

Initial Effects of Wood Ash Fertilization on Soil, Needle and Litterfall Chemistry in a Scots Pine (*Pinus sylvestris* L.) Stand

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Abstract

Initial effects of wood ash and/or N fertilization were investigated in a field experiment located in a 38-year-old Scots pine stand on a Haplic Arenosol in Kačerginė, Lithuania. There were in total six treatments, three levels of wood ash addition (1.25, 2.5 and 5.0 t ha⁻¹), one level of N addition (180 kg N ha⁻¹), one combined treatment (2.5 t ha⁻¹ of wood ash and 180 kg N ha⁻¹) and one untreated control. The treatments were repeated in four blocks.

The pH_{CaCl2} of the O horizon increased from 3.45 (control) to 6.15 for the highest ash dose and exchangeable Ca²⁺ and Mg²⁺ increased significantly (p<0.001). There were no changes in the mineral topsoil (0–5 cm) for the acidity but exchangeable Ca²⁺ and Mg²⁺ increased significantly (p<0.05) compared to the control for the highest ash treatment. Soil solution concentrations of Ca²⁺, Mg²⁺ and K⁺ increased at 20 cm depth as a result of the ash treatment but at 50 cm depth only Mg²⁺ concentration was higher than the control. Leaching of NO₃⁻ and NH₄⁺ increased in the N treatment compared to the control but no effect of the ash treatment was observed.

The wood ash increased the concentration of Ca in the current year but not one-year-old needles 6 months after the application. N concentration in the current and one-year-old needles and even litterfall increased as a result of the N treatment. Ca uptake seemed to be stimulated by high N availability as indicated by high Ca concentrations in needles from the N treatment. There were no other indications of interactions between the ash and N treatments.

Key words: wood ash, Scots pine, Arenosols, soil solution, needles, litterfall, chemical composition

Introduction

Biofuel extraction from forest through whole-tree harvesting where the fraction not used as commercial round wood is used for production of biofuel is steadily increasing (Kaberger 1997). Wood fuel in the near future can constitute a substantial proportion of primary energy sources in Lithuania. Due to an increase in production in the wood processing industry, the amount of wood residues is increasing and a concomitant increase in residues used for fuel has been observed. Each year, about 30% (close to 0.8 Mm³) of the biomass is left on clearfelling sites and this can be used as fuel wood in future (Kairiūkštis and Jaskelevičius 2003). The increase in biomass export from the forest through whole-tree harvesting compared to traditional logging is rather small, between 15–30% by weight (Ingerslev *et al.* 2001). However, the export of

nutrients from the forest ecosystem increases considerably, since the exported fractions branches, needles and tops have higher concentrations of nutrients than the stem-wood. Depending on nutrient and harvesting method, the increase in export when changing from conventional to whole-tree harvesting ranges from around 40% (P) to 180% (Mg) (Eriksson and Rosen 1994). In addition to the loss of nutrients, whole-tree harvesting intensifies the build-up of acidity in the soil that is caused by the excess uptake of cations over anions by trees (Olsson *et al.* 1996). To obtain a more sustainable utilisation of biomass fuels, the ash resulting from combustion of biofuels can be recycled back to the soil.

The major reasons for recycling wood ash would then be to return essential mineral nutrients to the forest and to counteract increasing soil acidity. Another argument that has been used to advocate ash

amendments is the preservation of plant species diversity (Ohno and Erich 1990; Levula *et al.* 2000). The introduction of landfill taxes and more demanding regulations on landfill construction have also increased the cost of depositing the ash on landfill, making the returning of the ash to the forest a cheaper alternative. Thus, wood ash recycling to forests will probably increase since ash production is increasing and forest land is available and usually found close to ash producers.

Wood ash consists of inorganic minerals and organic compounds remaining in the ash due to incomplete combustion. The major proportion of the minerals in the ash is a mixture of oxides, hydroxides, silicates and carbonates of the base-forming cations. Apart from N, which is volatilized during combustion, all the macronutrients are found in the ash. Some of the oxides and hydroxides in the ash dissolve easily in water and produce a strong alkaline reaction (liming effect) (Ljung and Nordin 1997). The solubility and the potential plant availability of the macronutrients in the ash are high, with the possible exception of P, and follows the order $K > Mg > Ca > P$ (Eriksson 1998b).

The addition of wood ash usually increases pH and base saturation in the O horizon. The effect is more drastic if raw ash is used as compared to aggregated ash (Bramryd and Fransman 1995; Arvidsson and Lundkvist 2003; Saarsalmi *et al.* 2001).

The pH and base saturation seem to stabilize at a higher level 5-10 years after application and remain at a higher level for a long period of time (Bramryd and Fransman, 1995; Arvidsson and Lundkvist 2003; Saarsalmi *et al.* 2001). The effect on pH and acidity in the mineral soil, if found at all, is by far less pronounced and appears much later after the treatment than in the O horizon (Bramryd and Fransman 1995; Levula *et al.* 2000; Saarsalmi *et al.* 2001).

