doi: 10.17221/83/2017-JFS

# Effect of wood ash mulch on growth of Scots pine seedlings after transplanting into peat soil: A pilot study

*Juha HEISKANEN*, Karri UOTILA, Hanna RUHANEN*

*Natural Resources Institute Finland (Luke), Suonenjoki, Finland*

**Corresponding author: juha.heiskanen@luke.fi*

**Abstract**

Heiskanen J., Uotila K., Ruhanen H. (2018): Effect of wood ash mulch on growth of Scots pine seedlings after transplanting into peat soil: A pilot study. J. For. Sci., 64: 9–16.

Wood ash production from power plants and the use of recycled ash for earthworks and forest peatland fertilization have increased markedly in Finland in recent decades. In this study, effects of wood-based ash on potted Scots pine seedlings were tested in a greenhouse. Seedlings were grown for one to two growing periods in peat with ash mulch thicknesses 0–8 cm. Seedlings grew well in ash thicknesses 0–4 cm during the first growing period. Seedling mortality (60%) occurred with the thickest ash mulch. Soluble nutrients in press water extracts were high compared with the control treatment. N and P levels were suboptimal also with ash mulch. During the second growing period, seedling mortality occurred (17%) already with the thinnest ash mulch. The results suggest that ash mulch around seedlings in quantities of less than 0.5 cm (or 7 $kg \cdot m^{-2}$) is feasible and is not detrimental to Scots pine seedlings. The results provide foundation for further field research on the longer-term impacts of wood ash mulch on planted seedlings on boreal forest sites and on the feasibility testing of the mulch as a supplement to or substitute for the soil preparation for seedling planting.

**Keywords**: ash recycling; forest soils; nutrients; soil additives; soil preparation; outplanting success

The increase in the use of forest chips for energy production has yielded a considerable increase in wood-ash production in Finland. At the moment, about 500,000–600,000 t of wood or mixed wood and peat ash is produced in Finnish power plants annually (Ojala 2010). A major part of this amount ends up being used in earthworks and road construction. Also the use of ash as a fertilizer has increased in recent years. Ash fertilizers are applied to about 10,000 ha annually (Finnish Forest Research Institute 2011), mostly in drained peatland forests where no N application is needed (Moilanen et al. 2002, 2005, 2012; Hytönen 2003).

The total forest regeneration area (planting and natural) is about 120,000 ha annually in Finland (Finnish Forest Research Institute 2014). Most of this area, about 110,000 ha, is also subjected to soil preparation (most commonly by mounding or disc trenching) before regeneration. Scots pine (*Pinus sylvestris* Linnaeus) is regenerated on 43,000 ha and Norway spruce (*Picea abies* (Linnaeus) H. Karsten) on 53,000 ha annually. On peatlands, Scots pine is a commonly grown tree species and ditch mounding is the major soil preparation method used with the arrangement of drainage (Pearson et al. 2011; Luoranen, Viiri 2012; Hökkä et al. 2016). Soil preparation enhances post-planting seedling growth but can also enhance the germination of such tree and shrub species that will later compete with the planted saplings (Raulo, Mälkönen 1975; Johansson et al. 2013; Uotila et al. 2014). Thus, the need for tending and release treatments can become critical and more labour intensive (Uotila et al. 2012, 2014).

The mulch is a layer of material applied onto the soil surface. Mulches such as bark, straw, gravel etc. have commonly been applied in agri- and horticulture for conserving soil moisture, improving fertility and health of the soil and reducing weed growth (Gliński et al. 2011). Mounds made mechanically by transferred mineral soil have also been successfully tested with forest seedling planting (Örlander, Wallertz 2007). In the forest plantation establishment, ash mulching might also act as a diminisher for soil preparation and reduce costs without compromising the plantation establishment. It could even substitute soil preparation when no major or imminent arrangement of drainage is needed at the planting site. Mulching of the planting spot with ash can potentially reduce competing surface vegetation and enhance nutrient availability to planted seedlings. Wood-based ash contains all the critical nutrients except N in well-balanced form for tree growth. On regeneration sites that suffer from nutrient shortages especially of K or B, ash fertilization has provided the good nutrient status of trees for decades (Moilanen et al. 2002, 2005, 2012; Hytönen 2003).

