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Wood ash in boreal, low-productive pine stands on upland and peatland sites: Long-term effects on stand growth and soil properties

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ABSTRACT

The effect of wood ash on growth of Scots pine was studied in 64- to 75-year-old stands on three upland sites (Exps. 402, 407 and 408) for 20 years and in a 30-year-old Scots pine stand on an oligotrophic peatland site (Exp. 251) for 25 years. In Experiments 407 and 251 the responses of soil chemical properties and soil microbiological processes related to C and N cycling were also studied. The upland experiments included a control and a treatment with 3 Mg ha^{-1} of wood ash. In Exp. 407, 120 kg N ha^{-1} was applied together with ash; this experiment also included a treatment with N alone. The peatland experiment included a control and a treatment with 4.8 Mg ha^{-1} of wood ash. All experiments had 3 replications. Wood ash significantly decreased soil acidity on all sites. On the upland site, after 20 years, the concentration of K_2SO_4-extractable DOC and the rates of C mineralization (CO_2–C production) and net N mineralization were all higher in the Ash + N treatment than in the control or N treatments. However, the treatments did not significantly affect the amounts of C or N in the microbial biomass or the concentration of NH_4–N. On the peatland site, after 27 years, ash stimulated C mineralization and cellulose decomposition, but microbial biomass C or N, net N mineralization or the concentration of N were not affected significantly. On both the upland and peatland site, net nitrification was very low in all treatments. In Exp. 408, the volume growth in the control and Ash treatment was during the 20-year study period 60 and 64 m^3 ha^{-1}, respectively, and in Exp. 402 108 and 120 m^3 ha^{-1}, respectively, the latter difference being significant. In Exp. 407, the volume growth in the Ash + N treatment was during the 20-year study period significantly higher (92 m^3 ha^{-1}) than in the N and control treatments (76 and 73 m^3 ha^{-1}, respectively). On the peatland site during the 25-year study period the growth was 145 and 169 m^3 ha^{-1}, in the control and Ash treatments, respectively. In conclusion, the long-term positive response of stem growth to wood ash on peatlands and N fertilized upland sites can be partly explained by changes in soil nutrient status and by microbial processes related to C and N cycling.

1. Introduction

In the Nordic countries, forest biomass is increasingly being used as a source of energy in order to reach targets for reductions of CO_2 emissions set by the European Union. In Finland in 2012, the annual domestic use of forest chips originating from harvesting residues and stumps was 8.3 million m^3; and the proportion of all wood-based fuels in the total consumption of energy was 24% (Ylitalo, 2013). The National Climate and Energy Strategy indicates that annual production of forest chips in Finland is to be increased to 13.5 million m^3 by the year 2020 (Ministry of Employment and the Economy, 2010). Consumption of primary biomass for energy production is generating increasing quantities of wood ash. In Finland, the total amount of wood ash produced annually by the forest industry and heating plants is estimated to be 200,000–300,000 Mg.

Recycling wood ash back into the forest is one possible way to close the nutrient cycle and to counteract increased soil acidity (Karltun et al., 2008). Wood ash contains all the major mineral nutrients in plants except for N and when returned to the soil has a liming effect. A decrease in soil acidity and an increase in base saturation following the application of wood ash on both upland and peatland soils have been widely reported (Khanna et al., 1994; Kahl et al., 1996; Saarsalmi et al., 2001, 2012; Ludwig et al., 2002; Moilanen et al., 2002, 2013; Brunner et al., 2004; Huotari, 2011). The effect of wood ash on acidity of the organic layer can be of long duration (Saarsalmi et al., 2001, 2012; Moilanen et al., 2002).

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On upland sites the availability of N is generally a limiting factor in biomass production (Viro, 1967; Kukkola and Saramäki, 1983; Tamm, 1991). Although wood ash does not contain N, it is thought, that due to its soil-ameliorating effect, on upland soils wood ash may also have a long-term positive impact on volume growth. So far, studies carried out in middle-aged and older coniferous stands within the boreal zone have not shown evidence of a growth response caused by wood ash during a short study period (⩽13 years) (Sikström, 1992; Jacobson, 2003; Saarsalmi et al., 2004, 2005; Moilanen et al., 2013). However, a positive growth response to wood ash has sometimes been reported in young stands on infertile upland sites (Tamminen, 1998; Perkiömäki et al., 2004; Saarsalmi and Levula, 2007; Mandre et al., 2006). When wood ash was given together with N, the positive growth response to Ash + N lasted longer than addition of N alone (Saarsalmi et al., 2012). However, this has not always been the case (Saarsalmi et al., 2010).

Most studies of ash on peaty soils have been carried out on mesotrophic and N-rich site types where the mineral nutrient deficiencies and imbalances in nutrient status of trees are most severe. On such peaty soils, long-lasting – even four or five decades – positive effects of wood ash on growth and nutrient status of conifers have been reported in several studies (e.g., Silverberg and Huikari, 1985; Moilanen et al., 2002, 2005). In oligotrophic peatlands – where nitrogen availability to trees is low – the effects of wood ash on soil or on tree stand have remained moderate (Silverberg and Huikari, 1985; Moilanen et al., 2013).

