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# Peat ash as a fertilizer on drained mires – effects on the growth and nutritional status of Scots pine

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**Abstract**

Finland's drained forested mires include approximately one million hectares of tree stands that require phosphorus and potassium treatments 1–2 times per generation to ensure sustainable nutrient status for tree growth. 300 000–400 000 tonnes of peat ash and mixed peat and wood ash are produced annually by Finland's energy production. Peat ash contains plant nutrients, e.g. phosphorus, and thus is a potential fertilizer in forestry. This study examines the effects of peat ash fertilization on the nutritional status and growth of Scots pine (*Pinus sylvestris* L.) on drained mire areas in which the trees were suffering from P and K deficiencies of varying degree.

Peat ash increased the volume growth of the stands, and the effect was progressively stronger all the way to the end of the study period, 30 years from the treatment. After 10–30 years, stand growth was 30–60% higher than on the unfertilized control, and the yearly increase in growth caused by the ash was 0.8–1.8 $m^3$ $ha^{-1}$. The growth response was, however, clearly smaller than that gained with wood ash on similar sites. Peat ash increased needle P concentrations to above the deficiency limit, but also seemed to aggravate K deficiency. Peat ash combined with potassium (from potassium chloride, K+micronutrient fertilizer or biotite) had a much more pronounced growth effect than peat ash alone and was comparable to PK-fertilizers or wood ash: the annual increase in Scots pine growth was 4–6 $m^3$ $ha^{-1}$ at its strongest. In practice, dosages larger than 5 t $ha^{-1}$ of peat ash are not necessary when ameliorating P deficiencies.

**Keywords**
phosphorus, potassium, needle analysis, drainage, stem volume, peat thickness

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# Contents

# 1 Introduction

Finland's energy industry produces annually an estimated 300 000–400 000 tonnes of peat ash and mixed peat and wood ash (Moilanen & Tillman-Sutela 2009). Peat ash is potentially a suitable fertilizer for forests, as it is rich in phosphorus (P). However, it is poor in other essential nutrients, and contains e.g. noticeably smaller amounts of potassium (K) and boron (B) than wood ash (e.g. Moilanen & Issakainen 2000). For this reason, it has been considered an inferior alternative to wood ash as a nutrient source for trees (Issakainen et al. 1994, Moilanen 2005). However, peat ash has a comparable amount of phosphorus with wood ash, with noticeably fewer amounts of harmful heavy metals, including cadmium (Cd). Peat ash also decreases soil acidity, as wood ash does (e.g. Moilanen & Issakainen 2000). Due to its smaller nutrient contents and lower pH, peat ash generally has a lesser impact on vegetation than wood ash (e.g. Silfverberg et al. 2010).

Study results concerning the use of ash as a fertilizer are needed primarily by forestry practitioners, ash producers and environmental officials. Drained mires in Finland hold about a million hectares of tree stands that require P and K treatments 1–2 times per generation to ensure sustainable nutrient status for tree growth (Moilanen et al. 2005). As the use of regular, established forest fertilizers has diminished to about a fifth (in area) since the prime years in the 1970s (The Statistical Yearbook of Forestry 2011), the use of alternative nutrient sources to improve forest growth and health has been studied (Kaunisto et al. 1993, Hytönen 1998, Veijalainen et al. 1993, Moilanen 2005). Disposing of wood and peat ash by dumping it into a landfill causes expenses and is harmful to the environment–and a potential nutrient source is wasted.

Likely Finland's first practical experiment with peat ash was carried out at Suolamminsuo in Oulu (Issakainen et al. 2007). An almost treeless bog was treated with 9 t $ha^{-1}$ of peat ash in 1952, and during the following 50 years, the growth of tree stand increased by 97 $m^3$ $ha^{-1}$ compared to the unfertilized control.

Compared to wood ash, there are considerably fewer studies on the effects of peat ash on the nutrient status and growth of trees. Peat ash has been noted to improve nutritional status and growth of Scots pine on drained mires (Silfverberg & Issakainen 1987, 1991, Issakainen et al. 1994, Moilanen & Issakainen 2003, Issakainen et al. 2007), but on a noticeably smaller scale than wood ash (e.g. Silfverberg 1996, Silfverberg & Issakainen 1996, Moilanen et al. 2002, 2004, Hytönen 2003). Needle analyses have confirmed increases in the trees' P status, but K has mostly remained below the deficiency limit. Longer-term effects of peat ash on the nutrient status and growth of Scots pine have this far been rather poorly known.

On former cut-away peatlands, peat ash has been noted to increase the initial development of ground vegetation, afforestation and vegetation biomass production (Mikola 1975, Kaunisto 1987, Lumme 1988, Hytönen 1998, 2000, Huotari et al. 2008, 2009, Mandre et al. 2010, Huotari 2011). Peat ash has also been studied in field afforestation (Hytönen & Aro 2005). Yli-Vakkuri (1959) studied prescribed burning at peatlands. On forested mineral soils, where the most limiting nutrient for growth is nitrogen, peat ash (which lacks N) did not have any significant effects on Scots pine growth (Oikarinen & Pasanen 1994).

This study examined the long-term effects of peat ash fertilization on the nutritional status and growth of Scots pine on drained mires. The main hypothesis, based on prior research, was that the response varies not only according to the ash dosage, but also according to the amount of supplemental K given with it. An additional aim was to compare the effects of peat ash and commercial PK fertilizers.

