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Effects of wood chip ash fertilization on soil chemistry in a Norway spruce plantation on a nutrient-poor soil

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ABSTRACT

Harvest of forest biomass for energy production may lead to export of nutrients from the forest. Recirculation of nutrients from wood chip combustion by ash spreading in forests has been proposed as a means for counteracting the nutrient export. This study was carried out to examine the effect of wood chip ash application on soil chemistry in a 44-year-old Norway spruce (*Picea abies*) plantation on a nutrient-poor soil in Denmark and to investigate the effect of applying different ash types and doses. Soil samples were collected and analyzed 2.5 years (3 growing seasons) after ash application. This study shows that, regardless of ash formulation, preparation or dose, application of wood ash to forest soil has a liming effect in the O-horizon manifested as an increase in CEC_e, BS and pH. This effect was not seen in the mineral soil within the time frame of this study. At the same time, an increase in Cd was found in the O-horizon, corresponding to the amount added in the ashes. Generally, no other increase in soil contents of the heavy metals was seen. Hardening of the wood ash did not decrease the chemical impact on the soil chemistry as compared to non-treated ash whereas an increase in ash application dose increases the liming effect.

1. Introduction

Sustainable forest management implies a balanced ecosystem in terms of nutrient input and output to insure the productivity of the forest ecosystem over the long term. Intensive harvesting of forest biomass, such as utilization of whole-tree biomass, logging residues and roots for energy production, intensifies the removal of nutrients from the forest ecosystem compared to the traditional stem harvesting (Blanco et al., 2005; Dyck et al., 1994; Olsson et al., 1996; Møller, 2000; Stupak, 2007).

Decreased tree growth following intensified biomass harvesting has been described in field experiment studies (Egnell et al., 1998; Egnell and Leijon, 1997; Egnell and Valinger, 2003; Helmisaari et al., 2011; Jacobsen et al., 2000; Swedish Energy Agency, 2006; Thiffault et al., 2011). However, the findings are often contradictory or the decrease in tree growth is not significant. Fertilization has been suggested for counteracting the decreased tree growth (Egnell and Leijon, 1997; Egnell et al., 1998). Recirculation of nutrients, by spreading the ashes from combusted wood chips, has been proposed as a method for fertilization (Egnell et al., 1998; Ingerslev et al., 2001; Karltun et al., 2008; Swedish Energy Agency, 2006).

Wood chip ashes consist mainly of metal oxides, hydroxides and carbonates, salts and soil minerals, and may often affect the soil acidity similar to application of limestone (Egnell et al., 1998; Karltun et al., 2008). Hence, application of wood chip ash has also been seen as a means of counteracting soil acidification caused by deposition of air pollution compounds (Örlander and Wickström, 2001; Ingerslev et al., 2001). In Denmark, most of the currently produced wood chip ashes are deposited on waste disposal sites for approximately 110 € pr. ton ash (Danish Energy Agency, 2011). Hence, application of wood chip ashes in the forest may have positive effects in the forest ecosystem and at the same time solve a waste deposit problem.

Several studies on how application of wood chip ash affects the soil and soil solution chemistry in forest ecosystems have been carried out in the Nordic countries, especially in Sweden and Finland (Arvidsson et al., 2002; Arvidsson and Lundkvist, 2003; Egnell et al., 1998; Egnell, 2011; Eriksson, 1998; Eriksson et al., 1998; Högbom et al., 2001; Jacobsen, 2003; Karltun et al., 2008; Moilanen et al., 2005; Pitman, 2006; Ring et al., 1998, 1999,

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2006; Saarsalmi et al., 2001, 2006; Silfverberg, 1998; Westling et al., 2004). Even though a notable number of these studies have addressed ash fertilization on mineral soils, knowledge on how ash application affects the nutrient-poor forest ecosystems in western Denmark is lacking. Only one experiment regarding ash application in a Danish forest has been carried out previously (Ingerslev et al., 2008).

As the wood chip ash contains reactive oxides and easily soluble salts (Ohlsson, 2000) there is a risk that application of ash can cause negative effects to the vegetation such as damage to plant tissue caused by the rapid increase in pH (Jacobsen and Gustafsson, 2001; Steenari and Lindqvist, 1997). Hardening of the ash has been thought to counteract these negative effects (Ohlsson, 2000; Steenari and Lindqvist, 1997) and Egnell et al. (1998) reported that hardening leads to lower pH increase in the O-horizon.

Based on the hypothesis that ash application only affects the soil chemistry in the O-horizon and upper 10 cm of the mineral soil within the three first growing seasons after application, the aim of the study is to investigate the effects of ash application on soil chemistry in a Norway spruce plantation in central Jutland, Denmark. Additionally, the study aims at investigating how the effect on the soil chemistry differs when applying different ash types and in different doses. Special emphasis was given to investigating the effect on the heavy metals in the soil.

