© Suoseura — Finnish Peatland Society
Helsinki 2016
ISSN 0039-5471
Suo 67(2): 53–66 — Tutkimusartikkelit

Peat ash and biotite in fertilization of Scots pine on an afforested cutaway peatland

Turvetuhka ja biotiitti männyn metsityslannoituksessa suonpohjalla

Jyrki Hytönen, Lasse Aro, Jorma Issakainen ja Mikko Moilanen

Jyrki Hytönen, Natural Resources Institute Finland, Silmäjärventie 2, 69100 Kannus, Finland; tel. +358503193405; email: jyrki.hytonen@luke.fi
Lasse Aro, Natural Resources Institute Finland, Itäinen Pitkäkatu 3, 20520 Turku, Finland. email: lasse.aro@luke.fi
Jorma Issakainen, Ratapellontie 11, 91500 Muhos, Finland
Mikko Moilanen, Natural Resources Institute Finland, Paavo Havaksen tie 3, 90014 University of Oulu; email: mikko.moilanen@luke.fi

In Finland peat is used in power generation, often burned with wood mixture resulting in mixed ash types. Peat ash is usually rich in phosphorus (P) but poor in potassium (K) and thus not as good fertilizer for peatland forests as wood ash. In this study we compared the effects of peat ash and peat ash with added potassium (potassium chloride or biotite) on the growth and nutrition of Scots pine seedlings on a cutaway peatland. In addition, peat ash was pelletized with biotite in one treatment. The treatments were applied around single trees with 10 replications. The study site was rich in N, but poor in P and K. Peat and foliar samples were analysed, and the height growth of seedlings was monitored for 17 years following the treatments. Pure peat ash had a positive effect on the growth of Scots pine but the survival rate of seedlings was not satisfactory. Peat ash enriched with potassium increased substantially growth of seedlings and increased the foliar K concentration compared to unfertilized control and peat ash alone. Pelletized peat ash and biotite gave similar results as the use of un-pelletized peat ash and biotite. Peat ash alone is not recommended for fertilization of Scots pine stands on drained peatlands. Adding K to peat ash enables recycling of large amounts of nutrients back to peatland forests, and is a good alternative to low-soluble P and K fertilizer. The granulation of the product would ensure good spreadability.

Key words: Cutaway peatland, potassium, biotite, potassium chloride, nutrition, Scots pine

Introduction

Ash is commonly classified according to its parent material, which also indicates the basic differences in nutrient contents. Ash contains plant nutrients in the form of basic compounds. Thus, it acts both as a liming agent, reducing soil acidity, and as a fertilizer, supplying nutrients to plants (Saarela 1991). Variation in the nutrient concentrations of ash of different kinds can be quite wide. The recycling of wood ash, especially rich in phosphorus (P) and potassium (K) as fertilizer has been studied quite intensively for several decades and research results show that the use of wood ash has several advantages, e.g. promoting tree growth and nutrition, and reversing acidification of forest soil (e.g. Aronsson & Ekelund 2004, Pitman 2006, Huotari et al. 2015).

In Finland and other countries having rich peat resources, peat is also used in energy generation in power and heating plants. Peat constitutes 5–7 % of the total energy consumption in Finland. Peat and wood are often burned as a mixture, resulting in mixed peat and wood ashes. As a by-product 350,000 tonnes of peat ash and mixed peat and wood ash are formed annually (Moilanen 2009). Recycling of the nutrients contained in peat ash, now mostly disposed off as waste, could be an interesting alternative for improving the nutritional status of soils.

Peat ash, as it is rich in phosphorus (P), is potentially suitable fertilizer for forests where P is the limiting nutrient for tree growth. Thus, peat ash can serve as a slowly soluble phosphorus fertilizer in peatland forests (Silfverberg & Issakainen 1987a, Issakainen et al. 1994, Moilanen et al. 2012). On the other hand, it is poor in other essential nutrients and contains, e.g. considerably smaller amounts of potassium (K), calcium (Ca), magnesium (Mg) and boron (B) than wood ash (e.g. Moilanen & Issakainen 2003, Mandre et al. 2010, Silfverbeg et al. 2010). The K content of peat ash is often less than 10% of the K content of wood ash (Silfverberg 1996). For this reason peat ash has been considered to be an inferior alternative to wood ash as an additional nutrient source for trees (Issakainen et al. 1994, Moilanen & Issakainen 2003).

However, even though less than wood ash, peat ash has also improved the nutrient status and growth of Scots pines on peatlands, especially at high rates of application (Silfverberg & Issakainen 1987a, Issakainen et al. 1994, Moilanen et al. 2012). Small positive growth responses have been reported in greenhouse studies (Moilanen et al. 1987, Saarela 1991), in pot studies conducted outdoors (Mandre et al. 2010), and in peatland forests (Silfverberg & Issakainen 1987a, Issakainen et al. 1994, Moilanen et al. 2012). Peat ash has also accelerated the initial development of downy birch (*Betula pubescens* Ehrh.) (Huotari et al. 2008, 2009), and at high application rates (50 Mg ha^{-1}), growth of silver birch (Lumme 1988) and energy willows (Hytönen 1998a) on cutaway peatlands. Besides the low K content of peat ash, the lower solubility of K in peat ash contributes to the low availability of K following peat ash fertilization (Nieminen et al. 2005). Peat ash also decreases soil acidity (e.g. Moilanen & Issakainen 2003), but compared to dolomitic limestone or wood ash, the application rates of peat ash should be much higher in order to achieve the same effect (Jokinen 1982, Saarela 1991).

In Finland, shortage of phosphorus and potassium can limit foremost the growth of trees in drained peatland forests and deficiencies of these nutrients are common (Kaunisto & Tukeva 1984, Moilanen et al. 2005, 2010, Pietiläinen et al. 2005). Potassium deficiencies are most common on thick-peated, originally treeless or sparsely treed fens (e.g. Kaunisto & Tukeva 1984). Tree growth problems are caused by the shortage of P and K and the imbalance with the abundant nitrogen (N) (Kaunisto & Tukeva 1984, Moilanen 1993, Silfverberg & Moilanen 2008, Moilanen et al. 2010, Moilanen et al. 2015). For example, in a study by Moilanen et al. (2010), every second experimental stand on drained peatland was suffering from P deficiency, every third stand from N deficiency and every fourth stand from severe K deficiency; imbalances in N:P and N:K ratios were most abundant in deep-peated and N-rich sites. On cutaway peatlands even more severe nutrient imbalances are typical (Aro et al. 1997).

In forest fertilization potassium has been mainly applied as water-soluble potassium chloride (Moilanen et al. 2005). The duration of the effect of potassium chloride fertilization has been shown to be ca. 15 years when the amounts suggested in the recommendations are applied (Pietiläinen et al. 2005). However, also slowly soluble forms of potassium compounds (e.g. biotite and phlogobite) have been tested in forest fertilization trials (Moilanen et al. 2005). Biotite is a silicate forming large platy mineral ($K(Mg, Fe)_3AlSi_3O_{10}(OH)_2$) and does not contain water-soluble potassium. Potassium ions are tightly fixed in the interlayer positions of mica and are only partly released by cation exchange reactions that depend on the amount of cations present in the soil. They have been shown to increase foliar K concentration initially slower than potassium chloride (Kaunisto et al. 1993, Moilanen et al. 2005). The duration of the fertilization effect with slowly soluble potassium fertilizers has been shown to be at least 19–25 years and thus longer than achieved with easily soluble potassium chloride (Kaunisto et al. 1993, 1999, Moilanen et al. 2005).