# 2 Data and methods

The data examined in this study comes from 13 fertilization experiments: 8 from Muhos, 4 from Oulu and 1 from Paltamo (Table 1). The sites were mostly oligotrophic cottongrass, small-sedge or tall-sedge type mires. Peat thickness varied from 0.4 m to over 1.5 m. The earliest ditches were from the 1930s with most of the sites receiving additional drainage operations when the experiments were established. Consequently, draining conditions were considered to have been good for the study period.

The experiments were established between 1952 and 2001 in cooperation with land owners (Metla/Metsähallitus, The City of Oulu, UPM-Kymmene Corporation). The peat ash originated – apart from experiment 12 – from the Oulu Toppila peat power plant, and had a moisture content of 10–21% depending on the experiment and the peat shipment (Table 2). The dosages were between 5 and 100 t $ha^{-1}$ (Table 3). In respect to present practical recommendations, the amount of P in these dosages was usually large, but the amount of K remained low. On experiments 1 and 2, the fertilized plots were also given a small amount (0.25–0.4 t $ha^{-1}$) of wood ash. In addition to pure peat ash treatments, the experiments included plots which were also treated with various substances containing K (potassium chloride, K+micronutrient fertilizer or biotite). Three experiments also included a commercial PK fertilizer for peatlands. A randomized block design was used. The size of treatment plot varied from 0.05 ha to 0.16 ha, and the treatments were repeated on 1–4 plots. All experiments also had unfertilized control plots. The Scots pine stand height at the time of the peat ash application was 2–12 m. Preliminary results have been published previously from seven of these experiments (Issakainen et al. 1994).

**Table 1.** Site characteristics at the point of peat ash application. n.d. = not determined.

| Experiment | Altitude, m above sea level | Site type (Huikari 1952) | N concen-tration in peat, % | Peat thickness, dm | Drainage year | Strip width, m | Stand height, m |
|---|---|---|---|---|---|---|---|
| 1. Muhos 1/78 | 76 | PsR-SsRoj | 2.04 | 4–10 | 1976, 1982 | 20 | 3 |
| 2. Muhos 171 A | 71 | TR-SsRmu | 2.10 | 7–10+ | 1932, 1978 | 20 | 3 |
| 3. Muhos 225 | 70 | Ram PsRoj | 2.15 | 4–8+ | 1967, 1981 | 20 | 2 |
| 4. Muhos 262 | 71 | PsRoj | n.d. | 4–8+ | 1950–, 1981 | 35 | 2–5 |
| 5. Muhos 263 | 73 | TR-SsRoj | n.d. | 10+ | 1967, 1989 | 26 | 3 |
| 6. Muhos 3/78 | 75 | SsRoj | 2.80 | 10+ | 1976 | 36 | 3 |
| 7. Muhos 334 | 63 | RhRmu | n.d. | 4–15+ | 1967, 1989 | 20 | 7–12 |
| 8. Muhos 99/18 | 71 | Ram TRmu | 2.55 | 10+ | 1967, 1980 | 20 | 2 |
| 9. Paltamo 8/80 | 180 | TR-SsRmu | 2.00 | 10+ | 1954, 1979 | 30 | 9 |
| 10. Oulu Suolamminsuo (1996) | 36 | (Ram) LkNmu | 1.34 | 10+ | 1931–35 | 60 | 4–8 |
| 11. Oulu Santerinräme | 47 | (Rh) SsRmu | 1.84 | 10+ | 1960–, 2002 | 35 | 5–9 |
| 12. Oulu Suolamminsuo (1952) | 36 | (Ram) LkNoj | 0.96 | 10+ | 1931–35 | 60 | < 1 |
| 13. Oulu Suolamminsuo (C 1–10) | 36 | Nn TSRmu | 1.20 | 10+ | 1932, 1981, 2005 | 35 | 4–8 |

**Table 2.** Typical nutrient contents of ashes from peat and wood compared to the nutrient contents of RautaPK, a commercial fertilizer for peatland forests (by dry mass).

| | kg $t^{-1}$ | | | | | | g $t^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|
| Ash source or fertilizer | P | K | Ca | Mg | Fe | Mn | Zn | B | Cu |
| Peat [1)] | 14 | 3 | 52 | 8 | 199 | 2 | 111 | 17 | 82 |
| Whole-tree | 24 | 75 | 262 | 37 | 10 | 22 | 972 | 298 | 288 |
| Peat and wood | 9 | 6 | 52 | 13 | 120 | 3 | 350 | 42 | 84 |
| Tree bark | 9 | 28 | 351 | 18 | 11 | 10 | 2 390 | 197 | 80 |
| Wood and sludge | 6 | 8 | 256 | 11 | 40 | 4 | 580 | 55 | 40 |
| Wood [2)] | 10 | 23 | 155 | 12 | 15 | 6 | 2 000 | 200 | 100 |
| Rauta PK-fertilizer | 80 | 140 | 148 | 4 | 25 | - | - | 3 000 | 1 000 |

[1)] This shipment was used for most of the experiments in this study
[2)] Ecolan ® T4000 ash for forests

**Table 3.** Peat ash treatments with their P and K contents. In exps 1 and 2 also small amount (0.25 – 0.4 t $ha^{-1}$) of wood ash was applied.

