Wood Ash Application and Liming: Effects on Soil Chemical Properties and Growth of Scots Pine Transplants

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Abstract

The effects of varying doses of wood ash (2.5 and 5.0 t ha^{-1}) and limestone (1.0, 2.0 and 4.0 t ha^{-1}) on soil chemical properties and growth of Scots pine (*Pinus sylvestris* L.) transplants on an acidic forest soil were investigated in a reforestation area in eastern Finland. The ash and limestone were applied either on the soil surface or were mixed into the topsoil using disc ploughing. All the treatments were replicated three times. Soil samples were taken from the unploughed plots only. Wood ash and liming had reduced acidity in both the organic layer and 0-10 cm mineral soil layer for 15 years after application. The pH increase in the organic layer was 1.6 and 2.7 pH units on the plots treated with 2.5 and 5 t ha^{-1} of ash, and 0.7, 1.0 and 1.7 units on the plots treated with 1, 2 and 4 t ha^{-1} of lime, respectively. Depending on the dose, ash application resulted in a significant 41 to 47% increase and liming 34 to 46% increase in the base saturation of the organic layer. Surface broadcast of ash and lime significantly increased height growth. On the ash plots the mean height after 15 years was 24-27% and on the limed plots 14-23% greater than on the control plots. There were also signs of an increase in breast height diameter caused by ash application and liming. Liming or ash application after being mixed into the surface soil by ploughing had no effect on height growth of the pines, except for the highest lime dose. Instead, ploughing as such had a significant increasing effect both on survival and height growth of the trees.

Key words: Base saturation, Cation exchange capacity, *Pinus sylvestris*, Reforestation, Soil acidity

Introduction

Increased soil acidification caused by acidifying deposition may lead to the dissolution of toxic inorganic Al and a decrease in the amounts of Ca and Mg in the exchangeable nutrient pool in the soil. Compared with traditional stem-wood harvesting, an increase in the use of wood, and especially the harvesting of felling residues, will further increase the removal of nutrients from the forest and result in soil acidification (Nykvist and Rosen 1985, Olsson *et al*. 1996). Soil acidification can be counteracted by increasing the acid-neutralizing capacity of the soil. Practical methods of achieving this include liming and ash fertilization. Moreover, as N is known to be the main nutrient limiting the growth of boreal forests on mineral soils (*e.g.* Kukkola and Saramäki 1983, Tamm 1991), an additional aim of liming or adding ash has been to speed up mineralization of the considerable reserves of organic N in the organic layer, and thus improve the supply of N for tree growth.

Liming applied on the soil surface has brought about a short- and a long-term decrease in soil acidity and an increase in base saturation in both the organic layer and in the uppermost mineral soil layer in Scots pine and Norway spruce stands (Hallbäcken and Popivic 1985, Derome *et al.* 1986, Hüttl and Zöttl 1993, Abrahamsen *et al.* 1994, Kreuzer 1995, Ingerslev 1997). In Finnish liming experiments, decreased soil acidity and increased base saturation were still detected 20 years after liming. In contrast to expectations, however, liming has not brought an overall improvement in tree growth, but instead has often had a long-term detrimental effect on stand growth (Derome *et al.* 1986, Hüttl and Zöttl 1993). For instance, Derome *et al.* (1986) reported that the volume growth of Norway spruce stands decreased by about 10% during the 18-year period after liming, and that there was also a slight, but non-significant decrease in Scots pine stands.

The effects of liming have also been investigated in reforestation experiments, in which liming has been mixed into the top soil in connection with soil preparation. In these experiments, liming has not retarded the development of pine seedlings during the first years (Derome and Levula 1990, Levula 1990 and

1991, Palmgren 1984, Derome *et al.* 2000). In fact, mixing the limestone into the topsoil could be one means of avoiding the sharp increase in pH that has been reported to have an adverse effect at least on the short-root development of both seedlings and mature Norway spruce trees, as well as on B availability (Lehto 1994a and 1994b, Lehto and Mälkönen 1994).