The untreated loose ash or fly ash is difficult to handle and its transportation and spreading in forests is technically difficult and presents health risks to operators because of the fine particles (Juntunen 1982). Nowadays almost all ash used in forestry is stabilized, and spread mostly in granulated form or smaller amounts as pelletized or self-hardened forms. Stabilizing could reduce the leaching of nutrients. For example, by using stabilized wood ash the possible shock effects of high pH are considered to be avoided (Steenari et al. 1999). K is the most soluble nutrient in hardened wood ashes, but its loss rate from hardened ash is somewhat lower than from loose ash (Eriksson 1998, Nieminen et al. 2005) due to formation of slower solubility compounds during the granulation process (Steenari et al. 1999). However, Nieminen et al. (2005) did not find any differences in K release between self-hardened ash granulates and loose ash. In the granulation process ash could be improved by mixing different kinds of ashes or adding nutrients (Hytönen 1998b, 1999). Peat ash complemented with fertilizers containing K could be an excellent fertilizer for peatlands (Moilanen et al. 2012). Since pelletizing and granulation of ash is nowadays a general procedure, the peat ash and biotite could be added in the process.

We hypothesized that mixing biotite containing slowly soluble K with peat ash would increase the usability of peat ash as a fertilizer by increasing K nutrition and growth of pines in K deficient sites.

Material and methods

The study area is located in Vaala, in the Pelso cutaway peatland area (64°31″N, 26°24″E) which was released from peat harvesting in 1992. The peat thickness in the area was 38 cm on average and varied from 13 to over 100 cm. Afforestation was done by planting one-year-old containerized Scots pine (*Pinus sylvestris* L.) seedlings in spring 1997. A fertilization experiment was established in spring 1998. The average temperature and precipitation in the summer months (June–August) during the study period was 14.2 °C and 211 mm, respectively (Fig. 1).

The five fertilization treatments tested were 1) unfertilized control (0), 2) peat ash (PA), 3) peat ash + potassium chloride (PA+Ks), 4) pelletized mixture of peat ash and biotite (PA+Bip) and 5) un-pelletized mixture of peat ash and biotite (PA+Bi) (Table 1). The application amount of P was 42 kg ha^{-1} in all fertilization treatments. K amount in the peat ash treatment was 12 kg ha^{-1} and in treatments where potassium chloride or biotite was added to peat ash it was 112 kg ha^{-1} (Table 1). Peat ash originating from the Haapavesi power plant using exclusively peat, was used at a rate of 4,000 kg ha^{-1}. Nutrient content of ash was: P 1.04 %, K 0.31 %, Ca 7.8 %, Mg 1.7 %. Biotite originated from Siilinjärvi (K 5 %, Ca 7 %, Mg 10 %). Potassium chloride (K 49.8 %, Mg 0.1 %) was applied at a rate of 200 kg ha^{-1} and biotite at a rate of 2,000 kg ha^{-1}. The pellets containing wood ash and biotite were made with a small pelletizing machine (Takalo 1997).

The experiment consisted of 50 experimental plots (single tree plots) with a sample tree in the centre. Diameter of the plots was 1.6 m (A = 2 m^2). The five treatments were assigned to sample plots in randomized block design with ten replications. Fertilizers were spread around seedlings in the plots in the beginning of June 1998. The seedlings were numbered.

The total height and height growth of the trees were measured at an accuracy of 1 cm. Measurements were done in autumn 2000, 2001, 2002, 2003, 2004 and 2014. In 2000 and 2003 also the base diameter of the seedlings was measured and in 2014 diameter at breast height was measured.

The number of needle age classes in the main stem of the pines was counted from each tree in 2000 and 2003. At the same time also the length of current-year needles was measured from the middle of the youngest shoots.

All trees were assessed for visual symptoms of K deficiency after three (2000), six (2003) and 17 (2014) growing seasons following fertilization.

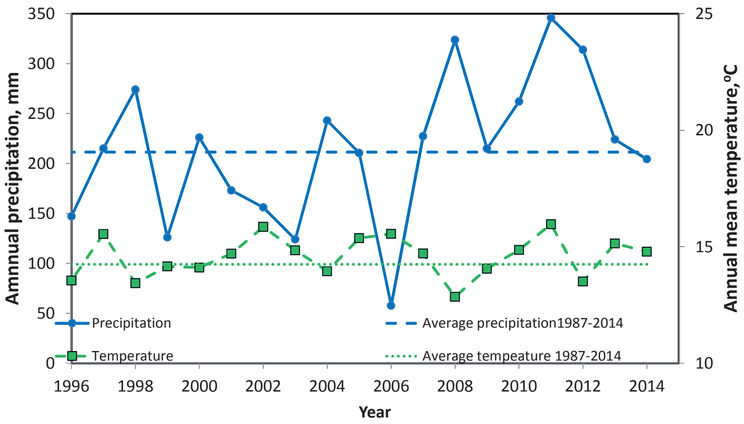


Figure 1. Annual mean temperature and precipitation in June–August during the study period and averages for 1987–2014 on the fertilisation experiment of cutaway peatland in Vaala.

Kuva 1. Kesä-elokuun vuotuinen keskilämpötila ja sademäärä tutkimuksen aikana sekä keskiarvot ajanjaksolle 1987–2014 Vaalan metsityslannoituskokeella.

Table 1. Fertilization treatments in the Scots pine seedling stand experiment on a cutaway peatland in Vaala, northern Finland.

Taulukko 1. Lannoituskäsittelyt suonpohjalle perustetulla männyn metsityslannoituskokeella Vaalassa Pohjois-Suomessa.

Treatment, *Käsittely*		Amount of nutrients *Ravinnemäärät* (kg ha^{-1})			
		P	K	Ca	Mg
0	Control	0	0	0	0
PA	Peat ash	42	12	312	68
PA+Ks	Peat ash + potassium chloride	42	112	312	68
PA+Bip	Peat ash + biotite pellet	42	112	452	268
PA+Bi	Peat ash + biotite	42	112	452	268

In young Scots pines K deficiency is presented as yellowing needle tips of the previous year needles and in severe cases needles of the whole shoot has visible symptoms (Reinikainen et al. 1998).

Current-year needle samples from the upper whorls were taken from the southern side of the trees. Samples were taken after six (December 2003), ten (November 2007) and 17 (November 2014) growing seasons following fertilization. The samples were taken from each living tree and combined to form four (2003, 2007) or three (2014) replicates. The samples were completely dried at 60 °C and ground. The N content was determined using the Kjeldahl method, and total P and B were analysed spectrophotometrically from samples taken in 2003 and 2007 (Halonen et al. 1983); total concentrations of K, Ca, Mg, iron (Fe), manganese (Mn), and copper (Cu) were determined by atomic absorption spectrometer. The samples taken in 2014 were analysed after wet digestion in a microwave oven by ICP, and C and N concentrations of needles were analysed using a CHN analyser (Leco CHN2000).