| Experiment | Largest peat ash dose t $ha^{-1}$ | Moisture % | P kg $ha^{-1}$ | K kg $ha^{-1}$ |
|---|---|---|---|---|
| 1. Muhos 1/78 | 5 | 15 | 70 | 13 |
| 2. Muhos 171 A | 8 | 10 | 126 | 18 |
| 3. Muhos 225 | 5 | 15 | 72 | 8 |
| 4. Muhos 262 | 5 | 15 | 72 | 8 |
| 5. Muhos 263 | 10 | 10 | 172 | 22 |
| 6. Muhos 3/78 | 5 | 15 | 70 | 13 |
| 7. Muhos 334 | 100 | 13–21 | 1 080 | 207 |
| 8. Muhos 99/18 | 5 | 15 | 71 | 11 |
| 9. Paltamo 8/80 | 6 | 10 | 71 | 16 |
| 10. Oulu, Suolamminsuo (1996) | 15 | 15 | 150 | 45 |
| 11. Oulu, Santerinräme | 20 | 15 | 340 | 58 |
| 12. Oulu, Suolamminsuo (1952) | 9 | n/a | n/a | n/a |
| 13. Oulu, Suolamminsuo (C 1–10) | 20 | 15 | 340 | 58 |

According to the visual observation in the stands, the unfertilised pines on control plots were suffering from severe P and K deficiencies, whereas no visible nutrient deficiencies we found on ash-fertilized plots (Fig. 1). Needles for determining the nutritional status of the tree stands were collected at the dormant period between November and March, in 2007 and 2009 (Table 4), as recommended by Paarlahti et al. (1971) and Reinikainen et al. (1998). At the time of the sampling, 12 years on average (range 1–36 years) had elapsed from the fertilization. One sample was collected from each unfertilized control plot and each fertilized plot. A sample consisted of 1–2 lateral shoots from the previous summer per tree (6–8 trees per plot). The branches were collected with a branch cutter from the southern side of the upper third of the green crown. Samples were not collected from trees growing near (< 3 m) the ditches. The samples were weighed (dry mass per 100 needles) and analyzed for nitrogen (N), P, K and B concentrations according to Halonen et al. (1983).

To determine the site fertility and potential productivity of the experimental stands, peat samples were collected from the unfertilized plots during the study period following fertilization (Fig. 2). One composite sample consisted of five sub-samples from the surface peat layer (0–10 cm or 0–20 cm, depending of the experiment), which were distributed uniformly over the plot, excluding a 5-meter wide area around the edge. The peat samples were dried at 70 °C for 48 hours and weighed, and the total nitrogen concentration was determined by the Kjeldahl method (Halonen et al. 1983).

**Fig. 1.** Scots pine branches from the upper green crown, experiment 2. Thirty years after ash application, eleven years after K re-fertilization. Treatments from left: control, PK fertilizer, peat ash, peat ash+K. Yellow discoloration is visible especially in the second-year needles indicating a severe K deficiency. Photo: J. Issakainen.

**Fig. 2.** Peat profiles from experiment 7, nineteen years after ash application. Treatments from left: control, peat ash 25 t $ha^{-1}$, peat ash 100 t $ha^{-1}$. The ash is visible as a bluish substance below the layer of plant litter and moss. Photo: J. Issakainen.

Interpreting the needle analyses was based on previous research on Scots pine on peatlands and recommendations on the deficiency limits and optimal concentrations of the different primary nutrients (see Paarlahti et al. 1971 and Reinikainen et al. 1998). The used nutrient concentration values (g $kg^{-1}$ ) for weak, adequate and optimal nutrient status were as follows:

| Nutrient | Weak | Adequate | Optimal |
|---|---|---|---|
| N | < 12 | 12–13 > | 13–18 |
| P | < 1.3 | 1.3–1.6 | > 1.6–2.2 |
| K | < 3.5 | 3.5–4.5 | > 4.5–5.5 |

In the surface peat, the N concentration varied between 0.96–2.80% (of dry matter) (Table 1). According to N availability, four of the sites (experiments 5, 10, 12 and 13) were classified as ”nitrogen-poor” and two (6 and 8) as ”nitrogen-rich”. A real deficiency of N was, however, apparent only at one site (experiment 3); N availability at all the other sites was considered satisfactory or good. P and K deficiencies, however, were common on unfertilized plots. Needle P concentrations were below the deficiency limit at all but two of the sites, whereas 9 of the 13 sites suffered from a severe K deficiency.

Most of the stand measurements were carried out at fall 2008 (Table 4). Trees to be included in the study were selected as follows: from a circle (r = 8–12 m) at the center of each plot, every third or fourth Scots pine of a minimum diameter of 50 mm was included, resulting in 15–20 sample trees per plot. The trees were measured for their height and height growth before and after the ash applications. The trees were drilled for increment cores dating to at least three years prior to the fertilization and measured for annual radial growth to a precision of 0.1 mm. Stem volume ($m^3$ $ha^{-1}$) at the time of the measurement and yearly stem volume growth ($m^3$ $ha^{-1}$ $a^{-1}$) were calculated using Metla's KPL program (Heinonen 1994).

The experiments had originally been established at different times with different study hypotheses, which is the reason for the varying treatments between sites, but they all include certain fertilization treatments. As a result, our analysis is performed by experiment groups, where all of the experiments that received specific treatments were combined into one group. The data from one particular experiment may thus be included in more than one group. A total of 128 experimental plots were included in both stand and needle analyses, and were grouped into the following categories:

Peat ash only (experiments 2, 3, 4, 5, 7, 8, 9, 10)
Peat ash combined with potassium (3, 4, 7)
Follow-up K fertilization on peat ash plots (5, 11, 12, 13)
Differences between peat ash and commercial PK fertilizer (1, 2, 8)