A cheaper and more sustainable alternative to liming is the use of wood ash. The increasing use of wood as a source of bioenergy is expected to result in an increased availability of wood ash in large quantities. Instead of being deposited as waste on landfills at considerable cost, the ash could be recycled in the forests. Most of the inorganic nutrients (except N) and trace elements in wood are retained in the ash during combustion. Wood ash is, at the same time, a source of nutrients and a liming agent. Hence, wood ash could be added to mineral soils not only as a method to counteract natural and anthropogenic soil acidification, but also as a means of counteracting the long-term depletion of nutrients in forest ecosystems that have been intensively harvested. In fact, a decrease in soil acidity and an increase in base saturation following the application of loose wood ash to forested mineral soils have been widely reported (Khanna *et al.* 1994, Bramryd and Fransman 1995, Kahl *et al*. 1996, Eriksson 1998, Saarsalmi *et al.* 2001, 2004, 2005 and 2006, Ludwig *et al*. 2002).

It is generally accepted that wood ash has a positive effect on the growth and yield of agricultural crops (Naylor and Smith 1989, Demeyer *et al.* 2001). A positive growth response has also been obtained in coniferous stands after the addition of wood ash on N-rich peatland sites (Silfverberg 1996, Moilanen *et al*. 2002 and 2004), and sometimes also on fertile upland sites (Jacobson 2003). A positive growth increment has also 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 N application was no longer detected (Saarsalmi *et al.* 2006). However, according to the experience gained in ash experiments in middle-aged stands on relatively infertile mineral soil sites with a C/N ratio > 30 in Fennoscandia, the trees usually show no growth response at all to wood ash or, in some cases, even a slight decrease in growth (Sikström 1992, Jacobson 2003, Saarsalmi *et al*. 2004 and 2005). In contrast, a positive response to wood ash has sometimes been reported in young stands (Tamminen 1998, Perkiömäki *et al.* 2004, Mandre *et al.* 2006).

The aim of this study was to investigate the effects of wood ash and liming, applied on the soil surface, on soil chemical properties and growth of Scots pine transplants on a reforestation area on acidic forest soil. The effect of mixing wood ash or limestone into the topsoil on the success of the reforestation was also investigated.

Material and methods

A reforestation experiment was established in a clearcut area at Ruokolahti (61º23' N, 28º35' E, 95 m a.s.l.), eastern Finland, in the summer of 1990. The Scots pine stand on the *Calluna vulgaris* site type (Cajander 1949) had been harvested in winter 1989-1990. The average thickness of the organic layer was 3.6 cm. The soil texture of the uppermost 0-20 cm mineral soil layer was sorted sand, and the soil type was Haplic Podzol (FAO-UNESCO 1988). The average thickness of the Eh, Bhs and Bs horizons was 5, 9 and 17 cm, respectively.

A split-plot design with a total of 36 sample plots (Jeffers 1960) was used in the establishment of the experiment. The fertilizer treatments consisted of an unfertilized control, liming at three levels of dolomitic limestone (1.0, 2.0 and 4.0 t ha^{-1}) and ash application at two levels of wood ash (2.5 and 5.0 t ha^{-1}) on 35 m x 35 m plots with six replications (Table 1). The finely ground limestone and loose wood ash were spread on the surface of the soil on 21st to 22nd, August, 1990. On three of the replications, the limestone and the wood ash was mixed into the topsoil (20 cm) using disc ploughing on 14th September, 1990. In spring 1991, the 2-year-old pine transplants (*Pinus sylvestris* L.) of local origin were planted for the experiment.

The tree stand was measured in autumn 1993 and in autumn 2005, *i.e.* 3 and 15 growing seasons after planting. A 25 m x 25 m sub-plot was delimited on each sample plot for the tree stand measurements. The number of living trees was counted. The breast height diameter of all the living trees on the sub-plots was measured with an accuracy of 1 mm from two directions. Tree height was measured on every fifth tree

Table 1. The amount of Ca, Mg, K and P applied in the limestone (L) and wood ash (A) in the different treatments. Lime/ash was applied either on the soil surface (unploughed or it was mixed into the topsoil by ploughing (ploughed plots)

Treatment	Dose of ash and limestone applied in the treatments, t ha^{-1}	Nutrients applied, kg ha^{-1}			
		Ca	Mg	K	P
C (control)	-	-	-	-	-
L1	1.0	231	41	0.4	0.3
L2	2.0	463	81	0.8	0.6
L4	4.0	926	162	1.1	1.2
A2.5	2.5	412	32	47	16
A5	5.0	824	65	118	31

using a Vertex hypsometer with an accuracy of 1 dm. The parameters of the height curve model presented by Näslund (1937) were calculated separately for each treatment using the BMDP/PAR programme. The volume of each tree was then estimated on the basis of breast height diameter and the estimated tree height using a function by Laasasenaho (1982).

