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

Jyrki Hytönen, Lasse Aro, Jorma Issakainen ja Mikko Moilanen

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, Silfverberg 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 & Tukeya 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 & Tukeya 1984). Tree growth problems are caused by the shortage of P and K and the imbalance with the abundant nitrogen (N) (Kaunisto & Tukeya 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)\(_3\)AlSi\(_3\)O\(_{10}\)(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 pelleted 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 (Hyttönen 1998b, 1999). Peat ash complemented with fertilizers containing K could be an excellent fertilizer for peatlands (Moilanen et al. 2012). Since pelleting 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) pelleted 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 m²). 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.
Hytönen et al.

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

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Amount of nutrients (kg ha⁻¹)</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PA</td>
<td>Peat ash</td>
<td>42</td>
<td>12</td>
<td>312</td>
<td>68</td>
</tr>
<tr>
<td>PA+Ks</td>
<td>Peat ash + potassium chloride</td>
<td>42</td>
<td>112</td>
<td>312</td>
<td>68</td>
</tr>
<tr>
<td>PA+Bip</td>
<td>Peat ash + biotite pellet</td>
<td>42</td>
<td>112</td>
<td>452</td>
<td>268</td>
</tr>
<tr>
<td>PA+Bi</td>
<td>Peat ash + biotite</td>
<td>42</td>
<td>112</td>
<td>452</td>
<td>268</td>
</tr>
</tbody>
</table>

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):

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Poor</th>
<th>Adequate</th>
<th>Optimal</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>&lt; 12</td>
<td>12–13</td>
<td>13–18</td>
<td>mg g⁻¹</td>
</tr>
<tr>
<td>P</td>
<td>&lt; 1.3</td>
<td>1.3–1.6</td>
<td>1.6–2.2</td>
<td>mg g⁻¹</td>
</tr>
<tr>
<td>K</td>
<td>&lt; 3.5</td>
<td>3.5–4.5</td>
<td>4.5–5.5</td>
<td>mg g⁻¹</td>
</tr>
<tr>
<td>B</td>
<td>&lt; 5</td>
<td>5–10</td>
<td>10–30</td>
<td>mg kg⁻¹</td>
</tr>
</tbody>
</table>

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.
Suo 67(2) 2016

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.

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 (D1.3) of trees (Fig. 4A). The D1.3 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.
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 (Paarlhati 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
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 WKHOLPLWYDOXHVUHSRUWHGIRUVHYHUH.GH¿FLHQF\\(\text{Fertilization by peat ash and biotite increased VLJQL¿FDQWO\IROLDU.FRQFHQWUDWLRQVIRUVL\[
\text{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 VOLJKWO\DERYHWKHOHYHORIVHYHUHGH¿FLHQF\\(mg kg\(^{-1}\)) (Fig. 7). Fertilization treatments did not DIIHFWVLJQL¿FDQWO\IROLDU%FRQFHQWUDWLRQ7KH 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\(^{-1}\)).

**Discussion**

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.

**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.

**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.
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 and eastern Finland (Aro et al. 1997, Huotari 2011). 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).
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 efficiencies 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 original K content of the growing substrate. Due to better growth, slightly higher amount of 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 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. 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 efficiencies 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 original K content of the growing substrate. Due to better growth, slightly higher amount of needle mass, fertilized pines had taken and accumulated much more K than unfertilized trees.

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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, Littek 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.

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