Interpretation of the needle analyses was based on the critical values, deficiency limits and optimal concentrations of different nutrients in the needles of Scots pine on drained peatlands in Finland (Paarlahti et al. 1971, Reinikainen et al. 1998):

Nutrient	Poor	Adequate	Optimal	Unit
N	< 12	12–13	13–18	mg g^{-1}
P	< 1.3	1.3–1.6	1.6–2.2	mg g^{-1}
K	< 3.5	3.5–4.5	4.5–5.5	mg g^{-1}
B	< 5	5–10	10–30	mg kg^{-1}

Peat thickness was measured close to each tree. Volumetric peat samples were taken from 0–10 cm peat layers from four unfertilized plots in November 2003 (each sample was composed of four subsamples). The samples were dried at 60 °C and ground. The ash content of the peat was 11 %. The N concentration was analysed with the Kjeldahl method, total P spectrophotometrically with the vanado-molybdate method, B concentration spectrophotometrically and total P, K, Ca, Mg, Mn and Cu contents with an atomic absorption spectrophotometer. In the 0–10 cm layer the mean amount of N was 3755 kg ha^{-1}, P 99 kg ha^{-1}, K 8 kg ha^{-1}, Ca 19 kg ha^{-1}, Mg 18 kg ha^{-1}, Fe 1429 kg ha^{-1}, Mn 3.8 kg ha^{-1}, Zn 0.6 kg ha^{-1}, Cu 0.2 kg ha^{-1} and that of B 0.1 kg ha^{-1}.

The statistical significance of treatments was studied using IBM SPSS 22 statistics software. When testing the effect of fertilization treatments on tree height and the nutrient concentrations, time and treatment-by-time interaction effects were tested using a repeated measures ANOVA model. Original height of seedlings, measured just before fertilization in the spring of 1998, was used as a covariate when testing the height of seedlings. In the analysis also peat thickness was tested as a covariate, but it was not found to be significant. Since in the repeated ANOVA models the Mauchly's test indicated that the assumption of sphericity had been violated, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. The foliar nutrient concentrations were tested by one-way ANOVA separately for each sampling year. Tukey's test was used to test differences between means using the 0.05 level of significance. When testing figures in percentage, variance stabilizing transformation of square root arcsine was used, and for tree volume square root transformation was used.

Results

Mortality of seedlings

During the study period some of the seedlings died, but only in control or peat ash treatments (Fig. 2). Three years after fertilization 10 % of seedlings had died in the peat ash treatment. In other fertilization treatments no mortality had occurred. During the following three years, i.e. six growing seasons from fertilization, mortality in the control and peat ash treatments was 22 and 31 %, respectively. The effect of treatment was statistically significant. During the following 11 years mortality increased only in the control treatment.

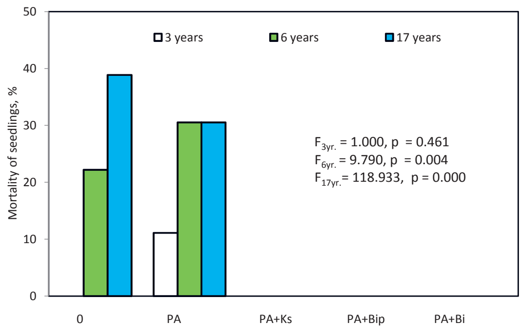


Figure 2. The percentage of dead planted Scots pine seedlings 3, 6 and 17 years after fertilisation treatment. For treatments, see Table 1.

Kuva 2. Kuolleiden männyn taimien osuus 3, 6 ja 17 vuotta lannoituskäsittelystä. Käsittelyjen kuvaus taulukossa 1.

Tree growth

At the end of the study period the mean height of unfertilized living seedlings was 2.0 m (Fig. 3A). The final height of seedlings fertilized with peat ash (3.7 m) was significantly higher compared with the control but significantly lower compared with other fertilization treatments (Fig. 3A). The seedlings were tallest when they were fertilized with peat ash with added potassium chloride (4.5 m) or biotite (5.2–5.4 m). Treatments including K in various forms did not differ significantly from each other. The order of the growth rate in the treatments was similar throughout the study.

During the first 5–6 years seedlings fertilized with peat ash and potassium chloride grew as well as those fertilized with peat ash and biotite (Fig. 3B). Later, seedlings fertilized with peat ash and potassium chloride were growing at a lower rate. According to repeated measures analysis of variance, the year-treatment interaction on the height of the living trees was statistically significant ($p < 0.001$).

Fertilization also affected breast height diameter ($D_{1.3}$) of trees (Fig. 4A). The $D_{1.3}$ of trees on the unfertilized plots at the end of study period was 2.0 cm and on fertilized plots from 4.9 cm to 8.0 cm, depending on the treatment. All treatments including K increased the diameter growth significantly.

The mean volume of living trees was lowest on the unfertilized plots (Fig. 4B). In the treatment fertilized with peat ash the mean volume of a tree was two times higher than without fertilization. When potassium was added to peat ash either as potassium chloride or biotite, mean volume of trees was 4–5 times higher than that of unfertilized trees. Pelletizing of peat ash and biotite did not affect significantly the volume of trees.

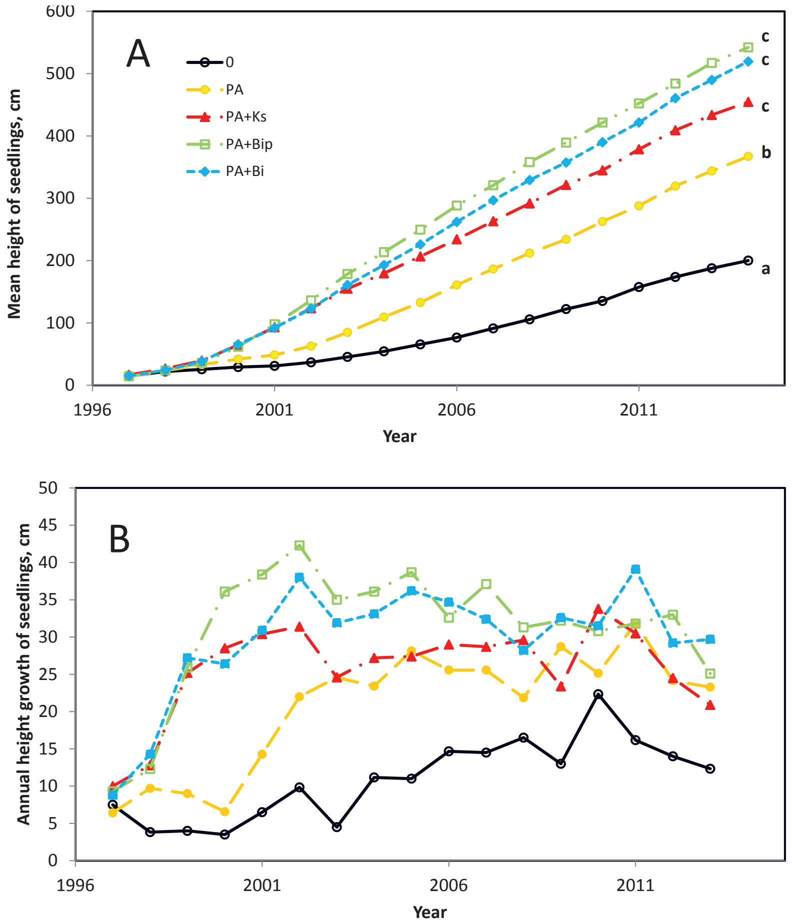


Figure 3. Mean height (A) and annual height growth of pine seedlings (B). Fertilizers were applied in spring 1998. Treatments marked with the same letters in A do not differ from each other according to Tukey's test at the 0.05 significance level. For treatments, see Table 1.