The aim of this preliminary study was to examine potential effects of wood ash on growth and survival of Scots pine seedlings on peat soils. A further objective was to acquire basic knowledge for carrying out future field research to test if wood-based ash could serve as a supplement to or even substitute for soil preparation at outplanting on reforestation sites. This bioassay was conducted with potted Scots pine seedlings in a greenhouse.

## MATERIAL AND METHODS

### Experimental design

**First growing experiment**. The Scots pine seedlings used in this study were standard nursery seedlings grown in peat-filled containers from a local seed source in an operational forest nursery in Suonenjoki, Finland (62°38'26.9"N, 27°03'16.5"E). The compliance of all marketed tree seeds and seedlings is supervised by authorities in Finland (www.evira.fi/en/plants/cultivation-and-production/forestry). The first-year seedlings were stored at –3°C from October until January, and thawed at 6°C for three days following standard procedures (Heiskanen 2013). After thawing and a couple of days adaptation at room temperature, the seedlings were transplanted with peat plugs into separate 20 l plastic pots (CombiPot A/S, Denmark), which were filled with natural, low-humified Sphagnum peat growing media (Kekkilä Oy, Finland; www.kekkila.fi/tuotteet/turvetuotteet/luonnonturve) by hand. Mean seedling height at the time of planting was 13.2 ± 0.52 cm.

The thickness of peat filled into pots was about 11 cm (pot diameter 29.5 cm) from the pot bottom. Wood-based granulated ash (Ecolan, Finland; Ecolan T4000 forest ash, with N-P-K-B concentrations 0-1-3-0.02%) was then added on top of the peat. Six different ash thicknesses were used; 0 (control), 0.5, 1, 2, 4 and 8 cm, which corresponded to 0 (control), 0.46, 0.92, 1.84, 3.67 and 7.34 ash in kilogramme per pot (ash density about 1.3 $g \cdot cm^{-3}$) or 0, 6.7, 13.5, 26.9, 53.7, 107.4 $kg \cdot m^{-2}$. In each ash thickness treatment, five pot replicates were used. Seedling pots were assigned to five growing blocks, in each of which there was one replicate from each treatment (5 × 6 = 30 in all).

Seedlings were grown in a greenhouse, where the diurnal light cycle was set to light for 18 h (high-pressure sodium lamps were on from 5 to 23 h). During the night, one interruption lamp was lit in order to prevent too early bud formation. The temperature was set to 20°C (day) and 15°C (night). Actual daily temperatures at seedling shoots were 20–32°C due to light warming. Full light yielded photosynthetically active radiation at the seedling shoot level of 380–450 $\mu E \cdot m^{-2} \cdot s^{-1}$. Relative humidity varied between 30 and 70%, being about 10% higher with no light.

Pots were watered manually with pure tap water 0–1 times per week to their target gravimetric masses. The target volumetric water content was aimed to equal to about one half of the total porosity (Heiskanen 2013). Once or twice a month, pots were watered similarly over the target masses so that a percolated water sample of equal amount could be taken from the bottom of the pots for monitoring pH and electrical conductivity (EC) (combined sample for treatments, i.e. $n = 1$).

Pot positions were changed once a week to reduce spatial variation in growing conditions. Seedling heights were measured weekly. After four months, seedlings were harvested and measured for morphological attributes: height, stem diameter (measured at a height of 11 cm from the peat surface, i.e. from the root collar), visual needle vigour (i.e. greenness and chlorotic tone) and dry masses of shoot and roots outgrown from the initial peat plug to the surrounding peat medium in pots.

