Forest Ecology and Management 278 (2012) 63–70

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

30-Year effects of wood ash and nitrogen fertilization on soil chemical properties, soil microbial processes and stand growth in a Scots pine stand

Anna Saarsalmi [a,*], Aino Smolander [a], Mikko Kukkola [a], Mikko Moilanen [b], Jussi Saramäki [c]

[a] Finnish Forest Research Institute, P.O. Box 18, FI-01301 Vantaa, Finland
[b] Finnish Forest Research Institute, P.O. Box 413, FI-90014 University of Oulu, Finland
[c] Finnish Forest Research Institute, P.O. Box 44, FI-69101 Kannus, Finland

ARTICLE INFO

Article history:
Received 15 February 2012
Received in revised form 27 April 2012
Accepted 7 May 2012
Available online 2 June 2012

Keywords:
Nitrogen
Pinus sylvestris
Soil acidity
Soil microbiological processes
Wood ash

ABSTRACT

The effects of different doses of wood ash, given together with urea-N fertilizer, on chemical properties of the organic layer, soil microbial processes related to C and N cycling, and stand growth were studied in a Scots pine (*Pinus sylvestris*) stand on mineral soil 30 growing seasons after fertilization. The treatments were an unfertilized control, a nitrogen treatment (N) and a combined treatment with N and three different doses of wood ash: 1, 2.5 and 5 Mg ash ha^{-1} (WA1 + N, WA2.5 + N and WA5 + N). There were six replications in the control and N treatment and two replications in each ash + N treatment. The amount of N applied was 185 kg ha^{-1}. Compared to the control, the WA5 + N treatment significantly increased the pH (0.5 pH units) and decreased the exchangeable acidity in soil (45%). The concentrations of exchangeable Ca, K and Mg in the soil in the WA2.5 + N and WA5 + N treatments and those of extractable P in all the wood ash + N treatments were significantly higher than in the control and N-alone treatment. The Ca concentrations in the WA2.5 + N were two times and in the WA5 + N treatment three times that in the control treatment. The mean increment in basal area of the tree stand was significantly higher in the WA1 + N and WA2.5 + N treatments than in the control or N-alone treatment during the 30-year study period. Although application of wood ash increased the growth response to N, at the end of the study period the response had virtually stopped. To compare the statistical significance of the differences in microbial biomass and activities between different treatments, all six WA + N plots were combined, regardless of the different ash doses. Amounts of C and N in the microbial biomass, the rate of C mineralization (CO_2 production) and concentration of K_2SO_4-extractable dissolved organic carbon were all higher in the WA + N treatment than in the N-alone treatment. The rate of net N mineralization, and the ratios between net N mineralization and C mineralization and between net N mineralization and microbial biomass N were all highest in the WA + N treatment, indicating better availability of N. In all treatments, however, both the rate of net nitrification and the NO_3–N concentrations were negligible. In conclusion, wood ash application together with N seems to have very long-term effects on soil chemical properties and microbial processes in C and N cycling which give at least some explanations for the response in tree growth to this treatment.

1. Introduction

Increasing demand for forest bioenergy resources has resulted in an increase in whole-tree harvesting. The consumption of logging residues for energy production in Finland is planned to increase from the current amount of 5.4 mill. m^3 (year 2009) to 8–12 mill. m^3 by the year 2015 (Kansallinen metsäohjelma 2015, 2008). More complete utilization of biomass leads to increased export of nutrients and to soil acidification (Mälkönen, 1976; Kimmins, 1977; Rosenberg and Jacobson, 2004).

