Forest Regeneration on Nutrient-Poor Peatlands: Effects of Fertilization, Mounding and Sowing

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The effects of wood ash and PK fertilization on natural regeneration and sowing of Scots pine (*Pinus sylvestris* L.) were studied in field experiments on nitrogen-poor (N_{tot} 0.87–1.26 %) peat substrates. The study material was derived from three drained, nutrient-poor pine mires (64°52' N, 25°08' E) at Muhos, near Oulu. The experimental fields were laid out in 1985 as a split-split-plot design including the following treatments: mounding, natural regeneration and sowing and fertilization; PK at a level of 400 and wood ash 5000 kg ha^{-1}. The seedlings were inventoried on 648 circles and vegetation on 324 circles in July–August 1991.

Changes in the vegetation were small and there were no statistical differences due to the fertilization treatments in the ground vegetation. PK or ash fertilization did not cause vegetational changes harmful to Scots pine regeneration on nitrogen-poor peatlands.

Both sowing and fertilization significantly increased the number of pine seedlings, but not their height. Wood ash increased seedling number more than PK fertilizer. The number of seedlings varied from 7963 (control) to 42 781 ha^{-1} (mounding + sowing + ash). The number of pine seedlings even on non-mounded, non-fertilized naturally regenerated plots was adequate for successful regeneration.

The number of birch seedlings varied more than that of pine (370–25 927 ha^{-1}). Mounding especially increased the number of birches. The difference between PK fertilizer and ash was less pronounced than that for pine. In addition to the field studies the effects of ash and PK fertilizer on the germination of Scots pine seeds was studied in a greenhouse experiment. Soaking in ash solutions strongly reduced seed germination, while the PK solution was less harmful.

Keywords Scots pine, seedling number, ground vegetation, PK fertilizer, peat nitrogen, wood ash, birch.
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1 Introduction

In Finland about 5,9 million hectares of peatland have been drained for forestry (Aarne 1993). Most of the drainage was done in the 1960's and 1970's, and extensive areas of older forest stands are now approaching the final felling stage (Paavilainen and Tiihonen 1988). This will increase the need for the regeneration of peatland forests. Depending on the site type, drained peatlands can develop a bottom layer dominated by species typical of mineral soil forests (*Pleurozium schreberi*, *Dicranum* spp. and *Hylocomium splendens*). This makes forest regeneration more difficult than on *Sphagnum* (e.g. Kaunisto and Päivänen 1985). A *Polytrichum*-layer can develop on sites with an imbalanced nutrient status (Reinikainen 1965) and raising Scots pine (*Pinus sylvestris*) seedlings on such peatlands may be problematic (Huikari 1951, Saarinen 1989). When natural regeneration or sowing appears to be insufficient, there is a need for soil preparation and planting (Valtanen and Lehtosaari 1991). Such measures are, however, expensive and soil preparation is often environmentally less desirable (op.cit., Kinnunen 1993).

Fertilization with wood ash commonly kills *Sphagna* on recently drained peatlands (e.g. Malmström 1952, Vasander et al. 1988). Combined with increased nutrient availability, this might lead to an increased number and growth of tree seedlings (Lukkala 1955, Bogdanov 1963). On the other hand, there is evidence from laboratory studies that wood ash can interfere with the germination or early development of coniferous seeds (Fabricius 1929, Eneroth 1931, Moilanen et al. 1987, Rikala and Jozefek 1990, Thomas and Wein 1990). These observations are contradictory to the beneficial experiences gained with wood ash in the establishment and initial development of seedlings in field conditions (Malmström 1952, Lukkala 1955). The effects of commercial fertilizers on the vegetation and tree regeneration on peatlands have been studied e.g. by Kaunisto (1975), Mannerkoski (1975), Moilanen and Issakainen (1981, 1984), Lindholm and Vasander (1988), Vasander et al. (1988) and Saarinen (1989). In general, the regeneration of Scots pine and birch (*Betula* spp.) is strongly promoted by fertilization with phosphorus and potassium.

This paper focusses on the effects of mounding, sowing and, particularly, fertilization (wood ash and PK) on 1) the number and development of Scots pine and birch seedlings, 2) the field and bottom layer vegetation, and 3) possible harmful effects of vegetation on Scots pine regeneration on drained, nitrogen-poor peatland. In addition, the effects of wood ash and PK fertilizer on the germination of pine seeds were studied in the greenhouse. The main aims as far as practical forestry is concerned are to elucidate whether wood ash fertilization could be an alternative to mounding and sowing, or at least an improvement for restocking and growth of the stands.