Kuva 3. Männyn taimien keskipituus (A) ja vuotuinen pituuskasvu (B) Vaalan kokeella. Koe lannoitettiin keväällä 1998. Käsittelyt, jotka on merkitty samalla kirjaimella eivät poikkea toisistaan Tukeyn testin mukaan riskitasolla 0.05. Käsittelyt esitetty taulukossa 1.

Number of needle age classes and length of needles

All treatments including K increased the number of needle age classes significantly three years after fertilization but the effect was not significant later (Fig. 5A). The unfertilized Scots pines had two needle age classes, while pines fertilized with peat ash and potassium had three classes, on average. In the final measurement 17 years after trial establishment, the average number of needle age classes had dropped below two in all treatments.

Fertilization increased the length of needles significantly (Fig. 5B). Peat ash had increased needle length three years after treatment by 47 % and treatments with peat ash and added potassium by 97–129 %. Six years after treatment the effect of fertilization on needle length was still significant but only the treatment with pelletized peat ash and biotite resulted in a higher needle length than the control.

Nutrient deficiencies and foliar nutrient concentrations

Nutrient deficiencies were visually assessed for each tree. Already three years after fertilization, K deficiency symptoms were observed in trees left unfertilized or fertilized only with peat ash (Fig. 6). Six years after fertilization visually observed K deficiency symptoms started to appear also in trees fertilized with peat ash and K. Even though unfertilized trees had the highest amount of visually observed deficiency symptoms in the final measurement, the difference between treatments was no longer significant.

Foliar N concentrations were high and in the optimum range for Scots pine on peatlands (Paarlahti et al. 1971, Reinikainen et al. 1998), and at the end of the study period even above the optimum values (Fig. 7). Foliar P concentrations were at a poor level during the whole study period of 17 years (1.27–1.29 g kg^{-1}), and there were no

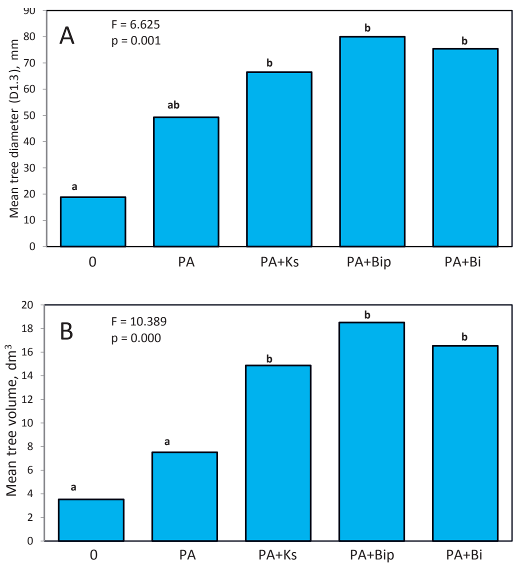


Figure 4. Mean diameter at breast height (d1.3) (A) and mean volume (B) of living trees at the end of the experiment, when 17 growing seasons were elapsed since the fertilization treatment. Treatments marked with the same letters do not differ from each other according to Tukey's test at the 0.05 significance level. For treatments, see Table 1.

Kuva 4. Elävien puiden keskiläpimitta (A) ja keskitilavuus (B) 17 vuoden kuluttua lannoituksesta. Käsittelyt, jotka on merkitty samalla kirjaimella, eivät poikkea toisistaan Tukeyn testin mukaan riskitasolla 0.05. Käsittelyt esitetty taulukossa 1.

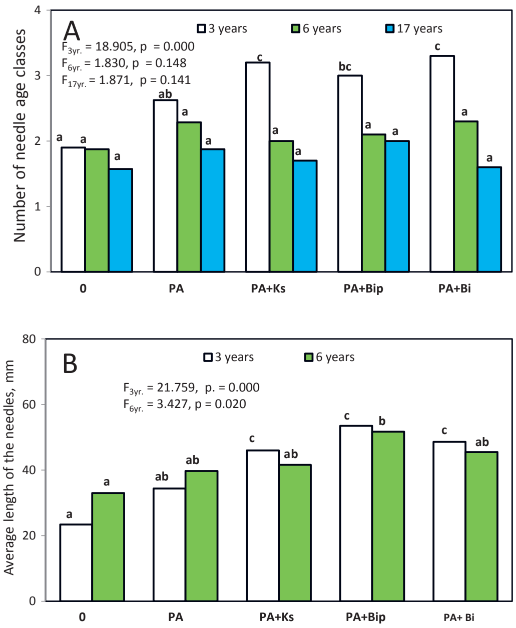


Figure 5. The number of needle age classes (A) and average length of current year needles (B) 3, 6 and 17 years from the fertilisation treatment. Treatments marked with the same letters in the same study year do not differ from each other according to Tukey's test at 0.05 significance level. For treatments, see Table 1

Kuva 5. Neulasvuosikertojen lukumäärä (A) ja neulasten keskipituus (B) 3, 6 ja 17 vuotta lannoituskäsittelystä. Käsittelyt, jotka ovat samana vuotena merkitty samalla kirjaimella, eivät poikkea toisistaan Tukeyn testin mukaan riskitasolla 0.05. Käsittelyt esitetty taulukossa 1.

differences in P concentrations between the treatments. Foliar K concentrations were low, mean values (2.5–3.1 g kg^{-1}) being much lower than the limit values reported for severe K deficiency. Fertilization by peat ash and biotite increased significantly foliar K concentrations for six years after fertilization. After 17 growing season the effect of fertilization was moderate ($p = 0.057$).

Foliar B concentrations decreased in all treatments during the study period but were still slightly above the level of severe deficiency (5 mg kg^{-1}) (Fig. 7). Fertilization treatments did not affect significantly foliar B concentration. The result was the same with Ca, Mn and Cu concentrations (results not shown here). Fertilized trees (except in the PA+Ks treatment) had higher Mg concentrations (0.99–1.03 g kg^{-1}) than unfertilized trees (0.77 g kg^{-1}).

Fertilization also increased the mass of needles (Fig. 7). Six and ten years after fertilization the needle mass in the trees fertilized with pelletized peat ash and biotite was higher than in the trees left unfertilized or fertilized with peat ash. Ten years after fertilization also the other treatment including biotite increased significantly the needle weight.

Discussion

Generally, compared to drained peatland forests the peat N stores in cutaway peatlands are higher, but those of P mostly equal and K much lower (Ferm & Kaunisto 1983, Kaunisto & Paavilainen 1988, Kaunisto & Viinamäki 1991, Hytönen 1995, Aro et al. 1997, Aro & Kaunisto 2003). In this study the total amount of N (3,755 kg ha^{-1}) cor-

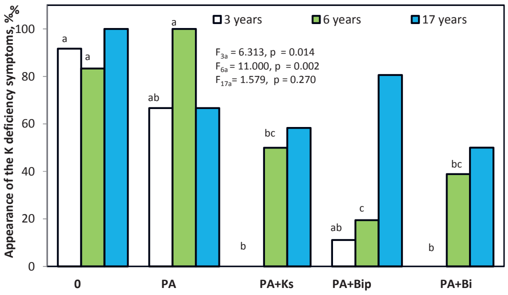


Figure 6. Visually assessed potassium deficiency symptoms in the pine needles after 3, 6 and 17 years elapsed since the fertilisation treatment (% of the all seedlings). Treatments marked with the same letters in the same study year do not differ from each other according to Tukey's test at the 0.05 significance level. For treatments, see Table 1.