The effects on the individual cations differ considerably. The relative proportions of exchangeable K^+ and Mg^{2+} compared to Ca^{2+} decrease when the soil is treated with ash (Arvidsson and Lundkvist 2003). This may occur even if the amount of exchangeable K^+ increases, since the CEC increases after wood ash application (Arvidsson and Lundkvist 2003; Saarsalmi *et al.* 2001).

There are only a few studies on the possible leaching of nutrients after wood ash application. Arvidsson (2001) found no treatment effects on pH and soluble Al^{3+} in the soil water sampled at 50 cm depth following application of hardened and crushed wood ash at four different locations in Sweden during a period of 6 years after application. Furthermore, no differences in pH and soil solution acidity were

found between treatment and control catchments at 30 cm depth during a 5-year period after wood ash application to forested catchments in central Sweden using a granulated wood ash (Fransman and Nihlgård 1995).

While the effect of wood ash application on pH of the soil solution in mineral soil is rather weak, there are consistent observations of increased downward transport of base-forming cations. Arvidsson (2001) found higher concentrations of Ca^{2+} , Mg^{2+} and K^+ in the soil solution at all of four different field experiments using two different crushed ash types, while Rumpf *et al.* (Rumpf *et al.* 2001) observed increased concentrations of both Ca^{2+} and K^+ below the organic layer and at 10 cm and 100 cm depth in the mineral soil.

Earlier studies on needle chemistry in Scots pine have revealed no or rather small and transient effects on Ca and K after wood ash treatments (Moilanen and Issakainen 2000; Vuorinen and Kurkela 2000; Jacobson 2001). Since wood ash amendment in tree stands on the mineral soils usually does not give any positive growth response in the tree stand (Saarsalmi *et al.* 2004; Jacobson 2001; Sikström 1992), a simultaneous addition of N has been proposed, especially on poor sites (Jacobson 2001). The effects of a combined N and wood ash amendment might be different compared to amendment with ash alone, *e.g.* concerning leaching and litterfall chemistry. There are few such studies in the literature. We are currently studying the ecological effects of wood ash application with and without N addition in a Scots pine stand in a field experiment in Kačerginė, Lithuania. Even though wood ash amendment should be considered a long-term measure in forestry, the most drastic changes are likely to occur directly after application of the ash. Better knowledge of the initial processes will facilitate the interpretation of the long-term effects. In this paper we describe how the application of raw wood ash affected the soil, soil solution, needle and litterfall chemistry in the first year after application.

Materials and methods

In 2002, a field experiment was established in SW Lithuania, in the Kačerginė forest district (54°55'N, 23°43'E) of the Dubrava Experimental and Training Forest Enterprise. The experiment was set up in a first generation Scots pine (*Pinus sylvestris* L.) stand, planted in 1964, on a sandy limnoglacial plain overlying old fluvioglacial sands. The soil is classified as a Haplic Arenosol (ISSS-ISRIC-FAO, 1998) (Table 1). The initial planting density was around 8 000 plants ha⁻¹. The bottom vegetation lay-

Table 1. Soil profile horizons and their basic characteristics for the Haplic Arensol used in this study. Horizon designation and subscripts (l – litter; lf – litter and fermentation; p – ploughing; s – illuvial accumulation of sesquioxides) according to FAO (1990)

Horizon	Depth, cm		pH (CaCl ₂)	N, g kg ⁻¹	C, g kg ⁻¹	Texture
	upper	lower				
O _l	-2	-1.5	-	7.47	519	
O _{lf}	-1.5	0	3.5	12.2	463	
E	0	1	3.5	0.91	19.0	medium sand
A _p	1	30	4.3	0.20	3.41	medium sand
B _s	30	65	4.8	0.04	0.41	medium sand
C	65	100	4.8	0.02	0.06	medium sand