2 Material and Methods

2.1 Field experiments

2.1.1 Study areas

The field study was carried out in three experimental fields, located a few kilometers apart, in Muhos near the city of Oulu, Finland (64°52'N, 25°08'E). The elevation above sea level was 69–74 m and the effective temperature sum (≥ +5°C) about 1000 °C d.d. The peat thickness varied between 0.2 and 1.5+ m and consisted of low-humified (H 3–4) *Sphagnum-Carex* peat with a total nitrogen content of 0.87–1.26 % (Table 1). The underlying mineral soil was coarse sand or till. According to Päivänen (1990) the site types studied are considered to be borderline cases for profitable drainage in this temperature sum area. Initial drainage (1967–1978) was followed by supplementary drainage and the strips were divided into two in the late spring of 1985. Every second strip was mounded (4000 mounds ha^{-1}) by a tractor digger (Fig. 1). The old pine stands were cut and the areas cleared in spring 1985. The distance to the nearest seeding pine forest was in most cases less than 50 m.

The experimental design was a split-split-plot one and the same on all three fields (Fig. 1). There were altogether 36 plots (size 500–1000 m^2) including two replicates, and the total area was 2.83 ha. Each plot was divided into two

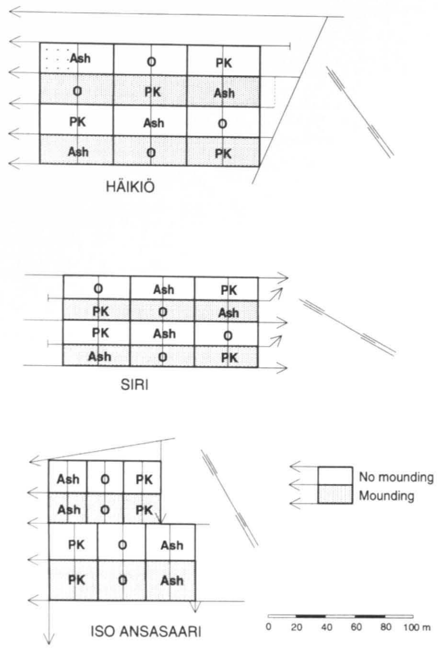

Fig. 1. Design of the experimental fields. Weak vertical lines indicate division into sowing and natural regeneration subplots, dots = inventory circles.

subplots (Fig. 1); one half was sown with Scots pine seed and the other left to regenerate naturally. Broadcast sowing was carried out on the peat surface in late May (Häikiö, Siri) and mid-June (Iso Ansasaari) 1985. The sowing density was 400 g/ha in Häikiö and Siri and 500 g/ha in Iso Ansasaari. The seed (M24-69-9/B4) originated from Kestilä, about 50 km south from the experimental fields. Fertilization was done during 29.–31.5. (Häikiö, Siri) and on 10.6.1985 (Iso Ansasaari). Bottom ash from the heating plant of the University Hospital in Oulu (5000 kg ha^{-1}) and granulated PK-fertilizer for peatlands supplied by Kemira Ltd (400 kg ha^{-1}) were used as fertilizers. The amounts applied corresponded to those widely used in practical forestry. The ash lots used were nutrient-rich and the ash dose contained much more nutrients than the PK fertilizer.

The nutrient amounts were as follows (kg ha^{-1}):

Treatment	Nutrient P	K	Ca	B
PK	35	66	94	0.8
Ash	122	231	1155	1.5

2.1.2 Measurements

The tree seedlings were inventoried during 25.7–7.8.1991 on systematically placed (Fig. 1) circles (1 m^2). The mid-point of each circle had been marked in early spring 1986 with a white plastic pin. During the inventory notes were made of the species, and the number, height and condition of the seedlings. Sprouts of birch were not included. There were 9 circles per subplot (Fig. 1); thus each experimental field contained 216 circles and the total material amounted to 648 circles.

The coverages of ground vegetation in the field and bottom layer were estimated only on the non-mounded plots (324 circles, see Fig. 1) simultaneously with the tree inventory. The scale

Table 1. Characteristics of the experimental fields.

Experimental field	Site type	Depth of peat, dm	N_{tot} in peat %, 0–20 cm	Years of drainage	Strip width, m	Seeds, g ha^{-1}
Häikiö	TR-PsRoj	> 15	1.00	1974, 1985	20	400
Siri	Ram TRoj	2	0.87	1978, 1985	15	400
Iso Ansasaari	TR-PsRoj	6	1.26	1967, 1985	20–25	500

TR = Cotton grass pine bog
Ram = *Sphagnum fuscum* hummocky
PsR = *Carex globularis* pine swamp
oj = recently drained peatland

(0–100 %) was free. The species nomenclature follows that of Eurola et al. (1990). The type of peat surface and percentage of bare peat surface were also recorded.