**Second growing experiment**. A second set of seedlings were grown at the same time with the first experiment using the same treatments but they were grown for two growing periods. The main treatment difference was that 1% slowly soluble nitrogen (Kukkasipuliravinne with N-P-K: 38-0-0%; Kekkilä Oy, Finland) was added to the peat medium (initially 0.7% N) in order to ensure N availability during the longer growing time and to mimic better the actual N content (about 1.7%) in natural peatlands (Laiho, Laine 1994; Korkalainen et al. 2007). After bud formation in March, the seedlings were short-day treated for three weeks (10 h light, 14 h dark), when the temperature was kept at 12°C in the light and 6°C in the dark. The seedlings were then hardened at cool temperatures (+3 to +4°C) for four weeks and moved into low light conditions at room temperature for a couple of days.

The second growing period was then started in May in the greenhouse when more natural light was available, but it was supplemented with night-time interruption light. Seedlings were assigned to six growing blocks with one replicate from each treatment (6 × 6 = 36 in all). After bud formation, seedlings were harvested and measured for morphological attributes like in the first period (but no dry masses were determined).

### Laboratory analyses

The volumetric water-retention characteristics of ash, peat and silt samples ($n$ = 5) were measured with a pressure plate apparatus (Soilmoisture Equipment Corp., USA) at decreasing matric potentials (i.e. desorption) (Klute 1986; Heiskanen 2013). An alluvial coarse silt soil was taken for analyses to compare ash and peat with a common medium-textured mineral soil. The filled metal cylinders ($d$ = 58 mm, $h$ = 60 mm) were first saturated overnight, allowed to drain freely (to –0.3 kPa) and then exposed to successive matric potentials down to –1,500 kPa. Bulk density was determined as the ratio of dry mass (dried at 105°C) to volume at –0.3 kPa. Particle density ($D_p$) was estimated using an average density of 2.65 g·cm$^{-3}$ applied for mineral and 1.5 g·cm$^{-3}$ for organic components (Hillel 1982). Total porosity (TP) was then estimated as Eq. 1:

$$TP = \frac{\left(D_p - D_b\right)}{D_p} \quad (1)$$

where:
$D_b$ – the bulk density.

The texture of the air-dried materials was determined by dry sieving. Ash was found to be the coarsest and peat the next coarsest material in comparison with silt, while in drying peat retained the most water and silt the least (Fig. 1).

pH and EC were measured from fresh samples of peat and ash in a water suspension with laboratory meters using standard procedures (1 + 5 method, ISO 11265, ISO 10390). Press water samples were extracted from peat growing media in pots at the end of the growing experiment one day after ample watering. The subsequent extracts were measured for pH and EC, filtered, and analysed also for dissolved major and trace elements with an ICP-emission spectrometer (Thermo Fisher Scientific, UK; iCAP 6500 Duo ICP-emission spectrometer) and a FIA-analyser (Zellweger Analytics, USA; Quikchem 8000 FIA, A83200). The analyses were done according to common standards (ISO 5667-3:2013, SFS 3021:1979, SFS-EN 27888, SFS-EN ISO 11732:2005, SFS-EN ISO 13395:1997, SFS-EN ISO