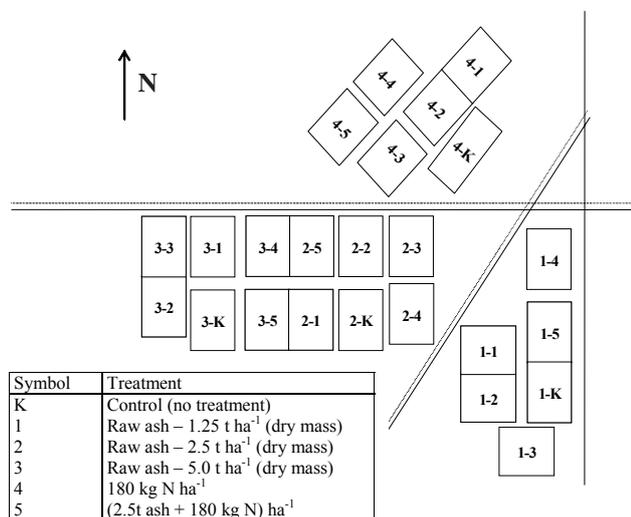


Figure 1. Experimental design of the wood ash fertilization experiment

er is dominated by mosses, with the most common species being *Pleurozium schreberi* (Brid.) Mitt., *Dicranum polysetum* Sw., *Dicranum scoparium* Hedw. and *Hylocomium splendens* (Hedw.) Schimp. The coverage of vascular plants is low (~ 7%) and the most common species are *Festuca ovina* L. and *Calluna vulgaris* (L.) Hull. This forest type of Scots pine stand is common in Lithuania. The experiment consists of 24 plots (25x20 m²) grouped into 4 blocks with 6 treatments in each block: 1) 1.25 t ha⁻¹ of wood ash; 2) 2.5 t ha⁻¹ of wood ash; 3) 5.0 t ha⁻¹ of wood ash; 4) 180 kg ha⁻¹ of N; 5) 2.5 t ha⁻¹ of wood ash + 180 kg ha⁻¹ of N; and 6) untreated control (Fig. 1). The raw wood ash from a district heating plant and N fertilizer (ammonium nitrate) was spread after the installation of the tension lysimeters on 25 - 27 June

2002. The chemical composition of the wood ash applied is presented in Table 2.

Table 2. Chemical composition of the wood ash applied in the field experiment

	Macronutrients, g kg ⁻¹	Heavy metals, mg kg ⁻¹	
P	2.15	Cr	9.51
K	5.29	Cd	0.62
Ca	72.0	Pb	4.53
Mg	9.45	Ni	8.05
		Cu	13.1
		Zn	73.7

The first soil sampling was carried out in October 2002, five months after wood ash application. From each plot, 20 soil sub-samples were collected from the O horizon, and from the upper layers of mineral soil (0-5, 5-10, and 10-20 cm). The soil samples were pooled to produce one composite sample from each depth and plot. Soil pH was measured with a glass electrode in the soil: water suspensions (1:2.5 W/W) in 0.01 M CaCl₂ for all soil samples collected. The soil chemical analyses were performed only on the O horizon and the 0-5 cm horizon samples according to the methods described in ICP-Forests manual (UNECE, 1998). The concentration of total N was analysed according to the Kjeldahl method. Total organic C was analysed by dry combustion at 900°C. *Aqua regia* extracts were prepared for the determination of total concentrations of macronutrients in the soil. In these extracts, Mg and Ca were analyzed by atomic absorption spectrophotometer (AAS), K by flame photometer and P using standard colorimetric methods. Exchangeable cations were determined in 0.1 M BaCl₂ extracts. Exchangeable Ca²⁺, Mg²⁺, K⁺ and Na⁺ were determined using the same methods as described above and exchangeable Al ions were determined by titration of the BaCl₂ extract.

Soil solution was sampled at 20 cm and 50 cm depth by tension lysimeters (P80 ceramic cups by Ceramitech) in April-May 2003. The lysimeters were installed systematically in all treatments and in the control. Altogether 144 tension lysimeters were installed, 6 in each plot (3 replicates per depth and plot). The lysimeters were de-pressurized to -70 kPa for sampling of soil solution.

The soil solution samples from both depths were analyzed for NH₄⁺, NO₃⁻, P, K, Ca, Mg ions, and DOC. NH₄⁺ was determined by a colorimetric method (hypochlorite), NO₃⁻ spectrometrically using sulphosalicylic acid. P was determined as molybdate-reactive P by a colorimetric method. K⁺ concentration was measured by flame photometer, Ca²⁺ and Mg²⁺ by AAS

and dissolved organic carbon (DOC) by a titrimetric method (UNECE 1998).

Needles were sampled from 5 Scots pine trees in each plot. Sampling trees belonging to Class II according to the Kraft classification were chosen. The current year and one-year-old needles were sampled from the 5-7th whorl from the upper 1/3 of the crown in October 2002.

The needles were removed from the twigs and grouped in two groups according to the age: current year and one-year-old needles. Before analysis, equal quantities of each of the five samples from each plot were pooled to form a composite sample and were dried at 60°C for 24 hours (UNECE 1998). Total N was analysed by the Kjeldahl method. For the determination of total P, K, Mg, and Ca, the needles were dry-ashed at 500°C and the residue was dissolved in 20% HCl to bring the mineral elements into solution. P was determined by the V-Mo-blue colorimetric method, K by flame photometry and Ca and Mg by AAS.

