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ASH FERTILIZATION IN OLD DRAINED SWEDISH PEATLAND FORESTS

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SUMMARY

Most earlier Swedish and Finnish experiences of the effects of wood ash on soil productivity on peatlands, are strongly positive. Investigations of the environmental effects, for example water quality and net effects on climate forcing gases, have so far not indicated reasons to refrain from this silvicultural measure. There is, however, still a need for further confirmation of these conclusions. Here, we report the effects of ash fertilization on the groundwater and on the nutrient status of pine (Pinus Silvestris (L.)) needles, three years after ash treatment, on five old-drained and forested peatlands in Northern Sweden. The series of trial areas comprises five sites, spread from lat. 62o N to 64.5o N. All sites have moderately deep peat (minimum 0.5 m to ca 1.5 m). The treatments, 0 (control), 5 and 10 tonnes of granulated wood ash per hectare, are repeated 2 – 6 times on each site. The ash treatment had only weak general effects on ground water quality after three years. The concentrations of potassium and sulphate increased, compared to control, whereas ammonium nitrogen showed decreased concentrations on most of the sites. The ash treatment did not affect pH or calculated alkalinity. Likewise, it did not affect leaching of nitrate, phosphate, or the total concentration of organic carbon (TOC) in the water. The groundwater concentration of methyl mercury appeared not to be affected. The ash treatment improved tree nutrition. Needle concentrations of phosphorus, potassium, sulphur, boron and silicon increased. The contents of magnesium decreased somewhat. Calcium and nitrogen, and some other minor elements, were not affected. Our results confirm that the main features of earlier findings are valid for large parts of Sweden and for old-drained peatland forests. Additionally, in the specific study of possible ash effects on methyl mercury in the groundwater, no significant effects were found.

Keywords: -

INTRODUCTION

Plant growth on boreal organic soils is often restricted by the availability of some mineral nutrients and the harvest of plant biomass from drained peatlands can result in severe deficiency symptoms and decreased production. This was made clear by agricultural experience in Northern Europe more than a century ago. Experiments with wood ash amendments of peatlands, to compensate for the element deficiencies and improve forest growth conditions, were established in Sweden and Finland (Malmström, 1935; Lukkala, 1955; Silfverberg and Huikari, 1985). Despite good results in terms of significantly increased growth and yield, ash fertilization of peat soils did not become a common silvicultural measure for most of the 20th century. Instead, wood ash additions to *mineral* forest soils have been recommended by forest authorities since the 1980´s. The purpose of that treatment, however, is different. It is intended to (1) compensate for the increased mineral nutrient export coupled to more intensive biomass harvesting and (2) counteracting ongoing soil and water acidification. Future ash fertilization of forested peat soils in Sweden, if implemented, will concern only areas of long time drained and forested peatlands, which are presently managed for forestry. The main motive for such ash fertilization would be to maintain or even enhance soil fertility, after the inevitable export of mineral nutrients with the harvested biomass. Investigations of the environmental effects, for example water quality and net effects on climate forcing gases, have so far not indicated reasons to refrain from wood ash fertilization of peatland forests (Ernfors *et al.,* 2010; Klemedtsson *et al.,* 2010; Ring *et al.,* 2011; Rütting *et al.,* 2014; Sikström *et al.,* 2012). There is, however, still a need for further confirmation of these conclusions. This study reports on effects of ash fertilization on groundwater quality and on the nutrient status of Scots pine needles, three years after ash treatment of five old-drained and forested peatland sites in Northern Sweden.

MATERIAL AND METHODS

The selection of experimental sites was designed both for this study and a subsequent survey of the tree production. The series of trial areas comprises five sites, spread from lat. 62° N (site S1) to 64.5° N (site S5). All sites had moderately deep peat (ca 0.5 - 1.5 m). The tree stands were pure or mixed medium aged Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.). Silver birch (*Betula pendula* Roth) and downy birch (*Betula pubescens* Ehrh.) occurred as complementary species. The treatments included 0 (control), 5 and 10 tons of granulated wood ash per hectare, represented by sample plots sized 30 x 30 m (net plot 20 x 20 m), or 30 x 40 m (net plot 20 x 30 m). Each treatment was repeated 2 – 6 times on each site. The ash used was a drum granulated fly ash from wood biomass with a mixed in peat proportion of 30% (Table 1). The ash was spread by helicopter in November 2011.