**Table 4.** The points of time of treatment, sampling and stand measurements.

| Experiment | Peat ash treatment | Plots/ treatments | Needle sampling | Peat sampling | Stand meas-urement | Growing seasons |
|---|---|---|---|---|---|---|
| 1. Muhos 1/78 | s 1978 | 9/3 | s 2007 | f 1986 | f 2008 | 31 |
| 2. Muhos 171 A | s 1979 | 12/4 | s 2007 | f 1992 | f 2007 | 29 |
| 3. Muhos 225 | s 1980 | 8/4 | s 2007 | f 1986 | s 2008 | 28 |
| 4. Muhos 262 | s 1980 | 8/4 | s 2007 | n/a | s 2008 | 28 |
| 5. Muhos 263 | s 1981 | 16/4 | s 2007 | n/a | s 2008 | 27 |
| 6. Muhos 3/78 | s 1980 | 9/3 | s 2007 | f 1986 | f 2008 | 29 |
| 7. Muhos 334 | s 1991 | 32/16 | s 2007 | n/a | f 2007 | 17 |
| 8. Muhos 99/18 | s 1978 | 8/4 | s 2007 | f 1986 | f 2007 | 30 |
| 9. Paltamo 8/80 | s 1980 | 4/2 | f 2007 | f 1992 | f 2007 | 28 |
| 10. Oulu, Suolamminsuo (1996) | s 1996 | 3/3 | s 2009 | f 2007 | f 2007 | 12 |
| 11. Oulu, Santerinräme | s 1980 | 6/3 | s 2009 | f 2007 | f 2008 | 29 |
| 12. Oulu, Suolamminsuo (1952) | s 1952 | 3/3 | s 2009 | f 2007 | f 2007 | 56 |
| 13. Oulu, Suolamminsuo (C 1–10) | s 1985 | 10/4 | s 2009 | f 2007 | f 2008 | 24 |

s = spring, f = fall, n/a = not sampled or analyzed

The changes in nutritional status and growth were tested by group with analysis of variance and covariance (SPSS program). At sites where it was possible to determine (exps. 6, 7, 13), stand growth 1–3 years prior to the fertilization was used as a covariate, and the growth curves in these cases uses the corrected value. Pairwise comparison of the treatments was done with Bonferroni and Tukey method.

# 3 Results

## 3.1 The effects of peat ash on the nutritional status and growth of trees

The response of Scots pine to a peat ash treatment was long-lasting, still visible 30 years from the application (Figure 3). The effect was also statistically significant. Ten or more years after the application, the stem volume growth was 35–60% greater for the fertilized trees compared to the unfertilized control. The treatment increased yearly growth by 0.8–1.8 $m^3$ $ha^{-1}$.

Needle P concentration was significantly higher on the fertilized plots after 20–30 years from the treatment, and on average, clearly above the deficiency limit of 1.30 mg $g^{-1}$ (Table 5). K concentration, on the other hand, was below the deficiency limit (4.0 mg $g^{-1}$) both on the control plots and even more so on the plots treated with peat ash, although the difference was not statistically significant. On fertile, nitrogen-rich sites, peat ash seemed to have aggravated K deficiencies further, and even large doses of peat ash did not ameliorate the lack of K. Only the most recently fertilized sites had slightly higher needle K concentrations than their controls. Needle K was, however, at a satisfactory level on the least thick-peated sites, regardless of the treatment.

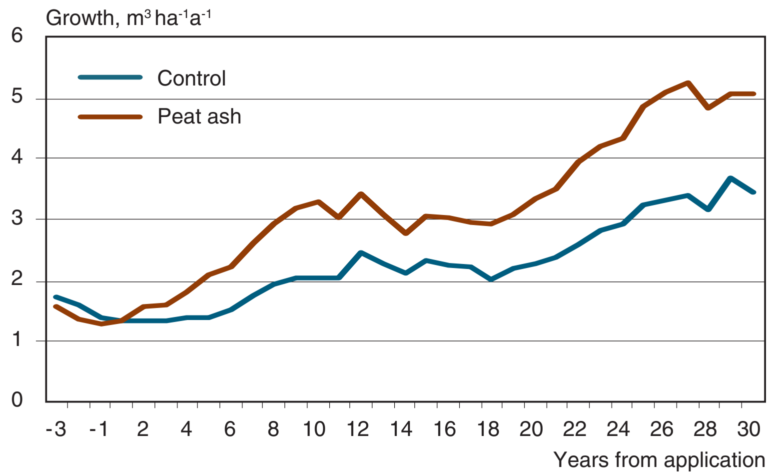


**Figure 3.** Volume growth of Scots pine before and after peat ash fertilization (experiments 2–5, 7–10; doses 5–25 t $ha^{-1}$ combined). The effect of peat ash was statistically significant when 8–11 and 18–28 years had elapsed since application (Bonferroni test).

**Table 5.** Scots pine needle nutrient concentrations and dry mass on plots treated with peat ash 20–30 years prior (experiments 2–5, 7–10; doses 5–25 t $ha^{-1}$ combined).

| Nutrient | Control | Peat ash | F value | p value |
|---|---|---|---|---|
| N, g $kg^{-1}$ | 14.8 | 14.8 | 0.18 | 0.675 |
| P, g $kg^{-1}$ | 1.22 | 1.58 | 47.35 | 0.000 |
| K, g $kg^{-1}$ | 3.80 | 3.63 | 0.22 | 0.642 |
| B, mg $kg^{-1}$ | 11.5 | 11.7 | 0.04 | 0.840 |
| Needle weight g (per 100) | 1.85 | 2.00 | 5.40 | 0.029 |

Needle N remained mostly unaffected by peat ash. N was below the deficiency limit (12 g kg $^{-1}$) at only 1 of 42 examined plots. As regards boron, the difference between treated and control plots was negligible, but amounts below the deficiency limit (7 mg $kg^{-1}$) were found more often on treated plots. Needle dry mass was on average higher on treated plots, with a statistically significant difference (Table 5). An interaction effect between treatments and experiments was not detected.