Litterfall has been monitored continuously since July 2002 and was sampled from 144 litter traps in the Scots pine stand or 6 litter traps in each plot (surface area of a trap – 0.25 m²) at the height of 1 m above the ground. The traps were made of wood and cotton bags allowing throughfall to percolate easily. Litterfall was collected every 4 weeks in spring, summer and autumn and once in wintertime, emptied in paper bags. Composite samples, made from 6 traps per plot, were air-dried and sorted into four fractions: needles, twigs and branches, bark and scales, and cones. The litterfall needles collected in May 2003, nine months after wood ash application, were analyzed in this study. The sorted samples were oven-dried at 60°C for 48 hours and weighed. The concentrations of N, P, K, Mg, and Ca were analysed in the litterfall needles using the same method as described above.

The data from the experiment have been statistically evaluated by ANOVA using the following model:

$$y_{ijk} = \mu + \alpha_i + \gamma_j + (\alpha\gamma)_{ij} + \beta_k + \varepsilon_{ijk}$$

where y is the estimated mean and i , j and k represent wood ash treatment, N addition and block, respectively. In cases where the model did not show significant differences ($p > 0.05$) the eventual effects of single treatments were considered non-significant. It should be observed that the experiment was not balanced, since the wood ash treatments 1.25 and 5.0 t ha⁻¹ did not have any combined treatment with N. In the event of significant effects, the direction of change and test of significance between treatment levels were investigated by pairwise t-tests.

Results

Chemical changes in the soil and soil solution

The pH of the O horizon (organic layer) increased from pH_{CaCl2} 3.45 (control) to pH_{CaCl2} 6.15 (5.00 t ha⁻¹ of ash) three months after the application (Fig. 2A). The increase in pH was proportional to the wood ash dose. There was no significant difference in pH_{CaCl2} of the mineral topsoil (0-5 cm) between the treatments (Fig. 2B), nor in the layers below (data not shown).

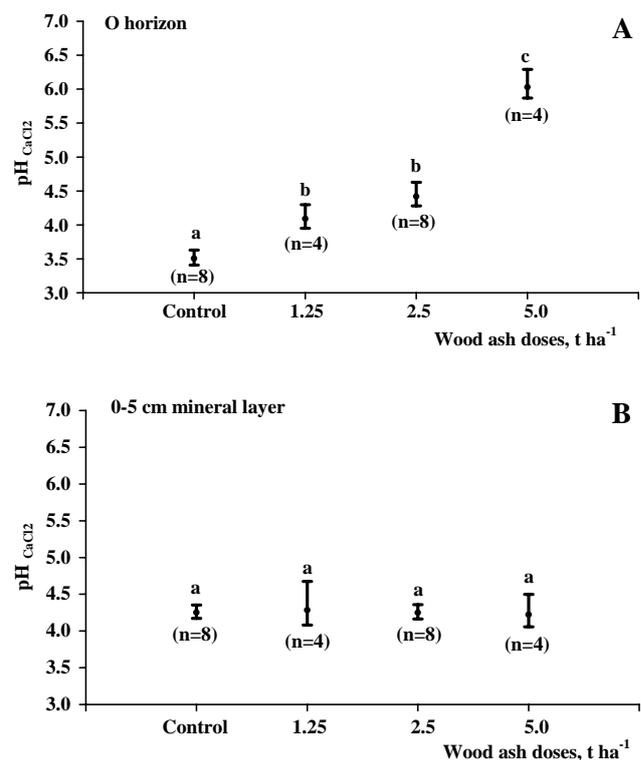


Figure 2. Effects of the wood ash treatment on average pH_{CaCl2} of the O horizon and the 0-5 cm layer of the mineral soil. The error bar indicates 95% confidence interval. Averages marked with the same letter are not significantly different ($p < 0.05$).

Increases in *aqua regia*-extracted Ca and Mg in the O horizon were statistically significant between each wood ash treatment following a dose-response relationship (Table 3, Mg data not shown). For *aqua regia*-extracted K, all wood ash treatments and for *aqua regia*-extracted P the two highest wood ash treatments were significantly different from the control in the O horizon. The N treatment (180 kg N ha⁻¹) did not result in any statistically significant change in total N in the O horizon (Table 3).

The application of wood ash significantly increased the concentration of exchangeable Ca²⁺ and exchangeable Mg²⁺ in the O horizon but had only a

Table 3. Effects of the wood ash and N treatment on the mean concentrations of different elements in the O horizon and the 0-5 cm layer of the mineral soil. Uncertainty is given as 95% confidence intervals. Evaluation of treatment effects by ANOVA (see Materials and Methods). Values followed by the same letter in each column and depth are not significantly different from each other. All the significant effects presented in the table refer to the ash treatment. There were no significant effects caused by the N treatment