Peat samples (0–20 cm) were taken for determining the total nitrogen content only from the control plots. Each sample consisted of 5 subsamples taken along the diagonals of the square plot and at the intersection of the diagonals. The subsamples were mixed, dried and analyzed for total nitrogen (Halonen et al. 1983).

2.2 Germination Experiment with Soaked Seeds

A soaking test was carried out in the greenhouse in order to improve the germination and viability of Scots pine *(Pinus sylvestris)* seeds. The pine seeds were collected in Muhos in December 1985 and extracted on 21.4.1986. The code was M 29852620, 1000-seed weight 4.25 g and germination 90 %.

The seeds were soaked in local tap water and three solutions (PK 1%, ash 1%, ash 10 %) for two periods of time (one day = 24h and one week) in late April 1989. There were 4 × 2 = 8 treatments, each with 2 replications. The PK fertilizer was a granulated form containing P 87 and K 166 g kg^{-1}. The ash was birch ash containing P 23.6, K 102 and Ca 222 g kg^{-1}, 85.8 % of the ash passing through a 0.5 mm sieve. Electrical conductivity and pH of the solutions (200 ml) were:

	Water	$PK_{1\%}$	$Ash_{1\%}$	$Ash_{10\%}$
Conductivity, mS cm^{-1}	76	7650	2670	19000
pH	7.86	5.68	11.29	11.88

There were initial problems with the soaking; the solubility of ash was not complete and the seeds tended to float instead of sinking. After soaking the seeds were carefully transferred to boxes (30 × 30 cm) containing pristine peat substrate supplied by VAPO Ltd. The material consisted of 100(seeds) × 8(treatments) × 2(replications) = 1600 seeds in total. The temperature and light conditions in the greenhouse during the study period were non-artificial. The peat surface was kept moist by irrigating daily. The germination percentage of the seeds was determined on 15.9.1989. The calculations were made with 2-V and the t-test using arcsin-transformation (e.g. Ranta et al. 1989).

2.3 Treatment of the Field Material

The lay-out the three experimental fields (Häikiö, Siri, Iso Ansasaari) was similar and they were therefore considered as blocks of one experiment despite the differences in peat (thickness, total nitrogen content), the strip width and year of drainage (see Table 1, also Table 3). The main plot factor was mounding, fertilization was the first subplot factor and sowing the second subplot factor. As every experimental field had two replications, the total number of replications thus obtained was six. The mean of 9 circles in each subplot was used as the calculating unit for the variables (Fig. 1).

Scots pine seedlings of different age were combined to form one category. The number and mean height of the seedlings were studied in relation to the treatments mounding, fertilization and sowing. Damaged or dead seedlings occurred in 10 circles only. Variables describing the condition of the pine seedlings were therefore omitted from the further calculations.

Downy birch (*Betula pubescens*) was overwhelmingly dominating among hardwoods and therefore *Betula pubescens* and *B. pendula* were united to *Betula* spp. Since only Scots pine was sown, the subplots for the treatments sowing and natural regeneration were united when studying the colonization of birch. The number of birch seedlings was thus studied only versus mounding and fertilization. Other observed hardwood species, *Salix* spp. and *Populus tremula*, were included in the field layer. The seedling numbers for pine and birch were statistically calculated with split-plot analysis of variance and the Tukey test using square root transformation (e.g. Ranta et al. 1989).

Ground vegetation was observed only for the non-mounded plots. It was assumed that the ground vegetation had not been strongly affected by the pine seedlings (the sowing and natural regeneration treatments). Accordingly only the effects of the fertilization treatments (unfertilized, PK and ash), were studied in the vegetation analyses. The occurrence of single species (coverage-%) in the field layer was examined with one-way analysis of variance (ANOVA). Species in the bottom layer were divided into four groups (*Sphagna*, *Polytrichum* spp., *Bryales alia*, lichens) and studied in the same way as for the species of field layer. A DCA ordination (Hill and Gauch 1980) for sample plots based on species coverage was made jointly for both layers.

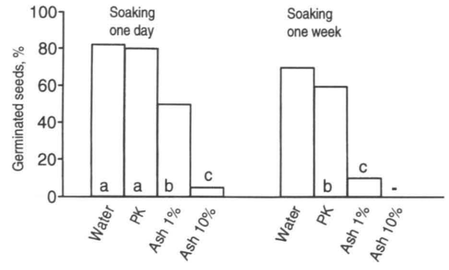

Fig. 2. Germination of Scots pine seeds after soaking in PK and ash solutions. Non-significant ($p > 0.05$) differences between single treatments shown by the same letters (a–c).

