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 Muosu, 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 (Aurne 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 (Pauvilaiven and Tihonen 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 (Picea abies and Betula pendula). The species composition and vulnerability of these forests has been discussed (e.g., Kaunisto and Pauvilaiven 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 (Vulkanen 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 Sphagnum-dominated 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 seedlings (Fabricius 1929, Eneroth 1951, Moina 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), Mannenkoski (1975), Moina and Isaksakini (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 focuses 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 aim as far as practical forestry is concerned is 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°25'N, 25°08'E). The elevation above sea level was 69 m and the effective temperature sum (≥5°C) above 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 Pauvilaiven (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 m²) including two replicates, and the total area was 2.83 ha. Each plot was divided into two

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Table 1. Characteristics of the experimental fields.

<table>
<thead>
<tr>
<th>Experimental field</th>
<th>Site type</th>
<th>Depth of peat, dm</th>
<th>NPK at 5 cm, %</th>
<th>Years of drainage</th>
<th>Strip width, m</th>
<th>Seeds, g ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hääkiö</td>
<td>TR-P-PrOj</td>
<td>&gt; 15</td>
<td>1.00</td>
<td>1974, 1985</td>
<td>20</td>
<td>400</td>
</tr>
<tr>
<td>Siri</td>
<td>Ram TKoj</td>
<td>2</td>
<td>0.87</td>
<td>1978, 1985</td>
<td>15</td>
<td>400</td>
</tr>
<tr>
<td>Iso Ansassaari</td>
<td>TR-P-PrOj</td>
<td>6</td>
<td>1.26</td>
<td>1967, 1985</td>
<td>20–25</td>
<td>500</td>
</tr>
</tbody>
</table>

TR = Cotton grass pine bog, Pk = Carex globularis pine swamp, Rm = Sphagnum fuscum hummocky, PrOj = recently drained peatland.
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 90.0%.

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 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: PK₀, Ash₀, Ash₁₀
- Conductivity, mS cm⁻¹: 7.6, 760, 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 a 2-V and the t-test using arcsin-transformation (e.g. Ranta et al. 1989).

2.3 Treatment of the Field Material

The layout of the three experimental fields ( Häkiö, Sirit, Iso Ankasari) 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 (Sphagnum, Polytrichum spp., Bryales, 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.

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 wood and PK treatments, 63 for ash₀ and only 60 for ash₁₀ (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. Ash₁₀ had only 8% germinating seeds and ash₀, 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 ash₀.

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 Sirit, where the peat layer was only 10–60 cm thick, did not differ significantly from the other two 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 per hectare (Table 3). The interaction between mounding and sowing was strong (Table 3, Fig. 3). Plots mounded and sown had 28 150 seed-
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 seedlings, 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 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).

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. *Rabus chamaemoros, 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. *Fusaria hygrometrica, Marchantia polymorpha* and *Saxifraga paludosa*. The 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).

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 Huitkari (1985). No
trogen-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 (Sarastö 1963, Salonen 1992, Vasan-der 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 Letho 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 unbleached 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 (Havaera 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 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 Huijiri 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 (7/63) 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 (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, Aare 1993, Saarinen 1993).

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