Intensive use of forest bioenergy generates vast amounts of ash. To prevent or reduce the negative effects of intensive harvesting and to avoid deposition of the ash as waste, it has been suggested that combustion ash be brought back to the forest (Karltun et al., 2008). During combustion, however, N is evaporated; and wood ash therefore does not compensate for deficiency of N, which is known to be the main nutrient limiting growth of boreal forests on mineral soils (Viro, 1967; Kukkola and Saramäki, 1983; Nohrstedt, 2001; Saarsalmi and Mälkönen, 2001). Wood ash includes base cations (Ca, Mg and K), P and B which are not primarily growth limiting nutrients on mineral soils except for B in eastern Finland (Saarsalmi and Tamminen, 2005). Due to large amount of Ca in ash, a decrease in soil acidity and an increase in base saturation after application of loose wood ash to forested mineral soils

* Corresponding author. Tel.: +358 29 532 5478.
E-mail address: Anna.saarsalmi@metla.fi (A. Saarsalmi).

0378-1127/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2012.05.006

have been widely reported (Bramryd and Fransman, 1995; Kahl et al., 1996; Saarsalmi et al., 2001, 2010; Ludwig et al., 2002; Brunner et al., 2004; Jacobson et al., 2004).

Several studies have shown increased microbial activities in soil after application of wood ash (reviewed by Perkiömäki and Fritze, 2005). In long-term studies, wood ash has been shown to stimulate litter and cellulose decomposition and carbon mineralization (Moilanen et al., 2002; Perkiömäki and Fritze, 2002; Perkiömäki et al., 2004). Long-term effects of ash fertilization on N cycling processes in forest soils are much less clear than the effects on C-cycling processes, but there are indications of slight positive effects on net N mineralization in some coniferous stands (Högbom et al., 2001; Rosenberg et al., 2010). Contrary to fertilization with wood ash, N fertilization seems to have long-term negative effects on microbial biomass and carbon mineralization in boreal forest soils but may stimulate net N mineralization (e.g. Nohrstedt et al., 1989; Smolander et al., 1994, 1995). There are few studies available in which the effects of combined ash and N addition have been evaluated. In a recent study, wood ash (3000 kg ha^{-1}) given together with N (150 kg ha^{-1}) tended to increase microbial biomass and both C and net N mineralization in a Scots pine stand 15 years after application, particularly when compared to N addition alone; but in a Norway spruce stand the response of microbial processes was not clear (Saarsalmi et al., 2010). Similarly, repeated liming (totaling 6000 kg ha^{-1} limestone in 30 years) seemed to compensate the suppressing effect of N addition on microbial biomass and the rate of C mineralization (Smolander et al., 1994).

Regardless of the positive effects caused by wood ash on the chemical and microbiological properties of soil, in middle-aged stands on relatively infertile mineral soil sites (C/N > 30), in Fennoscandia the growth response to wood ash has usually not been positive, at least not during the first 12 years; in some cases, there has even been a slight decrease in growth (Sikström, 1992; Jacobson, 2003; Saarsalmi et al., 2004, 2005). On fertile sites in southern Sweden, however, a weak tendency toward positive growth has been caused by ash treatment (Jacobson, 2003). Jacobson (2003) suggested that the reason for the positive growth response was that application of wood ash may have caused increased N-mineralization in the organic layer of soil on these sites.

Evidently, in Nordic upland coniferous forests as long as N remains the growth-limiting nutrient, addition of other nutrients will not increase growth. In such forests, application of 150 kg N ha^{-1} usually increases growth by 6–20 m^3 ha^{-1} (Nohrstedt, 2001; Nilsen, 2001; Saarsalmi and Mälkönen, 2001). The duration of the effect of N fertilization in mature stands in southern Finland has usually been about 7 years for pine and 10 years for spruce (Laakkonen et al., 1983). What then if on infertile sites wood ash is given together with N? The possible effects on tree growth by wood ash in combination with N seem to be complex. In experiments in which N has been added alone or in combination with wood ash, there has usually been no extra growth response in the combined treatment that could be attributed to addition of wood ash (Jacobson, 2003; Saarsalmi et al., 2010). In some cases the combined treatment has given a lower response than N addition alone (Pettersson, 1990; Jacobson, 2003). This effect was attributed to the loss of NH_3 to the atmosphere due to the high pH caused by simultaneous additions of ash and N. In contrast to these results, a positive growth response has been reported in a Scots pine stand on a low-productive mineral soil site, fertilized with wood ash and N, after the growth response to mere N application was no longer detectable; this response continued for at least 23 growing seasons (Saarsalmi et al., 2006).