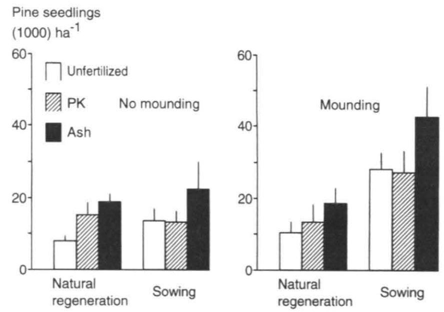

Fig. 3. Number of pine seedlings. Bars = standard error.

3 Results

3.1 Seed Soaking and Germination

Soaking in the PK fertilizer solutions and particularly in that of the wood ash decreased the germination of the Scots pine seeds. Both fertilization and soaking time, as well as their interaction, affected germination significantly ($p < 0.001$). The differences in germination percentage between most of the treatments were also significant (Fig. 2). In the one-day soaking treatment the germination percentage was over 80 for the water and PK treatments, 63 for $ash_{1\%}$ and only 6 for $ash_{10\%}$ (Fig. 2). After one-week soaking in water and the PK-solution the germination percentages were 74 and 63, respectively, but the effects of both wood-ash solutions were highly detrimental. $Ash_{1\%}$ had only 8 % germinating seeds and $ash_{10\%}$ had none (Fig. 2). The PK-fertilizer solution was thus less harmful to the seeds than wood ash, although it contained more P and K than $ash_{1\%}$.

3.2 Number and Height of the Seedlings

The distribution of the Scots pine seedlings in the field experiments was rather even. In 388 out of 648 circles there was at least one pine seedling; only one subplot (out of 72) lacked seedlings. Significant differences in seedling number between the three experimental fields were not found (Table 3). The number of seedlings in the experiment at Siri, where the peat layer was only 10–60 cm thick, did not differ significantly from the two other experiments. The effects of sowing and fertilization on the number of seedlings were statistically significant, while mounding was not. Significant interaction was found between sowing and mounding. The effect of ash differed significantly from the unfertilized treatment, but PK did not differ from either the ash or the unfertilized treatments.

Compared to the control plots the number of pine seedlings was increased by all experimental treatments. The control plots had the lowest number of seedlings, 7963 per hectare, while the PK plots had 15 186 and the ash plots 18 890 seedlings (Fig. 3). The interaction between mounding and sowing was strong (Table 3, Fig. 3). Plots mounded and sown had 28 150 seed-

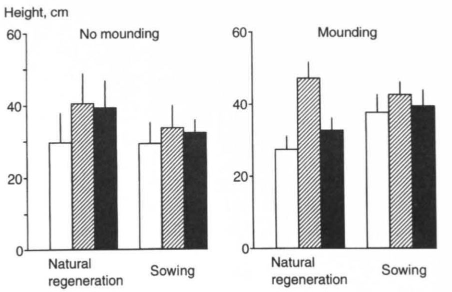

Fig. 4. Mean height of pine seedlings. For explanations, see Fig. 3.

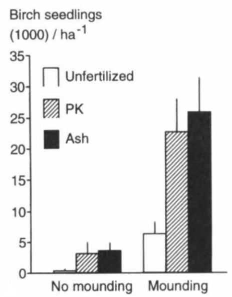

Fig. 5. Number of birch seedlings. For explanations, see Fig. 3.

lings per hectare, and when ash was also added there were 42 781 seedlings. This was the highest figure for any experimental treatment (Fig. 3). Mounding + sowing + PK had 27 224 seedlings.

The mean height of the pine seedlings varied between 27.3 and 47.1 cm for the experimental treatments (Fig. 4). However, no significant differences were noted (Table 3). In contrast to the effect on the seedling number, PK fertilizer seemed to increase mean height somewhat more than ash. The mean height of the seedlings on sown plots was equal to that of natural regeneration. The seedlings in the mounded plots were slightly higher than in the non-mounded plots. Mounding + PK was the experimental treatment having the tallest seedlings (Fig. 4).

The differences in the number of birch seedlings between the separate experimental fields and the interaction between experiment and fertilization were not statistically significant. The effects of mounding, fertilization (PK, ash) and their interaction were statistically significant (Table 3). Compared to control the experimental treatments had high numbers of seedlings varying from 370 (control) to 25 927 per hectare (Fig. 5). The increase for birch seedlings was thus stronger than that for pine. PK and ash fertilization increased the number of birch seedlings 8 to 10-fold. PK and ash deviated significantly from the unfertilized treatment. The plots only mounded accounted for almost twice the number of seedlings compared to PK or ash-fertilization merely. Mounding together with PK or ash resulted in over 20 000 birch seedlings per hectare (Fig. 5, see Table 3).