On the unploughed plots, soil samples were taken from the organic layer (L + F + H horizons) and the mineral soil using a cylinder (d = 58 mm) at the depth of 0–10 cm in November 2005. Samples were taken systematically at 20 sampling points and bulked by layer. The thickness of the organic layer was measured at the beginning of the study and in conjunction with soil sampling. The organic layer samples did not include living plant material.

The soil samples were dried in a ventilated chamber at a temperature of 30-40ºC. The organic layer samples were ground in a mill with a 2 mm bottom sieve, and the mineral soil samples were passed through a 2 mm sieve to remove gravel and larger roots.

Total N and C were determined on both the organic layer and mineral soil samples with a CHN analyser (Leco). Plant available nutrients and exchangeable acidity (EA) were determined on the soil samples by extraction with 0.1 M $BaCl_2$, followed by analysis by ICP-AES (ARL 3580). EA was determined by titration of the extract to pH 7.0. Soil pH was determined in a water suspension with a ratio of 10 ml of sample and 25 ml of distilled water. The analytical methods are described by Halonen *et al.* (1983).

The cation exchange capacity (CEC) was calculated as the sum of equivalent values of extractable Ca, Mg, K and Na and EA. Base saturation was calculated as the proportion of base cations out of CEC.

Statistical significance of the differences in the soil and stand parameters between different treatments were tested using analysis of variance. Treatment effects on the soil and stand parameters compared to the control were tested with Dunnett's test. Regression analysis was used to estimate the response of some soil parameters to the nutrient amounts added in wood ash and limestone (cf. Figs. 1 and 3). In all the statistical tests the significance level was set at p≤0.05.

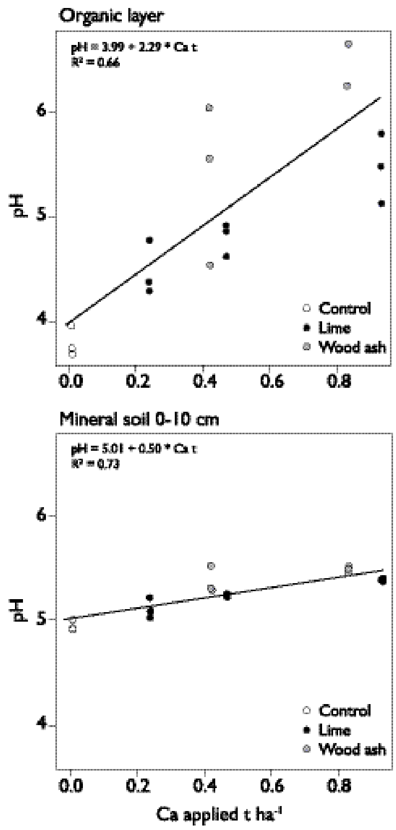

Figure 1. Response of the pH in the organic and 0-10 cm mineral soil layers to the amount of Ca added in the different doses of limestone and wood ash on the unploughed plots. See explanations in Table 1