Kuva 6. Neulasten värin perusteella arvioitujen kaliumpuutossymptomien esiintyvyys männyntaimilla 3, 6 ja 17 vuotta käsittelystä (% kaikista taimista). Käsittelyt, jotka on samana vuotena merkitty samalla kirjaimella eivät poikkea toisistaan Tukeyn testin mukaan riskitasolla 0.05. Käsittelyt esitetty taulukossa 1.

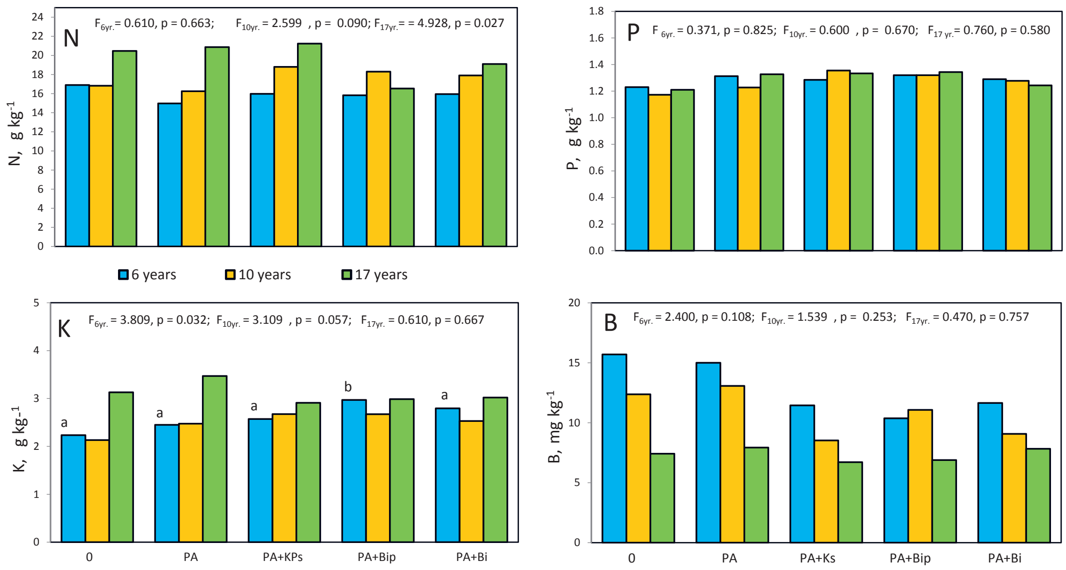
responded well to amounts measured in the same layer at two other cutaway peatlands in northern and eastern Finland (Aro et al. 1997, Huotari 2011), but was clearly higher than in southern cutaway peatlands (Kaunisto & Viinamäki 1991, Aro et al. 1997, Aro & Kaunisto 2003). However, the Pelso peat K (8 kg ha^{-1}) and P (99 kg ha^{-1}) stores in the 0–10 cm layer were extremely low compared to results from unfertilized peat in northern and eastern Finland (K 20–35 kg ha^{-1}, P 150–170 kg ha^{-1}, Aro et al. 1997, Huotari 2011). In the southern cutaway peatlands K and P stores in the surface 10-cm-thick peat layer have varied between 10–25 and 70–120 kg ha^{-1}, respectively (Kaunisto & Viinamäki 1991, Aro et al. 1997, Aro & Kaunisto 2003).

Due to high peat N but very low P and K stores at the Pelso cutaway peatland, nutritional imbalance was extremely severe. Therefore, the Pelso site was very suitable for testing P and K fertilizers. However, due to extreme nutritional conditions the duration of fertilizer response at the test site could be shorter than in peatland forests generally.

The seedlings grew extremely poorly when left unfertilized. At the end of the study period these trees were the shortest, and had the lowest volume. This treatment also showed the highest tree mortality (40 %). The unfertilized trees had also fewer needle age classes and the length of the needles was the shortest. Almost all control trees were classified as having visible symptoms of K deficiency. It is clear that the trees did not have contact with the mineral soil and thus they did not get mineral nutrients from there.

Peat ash did not increase foliar nutrient concentrations of seedlings and the K concentration was very low (2.5–3.5 g kg^{-1}). Also in several other studies peat ash has not been shown to increase foliar K concentration of Scots pines growing on peatlands (Issakainen et al. 1994, Silfverberg & Issakainen 1987b) or downy birches on cutaway peatlands (Huotari et al. 2011). Moilanen et al. (2012) even reported that especially in fertilized, nitrogen-rich sites peat ash seemed to have even aggravated K deficiencies and even large doses of peat ash did not ameliorate the lack of K. Also on afforested organic farmland peat ash proved to be a fairly poor source of K, and did not significantly increase foliar K concentrations two or eight years following application (Hytönen 2003). The acute K deficiency was seen in this study also visually as 60 to almost 100 % of trees fertilized with peat ash were classified as K deficient. Even though peat ash did not increase Scots pine foliar P concentrations in this study or in the study by Silfverberg & Issakainen (1987b), in some other studies mainly small increases have been reported especially at high application rates (e.g. Issakainen et al. 1994, Mandre et al. 2010) lasting even 20–30 years after fertilization (Moilanen et al. 2012).

In this study, 17 years after the treatments almost one third of seedlings fertilized with peat ash had died. Peat ash increased the height and mean volume of seedlings by 83 % and 188 % respectively compared to unfertilized control seedlings. Earlier Issakainen et al. (1994) measured a 21 % height increase during a period of 13 years in nine experiments with peat ash (4-10 t ha^{-1}) established on peatlands. Similarly, Moilanen et al. (2012) reported 35–60 % greater volume growth for the peat ash fertilized trees compared to unfertilized trees after ten or more years. In their study peat ash had a long-lasting effect on the growth of Scots pine (30 years after application).



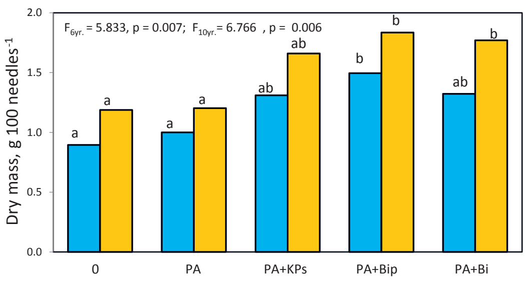


Figure 7. Foliar N, P, K, and B concentrations after 6, 10 and 17 years, and dry mass of 100 needles 6 and 10 years after treatments. Treatments marked with missing or same letters in the same study year do not differ from each other according to Tukey's test at the 0.05 significance level. For treatments, see Table 1.

Kuva 7. Neulasten N-, P-, K- ja B-pitoisuudet 6, 10 ja 17 vuotta lannoituksen jälkeen ja sadan neulasen massa 6 ja 10 vuotta käsittelystä. Keskiarvot, jotka eivät poikkea toisistaan tilastollisesti merkitsevästi samana vuonna, on merkitty eri kirjaimin. Käsittelyt esitetty taulukossa 1.