Table 2. Coverage (%) of field layer species with a frequency ≥50 % on non-mounded plots. No statistically significant differences.

Species	Unfertilized	PK	Ash
Empetrum nigrum	14.5	11.3	14.2
Betula nana	7.3	7.4	5.3
Vaccinium uliginosum	7.0	4.8	7.5
Eriophorum vaginatum	5.7	16.9	12.3
Ledum palustre	1.2	0.4	1.0
Vaccinium vitis-idaea	0.8	1.1	2.6
Carex globularis	0.8	1.4	1.1
Andromeda polifolia	0.8	0.4	0.5
Rubus chamaemorus	0.6	0.4	1.3
Chamaedaphne calyculata	0.4	0.4	0.2
Vaccinium oxycoccos	0.4	0.3	0.1
Total	39.5	44.8	45.1

3.3 Effect of Fertilization on the Vegetation

On the non-mounded plots 71 % of the peat surface was lawn and the rest was hummock. Only 2–3 % of the surface lacked vegetation or was covered by slash and litter. The effects of the fertilization treatments (PK, ash) on the field-layer were weak (Table 2) and no statistically significant differences were found for the coverage of the dominant species. *Eriophorum vaginatum* was most frequent on the PK plots. *Rubus chamaemorus*, *Eriophorum vaginatum* and *Vaccinium vitis-idaea* seemed to benefit from ash fertilization. Other dominant species were indifferent to the fertilization treatments or diminished after fertilization.

Changes in the bottom layer were also small. The coverage of *Sphagna* and the group Bryales alia was reduced by wood ash and PK fertilization, while *Polytrichum* spp. particularly suffered less from fertilization (Fig. 6). There were, however, no statistically significant differences. A total of 24 field-layer and 24 bottom-layer species were recorded. Species found only on the ash-fertilized plots were few: e.g. *Funaria hygrometrica*, *Marchantia polymorpha* and *Salix phylicifolia*. The mean number of field layer species per subplot was 16.5, 16.9 and 19.4 for the unfertilized, PK and ash, respectively.

The sample plots were grouped in DCA according to the coverages both field- and bottom layer species. The eigen-values were 0.4124 for axis 1 and 0.2596 for axis 2 (Fig. 7). On the basis of the grouping of single species with known ecological preferences, axis 1 was interpreted as a moisture factor and axis 2 was evidently a trophic factor. No special relationships were observed between fertilization treatments and the grouping of the sample plots in any of the experimental fields. The experimental fields were clearly distinguishable in relation to the axes (Fig. 7).

Table 3. Main effects and interactions for the variables studied. No calculation = -.

Treatment	Number of pines			Mean height of pines			Number of birches		
	df	MS	p	df	MS	p	df	MS	p
Mounding	1	9.45	0.432	1	237.6	0.566	1	131.33	0.037
Experiment	2	3.87	0.720	2	1261.7	0.289	2	14.88	0.261
Error 1	2	9.95	-	2	513.4	-	2	5.26	-
Fertilization	2	7.67	0.029	2	455.5	0.297	2	23.21	0.000
Mound × fert	2	0.45	0.610	2	1.8	0.993	2	4.05	0.047
Fert × experiment	4	0.16	0.924	4	52.6	0.930	4	2.98	0.062
Error 2	4	0.82	-	4	273.1	-	58	1.26	-
Sowing	1	20.07	0.000	1	1.6	0.925	-	-	-
Fert × sow	2	0.53	0.691	2	132.1	0.486	-	-	-
Mounding × sowing	1	13.79	0.003	1	369.9	0.159	-	-	-
Mound × sow × fert	2	0.23	0.849	2	8.9	0.951	-	-	-
Error 3	48	1.43	-	48	180.8	-	-	-	-

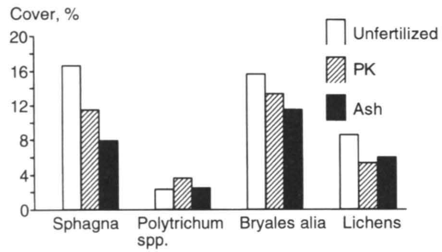

Fig. 6. Coverage of bottom layer groups on the non-mounded plots. No statistical significances due to fertilization were observed.