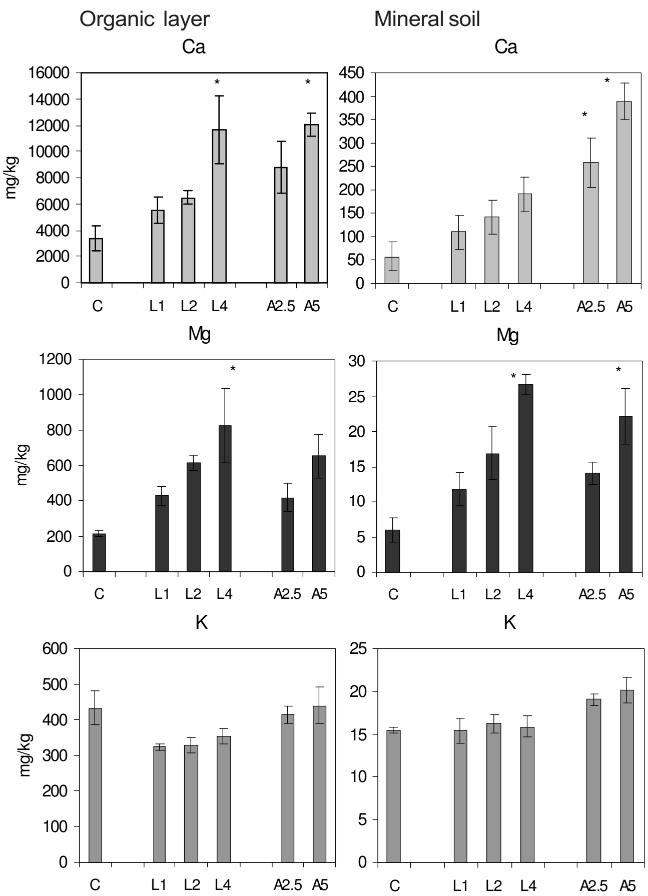

Figure 2. Extractable Ca, Mg and K concentrations in the organic and 0-10 cm mineral soil layers 15 years after the treatments on the unploughed plots. See explanations in Table 1. Standard error of the mean is marked on the columns by bars. Mean values marked with * within the same variable differ significantly ($p < 0.05$) from the control according to Dunnett's test

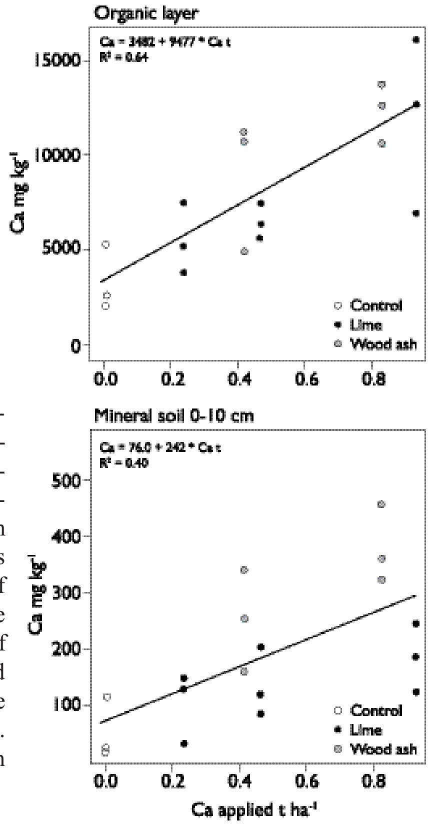

Figure 3. Response of the extractable Ca concentration in the organic and 0-10 cm mineral soil layers to the amount of Ca added in the different doses of limestone and wood ash on the unploughed plots. See explanations in Table 1

Results

Soil chemistry

Wood ash application and liming elevated the pH both in the organic layer and in the 0-10 cm mineral soil layer (Table 2). On the plots treated with doses of 2.5 and 5 t ha^{-1} of ash the increase in the organic layer pH after 15 years was 1.6 and 2.7 pH units, respectively. The corresponding increase on the plots treated with 1, 2 and 4 t ha^{-1} of lime was 0.7, 1.0 and 1.7 units, respectively. Depending on the dose, the increase in the mineral soil pH on the plots treated with ash was 0.4-0.5 units higher than on the control plots and on those treated with lime 0.2-0.4 units higher. Although the pH response was dose dependent within the fertilization regime, the amount of Ca added in ash gave a stronger pH response in both the organic layer ($p = 0.002$) and in the mineral soil ($p = 0.002$) than the same amount of Ca added in lime (Fig. 1). Thus, for example, the pH increase per 0.5 t ha^{-1} of applied Ca was 1.65 and 0.86 pH units in the organic layer for ash and lime, respectively (Fig. 1). In the mineral soil the corresponding increases were 0.31 and 0.21 pH units, respectively.

Exchangeable acidity (EA) showed a significant and dose-dependent decrease in the ash and lime treatments in the organic layer (Table 2). Liming decreased EA in the organic layer by 66-92% and ash application even more, by 82-98%.