Treatment	mg g ⁻¹				
	N	P	K	Ca	
<i>O horizon</i>					
Control	12.0 ^a ±0.30	0.64 ^a ±0.12	2.90 ^a ±0.48	4.10 ^a ±0.31	
1.25 t ha ⁻¹ ash	11.2 ^a ±1.1	0.78 ^{ab} ±0.10	3.98 ^b ±0.54	9.75 ^b ±1.95	
2.5 t ha ⁻¹ ash	11.0 ^a ±1.05	0.83 ^b ±0.05	4.28 ^b ±0.65	13.7 ^c ±4.01	
5.0 t ha ⁻¹ ash	9.45 ^a ±1.14	1.10 ^c ±0.04	7.40 ^c ±1.13	28.9 ^d ±3.29	
2.5 t ash + 180 kg N ha ⁻¹	10.6 ^a ±1.08	0.90 ^b ±0.23	4.78 ^b ±0.68	14.6 ^c ±3.87	
180 kg N ha ⁻¹	11.9 ^a ±1.08	0.66 ^a ±0.08	2.18 ^a ±0.22	4.60 ^a ±1.40	
<i>0-5 cm</i>					
Control	0.50 ^a ±0.10	0.27 ^a ±0.03	11.6 ^a ±1.27	3.03 ^a ±0.44	
1.25 t ha ⁻¹ ash	0.44 ^a ±0.09	0.29 ^a ±0.03	10.5 ^a ±1.99	2.55 ^a ±0.46	
2.5 t ha ⁻¹ ash	0.54 ^a ±0.02	0.29 ^a ±0.05	11.4 ^a ±0.52	2.84 ^a ±0.18	
5.0 t ha ⁻¹ ash	0.54 ^a ±0.12	0.32 ^a ±0.04	11.7 ^a ±0.41	3.08 ^a ±0.45	
2.5 t ash + 180 kg N ha ⁻¹	0.47 ^a ±0.11	0.29 ^a ±0.04	12.1 ^a ±0.72	2.91 ^a ±0.65	
180 kg N ha ⁻¹	0.44 ^a ±0.05	0.30 ^a ±0.07	11.6 ^a ±0.42	2.93 ^a ±0.36	

small influence on the concentration of exchangeable K⁺ (Fig. 3). Although the differences were much smaller and there were fewer statistically significant differences, the same treatment effects were found in the 0-5 cm mineral layer as in the O horizon.

Nitrate (NO₃⁻) and NH₄⁺ concentrations in the soil solution were significantly higher for the N treatment than for treatments that had not received any N addition, both at 20 cm and 50 cm depth (Table 4). The concentration of NO₃⁻ was higher at 50 cm depth than at 20 cm depth for the N (180 kg N ha⁻¹) treatment. There was a weak tendency, although not significant, towards elevated NO₃⁻ concentrations in the 5.0 t ha⁻¹ ash treatment but the NH₄⁺ concentrations remained very low (<0.1 mg L⁻¹) for all ash treatments. Phosphorous showed no treatment effects at any depth but the K⁺ concentration at 20 cm depth was significantly higher for the 5.0 t ha⁻¹ ash dose compared to other treatments. Calcium ions and Mg²⁺ had significantly higher concentrations in the soil solution in the two highest ash treatments but only the Mg²⁺ concentrations remained significantly higher at 50 cm depth. The concentrations of Ca²⁺ and Mg²⁺ followed a dose-response relationship for the ash treatments. However, it should be noted that the highest Ca²⁺ concentrations were found in the combined ash and N treatment at both depths and that the Mg²⁺ concentrations were higher in the combined ash and N treatment than in the

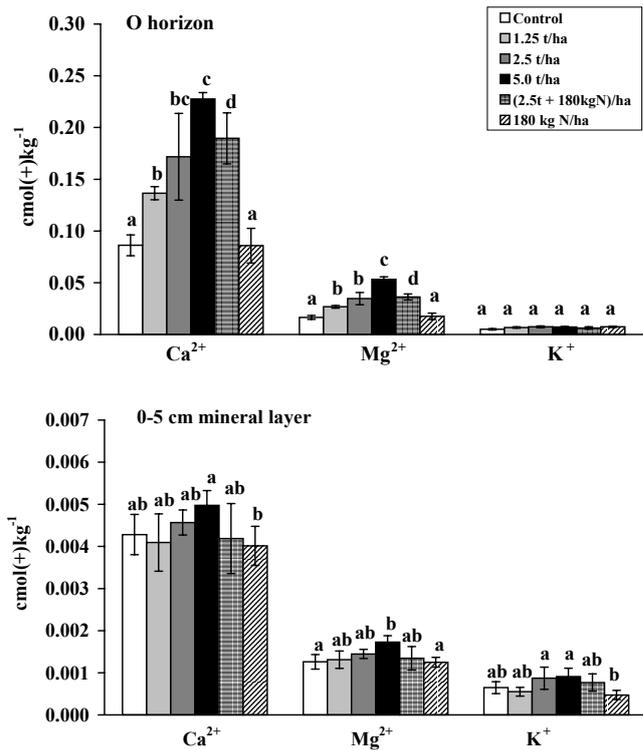


Figure 3. Effects of the wood ash treatment on the concentrations of exchangeable Ca²⁺, Mg²⁺ and K⁺ in the O horizon and the 0-5 cm mineral layer of the soil. The error bar indicates 95% confidence interval. Averages marked with the same letter are not significantly different

ash treatment with a corresponding ash dose (2.5 t ha⁻¹). The spatial variation in the DOC concentrations was high. There was a tendency for elevated DOC levels at the high ash doses at both depths, but there were no significant effects.