4 Discussion

The ground vegetation, including both the field and the bottom layer, on these effectively drained, but nitrogen-poor, sites changed only slightly after fertilization. Similar findings have earlier been reported by Malmström (1952), Lukkala (1955) and Silfverberg and Huikari (1985). No

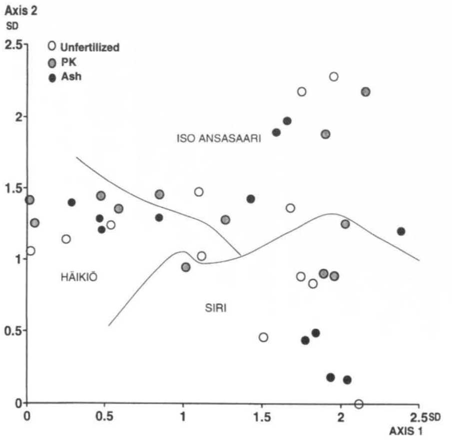

Fig. 7. DCA ordination of the non-mounded plots.

statistically significant differences were observed for the dominant species in the field layer. The greatest increase was noted for *Eriophorum vaginatum* as a result of PK fertilization (also Vasander et al. 1993). The dwarf shrubs were remarkably indifferent to ash fertilization. It appears that wood ash slightly increases the number of species, but on the other hand it favours some competitionally strong and dominant species (*Eriophorum vaginatum*, *Rubus chamaemorus*).

According to Vasander et al. (1993), fertilization increases both the coverage and biomass in the ground layer. The reduced coverage of especially *Sphagna* in the bottom layer (Fig. 6) could also be due to the increase in the coverage of dominants in the field layer (see Table 2). Some ash-favouring colonising species (e.g. *Marchantia polymorpha*) appeared in the hollows (see Sarasto 1963, Sarasto and Seppälä 1964, Vasander et al. 1988, 1993, Salonen 1992). *Polytrichum strictum*, which is a much more favourable seedling substrate than *P. commune* (Sarasto and Seppälä 1964) had a higher frequency than *P. commune*.

At the time of fertilization the sites had been drained for 7–18 years. Drained, nutrient-poor sites are subject to only slow vegetational changes (Reinikainen 1980). In contrast to better site types, fertilization (including wood ash) on nitrogen-poor peatlands does not bring about rapid or strong vegetational changes which would endanger the establishment and initial development of pine seedlings. In fact the moist bed of *Sphagnum* still forms a favourable substrate for seedling establishment (Sarasto 1963, Salonen 1992, Vasander et al. 1993).

In the greenhouse experiment the germination of Scots pine seeds was not improved by soaking in the fertilizer or ash solutions (see Lehto and Simolinna 1966). Soaking in wood ash solutions strongly decreased the germination percentage. Thomas and Wein (1990) also observed poor germination and survival for jack pine (*Pinus banksiana*) seedlings raised in unleached wood ash. They found the "high pH (10.6–12.5) caused by high hydroxide and bicarbonate levels to be directly harmful". These observations were supported by the results from the soaking experiment. Soaking in the PK (fertilizer) solution was clearly less harmful than soaking in the two ash solutions, despite its relatively high concentration of P and K. The negative effect of ash solution on germination was possibly due to the high concentration of hydroxyl ions (Thomas and Wein 1990).

Fertilization (PK, ash) alone increased the number of pine seedlings somewhat more than sowing and mounding. The enhancing effect of mounding on nutrient mineralization and the restricting effect on ground vegetation competition (Mannerkoski 1975, Moilanen and Issakainen 1981, 1984) could not compensate for the fertilization effect. The highest number of Scots pine seedlings was found on treatment mounding + sowing + ash.

The number of birch seedlings was, as expected, increased by mounding and fertilization (Kaunisto 1972, Moilanen and Issakainen 1981,1984, Päivänen 1990). However, in this early stage of development the birch seedlings hardly hampered the development of the pine seedlings.

The mean height of the pine seedlings was somewhat greater on the PK fertilized than on ash plots (see also Kaunisto 1987b). This is very likely due to the higher solubility of phosphorus in the PK fertilizer (Haveraaen 1986, Silfverberg 1991). Nitrogen shortage might become a growth limiting factor already in the early stage of seedling development. The peat nitrogen contents

(cf. Kaunisto 1987a, Moilanen 1993) and the yellowish colour of the needles suggest poor subsequent growth despite ash fertilization. Nitrogen mineralization, generally caused by wood ash (Karsisto 1979, Kaunisto 1987a,b), is perhaps not strong enough to increase seedling growth strongly. Furthermore, the enhancing effect of ash on nitrogen mineralization may be weak in the future. Generally wood ash fertilization is more suited for better site types than those examined in this study (Silfverberg and Huikari 1985, Kaunisto 1987a).