## 3.2 The effects of peat ash combined with potassium

The combined use of peat ash and a K fertilizer increased stand growth more than the simple application of either peat ash or K alone (Figure 4). The annual growth increase gained with peat ash+K was at its largest 4–6 $m^3$ $ha^{-1}$. The difference to other treatments became statistically significant 4 years after the application. The growth responses to independent treatments of peat ash or potassium only were only about half of that of the combined treatment. In experiment 7, varying the dosage of peat ash (25, 50, 100 t $ha^{-1}$) or using different sources of K (KCl, biotite, or a mixture of the two) did not result in any major differences.

The source of K at experiments 3 and 4 were fertilizers containing the easily soluble KCl. This resulted in, as might be expected, K being the only nutrient whose concentration was higher on the combination-treated plots than on peat ash plots (Table 6). The added K (50–100 kg $ha^{-1}$) increased needle K concentration compared to peat ash plots, although the difference was not statistically significant. This may partly be because of the rather long period after K application (27 years) and the fact that K status had already been relatively good also on the control plots. Needle B concentration had increased as a result of the K+micronutrient treatment, which contained B.

Experiment 7 included three different dosages of peat ash: 25, 50 and 100 t $ha^{-1}$, which were applied either independently or with the easily soluble KCl and the less soluble biotite. Varying the dosage did not have a significant effect on needle P concentration or on dry mass (Table 7). However, the ash treatments aggravated the already existing deficiency of K. With all ash dosages, the addition of KCl and/or biotite helped maintain a good status of K. Needle K concentrations were similar in both KCl and biotite plots. Mixing KCl and biotite did not produce significantly different results to those obtained with only KCl or biotite, either.

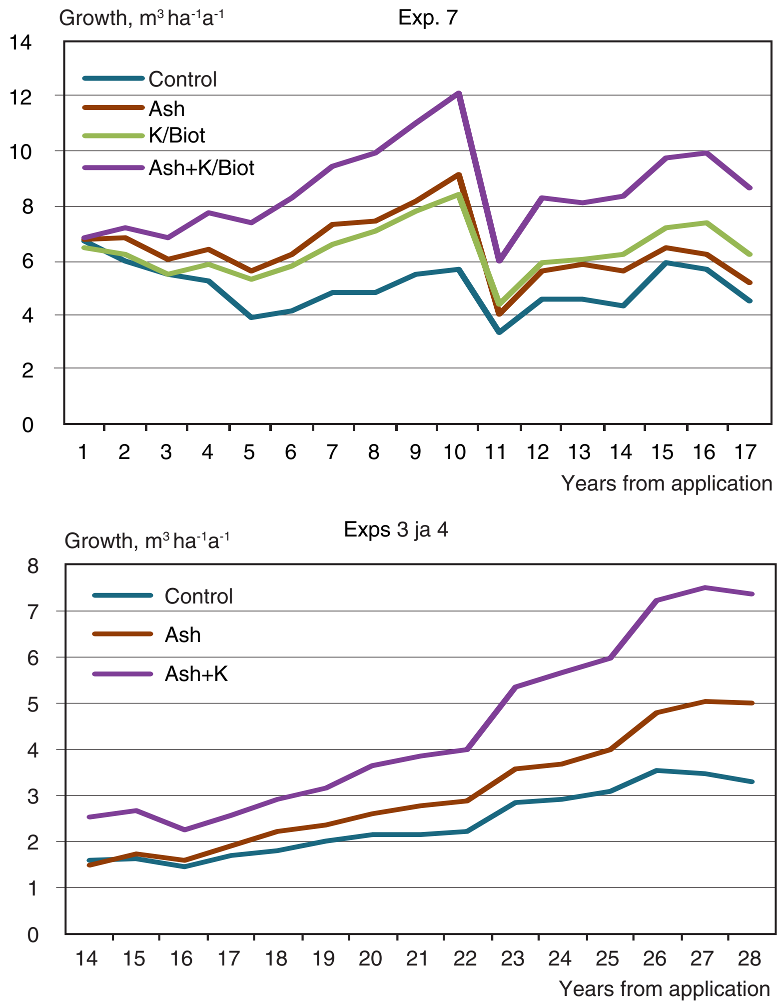


**Figure 4.** Volume growth of Scots pine after mere peat ash (Ash) and combined peat ash and potassium treatments (Ash+K; Ash+K/Biot ). In experiments 3 and 4 ash dosage was 5 t $ha^{-1}$, in experiment 7 it was 25, 50 and 100 t $ha^{-1}$ (here combined). In 3 and 4 the source of K was potassium chloride (KCl), in 7 it was KCl and biotite. Experiment 7 underwent thinning fellings 10 years after the treatment.

**Table 6.** Nutrient concentrations and dry mass in Scots pine needles on plots that received mere peat ash (Ash) or combined peat ash + potassium chloride (Ash+K) (experiments 3,4). Analyses after 27 years since fertilization.

| Nutrient | Control | Ash | Ash+K | F value | p value |
|---|---|---|---|---|---|
| N, g $kg^{-1}$ | 13.1 | 13.4 | 13.9 | 0.66 | 0.536 |
| P, g $kg^{-1}$ | 1.19 | 1.58 | 1.55 | 4.24 | 0.000 |
| K, g $kg^{-1}$ | 4.27 | 4.70 | 5.05 | 2.53 | 0.129 |
| B, mg $kg^{-1}$ | 11.2 | 13.2 | 15.9 | 0.24 | 0.791 |
| Needle d.m., g (per 100) | 1.77 | 2.18 | 2.45 | 5.16 | 0.029 |