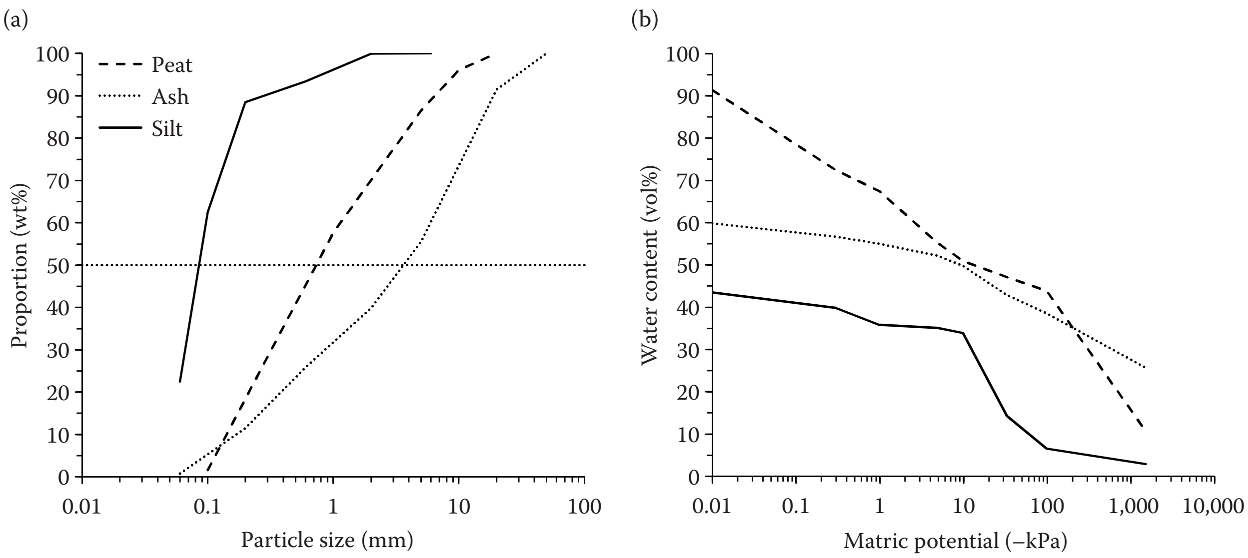


Fig. 1. Physical properties of the studied media: particle size in percentage passing sieve sizes for the fresh media ($n$ = 5), the horizontal line shows 50% proportion, note that ash granules tend to dissolve slowly when wet (a), water retention characteristics at desorption for the fresh media ($n$ = 5), leftmost values indicate calculated total porosities (b)

11905-1:1998, SFS-EN ISO 11885:2007). Concentrations of dissolved $NH_4$-N, $NO_3$-N and dissolved total N in the water extracts were determined using the FIA-analyser described above. Because our analysis of $NO_3$-N included $NO_2$-N, we estimated organic N as = N-total – $NH_4$-N – $NO_3$-N.

### Statistical analysis

The data was analysed with IBM SPSS Statistics (Version 22.0, 2016). ANOVA was used to test the effect of ash and N treatment on diameter (mm), height (cm), and root and shoot dry mass (g) of the seedlings, and hydrogen ion concentration (inverse log [pH]) and EC of peat water percolate. Logarithmic transformation (ln, except –log10 on hydrogen ion concentration) was used when necessary to better approximate normal distribution and homogeneity of variance according to Levene's test of equality of error variance. The least significance difference pairwise method was used in multiple comparisons.

Logistic regression analysis was used to test the effect of ash (0–8 cm) and nitrogen treatments (0, 1) on mortality of the seedlings. In logistic regression ash treatment was used as a continuous covariate (layer thickness, cm). The block effect was not significant as a covariate, nor was the initial seedling size, which is why they were not included in the final analyses.

In all of the applied analyses, the effects of ash and N treatments on seedling and water percolate attributes were tested in the first growing experiment. In the second growing experiment, all the pots had a similar N treatment, and thus only the effects of ash treatments were tested.

