula
b
Ref.
Year
0
NP+K 83 +P
NP+K 332 +P
NP+K 42 +P
NP + K 166 +P
NP+K664 +P
I_G, m²/ha/a
Kivisuo
a
Ref.
Th.
Year
0
NP+K 83
NP+K 332
NP
NP + K 166
NP+K 498
NP+K 42
I_G, m²/ha/a
Kivisuo
b
Ref.
Th.
Year
0
NP+K 83+P
NP+K 332+P
NP
NP+K 166+P
NP+K 498+P
NP+K 42+P

with nitrogen and phosphorus in 1976, a few years before the growth decline (Fig. 3).

In Kaakkosuo the needle potassium concentrations were low, whereas the phosphorus concentration was very high (1.81 mg/g on average) on the phosphorus-fertilized plots (see also Table 9). Although the needle nitrogen concentration was low (on fertilized plots 13.5 mg/g on average, see also Table 9), it is improbable that the trees in the area suffered from a nitrogen shortage as the fairly high peat nitrogen concentration (Table 4) supposedly offered at least reasonable conditions for nitrogen mineralization (Alexander 1967, Kaunisto 1982, 1987) and the basal area growth only vaguely responded to NP refertilization in 1976. Similarly, the fact that growth was the best with high potassium applications indicates that a potassium shortage has, at least partly, been the reason for the growth decline.

In the **Kettula** experiment growth increased on the refertilized plots for 19 and on the unrefertilized ones for 22 years (Fig. 3). After 22 years growth declined abruptly but became level again a few years later. Refertilization in 1976 with different combinations of nitrogen, phosphorus and micronutrients (cf. Table 1) increased growth in 5–6 successive years, after which growth returned to the level of the unrefertilized plots (see also Fig. 4). Despite the refertilization the needle nitrogen and phosphorus concentrations were near the shortage limits (on fertilized plots, N = 13.1 mg/g, P = 1.37 mg/g on average, see also Table 9), which may have affected the growth decline. Kettula was the nitrogen-poorest area. In such areas the effect of nitrogen fertilization is usually over within a few years (Karsisto 1976, Kaunisto 1977, Paavilainen 1977). In fact, the duration of the basic fertilization was suprisingly long for these conditions. It would be interesting to know, if the nitrogen fallout (a. 10 kg/ha/a in southernmost Finland) could have had any effect on the phenomenon. The differences in the basal area increment between the fertilized and unfertilized plots were statistically significant during six years in the 1970s and 1980s. No significant differences were found between the fertilized plots.

In **Kivisuo** the duration of the fertilization effect was 13–14 years, after which growth declined in all the fertilized sample plots in a very similar manner. The differences in the basal area increment between the fertilized and unfertilized plots were statistically significant from 1965 onwards and between the NP-fertilized and NPK-fertilized treatments in 1967–71.

Table 9.Needle nutrient concentrations and their standard deviations. Controls also included.

Taulukko 9. Neulasten ravinnepitoisuudet ja niiden standardipoikkeamat. Mukana myös vertailukoealat.

Experiment *Koe*	Nutrient — *Ravinne* N	P	K	B
Alkkia	14.5±1.8	1.63±0.25	3.80±0.60	6.8±3.8
Kaakkosuo	13.7±1.0	1.73±0.33	3.51±0.59	22.1±4.1
Kettula	12.9±1.0	1.34±0.16	3.72±0.42	17.5±3.9
Kivisuo	17.1±1.4	1.48±0.38	4.07±0.54	15.1±5.1

Refertilization with different combinations of nitrogen, phosphorus and micronutrients (Table 1) in 1976 produced only a temporary increase in growth (Figs. 3 and 4). On the other hand, after the thinning in winter 1984–85 growth increased on the potassium fertilized plots strongly and most on those fertilized with the highest potassium rates. The needle potassium concentrations were also higher on these than on the other plots (Fig. 2). At the inventory the average needle nitrogen and phosphorus concentrations were fairly high (on fertilized plots N = 16.3 mg/g, P = 1.58 mg/g on average, see also Table 9), although on some plots the needle phosphorus levels were below the deficiency limits given by Paarlahti et al. (1971) indicating even a severe phosphorus deficiency at the time of the inventory. The growth decline after 1979, however, was quite clear also on the plots refertilized either with P or NP (Fig. 3). The results imply that also in Kivisuo the growth decline was, at least partly, caused by a potassium shortage. On the other hand, thinning might have returned some potassium to the nutrient cycle of trees.