Combining biotite and peat ash increased significantly foliar K concentration for six years after fertilization, but not after ten or more years. Also, in earlier studies adding K to peat ash did not result in significantly higher downy birch foliar concentrations after five years (Huotari et al. 2011) or Scots pine foliar K concentrations after 13 (Issakainen et al. 1994) or 27 years from application (Moilanen et al. 2012). However, in peatland forests in general the potassium dose applied here has been shown to correct K deficiencies for 15–20 years when K is applied as potassium chloride and considerably longer when applied as biotite (Moilanen et al. 2005). However, in this study K concentration was below the deficiency limits in all treatments and sampling occasions probably due to the extremely low original K content of the growing substrate. Due to better growth, slightly higher amount of needle age classes, longer needles and significantly larger needle mass, fertilized pines had taken and accumulated much more K than unfertilized trees.

When potassium chloride or biotite was added to peat ash not a single seedling died during the study period. Addition of K to peat ash increased height growth of seedlings by 127–171 %. The height growth of seedlings was similar across all treatments where K was added (potassium chloride or biotite). However, it seemed that the effect of potassium salt was smaller, even though the difference between the treatments was not significant. The volume of trees with added K was 324–428 % higher than that of unfertilized trees and 98–147 % higher than those fertilized with mere peat ash. Earlier, Issakainen et al. (1994) also reported that in fertilization of Scots pine adding potassium chloride to peat ash increased the height growth of trees. Similarly Moilanen et al. (2012) reported that combined use of peat ash and K fertilizer increased stand growth more than the single application of either peat ash or K alone.

Peat ash pelletized with biotite was compared with un-granulated peat ash and biotite. There were no significant differences between these treatments. Even biotite, considered to be a slow-soluble potassium fertilizer, gave similar results as fast-soluble potassium chloride. Pelletizing ash and biotite did not decrease growth of seedlings compared to un-pelletized materials and growth was even slightly higher with pelletized fertilizer. However, this difference was not statistically significant. Pelletizing peat ash with biotite could increase the usability of peat ash.

In conclusion, the study showed that single-tree fertilization experiments can be cost effective and give similar results as experiments using large plots. Single-tree plots have also previously been successfully used to screen fertilization treatments (e.g. Binkley et al. 1995, Saarsalmi & Tamminen 2005, Littke et al. 2014). However, growth results obtained from single-tree plots cannot be directly converted to stand level.

Peat ash is primarily a P fertilizer and due to its low K content its use in fertilization of peatland forests is limited. On peatlands, peat ash fertilization resulted in a clearly smaller general growth response by trees compared to trees fertilized with wood ash or commercial PK-fertilizer (Issakainen et al. 1994, Moilanen & Issakainen 2003). Issakainen et al. (1994) recommended using peat ash mainly on sites where P deficiencies are profound. However, adding K to peat ash would make a good fertilizer for peatland forests. For example, Moilanen et al. (2012) reported that peat ash with added K fertilizer increased stand volume growth at a similar rate as PK-fertilizer and they both had a long-lasting effect. According to this study, pelletized peat ash and slow-soluble potassium fertilizer (biotite) gave results equivalent to those obtained with peat ash and potassium chloride.

Nowadays pure peat ash is not as common residue of power plants as in previously (Moilanen et al. 2012), since peat often burnt with wood. Thus, the mixed peat and wood ashes nowadays contain more K than pure peat ash, but still contain considerably less than pure wood ash. For these lower quality ashes, improvement by adding K would enable recycling of large amounts of nutrients into peatland forests. According to the Finnish Act on Fertilizer Products (Asetus lannoitevalmisteista 2011) adding inorganic materials to granulated ash to increase its usability is allowed. Thus, when low-soluble commercial PK fertilizer is not available, peat ash combined with K (potassium chloride or biotite) would be a good alternative. As suggested by Moilanen et al. (2012) a suitable dosage for peatland fertilization would be circa 2–4 t ha^{-1} of peat ash and 200–300 kg ha^{-1} of potassium chloride. The recommended amount of biotite would be just over one tonne per hectare. The granulation of the product would not decrease the usability of nutrients and would ensure good spreadability.

Acknowledgements

We would like to thank Heikki Vesala and Eero Saari for the fieldwork and Seppo Vihanta also for assistance in the computing of the results.

References

Aro, L, Kaunisto, S. & Saarinen, M. 1997. Suopohjien metsitys. Hankeraportti 1986-1995. (Summary: Afforestation of peat cutaways areas. Project report in 1986-1995). The Finnish Forest Research Institute, Research papers 634. 51 p.

Aro, L. & Kaunisto, S. 2003. Jatkolannoituksen ja kasvatustiheyden vaikutus nuorten mäntymetsiköiden ravinnetilaan sekä puuston ja juuriston kehitykseen paksuturpeisella suonpohjalla. (Summary: Effect of refertilisation and growing density on the nutrition, growth and root development of young Scots pine stands in a peat cutaway area with deep peat layers). Suo 54(2): 49–68.

Aronsson, K.A. & Ekelund, G.A. 2004. Biological effects of wood ash application to forest and aquatic ecosystems. Journal of Environmental Quality 33: 1595–1605.

Asetus lannoitevalmisteista 24/11. 13.9.2011 (Act on Fertilizer Products)

Binkley, D., Smith, F.W. & Son, Y. 1995. Nutrient supply and declines in leaf area and production in lodgepole pine. Canadian Journal of Forest Research 25(4): 621–628.

Eriksson, J. 1998. Dissolution of hardened wood ashes in forest soils: studies in a column experiment. Scandinavian Journal of Forest Research Suppl. 2: 23–32.

Ferm, A. & Kaunisto, S. 1983. Luontaisesti syntyneiden koivumetsiköiden maanpäällinen lehdetön biomassatuotos entisellä turpeennostoalueella Kihniön Aitonevalla. (Summary: Above-ground leafless biomass production of naturally generated birch stands in a peat cut-over area at Aitoneva, Kihniö). Folia Forestalia 558. 32 p.

Halonen, O., Tulkki, H. & Derome, J. 1983. Nutrient analysis methods. The Finnish Forest Research Institute, Research papers 121. 28 p.

Huotari, N. 2011. Recycling of wood- and peat-ash – a successful way to establish full plant cover and dense birch stand on a cut-away peatland. Acta Universitatis Ouluensis. Series A, Scientiae rerum naturalium A576. 48 p.

Huotari, N., Tillman-Sutela, E., Pasanen, J. & Kubin, E. 2008. Ash-fertilization improves germination and early establishment of birch (*Betula pubescens* Ehrh.) seedlings on a cut-away peatland. Forest Ecology and Management 255: 2870–2875.

Huotari, N., Tillman-Sutela, E. & Kubin, E. 2009. Ground vegetation exceeds tree seedlings in early biomass production and carbon stock on an ash-fertilized cut-away peatland. Biomass and Bioenergy 33(9): 1108–1115.

Huotari, N., Tillman-Sutela, E. & Kubin, E. 2011. Ground vegetation has a major role in element dynamics in an ash-fertilized cut-away peatland. Forest Ecology and Management 261: 2081–2088.

Huotari, N., Tillman-Sutela, E., Moilanen, M. & Laiho, R. 2015. Recycling of ash – For the good of the environment? Forest Ecology and Management 348: 226–240.

Hytönen, J. 1995. Effect of fertilizer treatment on the biomass production and nutrient uptake of short-rotation willow on cut-away peatlands. Silva Fennica 29(1):21–40.

Hytönen, J. 1998a. Effect of peat ash fertilization on the nutrient status and biomass production of short-rotation willow on cut-away peatland area. Biomass and Bioenergy 15(1): 83–92.

Hytönen, J. 1998b. Puutuhkasta ja muista jäteaineista valmistetut pelletit rauduskoivun taimien ravinnelähteenä. (Summary: Pellets made of wood ash and other wastes as nutrient sources for silver birch seedlings). Suo 49(2): 49–63.