Both wood ash application and liming increased the extractable Ca concentration in the organic layer, but the increase was significant only with the highest dose of ash and lime (Fig. 2). In these treatments, the increase in the Ca concentration after 15 years was 3.4- to 3.5-fold that on the control plots. No significant difference was found between ash and lime with respect to the extractable Ca concentration in the organic layer for the same amount of applied Ca (Fig. 3). In the mineral soil, however, the amount of Ca added in ash gave a significantly stronger response in the soil Ca concentration than the same amount of Ca added in lime (Fig. 3). In comparison to the control plots, the increase in the Ca concentration in the mineral soil was 6.8-fold and 3.3-fold with the highest dose of ash and lime, respectively.

In the organic layer, the extractable Mg concentration was 4- and 3-fold compared to that on the control plots with the highest dose of lime and ash, respectively (Fig. 2). In the mineral soil the corresponding increase was 4-fold. The treatments had no effect on the extractable K concentration in either the organic layer or mineral soil.

Wood ash and lime increased the CEC in the organic layer but not in the mineral soil (Table 2). In comparison to the control plots, the increase in CEC in the organic layer was 1.8- and 2.3-fold with doses of 2.5 and 5 t ha^{-1} of ash, respectively. The corresponding increase with doses of 2 and 4 t ha^{-1} of lime was 1.4- and 2.3-fold, respectively. Depending on the dose, ash application resulted in a significant 41 to 47%

Table 2. Mean pH, exchangeable acidity (EA), effective cation exchange capacity (CEC), and base saturation (BS) in the organic layer and in the mineral soil 15 years after the treatments on the unploughed plots. See explanations in Table 1. Standard error of the mean is given in parentheses. Mean values marked with bold differ significantly ($p < 0.05$) from the control according to Dunnett's test

Treatment	pH	EA	CEC	BS
		mmol/kg		
Organic layer				
C	3.81 (0.08)	85.3 (12.5)	286 (37)	68 (7)
L1	**4.49** (0.15)	**28.6** (12.5)	349 (48)	**91** (3)
L2	**4.81** (0.09)	**16.2** (3.0)	399 (28)	**96** (1)
L4	**5.47** (0.20)	**6.9** (3.0)	**667** (131)	**99** (0)
A2.5	**5.38** (0.44)	**15.1** (11.6)	502 (92)	**96** (4)
A5	**6.52** (0.13)	**0.2** (0.2)	**669** (34)	**100** (0)
Mineral soil, 0-10 cm				
C	4.95 (0.03)	15.7 (2.2)	20 (4)	18 (4)
L1	5.11 (0.06)	15.8 (2.0)	23 (4)	29 (5)
L2	**5.23** (0.01)	13.2 (0.3)	22 (2)	**40** (5)
L4	**5.38** (0.01)	**9.2** (0.6)	22 (2)	**57** (3)
A2.5	**5.36** (0.07)	9.8 (1.7)	25 (1)	**59** (9)
A5	**5.47** (0.02)	**8.7** (0.3)	31 (2)	**71** (2)

increase and liming a 34 to 46% increase in base saturation in the organic layer (Table 2).

Wood ash and liming had no significant effect on either the total N concentration or the C/N ratio in the organic layer and mineral soil layer (Table 3). Neither was there any significant response to ash or lime in the amount of organic matter in the organic layer.

Table 3. Total N concentration and C/N ratio in the organic and 0-10 cm mineral soil layers, and amount of organic matter (OM) in the organic layer 15 years after the treatments on the unploughed plots. See explanations in Table 1. DM = dry matter

Treatment	Organic layer						Mineral soil			
	N, g kg^{-1} OM		C/N		OM, t ha^{-1}		N, g kg^{-1} DM		C/N	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
C	17.4	0.2	33	0.4	38.2	6.0	0.90	0.06	33	1.3
L1	19.2	0.4	30	0.7	32.4	3.6	1.00	0.06	32	0.1
L2	19.1	0.0	30	0.1	33.3	5.4	0.97	0.09	33	1.9
L4	19.4	0.8	30	1.2	29.3	2.5	0.93	0.03	30	0.5
A2.5	18.7	0.6	31	0.9	33.3	5.6	1.03	0.07	32	0.4
A5	18.8	1.2	31	2.0	34.6	4.6	0.97	0.09	33	0.8