The source of potassium did not affect either the intensity of the fertilization effect or its duration in any experiment (Fig. 4).

Potassium balance in the potassium fertilized stands

The stand volume in the potassium fertilized sample plots varied between 43–152 m^3/ha (Table 8). According to Finér (1989) about 0.773 kg of potassium was fixed in the total above- and underground biomass for one stemwood cubic metre in a pure pine stand on a mire. The corresponding figures in a mixed pine-birch stand were 0.323 kg/m^3 in pine and 0.717 kg/m^3 in birch. In the Alkkia experiment the volume of birch varied between 21–27 m^3/ha. The other experiments were in pure pine stands.

Table 10 is based on the above-mentioned figures. Although the amount of potassium fixed in the ground vegetation in this study was not measured, it is obvious that fixation into the ground vegetation represents only a minor part in potassium losses (Paavilainen 1980, Vasander 1981, Finér 1989) and that the majority of potassium from the high fertilizer potassium rates was leached either to peat layers deeper than 30 cm or away from the experimental areas (also Vasander 1981).

CONCLUSIONS

Peat depth in all the experimental areas was over one metre. The stands were young and also partly uneven in the Alkkia, Kaakkosuo and Kettula experimental fields at the time of fertilization. The Kivisuo experimental area was fertilized in connection with planting. Thus there was very little needle mass that could fix potassium in Kivisuo and also in the other areas less than in more advanced fully-stocked stands. Thus the results cannot be directly generalized to other potassium-fertilized stands in deep-peat areas. However, previous investigations have shown that even in fully-stocked stands the effect of potassium fertilization has terminated in 10–15 years (Kaunisto and Tukeva 1984, Kaunisto 1989).

The results showed that the majority of the water soluble fertilizer potassium when applied in large amounts could not be used by trees (see also Kaunisto and Paavilainen 1988), but was supposedly leached away. On the other hand, the growth responses produced by even rather small applications (42 kg/ha of K) were essentially similar to those produced by larger amounts. The leaching of fertilizer potassium is known to be quite fast