Hytönen, J. 1999. Tuhkapellettien hajoaminen maastossa. Metsätieteen aikakauskirja 3/1999: 533–538.

Hytönen, J. 2003. Effects of wood, peat and coal ash fertilization on Scots pine foliar nutrient concentrations and growth on afforested former agricultural peat soils. Silva Fennica 37(2): 219–234.

Issakainen, J., Moilanen, M. & Silfverberg, K. 1994. Turvetuhkan vaikutus männyn kasvuun ja ravinnetilaan ojitetuilla rämeillä. (Resume: Effects of peat-ash fertilization on drained pine mires). Metsäntutkimuslaitoksen tiedonantoja 499. 22 p.

Jokinen, R. 1982. The efficiency of dolomitic limestone, basic slag and a peat ash as liming agents, and as calcium and magnesium sources for turnip rape. Journal of the Scientific Agricultural Society of Finland 54: 371–383.

Juntunen, M-L. 1982. Tuhkan levityksen terveydellisten haittojen arviointi. Metsäntutkimuslaitoksen tiedonantoja 62. 17 p.

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

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

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

Kaunisto, S., Moilanen, M. & Issakainen, J. 1999. Effect of apatite and phlogopite application on the needle nutrient concentrations of *Pinus sylvestris* (L.) on drained pine mires. (Tiivistelmä: Apatiitti- ja flogopiittilannoituksen vaikutus männyn neulasten ravinnepitoisuuksiin ojitetuilla rämeillä.) Suo 50(1): 1–15.

Kaunisto, S. & Viinamäki, T. 1991. Lannoituksen ja leppäsekoituksen vaikutus mäntytaimikon kehitykseen ja suonpohjaturpeen ominaisuuksiin Aitonevalla. (Summary: Effect of fertilization and alder (*Alnus incana*) mixture on the development of young Scots pine (*Pinus sylvestris*) trees and the peat properties in a peat cutover area at Aitoneva, southern Finland). Suo 42(1): 1–12.

Littke, K.M., Harrison, R.B., Zabowski, D. & Briggs D.G. 2014. Assessing nitrogen fertilizer response of coastal Douglas-fir in the Pacific Northwest using a paired-tree experimental design. Forest Ecology and Management 330: 137–143.

Lumme, I. 1988. Early effects of peat ash on growth and mineral nutrition of the silver birch (*Betula pendula*) on a mined peatland. Silva Fennica 22: 99–112.

Mandre, M, Pärn, H., Klõšeiko, J., Ingerslev, M., Stupak, I., Kört, M. & Paasrand, K. 2010. Use of biofuel ashes for fertilization of *Betula pendula* seedlings on nutrient-poor peat soil. Biomass and Bioenergy 34: 1384–1392.

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). Metsätieteen aikakauskirja – Folia Forestalia 820, 37 p.

Moilanen, M. 2009. Metsätuhkan ravinteet takaisin metsään. Motivan julkaisuja 12/2009. 4 p.

Moilanen, M., Ferm, A. & Issakainen, J. 1987. Kasvihuonekokeita erilaisten jäteaineiden vaikutuksesta hieskoivun alkukehitykseen turvealustalla. Metsäntutkimuslaitoksen tiedonantoja 281. 36 p. + appendices.

Moilanen, M. & Issakainen, J. 2003. Puu- ja turvetuhkien vaikutus maaperään, metsäkasvillisuuden alkuainepitoisuuksiin ja puuston kasvuun. Metsätehon raportti 162, 91 p. Available at: http://www.metsateho.fi/files/metsateho/Raportti/Raportti_162.pdf

Moilanen, M., Issakainen, J. & Silfverberg, K. 2012. Peat ash as a fertilizer on drained mires – effects on the growth and nutritional status of Scots pine. Working papers of the Finnish Forest Research Institute 231. 18 p.

Moilanen, M., Pietiläinen, P. & Issakainen, J. 2005. Long-term effects of apatite and biotite on the nutrient status and stand growth of Scots pine (*Pinus sylvestris* L.) on drained peatlands. Suo 56(3): 115–128.

Moilanen, M., Saarinen, M. & Silfverberg, K. 2010. Foliar nitrogen, phosphorus and potassium concentrations of Scots pine in drained mires in Finland. Silva Fennica 44(4): 583–601.

Moilanen, M., Hytönen, J., Hökkä, H. & Ahtikoski, A. 2015. Fertilization increased growth of Scots pine and financial performance of forest management in a drained peatland in Finland. Silva Fennica. 49(3): id 1301. http://dx.doi.org/10.14214/sf.1301

Nieminen, M., Piirainen, S. & Moilanen, M. 2005. Release of mineral nutrients and heavy metals from wood and peat ash fertilizers: Field studies in Finnish forest soils. Scandinavian Journal of Forest Research 20(2): 146–153.

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

Pietiläinen, P., Moilanen, M. & Vesala, H. 2005. Nutrient status and growth of Scots pine (*Pinus sylvestris* L.) on drained peatlands after potassium fertilisation. Suo 56(3): 101–113.

Pitman, R.M. 2006. Wood ash use in forestry – a review of the environmental impacts. Forestry 79: 563–588.

Reinikainen, A., Veijalainen, H. & Nousiainen, H. 1998. Puiden ravinnepuutokset – metsänkasvattajan ravinneopas. The Finnish Forest Research Institute, Research papers 688. 44 p.

Saarela, I. 1991. Wood, bark, peat and coal ashes as liming agents and sources of calcium, magnesium, potassium and phopshorus. Annales Agriculturae Fenniae 30: 375–388.

Saarsalmi, A. & Tamminen, P. 2005. Boron, phosphorus and nitrogen fertilization in Norway spruce stands suffering from growth disturbances. Silva Fennica 39(3): 351–364.

Silfverberg, K. 1996. Nutrient status and development of tree stands and vegetation on ash-fertilized drained peatlans in Finland. The

Finnish Forest Research Institute, Research papers 588. 27 p.
Silfverberg, K. & Issakainen, J. 1987a. Turpeentuhkan vaikutuksista puuston kasvuun ja ravinnetilaan käytännön lannoitustyömailla. (Summary: Growth and foliar nutrients in peat-ash fertilized stands). Suo 38(3–4): 53–62.
Silfverberg, K. & Issakainen, J. 1987b. Tuhkan määrän ja laadun vaikutus neulasten ravinnepitoisuuksiin ja painoon rämemänniköissä. (Abstract: Nutrient contents and weight of Scots pine needles in ash-fertilized peatland stands). The Finnish Forest Research Institute, Research papers 271. 15 p.
Silfverberg, K. & Moilanen, M. 2008. Long-term nutrient status of PK fertilized Scots pine stands on drained peatlands in North-Central Finland.(Tiivistelmä: PK-lannoituksen vaikutus männyn ravinnetilaan Pohjois-Pohjanmaan ojitusalueilla). Suo 59(3): 71–88.
Silfverberg, K., Huotari, N. & Kokkonen, A.-M. 2010. Puu- ja turvetuhkan vaikutukset kasvillisuuteen ja männyn taimettumiseen päätehakatulla turvekankaalla. Metsätieteen aikakauskirja 4/2010: 341–353.
Steenari, B.-M., Karlsson, L.G. & Lindqvist, O. 1999. Evaluation of the leaching characteristics of wood ash and the influence of ash agglomeration. Biomass and Bioenergy 16: 119–136.
Takalo, S. 1997. Tuhka ja jätteet pelleteiksi lieriöpuristimella. In: Nurmi, J., Hytönen, J. & Polet, K. (Eds.). Energiapuusta puutuhkaksi. The Finnish Forest Research Institute, Research papers 660: 59–62.