Growth

Liming and wood ash application seemed to increase height growth of the pines when lime or ash was applied on the soil surface without mixing it into the topsoil by ploughing (Table 4). On the plots treated with 2.5 and 5 t ha^{-1} of ash the mean height after 15 years was 24 to 27% greater than that on the control plots. On the limed plots the corresponding height increase was 14 to 23%. There was also a tendency towards an increase in the breast height diameter growth of the pines caused by surface broadcast of ash and liming. Neither liming nor ash application had any significant effect on survival of pine trees (Fig. 4). Liming or ash application after being mixed into the surface soil by ploughing had no effect on height growth of the pines, except for the highest lime dose (Table 4). On the other hand, ploughing as such had a significant increasing effect on height growth and also survival of the pines (Table 5).

Table 4. Stand characteristics 3 (1993) and 15 (2005) years after the treatments. On the plots lime/ash was applied either on the soil surface (unploughed plots) or mixed into the topsoil by ploughing (ploughed plots). See explanations in Table 1. Mean values marked with bold differ significantly ($p < 0.05$) from the control according to Dunnett's test

Stand characteristic	Treatment	unploughed plots		ploughed plots	
		Mean	S.E.	Mean	S.E.
Height$_{1993}$, m	C	1.17	0.06	1.48	0.17
	L1	1.12	0.03	1.59	0.17
	L2	1.22	0.14	1.52	0.20
	L4	1.20	0.00	1.46	0.20
	A2.5	1.34	0.07	1.49	0.16
	A5	1.27	0.07	1.44	0.06
Height$_{2005}$, m	C	4.05	0.20	5.42	0.20
	L1	**4.61**	0.16	5.30	0.10
	L2	**4.99**	0.13	5.37	0.15
	L4	**4.69**	0.14	**6.04**	0.18
	A2.5	**5.03**	0.08	5.53	0.14
	A5	**5.14**	0.17	5.51	0.07
D1.3, cm	C	6.65	0.59	7.60	0.55
	L1	7.72	0.51	7.41	0.29
	L2	7.21	0.36	7.49	0.38
	L4	7.37	0.52	7.44	0.42
	A2.5	7.63	0.26	7.60	0.38
	A5	7.89	0.53	7.85	0.27
Volume, m^3 ha^{-1}	C	17.24	3.92	36.56	8.00
	L1	12.70	0.76	35.30	6.68
	L2	16.34	4.57	34.67	4.61
	L4	20.16	1.83	34.68	7.57
	A2.5	24.91	2.10	37.85	5.96
	A5	24.36	1.84	35.30	3.94

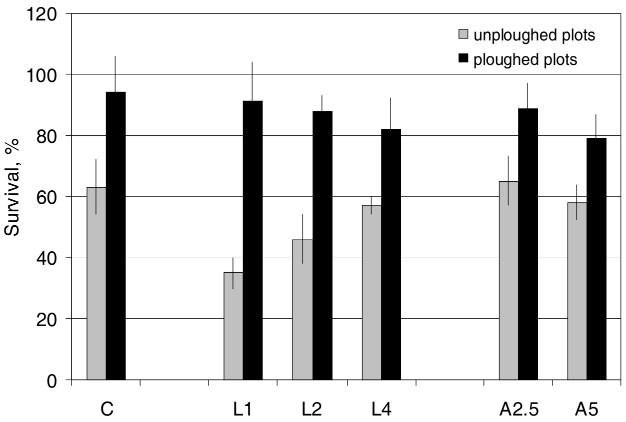

Figure 4. Survival of pines 15 years after the treatments, as percentage of the pines planted on the unploughed and ploughed plots. See explanations in Table 1

Table 5. Two-way ANOVA for the lime/ash and ploughing treatments and estimated marginal means for the ploughing treatment. See explanations in Table 1

Effect	df	F_{value}	p_{value}
Height$_{1993}$			
Lime/ash	5	0.12	0,986
ploughing	1	13.42	0.001
Lime/ash * ploughing	5	0.41	0.840
Height$_{2005}$			
Lime/ash	5	5.50	0.002
ploughing	1	81.67	0.000
Lime/ash * ploughing	5	4.93	0.003
D1.3			
Lime/ash	5	0.68	0.643
ploughing	1	0.38	0.544
Lime/ash * ploughing	5	0.50	0.774
Volume			
Lime/ash	5	0.62	0.684
ploughing	1	34.02	0.000
Lime/ash * ploughing	5	0.40	0.842
Survival			
Lime/ash	5	1.04	0.420
ploughing	1	46.44	0.000
Lime/ash * ploughing	5	1.29	0.301