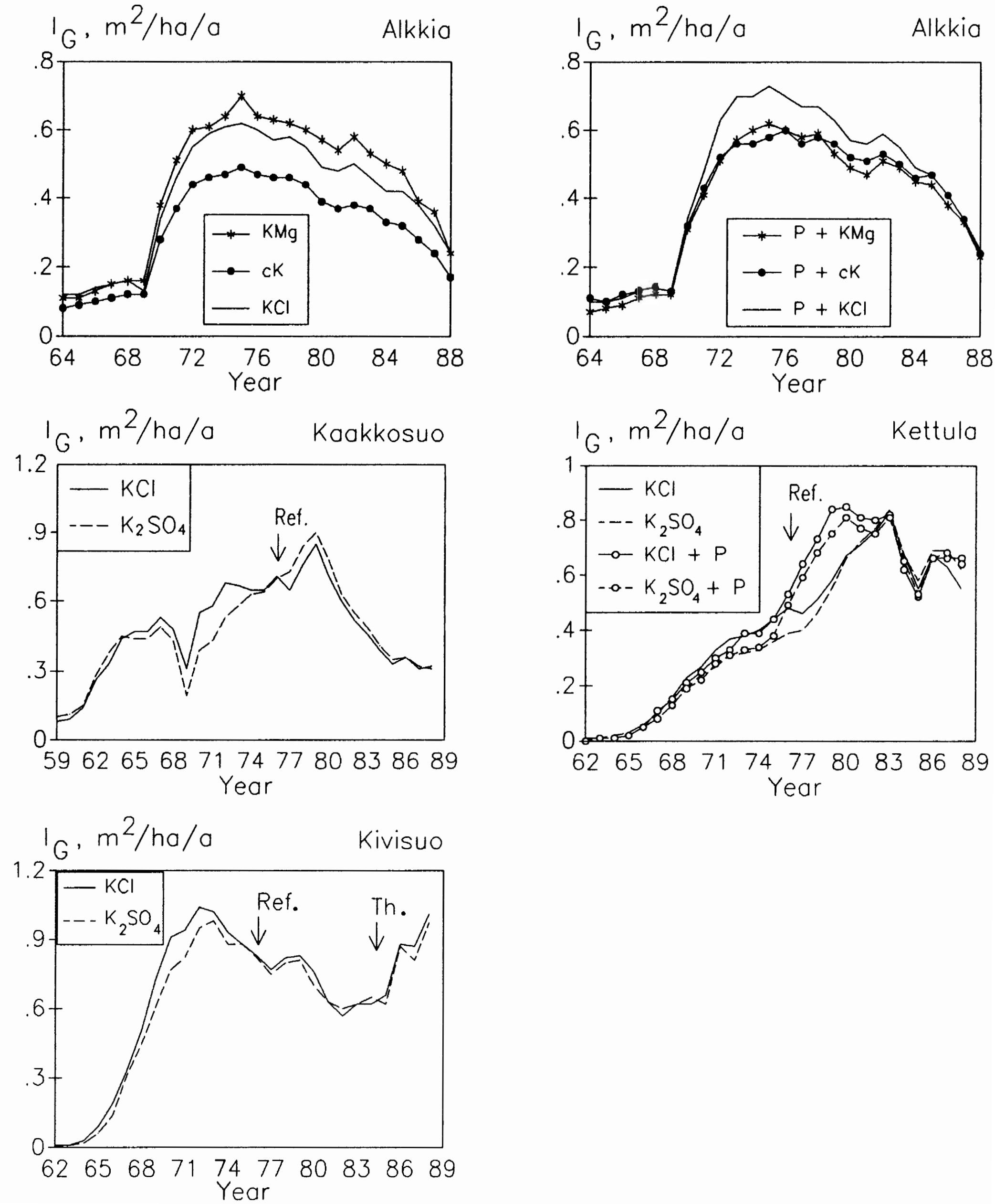

I_G, m2/ha/a
Alkkia
.8
.6
.4
.2
0
64 68 72 76 80 84 88
Year
KMg
cK
KCl
I_G, m2/ha/a
Alkkia
.8
.6
.4
.2
0
64 68 72 76 80 84 88
Year
P + KMg
P + cK
P + KCl
I_G, m2/ha/a
Kaakkosuo
1.2
.9
.6
.3
0
59 62 65 68 71 74 77 80 83 86 89
Year
KCl
K2SO4
Ref.
I_G, m2/ha/a
Kettula
1
.8
.6
.4
.2
0
62 65 68 71 74 77 80 83 86 89
Year
KCl
K2SO4
KCl + P
K2SO4 + P
Ref.
I_G, m2/ha/a
Kivisuo
1.2
.9
.6
.3
0
62 65 68 71 74 77 80 83 86 89
Year
KCl
K2SO4
Ref.
Th.

Figure 4. (Left) Effect of the fertilizer source on the annual basal area increment in the experiments. All potassium rates combined. In basic fertilization also NP was given in Kaakkosuo, Kettula and Kivisuo. Refertilization in Kaakkosuo, Kettula and Kivisuo in 1976. Key in Fig. 3.

Kuva 4. (Vas.) Ravinnelähteen vaikutus puuston vuotuiseen pohjapinta-alan kasvuun. Kaikki kaliumtasot yhdistettynä. Kaakkosuolla, Kettulassa ja Kivisuolla peruslannoituksessa annettiin myös typpeä ja fosforia. Jatkolannoitus Kaakkosuolla, Kettulassa ja Kivisuolla v. 1976. Selitykset kuvassa 3.

(Ahti 1983, Kaunisto and Tukeva 1984). Therefore trees have to take the potassium from the fertilizer in a rather short time, maybe in the first few years after fertilization. It is important that the area is fully stocked by trees and that trees at the time of fertilization are in good condition and capable of taking up potassium effectively. The potassium store fixed by trees circulates actively internally (Paavilainen 1980, Finér 1989). However, some of the potassium is removed from the cycle, leading to a shortage again. This is seen also in the fact that the potassium concentrations of tree litter decline quite rapidly after potassium fertilization (Paavilainen 1990).