In the present study the aim was to ascertain, whether changes in the chemical properties and microbiological processes of soil related to C and N cycling could provide explanations for the growth increase caused by wood ash and N addition reported by Saarsalmi et al. (2006), and whether the tree response still continued after 23 growing seasons. Our hypothesis was that addition of wood ash combined with N addition causes changes in soil microbial processes related to C and N cycling, resulting in a growth increase greater than that of N alone.

2. Materials and methods

2.1. Site and treatments

A field experiment was established in a pole stage, 60-year-old Scots pine stand (64°43′N, 26°02′E, 54 m a.s.l.) located in the northern boreal coniferous zone, near the city of Oulu in northern Finland, in autumn 1977. The stand was thinned in winter 1977/1978. The average dominant height of the stand after thinning was 12 m, the stem volume 51 m^3 ha^{-1} and the average stem number 1122 ha^{-1}. The site type, a N-poor dry heath, was classified as *Empetrum nigrum–Calluna vulgaris* forest site type (CT, see Cajander, 1949). The humus layer was mor, the soil texture was sorted sand, and the soil type was haplic podzol (FAO-UNESCO, 1988). The long-term (1977–2008) mean annual temperature sum is 1101 °C and mean annual precipitation is 538 mm.

The treatments were a control with no ash or nutrient addition, a nitrogen treatment (N) and a treatment with N and three different doses of wood ash (WA): 1, 2.5 and 5 Mg ash ha^{-1} (WA1 + N, WA2.5 + N and WA5 + N). There were six replications in both the control and N treatment and two replications in each WA + N treatment. The experimental set-up followed the principles of randomized blocks. The same amount of N (185 kg N ha^{-1}) was applied as urea fertilizer (46% N) in both the N and ash treatments. The dust-like ash, which originated from wood fuel, was produced at a thermal plant in Oulu. The composition of the wood ash was P 18, K 75, Ca 282, Mn 27, Zn 0.90, Cu 0.18 and B 0.30 g kg^{-1}. The fertilizers were applied manually, urea in autumn 1978 and the ash in March 1979, on the snow. The size of each sample plot was 50 m × 50 m.

2.2. Soil sampling

Soil samples were taken from the organic layer (O_{fh}) in August 2008, i.e. 30 growing seasons after the treatments. The samples were taken systematically using a cylinder (d = 60 mm) at 20 sampling points on each plot, and the sub-samples from each plot were combined to give one composite sample per plot. Green parts of higher plants and mosses and possible litter were removed at the time of sampling. Thickness of the organic layer was on an average 3.1 cm (2.8–3.6) without statistically significant differences between treatments.

2.3. Soil chemical analyses

Soil samples were air-dried at 40 °C. After larger roots were removed, samples of the organic layer were ground in a mill with a 2 mm bottom sieve.

All samples were extracted with 1 M acid ammonium acetate (pH 4.65). Then 10 ml of sample and 100 ml of extractant were shaken for 2 h and filtered, and exchangeable concentrations (Ca, K, Mg and P) were determined with the ICP device Thermo Jarrel Ash Iris Advantage. Total element concentrations (Ca, K, Mg, P, B, Cd, Cu, Fe, Mn, Ni, Pb and Zn) were determined on the soil samples by dry ashing (550 °C for 2 h), extraction of the ash with HCl, and analysis of the extract with the ICP device Thermo Jarrel Ash Iris Advantage. Total concentrations of N and C in the soil samples were determined with a Leco CHN 1000 device. The analytical methods are described in Halonen et al. (1983). pH was determined in a water slurry, where 10 ml of sample was completely wetted with