Stand characteristic	unploughed	ploughed
H_{1993} (m)	1.22	1.50
Range	0.99-1.48	1.06-1.84
H_{2005} (m)	4.75	5.53
Range	3.65-5.32	5.10-6.27
$D1.3_{2005}$ (cm)	7.41	7.57
Range	5.52-8.70	6.62-8.64
Vol_{2005} (m^3 ha^{-1})	19.3	35.7
Range	9.1-29.0	22.7-50.4
$Survival_{2005}$ [1)]	54	87
Range	30-78	64-112
n	15	15

1) Survival of pines in 2005, % of those planted in 1991.

Discussion

In accordance with our results, decreased acidity and increased base saturation in the organic layer following liming and wood ash application have also been reported in several earlier studies (*e.g*. Hallbäcken and Popovic 1985, Derome *et al*. 1986, Khanna *et al.* 1994, Bramryd and Fransman 1995, Kreuzer 1995, Kahl *et al.* 1996, Saarsalmi *et al*. 2001 and 2006, van Hees *et al*. 2003).

The neutralization effect of lime and wood ash on forest soil can last for a considerable period of time. In our study the response of soil acidity and base saturation to liming and wood ash application was still evident after 15 years. Nihlgård *et al.* (1996) found increased concentrations of exchangeable Ca 70 years after the application of 5-20 ha^{-1} of lime. In coniferous stands in Finland, the increase in base saturation 20 years after liming with 2 t ha^{-1} was still about 20-40% (Derome *et al.* 1986). In Finland, Saarsalmi *et al.* (2001) reported significant increases in pH and base saturation 16 years after wood ash application with 3 t ha^{-1}. Liming and wood ash application is, however, associated with some undesirable effects. Nitrate leaching, accumulation of heavy metals and in the case of liming also B deficiency, are of great concern.

According to Smolander *et al.* (1996), the effects of liming on substrate quality are unfavourable; decreasing slightly the degradability of the needle litter. They concluded that this might contribute to the long-term accumulation of organic matter in the organic layer reported in long-term field experiments after liming (Derome *et al*. 1986). Liming did not, however, affect the amount of organic matter in a young plantation on a reforestation area in our study. The result that liming and wood ash had no effect on the C/N ratio either in the organic layer or in the mineral soil in our study is in agreement with the experience usually gained in coniferous stands (Derome *et al.* 1986, Saarsalmi *et al.* 2001, 2004 and 2005).

Nutrient management has been used successfully to ensure the survival and growth of seedlings and newly established stands on nutrient-poor sites, especially on former heathland (mostly *Calluna* heath) in parts of Denmark, Iceland and Norway (Ingerslev *et al.* 2001). In Finland, on the other hand, fertilization has not improved the initial development of upland forest seedling stands because tilling usually increases the availability of nutrients, and because the nutrient requirements of the seedlings are small (Viro 1966, Leikola and Rikala 1974). The effect of fertilization on seedling stands has also been reported to be negligible (Viro 1966) because the nutrients added as fertilizers are mainly used by the understorey vegetation.

The results of this study indicate that both wood ash and liming can have a positive effect on the growth of Scots pine transplants on a reforestation area. The reason for this is unclear, because it has been observed earlier that the growth is dependent, in the first place, on N on these poor pine sites (Viro 1967, Derome *et al*. 1986). However, similarly to the results obtained in our study, Tamminen (1998) also reported a significant increase of 14 to 39% in annual height growth compared to the control 3 to 6 years after wood ash application in a Scots pine seedling stand on relatively infertile mineral soil. In a young Scots pine plantation on infertile mineral soil, Perkiömäki et al. (2004) found an increase in stem volume 16 years after wood ash application with a dose of 3 t ha^{-1}. Mandre *et al.* (2006) reported that the addition of wood ash in doses of 2.5 t ha^{-1} favoured to some extent growth (height, diameter and stem biomass) in a 18-year-old Scots pine stand growing on a dry site type, although not significantly, during the 2-year period after the treatment. In contrast to the results obtained in our study, Mandre *et al*. (2006) stated that the height of the trees was less affected by wood ash application than the breast height diameter. They further reported that a dose of 5 t ha^{-1} of wood ash decreased the diameter increment and biomass of the trees. Similarly, Prescott and Brown (1998) reported that an addition of wood ash (5 t ha^{-1}) to a young western red cedar (*Thuja plicata* Donn ex D. Don) plantation on N-poor soil in British Columbia resulted in a significantly reduced height growth during the 5-year period following ash addition. However, in our study both of the ash doses (2.5 and 5 t ha^{-1}) increased height growth similarly during the 15-year period.