A heavy potassium fertilization because of high expenses is not sensible at least in young stands, because growth does not correspondingly increase. Instead, in practical fertilizations it might be possible to manage with smaller rates applied more frequently. Another possibility would be to develop a potassium fertilizer with both slowly soluble and readily soluble parts.

Table 10. Estimated potassium balance on the potassium fertilized plots.

Taulukko 10. Arvioitu kaliumtase kalilannoitetuilla koealoilla.

Experiment	Potassium — Kalium				
	Stand volume	In stand biomass [1]	Given max. rate	In analysed soil layer	In stand and peat (0–30 cm) from max. rate
Koe	*Puuston tilavuus*	*Puuston biomassassa* [1]	*Annettu maksimimäärä*	*Analysoidussa turvekerroksessa*	*Puustossa ja turpeessa (0–30 cm) maks. annoks.*
	m^3/ha	kg/ha	kg/ha	kg/ha	%
Alkkia	73–85	56–66	166	18–23	45–54
Kaakkosuo	68–152	53–117	664	35–50 [2]	13–25
Kettula	43–60	33–46	664	37–47	11–14
Kivisuo	79–90	61–72	492	35–50	20–25

1) An estimate based on the data by Finér (1989). — *Arvio perustuu Finérin (1989) tutkimuksiin.*
2) An estimate based on K concentrations in peat in this investigation and on bulk density on a corresponding site nearby (Kaunisto and Paavilainen 1988, VSR at Jaakkoinsuo). — *Arvio perustuu K-pitoisuuksiin turpeessa tässä tutkimuksessa ja tiheyteen vastaavalla lähettyvillä sijaitsevalla kasvupaikalla (Kaunisto ja Paavilainen 1988, VSR Jaakkoinsuolla).*

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TIIVISTELMÄ:

KALILANNOITUKSEN VAIKUTUS MÄNNYN KASVUUN JA RAVINNETILAAN

Typen ja kalsiumin jälkeen puut käyttävät kasvinravinteista eniten kaliumia. Etenkin paksuturpeisilla turvemailla sitä on turpeessa kuitenkin luontaisesti yleensä niukasti. Puuston kaliumtaloutta voidaan parantaa lannoittamalla. Tähän saakka lannoitteissa kaliumin lähteenä on käytetty kalisuolaa, joka on kokonaan vesiliukoista. Näin se on välittömästi puiden käytettävissä, mutta toisaalta myös erittäin altis huuhtoutumiselle, koska se kiinnittyy vain heikosti kationinvaihtopaikkoihin. Kalilannoituksen vaikutusajan kesto jääkin usein lyhyehköksi käytettäessä nykyisen lannoitussuosituksen mukaista alkuainemäärää (n.80 kg/ha K).

Tämän tutkimuksen tarkoituksena on selvittää erilaisten kaliumin lähteiden (KCl, K_2SO_4, kalimagnesia = kalium- ja magnesiumsulfaatin kaksoissuola ja Paraisten kali = sementtitehtaan piipun pölyä) ja erilaisten lannoitekaliumin määrien vaikutusta puuston reaktioon ja lannoitusvaikutuksen kestoon sekä kasvualustan ravinnetilaan.

Tutkimuksen aineisto on kerätty Metsäntutkimuslaitoksen suontutkimusosaston toimesta 1960-luvulla perustetuilta Kivisuon (1960), Kaakkosuon (1961), Kettulan (1961) ja Alkkian (1969) kokeilta. Kokeissa käytetyt lannoitteet ja ravinneyhdistelmät sekä koealojen jakautuminen eri käsittelyihin ilmenevät taulukoista 1 ja 2. Lannoitekaliumin määrän vaihtelu eri käsittelyissä oli 21–664 kg/ha (taulukko 2). Kaikissa kokeissa oli myös lannoittamattomia koealoja. Lisäksi Alkkian, Kaakkosuon ja Kivisuon kokeissa oli fosforilla tai fosforilla ja typellä lannoitettuja vertailukoealoja. Kaakkosuon, Kivisuon ja Kettulan kokeissa kaikki kalilannoitetut koealat saivat kokeita perustettaessa myös typpeä ja fosforia. Lisäksi niitä jatkolannoitettiin v. 1976 typellä ja fosforilla tai typen, fosforin ja hivenseoksen erilaisilla yhdistelmillä tietyn kaavion mukaan. Jatkolannoituskäsittelyjen erillisvaikutuksia ei ole kuitenkaan voitu käsitellä.

