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Effect of wood ash on the biomass production and nutrient status of young silver birch (*Betula pendula* Roth) trees on cutaway peatlands in Estonia

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ABSTRACT

The objective of the study was to quantify the effect of wood ash on the growth and nutrition of silver birch (*Betula pendula* Roth) on cutaway peatlands in Estonia. Two experimental areas were established: the Ulila experimental area (South Estonia) with treatments of 5 and 10 t ha^{-1} wood ash and control (unfertilised plot) in 2009 and the Puhatu experimental area (Northeast Estonia) with treatments of 10 and 15 t ha^{-1} wood ash and control in 2011. The best results were achieved with the wood ash dose of 10 t ha^{-1} on the Ulila area and with 15 t ha^{-1} on the Puhatu area, which means that the largest amounts of wood ash applied were the most favourable for the growth of young birches. Fertilisation with wood ash improved the balance of nutrients on the Ulila and Puhatu experimental area: the concentration of extractable P, K, Ca and Mg in the ash-treated peat had significantly increased. Already after the first growing season the annual height increment of trees on the ash-fertilised plots was greater (0.5–0.6 m), than control (3–7 cm) on both experimental areas, during the next two years more than 1 m on the Ulila ash-treated experimental area. The mean root collar diameter of birches on the plot treated with 10 t ha^{-1} ash was 3.3 cm on the Ulila experimental area and 1.9 cm on the Puhatu experimental area. In the second year after fertilisation the mean tree biomass was 167.2 g on the treated with 10 t ha^{-1} plot while on the control plot the mean tree biomass was only 1.4 g on the Ulila area; in the fourth year the respective biomasses were 961.0 g and 6.3 g on the Ulila experimental area. On the Puhatu experimental area the mean tree biomass was 216.9 g on the plot treated with 15 t ha^{-1} and 9.6 g on the control plot in the second year. In the second year the mean annual biomass increment on the treated with 10 t ha^{-1} at Ulila was 136 g year^{-1}, and almost the same results were obtained on the Puhatu experimental area with 15 t ha^{-1} wood ash treatment. On the Ulila experimental area the root mass ratio was higher on the control than on the ash-fertilised plots, but on the Puhatu experimental area the root mass ratio did not statistically differ between the treatments. On the plots treated with higher amount of wood ash a significant increase in the concentration of elements dominating in wood ash (P, K, Ca) was observed in assimilating organs.

1. Introduction

Peatlands cover an estimated area of 400 million hectares in some 180 countries, equivalent to 3% of the Earth's land surface (Clarke and Rieley, 2010). Peatlands occur on all continents, from the tropical to boreal and Arctic zones from sea level to high alpine conditions (Joosten and Clarke, 2002). Since 1800 the global area of peatlands has been reduced significantly (according to estimates, by at least 10–20%) by climate change and human activities, particularly by drainage for agriculture and forestry. Nearly 150 000 km^2 of the world's peatlands have been drained for commercial forestry. The percentage of mire areas of country area is high in Finland, Sweden and Estonia being 33.5%, 23.1% and 22.5% of land area respectively (Leupold, 2004). In Estonia peat harvesting with milling technology, which enables extraction of peat in large amounts and on wide areas, began in 1938 (Luberg, 1995). Today Estonia has already 9371 ha of peatland damaged by harvesting peat by milling (Ramst and Orru, 2009), and this area is growing from year to year.

When peat harvesting ends the areas are free from vegetation, and in many cases the bottom peat is well humified and has high nitrogen content, but low contents of mineral nutrients (e.g. P, K, Ca, Mg). Moreover, the conditions prevailing on cutaway peatlands are unsuitable for the development of new vegetation: the microclimate is characterised by late and early frosts and extreme surface temperatures in summer, the water regime is unfavourable and the

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surface is eroded away by wind and water. Therefore natural revegetation of these areas is complicated and may take several decades (Campbell et al., 2002; Groeneveld and Rochefort, 2002; Hytönen and Aro, 2012; Hytönen and Saarsalmi, 2009; Kaunisto and Aro, 1996; Lavoie et al., 2005; Pikk, 2001). As the vegetation free bottom peat carbon dioxide is no longer bound in these areas while in the course of the mineralisation of peat large amounts of CO_2 are emitted into the atmosphere. For this reason cutaway peatlands are considered to be one of the sources of greenhouse gases (Sundh et al., 2000; Tuittila et al., 1999). In Estonia the emission of CO_2 from drained peatlands amounts to 10 million tonnes annually (from 10 000 ha cutaway peatlands about 200 000 tonnes is emitted annually), being here one of the main sources of greenhouse gases (Ilomets, 2001). Therefore rapid re-vegetation of these areas is of vital importance, which helps to reduce the CO_2 emission.

Investigations made in several countries suggest that one of the most promising and cost effective ways of using cutaway and cutover peatlands is their afforestation (Huotari et al., 2008; Kaunisto and Aro, 1996; McNally and Kildare, 1995; Pikk, 2001; Selin, 1995; Valk, 1981, 1992). Productivity of the forests in cutaway and cutover peatlands depends on the fertility of the site, peat depth and type, drainage intensity and tree species and age (Paavilainen and Päivänen, 1995). Afforestation of cutaway peatlands also restores CO_2 binding and accumulation of carbon in woody plants (Huotari et al., 2009).