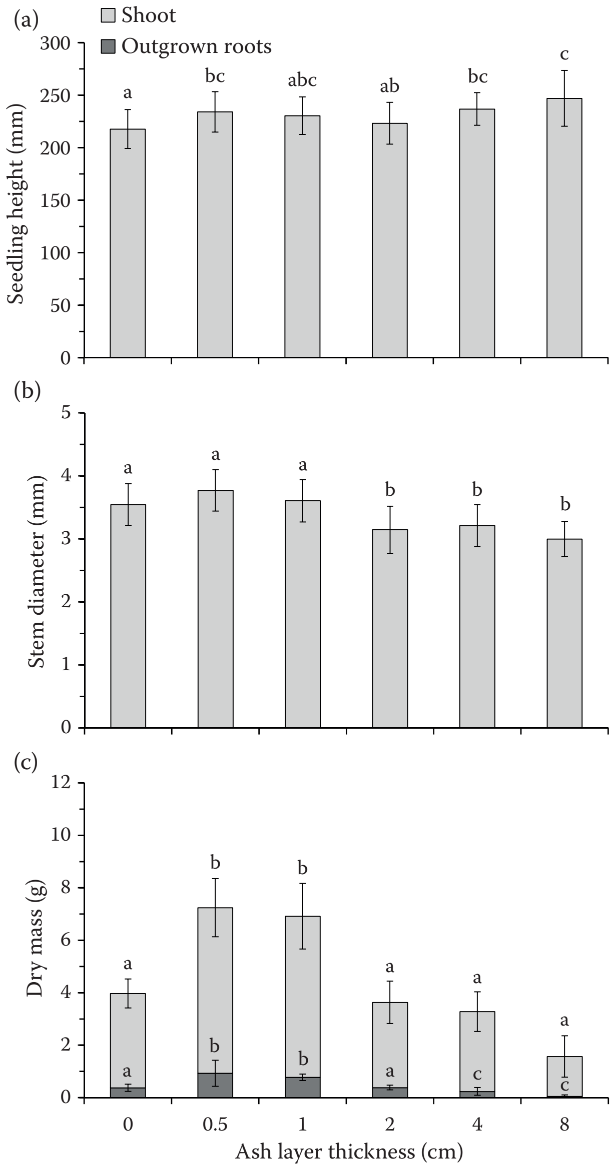


Fig. 2. Height (a), stem diameter (b), dry masses (c) of shoot and roots outgrown from the peat plug in pots at the end of the first growing period (from survived seedlings). Vertical bars indicate standard deviation ($n = 5$ for dry masses and $n = 11$ for height and diameter) and different letters significant differences between treatments ($P < 0.05$)

## RESULTS

### First growing experiment

At the end of the first growing experiment, seedling height was lowest in the control treatment. Seedling height differed between ash treatments ($P = 0.048$) but nitrogen fertilization did not affect seedling height ($P = 0.133$). Stem diameter, shoot and root dry masses as well as EC and hydrogen ion concentration of peat water percolate differed between the ash and N treatments ($P < 0.001$). Seedling masses of shoot and outgrown roots from the peat plug as well as stem diameter were highest in the ash treatment of 0.5 and 1 cm (Fig. 2). In the thickest ash treatments of 8 cm, seedling height was tallest but the biomass of seedling shoot and outgrown roots was lowest.

Seedling mortality was 60% in the treatment with the 8 cm layer of ash and 0% in the other treatments. Needles with browned tips occurred in the treatments with the ash layer of 2 to 8 cm. Also late summer shoot growth or lammas growth occurred randomly in all treatments.

The soluble nutrients in press water extracts were relatively low in the control treatment (no ash mulch) when compared with the recommended levels for seedling growing (Table 1). Especially P,

Table 1. Analysis of the peat press-water extract at the end of the first growing period ($n$ = 1 combined sample) with the recommended ranges for forest tree seedlings shown for comparison (Heiskanen et al. 1996). Analysis of fresh ash and peat growing medium in water suspension (1 + 5 method) is also given