Wood ash and PK fertilization increased the number of seedlings, but is hardly necessary in practical regeneration in addition to sowing and/or mounding. The number of Scots pine seedlings (7963) on the control plots readily exceeded the minimum number required (Kaunisto and Päivänen 1985). The general relevance of regeneration on nutrient-poor peatlands needs closer consideration. In this effective temperature sum (1000 °C d.d.) area the site types studied are on the borderline of profitable drainage (Päivänen 1990). Peatland forestry measures in general, will probably remain at a very low level on such nutrient-poor sites in the future (Saarinen and Silver 1992, Aarne 1993, Saarinen 1993).

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References

Aarne, M. (ed.). 1993. Yearbook of forest statistics 1992. SVT Agriculture and Forestry 1993:5. 317 p.

Bogdanov, P. L. 1963. Liming as a method of combating mosses in forest stands on moss-covered felled areas and drained swamps. (Izvest' kak sredstvo bor'by so mkhami iri lesnykh kul'turakkh na zamshelykh vyrubkakh i osushaemykh bolotakh). In: The increase of productivity of swamped forests. Symposium paper, Akademia Nauk SSSR. Tridy Institut a lesa. Israel Program for Scientific Translations, Jerusalem. p. 116–124.

Eneroth, O. 1931. Försök rörande hyggesaskans inverkan på barrträdsfröets groning och plantornas första utveckling. Commentationes Forestales 5: 1–67.

Eurola, S., Bendiksen, K. & Rönkä, A. 1990. Suokasviopas. Oulanka Biological Station University of Oulu, Oulanka Reports 9. 205 p.

Fabricius, L. 1929. Forstliche Versuche V. Die Einwirkung von Waldbrandasche auf Samenkeimung und erste Pflanzenentwicklung. Forstwissenschaftliches Centralblatt H8.

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

Haveraaen, O. 1986. Ash fertilizer and commercial fertilizers as nutrient sources for peatland. Communications of the Norwegian Forest Research Institute 39(14): 251–263.

Hill, M.O. & Gauch, H.G. 1980. Detrended correspondence analysis: an improved ordination technique. Vegetatio 42: 47–58.

Huikari, O. 1951. Havaintoja ojitettujen rimpinevojen taimettumista ehkäisevistä tekijöistä. Suo 2(1): 1–4.

Karsisto, M. 1979. Maanparannustoimenpiteiden vaikutuksista orgaanista ainetta hajoittavien mikrobien aktiivisuuteen suometsissä. Osa II. Tuhkalannoituksen vaikutus. Summary: Effect of forest improvement measures on activity of organic matter decomposing micro-organisms in forested peatland. Part II. Effect of ash fertilization. Suo 30(4–5): 81–91.

Kaunisto, S. 1972. Lannoituksen vaikutus istutuksen onnistumiseen ja luonnontaimien määrään rahkanevalla. Tuloksia Kivisuon koekentältä. Summary: Effect of fertilization on successful planting and the number of naturally born seedlings on a fuscum bog at Kivisuo experimental field. Folia Forestalia 139. 11 p.

— 1975. Suometsien luontaisen uudistamisen edistäminen. Metsäntutkimuslaitoksen Pyhäkosken tiedonantoja 14: 37–41.