Since cutaway peat is very poor in mineral nutrients, deficiencies of phosphorus and potassium are considered to be the most limiting factors to plant growth (Paavilainen and Päivänen, 1995). Thus it is necessary to add nutrients to the substrate when afforesting cutaway peatlands. One of the options in compensating for the lack of nutrients and balancing their content in abandoned peat milling fields is to mix wood ash into the peat (Hånell and Magnusson, 2005; Hytönen and Aro, 2012; Hytönen and Saarsalmi, 2009; Kikamägi and Ots, 2010; Silfverberg and Huikari, 1985). Using ashes that are rich in potassium (e.g. wood ash) as fertilisers in afforestation of cutaway peatlands would allow influencing important functions of trees: K content improves the resistance of trees to low temperatures and draught, raises water uptake by roots and intensifies lignification of cell walls by activating the synthesis of remote precursors of lignin (Miidla, 1984).

Wood ash contains all nutrients that plants need except for nitrogen, which volatilises in the course of burning (Karltun et al., 2008). Someshwar (1996) states that wood ashes tend to be higher in Ca, K and Mn but lower in Al, As, Cr, Fe, Hg and Se than coal ashes and levels of dioxins, furans and polyaromatic hydrocarbons are strongly dependent on the chemical composition of the fuel source (e.g. wood type, species, part of tree, combustion temperature, etc.). In addition to essential macro- and microelements wood ash also contains low to moderate levels of trace elements and heavy metals such as B, Cd and Zn. Treatment of soils with lime fertilisers (e.g. wood ash, which act as liming agent also) improves the availability of P compounds to plants and also the effect of several N fertilisers will increase (Hallik, 1947; Raid, 1979). Using wood ash as a fertiliser for woody plants in cutaway peatlands helps to mitigate the problem of waste ashes, which is especially important considering that with the increasing use of biofuels for energy production also the amounts of waste ash will increase. Today in Estonia the amount of wood ash produced as energy generation waste is about 20 000 tonnes a year (Pärn et al., 2010). Therefore, application of wood ash, which is rich in nutrients as a fertiliser of cutaway peatlands might be one of its recycling options.

In abandoned cutaway peatlands, birch has been found to be a successful pioneer species (Päivanen, 1998; Raid, 1981). Therefore birch should also be an excellent species for afforestation of cutaway peatlands, which has been proved by numerous investigations conducted in Finland and Ireland (Huotari et al., 2008; Hytönen and Aro, 2012; Hytönen and Kaunisto, 1999; Hytönen and Saarsalmi, 2009; Kaunisto and Aro, 1996; Renou et al., 2007; Renou-Wilson et al., 2010). Birch has many ecologically beneficial properties: it raises soil fertility and soil saturation with bases, increases the content of humus, nitrogen and other major nutrients and improves physical properties of soil (Raid, 1981). Fertilisation does not affect the production of mature birch stands, but N fertilisers promote the growth of young birch stands on mineral soils and treatment with wood ash and PK and NPK fertilisers increases significantly the production of young birch stands on peat soils (Hytönen and Kaunisto, 1999; Hytönen and Saarsalmi, 2009). Hytönen and Aro (2012) found that with longer rotations native birch, both silver birch (*Betula pendula* Roth) and downy birch (*B. pubescens* Ehrh.), could be attractive for biomass production: birch stands growth has increased on well-drained peatlands fertilised with wood ash.

The aim of the study was to investigate the effect of fertilisation with different amounts of wood ash (5, 10 and 15 $t\,ha^{-1}$) on the growth of young silver birch seedlings on the Ulila (South Estonia) and Puhatu (Northeast Estonia) cutaway peatlands in the first years after treating with ash. In particular, this research focuses on the influence of wood ash on the survival, above- and belowground biomass, biomass production, annual height increment, root collar diameter, and nutrition of silver birch (*Betula pendula* Roth) seedlings on cutaway peatlands in Estonia.

We hypothesised that use of wood ash in afforestation of cutover peatlands helps balance the content of nutrients in peat substrate, which improves survival of cultivated seedlings and increases significantly bioproduction. Thus the biodiversity of these areas will improve and production wastes (wood ash) containing nutrients (P, K, etc.) necessary for plant growth will be recycled.

2. Materials and methods

2.1. Study site and treatments

The experimental area of Ulila is located on a cutaway peat-milling area (58°22′ N, 26°26′ E) 1 km north-west of the settlement of Ulila in Tartu County (South Estonia). The average thickness of Ulila cutaway peatland of the poorly decomposed peat layer is 0.9 m and the well-decomposed peat is 2.4 m thick (Ramst et al., 2006), the remaining peat thickness reach in some places to 3.3 m. The peat harvesting in Ulila was completed in about 2003. The plants growing on the area include *Eriophorum* spp., whose coverage is 5–10%, and *Calluna vulgaris*, *Ledum palustre*, *Andromeda polifolia*, *Vaccinium vitis-idaea* and *Empetrum nigrum*, which grow by ditches, in lower places patches of *Eriophorum angustifolium* are found. The moss layer is mainly made up of *Polytrichum strictum*. In ditches *Carex rostrata* and *Comarum palustre* are growing. The total vegetation coverage is 14%. The amount of precipitation was 805 mm in 2009, 838 mm in 2010, 511.3 mm in 2011 and 771.5 mm in 2012. The mean annual temperature on the Ulila study area was 6 °C in 2009, 5.1 °C in 2010, 6.9 °C in 2011 and 5.3 °C in 2012 (www.emhi.ee, accessed 02.04.2013).

The experimental area of Puhatu is located on a cutaway peat-milling area in Ida-Viru County (Northeast Estonia) (59°19′ N, 27°35′ E). The average thickness of the well-decomposed peat is 0.9 m (Ramst et al., 2006). The peat harvesting in Puhatu was completed in about 2001. The number of trees on the plots is small; the coverage of *Eriophorum vaginatum* is on average 10%; in lower places *Phragmites australis*, *Eriophorum angustifolium*, *Carex* spp. and *Equisetum fluviatile* are growing. Ditches are half filled with peat and have rich growth of *Eriophorum vaginatum*,