| Attribute | Ash treatment (cm) | | | | | | Ash (1 + 5) | Peat (1 + 5) | Recommended ranges |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.5 | 1 | 2 | 4 | 8 | | | |
| Acidity (pH) | 3.81 | 4.92 | 5.19 | 4.01 | 4.1 | 4.35 | 10.61 | 4.13 | 4.3–5.5 |
| EC ($mS \cdot cm^{-1}$) | 0.38 | 3.30 | 4.84 | 9.12 | 14.2 | 22.0 | 7.68 | 0.05 | 1–2 |
| Al ($mg \cdot l^{-1}$) | 1.85 | 0.81 | 0.59 | 3.45 | 5.54 | 5.22 | 1.60 | 0.19 | < 5 |
| B ($mg \cdot l^{-1}$) | 0.064 | 4.35 | 5.82 | 7.56 | 11.2 | 9.09 | 1.68 | 0.036 | 0.1–0.5 |
| Ca ($mg \cdot l^{-1}$) | 15.9 | 161 | 199 | 287 | 436 | 586 | 11.2 | 1.4 | 20–100 |
| Cd ($mg \cdot l^{-1}$) | < 0.0007 | 0.0014 | 0.0016 | 0.0056 | 0.0089 | 0.011 | < 0.0007 | < 0.0007 | |
| Cr ($mg \cdot l^{-1}$) | 0.0022 | 0.0013 | 0.0013 | 0.002 | 0.0026 | 0.0029 | 0.15 | < 0.001 | |
| Cu ($mg \cdot l^{-1}$) | 0.0111 | 0.0037 | 0.0027 | 0.0026 | 0.0027 | 0.0029 | 0.0011 | 0.0031 | 0.1–1 |
| Fe ($mg \cdot l^{-1}$) | 1.48 | 0.19 | 0.16 | 0.20 | 0.18 | 0.13 | 0.00 | 0.16 | 1–5 |
| K ($mg \cdot l^{-1}$) | 5.5 | 407 | 704 | 1,530 | 2,570 | 4,490 | 1,810 | 2.2 | 100–200 |
| Mg ($mg \cdot l^{-1}$) | 6.7 | 36.9 | 42.8 | 66.7 | 89.6 | 91.7 | 0.1 | 0.5 | 20–500 |
| Mn ($mg \cdot l^{-1}$) | 0.26 | 1.32 | 1.51 | 2.59 | 3.38 | 3.23 | 0.00 | 0.02 | 0.2–2 |
| Na ($mg \cdot l^{-1}$) | 8.1 | 164 | 283 | 600 | 1,000 | 1,680 | 569 | 1.0 | < 50 |
| Ni ($mg \cdot l^{-1}$) | 0.003 | 0.004 | 0.003 | 0.010 | 0.015 | 0.016 | < 0.002 | < 0.002 | |
| P ($mg \cdot l^{-1}$) | 0.08 | 1.97 | 1.70 | 1.65 | 0.99 | 0.39 | 0.09 | 0.01 | 20–50 |
| Pb ($mg \cdot l^{-1}$) | < 0.005 | < 0.005 | < 0.005 | < 0.005 | < 0.005 | < 0.005 | < 0.005 | < 0.005 | |
| S ($mg \cdot l^{-1}$) | 25.5 | 259 | 359 | 683 | 1,230 | 1,970 | 538 | 1.4 | 10–50 |
| Si ($mg \cdot l^{-1}$) | 15.8 | 39.1 | 43.8 | 34.9 | 35.1 | 30.5 | 10.1 | 1.6 | 5–50 |
| Zn ($mg \cdot l^{-1}$) | 0.12 | 0.19 | 0.23 | 0.47 | 0.69 | 0.75 | < 0.005 | 0.04 | 0.2–2 |
| $NH_4$ ($mg \cdot l^{-1}$) | 14.2 | 11.5 | 13.3 | 28.6 | 36.7 | 44.5 | 0.13 | 0.11 | 0–200 |
| $NO_2$ + $NO_3$ ($mg \cdot l^{-1}$) | 0.29 | 8.04 | 11.5 | 5.75 | 7.53 | 6.47 | 1.39 | < 0.01 | 0–200 |
| $N_{tot}$ ($mg \cdot l^{-1}$) | 19.3 | 22.5 | 27.5 | 35.9 | 48.5 | 51.4 | 2.09 | 1.41 | 100–200 |
| $N_{org}$ ($mg \cdot l^{-1}$) | 4.81 | 2.96 | 2.7 | 1.55 | 4.27 | 0.43 | 0.57 | 1.30 | |

EC – electrical conductivity, $N_{tot}$ – total N, $N_{org}$ – organic N

but also K and N concentrations were low in the control treatment. In ash treatments, nutrients were overall on supra-optimal levels, but N and P were suboptimal.