Kaakkosuota lukuunottamatta koealueet olivat niukkaravinteisia (taulukko 4). Kettulan koealue oli erityisen karu. Inventointihetkellä, 19–29 vuoden kuluttua lannoituksesta, kalilannoituksen vaikutus ei enää näkynyt turpeen kaliumin määrissä (kuva 1) tai pitoisuuksissa (taulukko 5). Neulasten kaliumpitoisuudet sitä vastoin jonkin verran kohosivat nousevien lannoitekaliumin määrien myötä (kuva 2). Nykyistä lannoitussuositusta (n. 80 kg/ha) suuremmat määrät näkyivät neulasten kaliumpitoisuuksissa tilastollisesti merkitsevästi 83 kg/ha:n tasoon verrattuna kuitenkin vain Kettulan kokeessa. Kaliumin lähde ei vaikuttanut kaliumin määrään maassa (taulukko 6) eikä neulasten kaliumpitoisuuteen (taulukko 7).

Puusto reagoi lannoitukseen voimakkaasti kaikilla koealueilla. Alkkiassa jo pelkkä P-lannoitus ja Kivisuolla NP-lannoitus lisäsi pohjapinta-alan kasvua (kuva 3). Kalilannoitus fosforin tai typen ja fosforin ohella lisäsi kasvua edelleen (kuva 3). Kaakkosuolla kalilannoitus oli puuston kasvulle välttämätön kokeen perustamisesta saakka. Peruslannoituksen jälkeen puuston pohja-pinta-alan kasvu lisääntyi Alkkiassa 7–8, Kivisuolla 13–14, Kettulassa 19–22 ja Kaakkosuolla 19 vuoden ajan, jonka jälkeen pohjapinta-alan kasvu alkoi pienentyä, Kaakkosuolla jopa varsin jyrkästi (kuva 3). Ainakin osittain oli syynä useimmissa tapauksissa kaliumin puutos. Kalilannoitetuilla koealoilla puuston reaktio oli kaliumin määrästä ja kaliumin lähteestä riippumaton (kuvat 3 ja 4), joskin Kivisuon fosforilla jatkolannoitetuilla koealoilla oli viitteitä siitä, että pienimmän kaliumin määrän (42 kg/ha) saaneilla koealoilla kasvun taantuma oli jyrkin (kuva 3, Kivisuo b). Vuoden 1976 jatkolannoituksen (P, NP ja osalla myös hivenaineita) vaikutus Kaakkosuolla, Kivisuolla ja Kettulassa jäi lyhytaikaiseksi. Vaikka kaliumista jonkin verran oli ilmeisesti sitoutunut myös pintakasvillisuuteen, lienee valtaosa suurista lannoitekaliumin määristä huuhtoutunut joko tutkittua 30 cm:n pintakerrosta syvemmälle tai pois tutkimusalueilta (taulukko 10).

Tulosten perusteella on ilmeistä, että ainakaan taimikoissa ei ole syytä käyttää nykyistä lannoitussuositusta (n. 80 kg/ha) suurempia kaliumin määriä, koska määrää lisäämällä ei vastaavasti saavuteta suurempaa kasvureaktiota tai pitempää vaikutusaikaa. Tutkimus antaa viitteitä, että saatettaisiin tulla toimeen jopa lannoitussuositusta pienemmillä kaliumin määrillä. Lannoitekalium ilmeisesti huuhtoutuu verrattain nopeasti puiden tavoittamattomiin. Tästä syystä olisi tärkeätä, että puusto lannoitettavalla alueella olisi täystiheä ja lannoitushetkellä hyvässä kunnossa kyetäkseen ottamaan lannoitekaliumia tehokkaasti. Käytännön lannoitusratkaisuna saattaisi olla nykyistä useammin ja pienemmillä kaliumin määrillä toistuva lannoitus. Toinen mahdollisuus olisi kehittää kalilannoite, jossa on sekä nopealiukoinen että hidasliukoinen, pitkävaikutteinen osa.

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