Tiivistelmä: Turvetuhka ja biotiitti männyn metsityslannoituksessa suonpohjalla

Puun ja turpeen poltossa syntyvien tuhkien ravinnepitoisuuden vaihtelu voi olla suurta. Puutuhkan, jossa on melko runsaasti fosforia (P) ja kaliumia (K), kierrätystä on tutkittu melko intensiivisesti vuosikymmenten ajan. Tutkimustulokset osoittavat, että puutuhkan käytöllä suometsissä on monia etuja. Sen on todettu lisäävän puuston kasvua ja parantavan ravinnetaloutta sekä vähentävän maaperän happamoitumista (esim. Aronsson & Ekelund 2004, Pitman 2006, Huotari ym. 2015).

Useissa turvetalousmaissa turvetta käytetään voima- ja lämpölaitoksissa. Suomessa turve muodostaa 5–7 % kokonaisenergian kulutuksesta. Nykyisin turvetta poltetaan useimmiten yhdessä puun kanssa, jolloin syntyy sekatuhkia. Turvetuhkaa ja sekatuhkia arvioidaan syntyvän Suomessa vuosittain 300 000–400 000 tonnia (Moilanen 2009). Sekä puutuhkan että turvetuhkan sisältämien ravinteiden kierrätys on kiinnostava vaihtoehto kaatopaikoille ja läjitysalueille viennin sijaan. Turvetuhka sisältää runsaasti fosforia ja voisi sopia suometsien lannoitukseen. Toisaalta lannoiteominaisuuksia heikentää hyvin alhainen kaliumpitoisuus.

Irtotuhkan levitys metsiin on teknisesti hankalaa. Rakeistaminen parantaa tuhkan levitettävyyttä ja rakeistamisen yhteydessä turvetuhkaan on lisättävissä haluttuja ravinteita.

Tutkimuksen tavoitteena oli selvittää, parantaako kaliumlisäys turvetuhkan lannoitusvaikutusta männyntaimien alkukehitykseen suonpohjalla. Kaliumlähteinä verrattiin nopealiukoista kalisuolaa ja hidasliukoista biotiittia. Lisäksi haluttiin selvittää, millainen on turvetuhka-biotiittipelletin lannoitusvaikutus. Vertailuna käytettiin lannoittamatonta käsittelyä ja pelkkää turvetuhkakäsittelyä (Taulukko 1). Tutkimus tehtiin turvetuotannosta vapautuneella suonpohjalla Vaalan Pelsonsuolla. Jäljelle jääneen turvekerroksen keskimääräinen paksuus oli 38 cm. Vaikka suonpohjan 0–10 cm:n kerroksessa oli runsaasti typpeä (3755 kg ha^{-1}), olivat fosfori- (P 99 kg ha^{-1}) ja etenkin kaliummäärät (K 8 kg ha^{-1}) alhaiset. Siten koealue sopi hyvin kaliumlannoitteiden vaikutusten tutkimiseen.

Koealueelle istutettiin yksivuotiaita männyntaimia keväällä 1997. Lannoituskoe perustettiin seuraavana keväänä. Lannoituskäsittelyt olivat 1) lannoittamaton vertailu, 2) turpeen tuhka 3) turpeen tuhka + kalisuola, 4) pelletoitu turpeentuhkan ja biotiitin seos ja 5) irtotuhka ja biotiitti. Ravinnemäärä on esitetty taulukossa 1. Koe tehtiin taimikohtaisesti levittämällä lannoitetta 1,6 m:n säteelle taimien ympärille. Koe toistettiin satunnaistettujen lohkojen menetelmällä 10 kertaa, joten kokeessa oli yhteensä 50 tainta. Taimien pituus mitattiin useita kertoja 17-vuotisen seurantajakson aikana. Lisäksi laskettiin kahtena ajankohtana neulasvuosikertojen määrä ja neulasten pituus. Neulasten värin perusteella arvioitiin silmävaraisesti kaliumin puutosten esiintyminen 3, 6 ja 17 vuoden kuluttua lannoituksesta.

Tutkimusjakson aikana taimia kuoli lannoittamattomilla koealoilla ja turvetuhkaa saaneilla aloilla. Kuusi vuotta kokeen lannoittamisen jälkeen taimia oli kuollut mainituilla käsittelyillä 22–31 % (kuva 2). Ilman lannoitusta taimet kasvoivat huonosti ja elävien puiden keskipituus oli kokeen lopussa 2,0 m (kuva 3). Turpeen tuhka lisäsi tilastollisesti merkitsevästi taimien kasvua ja puiden pituus kokeen lopussa oli 3,7 m. Pisimmät taimet löytyivät koealoilta, joille oli tuhkan lisäksi annettu kaliumia joko kalisuolana tai biotiittina. Kaliumlähteiden välillä ei todettu eroja. Turvetuhka-kalisuola-käsittelyllä puiden keskipituus kokeen lopussa oli 4,5 m ja turvetuhka-biotiittikäsittelyllä puut olivat 5,2–5,4 m pitkiä. Tuhkan ja biotiitin rakeistus ei vaikuttanut mitattuihin puustotunnuksiin. Puiden keskitilavuus oli turvetuhka-aloilla kaksinkertainen verrattuna lannoittamattomiin aloihin (kuva 4). Kun lannoituksessa käytettiin turvetuhkan lisäksi kaliumia, taimien keskitilavuus oli 4–5 kertaa lannoittamattomia suurempi.

Lannoitus lisäsi neulasten vuosikertojen lukumäärää ja neulasten pituutta (kuva 5). Kaliumin puutoksia esiintyi lannoittamattomissa taimissa ja tuhkalannoitetuissa taimissa kolme vuotta kokeen perustamisen jälkeen (kuva 6). Kuusi vuotta lannoituksen jälkeen ravinnepuutosoireita alkoi esiintyä myös turvetuhkalla ja kaliumilla lannoitetuissa taimissa. Neulasten typpipitoisuudet olivat hyvin korkeita, mutta fosfori- ja kaliumpitoisuudet olivat alle puutostason (kuva 7). Lannoitus kohotti neulasten kaliumpitoisuuksia kuusi vuotta lannoituksen jälkeen, mutta vaikutus oli pieni 17 vuoden kuluttua.

Tutkimuksen mukaan turvetuhkan ja biotiitin yhdistelmä on hyvä lannoite fosforin ja kaliumin puutoksista kärsiville suonpohjille. Tuloksia voidaan yleistää myös sellaisille metsäojtetuille soille, joilla tavattavat puiden ravinnetalousongelmat ovat samankaltaisia kuin suonpohjilla. Koska hidasliukoista kaupallista PK-lannoitetta ei ole markkinoilla, biotiitin lisääminen turvetuhkaan mahdollistaisi tuhkaan perustuvien lannoitteiden raaka-ainepohjan laajentamisen. Raaka-aineseosten rakeistaminen tai pelletoiminen helpottaa levitystä, eikä näyttäisi vaikuttavan puuston kasvureaktiota vähentävästi.

(Received 18.3.2016, Accepted 10.8.2016)