### Second growing experiment

Seedling mortality was zero in the control treatment, but increased with the level of the ash thickness (Table 2, Fig. 3). Mortality was 1/5 to 1/3 with a mulch thickness of 0.5 to 1 cm and over 4/5 with a mulch thickness of 2 cm or higher. The effect of ash treatment was significant ($P$ = 0.007). Survived seedlings were too few to be analysed for seedling attributes after the second growing experiment, but EC and hydrogen ion concentration differed between the ash treatments ($P < 0.005$). EC was relatively high (3.0 $mS \cdot cm^{-1}$) already in the control treatment (Table 2).

Table 2. Mean seedling attributes (diameter, height and growth of survived seedlings) and pH and electrical conductivity (EC) of peat water percolate in the ash treatments (ash layer in cm) after the second seedling growing period. Survived seedlings were too few for statistical analysis of seedling attributes (initial $n$ = 6)

| Treatment (cm) | Mortality (%) | Diameter (mm) | Height (mm) | Shoot growth (mm) | EC ($mS \cdot cm^{-1}$) | pH |
|---|---|---|---|---|---|---|
| 0 | 0.0 | 4.56 | 204 | 105 | 3.0 | 3.6 |
| 0.5 | 16.7 | 4.16 | 222 | 91 | 6.2 | 3.5 |
| 1 | 33.3 | 4.32 | 235 | 109 | 7.2 | 3.6 |
| 2 | 83.3 | 3.40 | 195 | 105 | 8.5 | 3.5 |
| 4 | 83.3 | 3.86 | 255 | 110 | 13.5 | 3.6 |
| 8 | 100.0 | – | – | – | 19.4 | 3.6 |

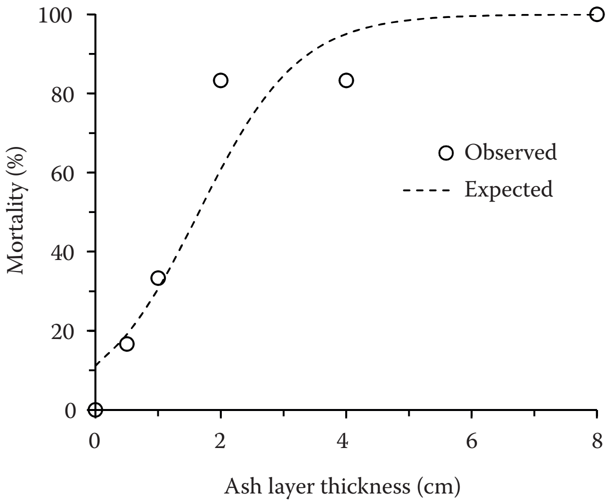


Fig. 3. Seedling mortality after the second growing period according to the ash layer thickness. The expected curve is from the binary logistic regression ($P$ = 0.007)

## DISCUSSION

In the present study, Scots pine seedlings grew well in ash mulch thicknesses from 0 to 4 cm during the first growing period. An ash thickness of 8 cm yielded slender seedlings with low seedling biomass and elevated mortality (60%). During the second growing period, elevated seedling mortality was found even in the thinnest ash mulch treatment (17%). This may be due to excessive ash application when too high nutrient levels and/or biased nutrient relations may have caused imbalances and even toxicity (Rikala, Huurianainen 1990; Heiskanen et al. 1996; Huurinainen 1999). Furthermore, inadequate formation of cold sum and poor hardening-off before and during the cool storage can contribute to elevated mortality after the first growing season (Repo et al. 2000; Hänninen et al. 2013). Strong growth, long needles and lammas growth observed in the first growing period may have suggested a need for a longer hardening-off phase than that which was actually used.