**Table 7.** Scots pine needle nutrient concentrations and dry mass on peat ash plots and peat ash+potassium plots, experiment 7. Ash = peat ash 25, 50 and 100 t ha$^{-1}$, K = potassium chloride, Biot = biotite. 16 years after application.

| Nutrient | Control | K+ Biot | Ash | Ash +K | Ash+ Biot | Ash+ K + Biot | F value | p value |
|---|---|---|---|---|---|---|---|---|
| N, g kg$^{-1}$ | 17.1 | 16.0 | 15.8 | 15.0 | 15.6 | 16.2 | 1.55 | 0.208 |
| P, g kg$^{-1}$ | 1.32 | 1.18 | 1.45 | 1.53 | 1.47 | 1.48 | 6.67 | 0.000 |
| K, g kg$^{-1}$ | 3.89 | 4.49 | 3.39 | 4.58 | 4.33 | 4.47 | 12.1 | 0.000 |
| B, mg kg$^{-1}$ | 15.9 | 16.5 | 16.7 | 14.7 | 15.6 | 16.3 | 0.32 | 0.895 |
| Needle d.m., g (per 100) | 2.57 | 2.71 | 2.56 | 2.71 | 2.69 | 2.83 | 0.44 | 0.814 |

## 3.3 The effects of follow-up K fertilization at peat ash sites

The effects of a later, additional K treatment were examined at four sites previously treated only with peat ash (experiments 5, 11, 12 and 13). Compared to the control and to sites that received peat ash only, a follow-up K treatment increased stand volume and basal area growth noticeably (Figures 5 and 6). After 5–10 years from the follow-up treatment, the trees' fertilization response was roughly double with the easily soluble K+micronutrient fertilizer compared to peat ash only (Figure 5). With the less soluble biotite, the effect was much more modest (Figure 6).

The additional K (from KCl or biotite) increased needle K concentration more effectively than mere peat ash, with a statistically significant difference at 5–9 years from the application (Table 8). None of the plots that received additional K had deficiencies in boron, and the B status was generally quite good also on peat ash plots. Needle B concentrations increased most noticeably on plots that received a K fertilizer that contained B. There was an increase in needle dry mass, as well.

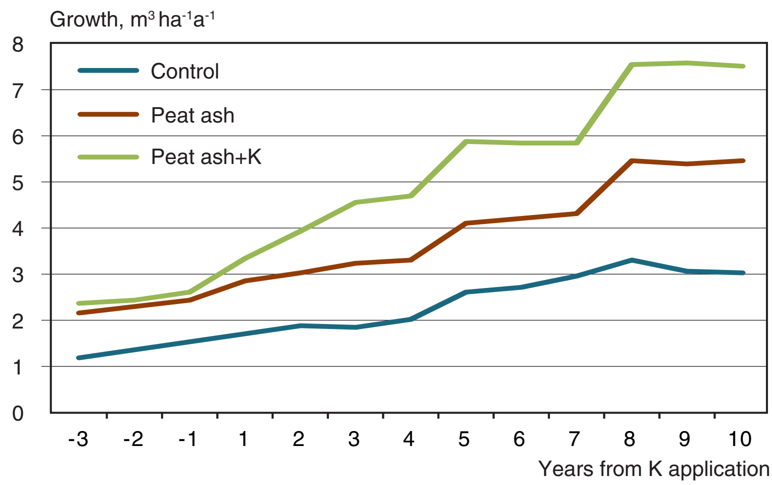


**Figure 5.** Volume growth of Scots pine on peat ash plots with follow-up K treatment compared to control and mere peat ash treatments (experiments 5, 11 and 12). Potassium was applied 17–43 years after peat ash fertilization.

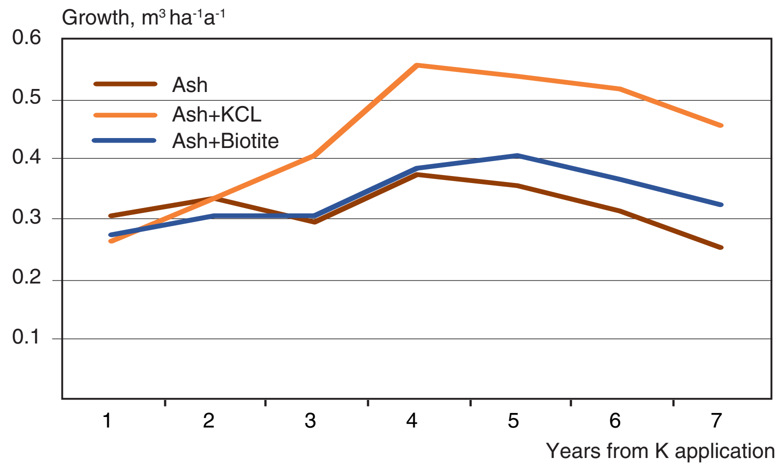


**Figure 6.** Basal area growth of Scots pine on peat ash plots with follow-up K treatment compared to mere peat ash treatment (experiment 13). Potassium applied 17 years after peat ash application.