Chemical changes in needles and litterfall

There were no significant effects on N concentrations in the current, one-year-old and litterfall needles 6 months after the application of 5.0 t ha⁻¹ of wood ash. The N concentration was significantly higher (p < 0.05) in the plots treated with 180 kg N ha⁻¹ compared with the control in the current year, one-year-old and litterfall needles (Fig. 4, litterfall data not shown). The N concentrations in both the current year and one-year-old needles were similar. However, the differences in N concentrations due to treatments were more evident in the current year needles than in one-year-old and litterfall needles. The N concentrations in the one-year-old needles were higher compared to the concentrations in litterfall needles. In the current year needles, Ca concentration was significantly elevated by both the ash and the N treatment (Fig. 4). The concentrations of P, K,

Table 4. Effects of the wood ash treatment on the mean concentrations of some different ions and DOC in the soil solution at 20 cm and 50 cm depths. Values followed by the same letter are not significantly different from each other. Uncertainty of the means is given as 95% confidence intervals. Evaluation of treatment effects by ANOVA (see Materials and Methods). One asterisk (*) denotes that significance is given with respect to the ash treatment with no significant effect by the N treatment and two asterisks (**) denote that significance is given with respect to the N treatment with no significant effect by the ash treatment

Treatment	NO ₃ ⁻	NH ₄ ⁺	P	K ⁺	Ca ²⁺	Mg ²⁺	DOC
Amount ha ⁻¹	mg L ⁻¹						
<i>20 cm depth</i>							
Control	0.43 ^{***} ±0.02	0.03 ^{***} ±0.04	0.05 [*] ±0.07	0.59 ^{**} ±0.57	4.08 ^{**} ±1.23	0.71 ^{**} ±0.08	39.0 [*] ±6.56
1.25 t ash	0.59 ^{***} ±0.36	0.04 ^{***} ±0.03	0.06 [*] ±0.07	1.70 ^{**} ±1.36	5.2 ^{ab*} ±2.54	1.13 ^{ab*} ±0.17	45.3 [*] ±22.2
2.5 t ash	0.59 ^{***} ±0.42	0.06 ^{***} ±0.02	0.12 [*] ±0.11	0.76 ^{**} ±0.48	6.83 ^{b*} ±2.45	1.41 ^{b*} ±0.56	51.0 [*] ±11.3
5.0 t ash	1.61 ^{***} ±2.2	0.05 ^{***} ±0.04	0.13 [*] ±0.09	2.55 ^{b*} ±1.43	8.70 ^{b*} ±5.77	3.29 ^{c*} ±1.40	52.3 [*] ±22.3
2.5 t ash + 180 kg N	7.01 ^{b**} ±2.4	1.39 ^{b**} ±1.46	0.06 [*] ±0.06	2.10 ^{**} ±0.83	12.1 ^{b*} ±7.70	2.43 ^{b*} ±1.28	39.9 [*] ±4.99
180 kg N	3.61 ^{b**} ±1.93	1.99 ^{b**} ±1.99	0.15 [*] ±0.08	0.50 ^{**} ±0.45	4.98 ^{ab*} ±1.87	1.03 ^{a*} ±0.27	41.8 [*] ±2.3
<i>50 cm depth</i>							
Control	0.42 ^{**} ±0.03	0.02 ^{**} ±0.02	0.05 [*] ±0.04	0.35 [*] ±0.43	3.30 [*] ±1.21	0.75 ^{a*} ±0.19	23.4 [*] ±7.66
1.25 t ash	0.54 ^{***} ±0.26	0.06 ^{***} ±0.05	0.06 [*] ±0.07	0.70 [*] ±0.64	5.00 [*] ±1.32	1.10 ^{ab*} ±0.09	25.8 [*] ±11
2.5 t ash	0.51 ^{***} ±0.10	0.04 ^{***} ±0.03	0.10 [*] ±0.09	0.73 [*] ±0.47	6.20 [*] ±2.33	1.33 ^{bc*} ±0.39	40.4 [*] ±16.2
5.0 t ash	1.48 ^{***} ±1.8	0.08 ^{***} ±0.04	0.15 [*] ±0.14	0.90 [*] ±0.77	9.13 [*] ±6.62	2.25 ^{c*} ±1.33	46.2 [*] ±18.1
2.5 t ash + 180 kg N	10.1 ^{b**} ±5.13	0.33 ^{b**} ±0.27	0.06 [*] ±0.08	0.70 [*] ±0.70	9.75 [*] ±2.43	2.17 ^{bc*} ±0.46	26.7 [*] ±8.06
180 kg N	13.7 ^{b**} ±7.6	2.5 ^{b**} ±2.36	0.03 [*] ±0.02	1.98 [*] ±2.31	6.93 [*] ±3.85	1.34 ^{a*} ±0.69	25.0 [*] ±10.1