Wood ash has been shown to stimulate litter and cellulose decomposition and carbon mineralization in forest soils over the long term (Moilanen et al., 2002, 2012; Perkiömäki and Fritze, 2002, 2005; Perkiömäki et al., 2004; Rosenberg et al., 2010). The positive effect of wood ash has also been observed to counteract the negative effects of N fertilization on the amount of C and N in the microbial biomass and on C mineralization (Saarsalmi et al., 2010, 2012). Increase in microbial activities related to C cycling after application of wood ash has been explained by both direct and indirect effects of the increase in soil pH (Jokinen et al., 2006). Much less is known about the long-term effects of ash on N cycling. Some results have indicated increased net N mineralization (Högbom et al., 2001), but lowered mineral N concentrations have also been reported (Eriksson, 1996). Wood ash and N fertilization given together increased net N mineralization in two Scots pine stands over the long term (Saarsalmi et al., 2010, 2012).

Saarsalmi et al. (2004) investigated the response of Scots pine growth and the chemical properties of soil to wood ash application on three N-poor upland sites 10 years after application; on one of the sites, wood ash was applied together with N fertilizer. They found no essential difference in growth response between the control and the wood-ash-alone treatments. If wood ash was added together with N, volume growth still tended to be higher than in the control during the second 5-year period when the response to the N-alone treatment had ceased. In the present study, we report results of the same three stands after 20 years. Studies comparing the stand responses between N-poor upland and peatland soils are almost lacking, except the study by Moilanen et al. (2013). Therefore, for comparison, the response of Scots pine growth to wood ash application on an oligotrophic peatland site after 25/27 years is also reported. Our aim was also to determine whether changes in soil chemical properties and microbiological processes related to C and N cycling could explain the growth response.

Our hypothesis was that addition of wood ash on peatlands and addition of wood ash together with N on upland soil sites increase stem growth over the long term. We also hypothesized that changes in soil nutrient status and microbial processes related to C and N cycling explain the growth responses.

2. Materials and methods

2.1. Sites and treatments

2.1.1. Upland sites

Field experiments were established in three naturally regenerated, thinned 64- to 75-year-old Scots pine (*Pinus sylvestris* L.) stands on dry upland sites (Table 1 and Fig. 1). The organic layer was mor, with a thickness of 1–3 cm. The mineral soil texture was sorted fine sand. The sites are rather infertile, with C/N ratios of 44, 47 and 49 in Experiments 402, 407 and 408, respectively (Saarsalmi et al., 2004). According to the ammonium acetate-extractable nutrient concentrations at the time of the experiments were established, the organic layer in Exp. 408 was clearly the most nutrient-poor. It was also the most acidic. At the time the experiments were established, the needle N concentrations were 12.5, 11.3 and 10.8 g kg^{-1} in Experiments 402, 407 and 408, respectively (Saarsalmi et al., 2004). The average stem volume was 91, 47 and 54 m^3 ha^{-1} in Experiments 402, 407 and 408, respectively. For more details of stand characteristics, soil chemical properties and needle nutrient concentrations, see Saarsalmi et al. (2004).

In each experiment, a randomized block design was applied and the treatments were replicated three times on 0.09 ha plots. The amount of 3 Mg ha^{-1} of loose wood ash (Ca 209–232, K 18–40, Mg 14–36 and P 7–15 g kg^{-1} depending on the experiment, see Saarsalmi et al., 2004), originating mainly from chip-wood fuel used in a thermal power plant, was applied manually in May 1991 in Experiments 402 and 407, and in May 1992 in Exp. 408. In Exp. 407, 120 kg N ha^{-1} as ammonium nitrate with lime (N 27.5%, Ca 4%, Mg 1%) was applied together with wood ash. A treatment with 120 kg N ha^{-1} as ammonium nitrate with lime, but no ash was also included in Exp. 407. In this treatment 2 kg B ha^{-1} as fertilizer borate ($Na_2B_2O_7x5H_2O$) was also applied. This was due to the fact that needle B concentrations in this experiment were low (6 mg kg^{-1}) at the time of the establishment (see Saarsalmi et al., 2004). Moreover, low boron concentration in needles has been caused experimentally by repeated nitrogen fertilization, especially in the north (Möller, 1983; Jalkanen, 1993). In the control treatment no ash or nutrients were added.

2.1.2. Peatland site

The peatland experiment (Exp. 251) was situated on a barren mire drained for forestry in 1976 with ditch spacing of 25 m (supplemented in 1982) (Fig. 1). Before drainage the pristine-mire site type was dwarf-shrub pine bog (IR, classification see Vasander and Laine, 2008), and the peat thickness ranged from 25 to 55 cm. After drainage, the site had transformed to dwarf-shrub forest site type (Vatkg) and with regard to the nutrient demands of trees, such as nitrogen, was classified as an oligotrophic fertility type (Table 1).

A field experiment was established in an unthinned 30-year-old stand consisting mainly of Scots pine and a few downy birches (*Betula pubescens* Ehrh.) as a mixture of tree species, with a dominant tree height of 7–10 m, density of 1100–1890 stems per hectare and average stem volume of 35 m^3 ha^{-1}.

The fertilization experiment was established in 1982 with 6 sample plots, each 0.08–0.10 ha. The two treatments were: an unfertilized control and a wood Ash treatment. The experimental layout followed a randomized block design with three replications. The loose wood ash, 4.8 Mg ha^{-1} (Ca 262, K 75, Mg 37 and P 24 g kg^{-1}), originating mainly from chip-wood fuel used in a thermal power plant, was applied manually in April 1982.