**Table 8.** Scots pine needle nutrient concentrations and dry mass on peat ash plots and peat ash+follow-up K plots, experiments 5, 11, 12 and 13. 24–57 years from peat ash treatmet, and 5–9 years from follow-up K treatment. * = Peat ash+follow-up K treatment differs significantly from mere peat ash treatment.

| Nutrient | Control | Peat ash | Peat ash +K | F value | p value |
|---|---|---|---|---|---|
| N, g $kg^{-1}$ | 13.7 | 14.7 | 15.0 | 1.00 | 0.384 |
| P, g $kg^{-1}$ | 1.20 | 1.58 | 1.55 | 5.72 | 0.011 |
| K, g $kg^{-1}$ | 3.69 | 3.55 | 4.55* | 9.99 | 0.001 |
| B, mg $kg^{-1}$ | 14.9 | 14.7 | 20.2 | 2.22 | 0.134 |
| Needle d.m., g (per 100) | 1.65 | 1.81 | 2.01 | 6.64 | 0.006 |

d.m. = dry mass

## 3.4 Comparing peat ash with commercial PK fertilizers

Suometsien PK (PK fertilizer for peatland forests, corresponds to today's RautaPK), used in three of the experiments, had an effect comparable to that of peat ash (Figure 7). Both the ash and the PK fertilizer increased stand volume growth significantly, when 10 years had passed, and in both treatments the effect increased progressively through to the end of the study period. In one experiment the PK fertilizer and a treatment of combined peat ash+potassium were compared (Figure 8). Both treatments resulted in a strong and long-lasting response, increasing growth at a similar rate. The treatments nearly doubled volume growth for the period of 10–15 years, and the response did not yet show signs of diminishing at the end of the study period.

In any measured needle nutrient the differences in the effects of peat ash and PK fertilizer were minor and statistically insignificant (Table 9). Needle P concentration was somewhat higher on peat ash plots. Needle K concentration remained below the deficiency limit in both treatments.

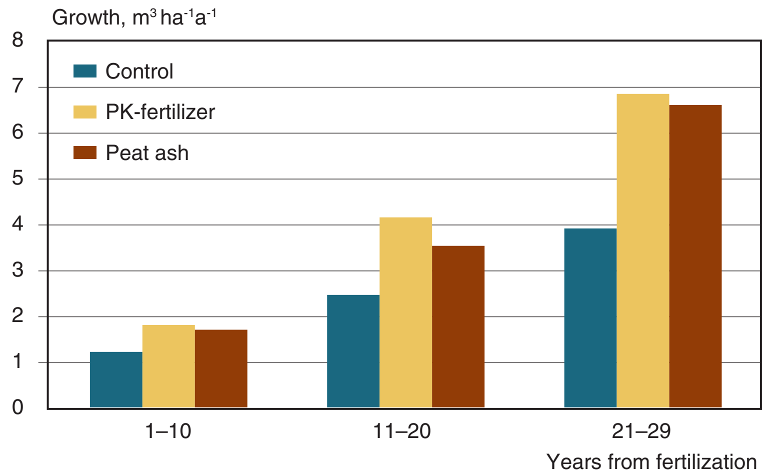


**Figure 7.** Volume growth of Scots pine on PK fertilized plots and peat ash plots (experiments 1, 2, 8). Their differences to control were statistically significant for all three time periods.

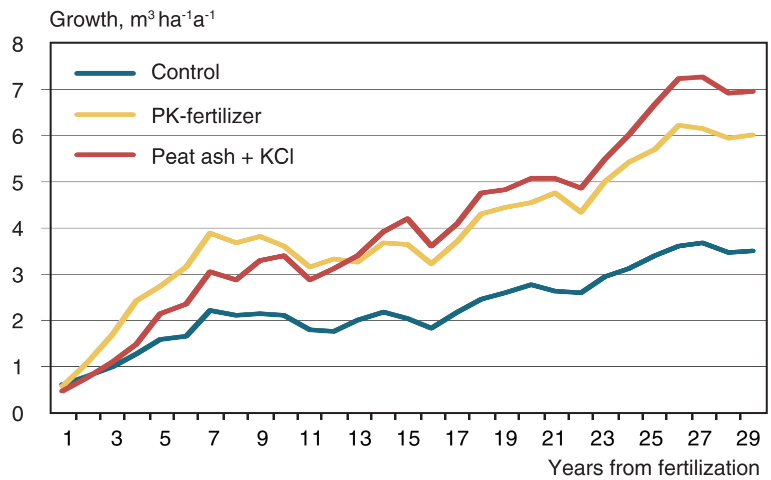


**Figure 8.** Volume growth of Scots pine on PK fertilized plots and plots with peat ash+KCl (experiment 6).

**Table 9.** Scots pine foliar nutrient concentrations and dry mass on peat ash plots and PK fertilized plots (experiments 1, 2, 6, 8). 27–29 years from the treatment.

| Nutrient | Control | Peat ash | PK-fertilizer | F value | p value |
|---|---|---|---|---|---|
| N, g $kg^{-1}$ | 16.7 | 15.4 | 15.4 | 1.45 | 0.255 |
| P, g $kg^{-1}$ | 1.15 | 1.30 | 1.41 | 12.1 | 0.000 |
| K, g $kg^{-1}$ | 3.52 | 3.77 | 3.57 | 0.79 | 0.465 |
| B, mg $kg^{-1}$ | 7.80 | 9.60 | 9.50 | 0.64 | 0.534 |
| Needle d.m., g (per 100) | 1.94 | 2.06 | 2.01 | 0.58 | 0.569 |

d.m. = dry mass

# 4 Discussion

Our data originates from sites drained for forestry that are typical to Northern Ostrobothnia. This, combined with the uniform quality of the used ash, and the fact that data was available on the nutritional values of the treatments, helps make the results applicable in a more general manner. The large differences in the nutritional statuses of the experimental stands caused variation in the results, and in some experiments the small amount of treatment replications and varying the used dosage also caused fluctuation in the results. The effects of pure peat ash on the growth and nutritional status of Scots pine on drained peatlands during a period of 30 years can be quite reliably inferred from the results. In a few of the experiments small amounts of wood ash alongside peat ash were used. However, the wood ash amounts in these mixtures were so small (0.25–0.40 t $ha^{-1}$) that no conclusions regarding the types of mixed ashes that are produced today in Finland can be made.