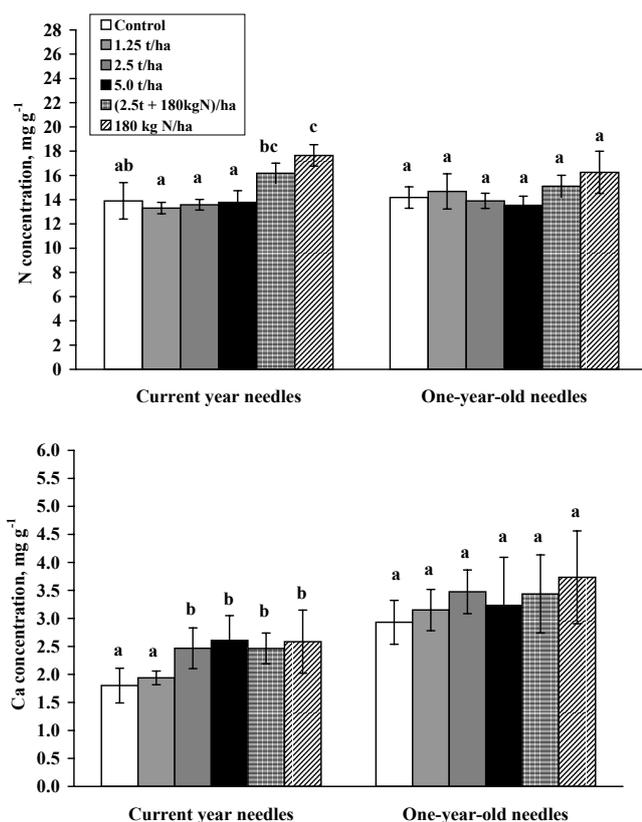


Figure 4. Effects of wood ash treatment on N and Ca concentrations in the current and one-year-old needles. The error bar indicates 95% confidence interval. Averages marked with the same letter are not significantly different.

and Mg were not significantly affected either by the wood ash or the N treatment for any of the needle types.

Discussion

Chemical changes in the soil and soil solution

The wood ash amendment caused rapid changes in the O horizon. The pH_{CaCl2} increased by as much as 2.7 units for the highest wood ash dose compared to the control and the levels of *aqua regia*-extractable Ca, Mg, K and P increased significantly, as did exchangeable Ca²⁺ and Mg²⁺. For these variables there were also evident dose-response relationships. Even though wood ash experiments on the site type studied here are rare, the results are similar to those found for other site types (Saarsalmi *et al.* 2004). The rapidly increasing pH can be explained by neutralization of acidity in the O horizon caused by the alkaline components (mainly oxides, hydroxides and carbonates) in the ash (Steenari 1998). A contributing factor to the drastic effects is that the ash was applied as highly soluble raw ash, which is more reactive than ash that has been pre-treated to make it less soluble (Eriksson *et al.* 1998). Normally, the effects of ash on exchangeable cations shortly after wood ash amendments in the mineral soil horizons underlying O horizons are small or none (Eriksson 1998a) but appear several years after the treatment (Saarsalmi *et al.* 2001; Arvidsson and Lundkvist 2003). In this case there were significant effects on

the exchangeable cations in the top of the mineral soil. The most important reason for these early effects appearing in the mineral soil is probably the thin O horizon (see Table 2), which does not have the capacity to hold all the cations in the applied ash. This is also indicated by the elevated concentrations of Ca^{2+} , Mg^{2+} and K^{+} found in the soil solution at 20 cm depth. Despite the effect on the exchangeable base-forming cations, there was no effect on pH.

Potassium in wood ash is usually highly soluble (Steenari *et al.*, 1999) but in the present study exchangeable K^{+} in the O horizon was unaffected by the ash treatment. This may be explained by rapid leaching of K^{+} and the poor ability of K^{+} to compete with divalent cations such as Ca^{2+} and Mg^{2+} for exchange sites. Increased levels of K^{+} in the soil solution were also found in the highest ash treatment. However, the *aqua regia*-extractable fraction of K was also higher than in the control, which indicates that some of the added K is still in the O horizon but found in rather insoluble mineral fractions, *e.g.* K containing primary minerals in sand and silt particles found in the ash (Steenari *et al.* 1999).

The concentrations of NO_3^- and NH_4^+ were significantly elevated in the N treatments even at 50 cm depth, indicating that some of the N had been leached from the soil profile. The DOC levels were not significantly affected by the treatments in this study, contrary to what had been found in other experiments (Eriksson 1996) but the high spatial variability between the lysimeters might have concealed such an effect.