2. Materials and methods

2.1. Site description

The research site is located in a 44-year-old Norway spruce plantation at Søhøjlandet State Forest District in central Jutland, Denmark (56°10′14″N. latitude; 09°37′34″E. longitude, datum: WGS 84), 90 km from the North Sea and 60 km from Kattegat. The trees are planted in rows and have a stand density of 1430 trees pr. ha. The stand is located 38 m above sea level. The topography is flat, originally a heath plain covered by mixed heather and grass that was extensively grassed, and the parent material consists of glacio-fluvial sand. In 1963, the area was deep ploughed to a depth of 60–75 cm prior to planting. Hence, the soil consists of a systematically disturbed podzol with a distance between the furrows of approximately 70 cm. The original podzol profile is facing upside down in the furrows. The initiation of a new podzol profile can be recognised by the development of A, E and Bh horizons within the upper 3–5 cm of the mineral soil. An organic layer (mor humus) of 6 cm covers the mineral soil. The soil is nutrient-poor compared to the majority of Scandinavian forest soils, and consists mainly of coarse well drained sand with low clay and silt content (Table 1). The mean annual precipitation is 780 mm. Annual mean temperature is 7.5 °C with a mean January temperature of −0.2 °C and a mean July temperature of 15.4 °C.

2.2. Wood ash application

The study was established in April 2007 with four different ash types: fresh bottom ash (FrBo), fresh fly ash (FrFl), hardened fly ash (HF) and pelletized fly ash (PeFl). The utilized ash came from Ebeltoft district heating plant (DH). Ebeltoft DH has two individual wood chip fired combustion systems. Ash from the smallest boiler (maximal nominal production of 5.0 MW) was utilized. A more detailed description of this combustion system including the mass and element flux for this boiler was studied by Ingerslev et al. (2011). All utilized ash originated from burning of pure wood chips with no addition of fossil or other fuels. The wood chips came from whole tree harvesting of spruce and pine in vicinity of Ebeltoft DH.

The FrBo and FrFl ashes were collected directly from the ash containers at Ebeltoft DH one week before spreading. The containers were equipped with a water sprinkling system that continuously added water to the ash. The HF ash was produced in August 2006 and water was added to the ash to obtain a water content above 65% (dry weight at 55 °C). The ash and water were thoroughly mixed with shovels and placed outdoor under a roof with free air passage between the ash heap and the roof. The ash heap was thoroughly mixed with shovels twice between August 2006 and April 2007. The PeFl ash was produced in March 2007 from fly ash that had never received water. Pilot experiments with ash pelletizing had revealed that it was difficult to produce pellets with a sufficient dimensional stability due to the relatively high content of unburned charcoal particles. However, a notable amount of these particles was easily removed by sieving through a 1.4 mm sieve, and the sieved fly ash could be pelletized. After sieving, the water content was adjusted to 20% (dry weight at 55 °C) and the pellets were produced by a circular matrix pellet mill from Sprout-Matador (pellet output diameter = 5 mm, matrix ring thickness = 50 mm and conic: P27). Samples of all four ash types were collected at the time of spreading for chemical analysis and were dried to 55 °C and milled in a Teflon coated mill.

The study includes five different treatment plots and an untreated control plot, all randomly repeated in three blocks. The five treatments are: 3 ton ha^{-1} (dry weight, 55 °C) of FrBo, FrFl, HF30 and PeFl respectively, and one treatment with 4.5 ton ha^{-1} (dry weight, 55 °C) of HF45. Each plot consists of an ash treated plot and a smaller examined net-plot where edge and neighbouring treatment effects are assumed insignificant. The area of each plot is 15×16 m (240 m^2) and the net-plots are 13×15 m (195 m^2). The plots contain on average 43 trees. The ashes were applied by hand in April 2007.

2.3. Soil sampling

Soil samples were collected three growing seasons (2.5 years) after ash application in November 2009. The soil samples were collected from three randomly chosen sampling areas in each plot. In each sampling area one O-horizon sample was sampled quantitatively in sampling frame squares of 25×25 cm. Living mosses and lichens were included in the sample when present. The samples were dried at 55 °C till constant weight (21 days) and coarsely ground to a particle size less than 2 mm. The samples were pooled for each plot and a subsample was ground to powder before chemical analysis. The mineral soil was sampled in each of the three sampling areas by three soil core samples down to 90 cm depth. All nine soil cores from one plot were separated in three parts in the depth intervals: 0–10, 10–75 and 75–90 cm and pooled for each depth. The soil samples were dried at 55 °C, sieved (2 mm)

Table 1
Soil texture, mean density and area weight of the O-horizon and the mineral soil layers.

Depth	Humus (–)	Clay (–)	Silt (–)	Fine sand (wt.%)	Coarse sand (–)	Stones (–)	Mean density (kg m^{-3})	Area weight (t ha^{-1})
O-hori.							117.3	70.38
0–10	0.1	1.4	0.3	5.6	91.6	1	1440	1440
10–75	1.1	0.4	0.5	5.8	91.2	1	1440	9370
75–90	0	1	0	12.8	85.2	1	1470	2210