The use of peat ash alone resulted in a noticeable growth response in all of the experimental stands. Stand volume growth response increased progressively in strength during the years, and was still visible 30 years from the application. It is very likely that there will be a difference to an unfertilized stand all through the stand's life span. However, the growth response was in general clearly smaller than that gained with wood ash at similar locations (Moilanen & Issakainen 2000, Moilanen et al. 2002), which can be attributed to the low potassium content in peat ash.

The ash dosages varied mostly between 5–10 t $ha^{-1}$, with one experiment having "very high" dosages (25, 50 and 100 t $ha^{-1}$). The amount of phosphorus recommended in practical forestry was already gained with the lowest dosage, and increasing the dosage did not have a noticeable effect on either the growth response or on needle P concentrations. Thus, in practice, it is probably not useful to exceed the amount of 5 t $ha^{-1}$ – possibly even 3–4 t $ha^{-1}$ is an adequate amount when ameliorating P deficiencies. On the other hand, even the very high dosages did not seem to have any detrimental effects. Concerning the environment, peat ash seems cause less strain than wood ash. When using large doses, both the positive and negative effects are smaller in scale with peat ash compared to wood ash (Rehell 1991, Silfverberg & Issakainen 1987, 1991, Kaunisto 1987).

The most common nutritional problem in peatland forests is the low availability of phosphorus (Moilanen 2005). The considerable and long-lasting (at least 30 years) effects of P fertilizers (including apatite phosphorus or rock phosphate) on the nutritional status and growth of stands suffering from P deficiency have been verified in numerous studies in Finland during the last decades (e.g. Veijalainen & Paarlahti 1988, Moilanen 1993, Silfverberg and Hartman 1999, Silfverberg & Moilanen 2008). The data from the stands examined in this study shows that P deficiency in Scots pine can also be eliminated with peat ash. However, peat ash did not affect potassium, or even diminished it, thus accentuating existing nutrient imbalances and K deficiencies. In this regard, the results also confirm earlier assessments about the unsuitability of only using P for peatland fertilization (Veijalainen & Paarlahti 1988, Moilanen 2005, Issakainen & Huotari 2007, Issakainen et al. 2007). Because of its low K content, peat ash alone is not a suitable fertilizer for peatland forests suffering from K deficiency–which is quite common on thick-peated drainage areas (Laiho et al. 2005). Peatland forests that suffer only from P deficiency would make good targets for peat ash fertilization, but they are very uncommon on drained peatlands (Moilanen et al. 2010, Silfverberg & Moilanen 2008). The best target for peat ash might be thin-peated sites where the trees suffer from P deficiency, but are able to obtain K from mineral soil below the peat–however, these kinds of sites are probably quite scarce, as well. Regarding other nutrients, peat ash did not noticeably worsen tree nitrogen or boron statuses.

Treatments that included peat ash with additional potassium, either applied simultaneously (‘combined’) or later (‘follow-up’), eliminated K deficiencies and increased stand volume growth much more effectively than peat ash alone. Although the K treatment’s effect on needles started to diminish after 15–20 years, the growth increase continued still. Several earlier studies have also reported that when using readily soluble K compounds, the tree stand’s K status starts to go down again after 20 years from the application (e.g. Silfverberg & Moilanen 2008). The fact that growth remains at a clearly better level than on unfertilized plots even after this is a result of the increased total volume gained during the initial period following fertilization. This seems to be the case also in the tree stands examined in the present study. To make full use of a site’s yield potential, however, probably requires a second application of K before final fellings. The use of a less soluble form of K, biotite, was also examined, but due to the relatively short study period, no adequate data from its long-term effects could be gained.

Peat ash was compared with a PK fertilizer at three of the experiments. Peat ash fared surprisingly well in comparison to the fertilizer, showing a growth response of similar magnitude. However, a small amount of wood ash was applied at two of these three sites to ensure an initial effect, which might have evened out the differences somewhat. It is possible that the growth results include the effect of the initial wood ash application, and that the strong growth reaction would be a case of mixed peat and wood ash. It should also be noted that the type of PK fertilizer used at the time contained less potassium than modern peatland fertilizers, which perhaps makes the results less applicable in today’s forestry.

The combined treatment of peat ash+KCl increased growth in much the same way as the PK fertilizer, as was expected. While it has been noted that wood ash has an effect comparable to a PK fertilizer (Moilanen et al. 2004), now we might conclude, in turn, that peat ash “reinforced” with potassium is comparable to wood ash in its effects, which are also long-lasting. The stand growth increase gained with peat ash was evident in all of the experiments still at the end of the study period.

Today, pure peat ash is not as commonly produced as before. Power plants utilizing peat often burn it in conjunction with wood, so today’s mixed ash from plants usually contains more potassium and boron than the peat ash that was used at the sites examined in this study.

Adding potassium to peat ash at the granulation plants should be considered as a possible course of action. A suitable dosage for peatland fertilization is around 3–4 t $ha^{-1}$ of peat ash and 200–300 kg $ha^{-1}$ of potassium chloride. If biotite is used as the source of K, the recommended amount would be just over a tonne per hectare.

As a conclusion, peat ash should be considered as a relatively slow-dissolving phosphorus fertilizer for peatlands. When combined with a source of potassium, or mixing it with K-rich wood ash, the potential fertilization response could be comparable to that gained with high-quality wood ash (Silfverberg & Huikari 1985, Silfverberg 1996).

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