Soil preparation using ploughing after wood ash or lime application almost totally obscured the effects of lime and ash. Soil preparation has proved to enhance the physical and chemical properties of forest soil, and thus to increase the success of reforestation and seedling growth (Mälkönen 1976, Pohtila 1977, Palmgren 1984, Ritari and Lähde 1978, Levula 1990 and 1991). The increase in soil temperature caused by soil preparation has an increasing effect on the biological properties of the soil (Voss-Lagerlund 1976, Palmgren 1984). Soil preparation has usually been carried out on moister sites than the site in our study, and one of the reasons for the positive growth response obtained in those experiments is assumed to be the improved drainage and temperature (Ritari and Lähde 1978). Soil preparation also makes stand establishment easier. The role played by soil management in increasing plant available nutrients is also emphasized, as was probably the case in our study.

Conclusions

Surface broadcast of wood ash and lime on a reforestation area lead not only to an increase in soil pH and base saturation but also to an increase in height growth during the 15-year study. The reason for this important result is unclear, because on these poor sites the growth is mainly dependent on N availability. Whether the reason for the growth increase was a change in the net rate of mineralization of N caused by ash and lime application needs further study. Soil ploughing after wood ash and lime application almost totally obscured the effects of lime and ash. This is probably mainly due to an increase in plant available nutrients caused by soil preparation, and also due to the fact that stand establishment becomes easier.

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ПРИМЕНЕНИЕ И ОГРАНИЧЕНИЕ ДРЕВЕСНОЙ ЗОЛЫ: ВЛИЯНИЕ НА ХИМИЧЕСКИЕ СВОЙСТВА ПОЧВЫ И РОСТ ПЕРЕСАЖЕННОЙ СОСНЫ ОБЫКНОВЕННОЙ

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Резюме

В восточной Финляндии исследовались воздействия различных доз древесной золы (2.5 и 5.0 т га$^{-1}$) и известняка (1.0, 2.0 и 4.0 т га$^{-1}$) на химические свойства почвы и рост пересаженной сосны обыкновенной (*Pinus sylvestris* L.). Древесная зола и известняк вносились как на поверхность почвы, так и смешивались дисковым плугованием. Все действия повторялись трехкратно. Пробы почвы брались только с нетронутых плугом участков. Древесная зола и известняк снижали кислотность как в органическом слое, так и 0-10 cm слое минеральноного почвенного слоя, спустя 15 лет после обработки. Увеличение pH в органическом слое достигала 1.6 and 2.7 pH единиц на участках, обработанных золой 2.5 и 5 т га$^{-1}$, а на участках, обработанных известняком 1, 2 and 4 т га$^{-1}$ - 0.7, 1.0 и 1.7 pH единиц соответственно. В зависимости от дозы, при обработке золой базовая насыщенность в органическом слое увеличивалась значительно на 41 - 47%, а известняком – на 34 to 46%. Внесение золы и известняка значительно увеличивает рост. На участках, обработанных золой, средний рост после 15 лет был на 24-27% и на участках, обработанных известняком – на 14-23% больше, чем на контрольных участках. При обработке золой и известняком проявлялись признаки увеличения диаметра на уровне груди. При этом, обработка золой и известняком при смешивании поверхностного слоя дисковым механизмом не дает эффекта увеличения роста сосны, за исключением увеличения дозы известняка. Одновременно, дискование как таковое давало значительный эффект как на выживаемость, так и на увеличения роста деревьев.

Ключевые слова: базовая сатурация, способность обмена катионов, *Pinus sylvestris,* возобновление, кислотность почвы