— 1987a. Effect of refertilization on the develop-

ment and foliar nutrient contents of young Scots pine stands on drained mires of different nitrogen status. Communicationes Instituti Forestalis Fenniae 140. 58 p.
— 1987b. Lannoituksen ja muokkauksen vaikutus männyn ja rauduskoivun istutustaimien kasvuun suonpohjilla. Summary: Effect of fertilization and soil preparation on the development of Scots pine and silver birch plantations on peat cutover areas. Folia Forestalia 681. 23 p.
— & Päivänen, J. 1985. Metsänuudistaminen ja metsittäminen ojitetuilla turvemailla. Kirjallisuuteen perustuva tarkastelu. Summary: Forest regeneration and afforestation on drained peatlands. A literature review. Folia Forestalia 625. 75 p.
Kinnunen, K. 1993. Männyn kylvö ja luontainen uudistaminen Länsi-Suomessa. Abstract: Direct sowing and natural regeneration of Scots pine in Western Finland. Metsäntutkimuslaitoksen tiedonantoja 447. 36 p.
Lehto, J. & Simolinna, J. 1966. Metsäpuiden taimien kasvattaminen. Kirjayhtymä, Helsinki. 235 p.
Lindholm, T. & Vasander, H. 1988. Effect of readily and slowly soluble PK and NPK fertilizers on the growth of Scots pine on a drained raised bog in southern Finland. Proceedings, the 8th International Peat Congress, USSR Leningrad, August 14–21, 1988, Vol. 3: 144–152.
Lukkala, O.J. 1955. Maanparannusaineet ja väkilannoitteet metsäojituksen tukena II. Summary: Soil improving substances and fertilizers as an aid to forest drainage. Metsätaloudellinen Aikakauslehti 8: 273–276.
Malmström, C. 1952. Svenska gödslingsförsök för belysande av de näringsekologiska villkoren för skogsväxt på torvmark. Communicationes Instituti Forestalis Fenniae 40.17. 27 p.
Mannerkoski, H. 1975. Vanhan ojitusalueen uudistaminen mätästysmenetelmällä. Summary: Hummock-building method in reforestation of an old drainage area. Suo 26(3–4): 65–68.
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 p.
— & Issakainen, J. 1981. Lannoituksen ja muokkauksen vaikutus kuusen ja koivun uudistumiseen eräillä Kainuun vaara-alueen paksuturpeisilla soilla. Summary: Effect of fertilization and soil preparation on the regeneration of birch and spruce on thick peat soils in Kainuu. Folia Forestalia 481. 16 p.
— & Issakainen, J. 1984. Ojituksen, lannoituksen ja muokkauksen vaikutuksesta luontaiseen uudistumiseen piensararämeellä. Metsäntutkimuslaitoksen tiedonantoja 133. 17 p.
— , Ferm, A. & Issakainen, J. 1987. Kasvihuonekokeita erilaisten jäteaineiden vaikutuksesta hieskoivun alkukehitykseen turvealustalla. Metsäntutkimuslaitoksen tiedonantoja 281. 36 p.
Paavilainen, E. & Tiihonen, P. 1988. Suomen suometsät vuosina 1951–1984. Summary: Peatland forests in Finland in 1951–1984. Folia Forestalia 714. 29 p.
Päivänen, J. 1990. Suometsät ja niiden hoito. Kirjayhtymä, Helsinki. 231 p.
Ranta, E., Rita, H. & Kouki, J. 1989. Biometria. Tilastotiedettä ekologeille. Yliopistopaino, Helsinki. 569 p.
Reinikainen, A. 1965. Vegetationsuntersuchungen auf dem Walddüngungs-Versuchsfeld des Moores Kivisuo, Kirchsp. Leivonmäki, Mittelfinnland. Communicationes Instituti Forestalis Fenniae 59(5). 62 p.
— 1980. Suoekosysteemi toimii. Suomen luonto 3. Kirjayhtymä, Helsinki. p. 211–261.
Rikala, R. & Jozefek, H.J. 1990. Effect of dolomite lime and wood ash on peat substrate and development of tree seedlings. Silva Fennica 24(4): 323–324.
Saarinen, M. 1989. Metsien uudistaminen vanhoilla ojitusalueilla. (Forest regeneration in old forest drainage areas.) Suo 40(1): 31–36.
— 1993. Virheojitukset eri inventointien valossa. Metsäntutkimuslaitoksen tiedonantoja 495: 8–14.
— & Silver, T. 1992. Karujen rämeiden kunnostusojituskelpoisuus. (Evaluation of ditch network maintenance on drained poor pine mires.) Suo 43(3): 69–75.
Salonen, V. 1992. Plant colonization of harvested peat surfaces. Biological Research Reports from the University of Jyväskylä 29. 29 p.
Sarasto, J. 1963. Ruskosammalia lyhytkortisella nevalla. Suo 14(3): 44–45.
— & Seppälä, K. 1964. Männyn kylvöistä ojitettujen soiden sammal- ja jäkäläkasvustoihin. Summary: On sowing pine in moss and lichen vegetation on drained swamps. Suo 15(3): 54–58.

Silfverberg, K. 1991. Träaska, PK-gödsel och markförbättringsmedel på dränerade tallmyrar. Abstract: Wood ash, PK-fertilizer and two soil ameliorating additives on drained pine mires. Suo 42(2): 33–44.
— & Huikari, O. 1985. Tuhkalannoitus metsäojitetuilla turvemailla. Summary: Wood-ash fertilization on drained peatlands. Folia Forestalia 633. 25 p.
Thomas, P.A. & Wein, R.W. 1990. Jack pine establishment on ash from wood and organic soil. Canadian Journal of Forest Research 20: 1926–1932.
Valtanen, J. & Lehtosaari, A. 1991. Männyn uudistumiseen vaikuttavista tekijöistä Siikalatvan alueella. Metsäntutkimuslaitoksen tiedonantoja 388. 120 p.
Vasander, H., Lindholm, T. & Kaipiainen, H. 1988. Vegetation patterns on a drained and fertilized raised bog in southern Finland. Proceedings, the 8th International Peat Congress, USSR Leningrad, August 14–21, 1988, Vol. 1. p. 177–184.
— , Kuusipalo, J. & Lindholm, T. 1993. Vegetation changes after drainage and fertilization in pine mires. Suo 44(1): 1–9.

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