The soluble nutrients in press water extracts taken after the first growing period were high compared with the control treatment (natural peat without ash mulch). In the control, the nutrient levels were suboptimal in comparison with the recommended levels for nursery seedling growth (Heiskanen et al. 1996). Especially the concentrations of main nutrients N, P and K were low. N and P levels were also low in all the ash treatments. This is likely because of the negligible N content of ash and the poor solubility of P (see below). Also ample watering during growing may have diluted nutrients from the peat medium. Furthermore, water extracts were filtered with a 0.45 μm membrane filter before nutrient analyses, which may have affected the commensurability of nutrients with respect to the recommendation. Also other nutrient levels and their relations may have affected seedling growth and survival (Rikala, Huurinainen 1990; Heiskanen et al. 1996; Huurinainen 1999).

All the used ash treatments showed almost an optimal pH range (3.8–5.2) for seedling growth (Rikala, Jozefek 1990). The effect of ash on pH in press water extracts was relatively small probably due to the high buffering capacity of peat (McNevin, Barford 2001).

Wood-based ash fertilization is usually applied in quantities of about 5 t·ha$^{-1}$ in peatland forests (Moilanen et al. 2002, 2005, 2012; Ahola 2014), which corresponds to ash mulching of planting spots with a 0.5 cm thick layer of ash (about 2,000 spots per hectare each 0.4 m$^2$ in area equals 5.6 t·ha$^{-1}$). These amounts can increase soil pH, EC and nutrient concentrations, but these changes are often relatively small at least in the short term (Nieminen et al. 2005; Maljanen et al. 2014; Saarsalmi et al. 2014). According to these studies, easily available P is scarce in wood ash, as the main part of P readily forms compounds with Ca, Fe and Al. P can also adhere to organic compounds. The commonly applied granulated ash is also more slowly soluble than powdered ash. On the other hand, B, K and Na of ash are usually easily soluble and may leach away. In general, the wood ash application has shown no or minor detrimental long-term impact on the water environment (Piirainen et al. 2013), while the site preparation has shown unfavourable impacts on the runoff water quality from the forest regeneration sites on peatlands (Nieminen 2003; Nieminen et al. 2005).

The most common soil preparation method used with planting is excavator mounding, for which the average cost was 366 EUR·ha$^{-1}$ in Finland in 2013 (Finnish Forest Research Institute 2014). Spreading of granulated ash as a fertilizer with a forwarder-based machine on the other hand costs about 220–380 EUR·ha$^{-1}$, including material cost (Ahola 2014). Mulching of planting spots might be equally or somewhat more costly.

Substituting or supplementing the soil preparation with ash-based mulches could act as a novel means to increase silvicultural productivity and also to diminish environmental drawbacks of reforestation with planting. Even though ash would be suitable only as a supplement for other soil preparation methods, it could still be beneficial because ash has very long-term fertilization effects on growth on forest sites suffering from nutrient shortages other than N deficiency. Ash-based mulches could also decrease the germination of competing vegetation and reduce costs associated with release treatments. Release treatments constitute a large proportion of stand establishment costs, typically ranging from 400 to 900 EUR·$ha^{-1}$ (Uotila et al. 2010).

In conclusion, this preliminary greenhouse study suggested that ash mulch around seedlings in quantities of less than 0.5 cm per planting spot (< 3 kg per spot) is not detrimental to planted Scots pine seedlings. However, the greenhouse conditions in this study might overestimate this critical ash dosage because of higher mineralization at higher temperatures and limited nutrient dilution in confined pots in comparison with natural outdoor conditions on forest regeneration sites. The results provide foundation for further field research on the longer-term impacts of wood ash mulch on planted seedlings on boreal forest upland sites and peatlands and on feasibility tests of ash mulching as a supplement to or substitute for the soil preparation with seedling planting.

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Received for publication May 31, 2017
Accepted after corrections November 9, 2017