Chemical changes in needles and litterfall

Our results showed that the N treatment resulted in significantly elevated N concentrations in the current year needles, one-year-old needles and litterfall while wood ash alone had no influence on N concentration in Scots pine needles nine months after the treatment. The lower concentration of N in older needles is in agreement with other studies, which have shown that older needles have lower N concentrations than the current-year needles (Finér 1992; Linder 1995). A contributing factor to the effect on the litterfall needles could be that Scots pine needle retention is low in the region: a needle retention of only 2.1-2.6 years is characteristic of the majority (70%) of Scots pine trees in Lithuania (Ozolinčius and Stakėnas 1996).

The Ca concentration in the needles was significantly increased by both the wood ash and the N treatment and there was a significant co-variance effect between the two treatments. No significant effects on Ca concentrations were found for the one-year-old

needles for any of the treatments. The high availability of N in the nitrogen treatment seem to have stimulated uptake of Ca in younger needles.

The results from this study confirm that the effects of wood ash application on needle concentrations in Scots pine are quite small. Moilanen and Issakainen (2000) found a slight increase in the concentrations of Ca and K in the needles 18 months after wood ash application in a Scots pine stand where wood ash treatments applied with different procedures and at different doses were studied. Application of 3 t ha⁻¹ wood ash to a Scots pine stand in Northern Finland showed no effect on needle nutrient concentrations one year after the treatment (Vuorinen and Kurkela, 2000). Jacobson (2001) showed that wood ash tended to increase needle K concentrations 1-2 and 3-5 years after ash application, but that this effect disappeared with increasing time after the application.

Conclusions

The O horizon has a high capacity to overwhelm added alkalinity and divalent cations and prevent penetration to the mineral soil. However, wood ash addition on a highly permeable soil with a low nutrient holding capacity like the soil in this study tends to result in initial leaching losses, especially of K^{+} and Mg^{2+} . Likewise, leaching losses of N, both as NH_4^+ and NO_3^- , occur after application of N fertilizer. It is difficult to improve the plant available K status in the soil by wood ash addition, since no increase in exchangeable K can be found after application of wood ash. The effects of wood ash on Scots pine needle chemistry are small and do not indicate any serious nutrient imbalances. Except for an increased uptake of Ca after N addition, there were no documented interactions between the N and wood ash treatments.

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ПЕРВИЧНЫЕ ЭФФЕКТЫ ВЛИЯНИЯ УДОБРЕНИЯ ДРЕВЕСНОЙ ЗОЛОЙ В ДРЕВОСТОЯХ СОСНЫ ОБЫКНОВЕННОЙ (*PINUS SYLVESTRIS* L.) НА ХИМИЧЕСКИЕ СВОЙСТВА ПОЧВЫ, ХВОИ И ОПАДА

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Резюме

Первичные эффекты влияния древесной золой или азотом исследовалось в эксперименте, который был заложен в 38-летнем сосняке, растущем на песчанной Narplis Aregosol почве (окрестности Качергине, Литва). Всево в эксперименте существуют 6 вариантов: в трёх из них применялись разные дозы древесной золы (1,25; 2,5 и 5,0 т га⁻¹); в одном - только азотные удобрения (180 кг N га⁻¹); в одном - древесная зола (2,5 т га⁻¹) вместе с азотными удобрениями (180 кг N га⁻¹), а один вариант оставлен как контроль. Все варианты заложены с четырёхкратной повторностью.

Исследованиями, проведёнными 5-12 месяцев после закладки эксперимента, установлено, что только самая высокая доза древесной золы значительно (от рН_{CaCl2} 3,45 до рН_{CaCl2} 6,15) снизило кислотность О горизонта (лесной подстилки) и увеличило в нём содержание обменных Ca²⁺ и Mg²⁺. При этом рН показатель поверхностного слоя минеральной почвы (0-5 см) не изменился, хотя в этом слое достоверно (p<0,05) увеличилось концентрации Ca²⁺ и Mg²⁺. Кроме того, в почвенном растворе на глубине 20 см установлены повышенные концентрации Ca²⁺, Mg²⁺ и K⁺, однако, из этих катионов на глубине 50 см увеличилась лишь концентрация Mg²⁺.

После применения древесной золы в почвенном растворе не повысились концентрации NO₃⁻ и NH₄⁺, их выщелачивание увеличилось лишь после применения азотных удобрений.

Концентрация Са увеличилась только в хвое текущего года. При этом, азотные удобрения повысили концентрации N не только в хвое текущего и прошлого года, но и в опаде. Поскольку в хвое увеличилась и концентрация Са, делается предпосылка, что применение азотных удобрений вместе с древесной золой может стимулировать освоение Са.

Ключевые слова: древесная зола, сосна, почвенный раствор, хвоя, опад, химический состав.