Water sampling

Ground water samples were collected from all experimental sites during September 1-12, 2014. Temporary ground water wells were made with a soil auger (diameter 7.5 cm). The depth of the well was decided by the current groundwater level, in order to collect the most recently formed (uppermost) ground water. On plots with slightly sloping ground surface the well was dug at a downslope position (often close to a drainage ditch). On plots without discernible slope, lacking a bordering ditch, the well was dug at the plot centre. The average well depth was 0.7 m. The wells were left until the next day, when the water samples were collected through PTFE tubing by means of a hand-held evacuation pump connected to a sampling bottle. Water samples for methyl mercury analyses were collected in separate (glass) bottles.

Table 1: Chemical characteristics of the applied wood ash

General			
Loss on ignition (Org C), % of DM: 12.1			
pH (H_2O):	12,34		
Lime effect, % of CaO:	22		
Main elements, % of DM		***Trace elements, mg/kg DM***	
Al	2.9	As	14
Ca	17	B	130
Fe	2.5	Pb	67
K	3.3	Cd	8,3
Mg	1.9	Co	14
Mn	0.77	Cu	85
Na	1.5	Hg	0,2
P	0.97	Mo	6,9
S	1.4	Ni	53
Si	15	Zn	1640

Needle sampling

Needle samples were collected in October 2014. Only Scots pine trees were sampled since this species was found on all plots. Annual shoots from the upper part of the canopy, within the sector SW – SE, were cut with pruning shears, extendable up to 14 m. A sample of 10-15 needle pairs was collected from each of ten randomly selected pines at each net plot.

Water analyses

The following variables were determined in ground water: pH, TOC (organic carbon), elemental Na^+, K^+, Mg^{2+}, Ca^{2+}, Al^{n+}, N-NH_4^+, N-NO_3^-, P-PO_4^{3-}, F^-, Cl^-, S-SO_4^{2-}, and methyl mercury (MeHg). pH was determined in a Mettler-Toledo instrument with a Mettler-Toledo Inlab combination electrode. TOC was determined in a Shimadzu TOC-V instrument. An Omniprocess Autoanalyzer AA3 Spectrofotometer was used to determine NH_4^+, NO_3^- and PO_4^{3-}. For the other anions a Dionex ICS90 instrument with a AS-DV auto sampler and a AS22 Dionex column was used. MeHg in groundwater was determined on a GC-ICP-MS instrument, after isotope dilution, extraction and ethylation. ANC (Acid Neutralizing Capacity) was calculated as the difference between sum of charges for non-acid cations (Ca + Mg + K + Na) and sum of charges for conservative anions, except fluoride (Cl + NO_3 + SO_4).

The detection limits for analysed variables were as follows:
TOC = ca. 0,5 mg L^{-1}; N-NH_4, N-NO_3 and P-PO_4 = <10 ng L^{-1}; Na = 0,01 mg L^{-1}; K = 0,02 mg L^{-1}; Mg = 0,001 mg L^{-1}; Ca = 0,02 mg L^{-1}; Al = 0,001 mg L^{-1}; F = 0,2 mg L^{-1}; Cl = 0,2 mg L^{-1};S-SO_4 = 0,1 mg L^{-1}; ; MeHg = 0,03 ng L^{-1}.

Needle analyses

After drying of needles (70° C, 3 days), 100 randomly selected needle pairs were weighed and the 100-needle weight for the plot was registered. The whole sample was then ground in a ball mill. The needles were analysed for total content of macronutrients N, K, Ca, Mg and S, micronutrients B, Fe, Cu, Mn, Na, Si and Zn, and the content of Al. N and P were determined after Kjeldahl digestion in 8% sulphuric acid with an Omniprocess Autoanalyzer AA3 Spectrofotometer, whereas the determination of other elements was made after digestion in concentrated HNO_3 with a Spectro Ciros Vision ICP-OES instrument.

Statistical analyses

Differences between ash fertilizing treatments 0, 5 and 10 t ha^{-1}, regarding both groundwater and needle analyses, were tested with linear analysis of variance (ANOVA). In addition to treatment (TREAT) also experimental site location (SITE) and block No. (BLOCK) were included in the model used to explain the variation of the effect variable Y:

$$Y = constant + TREAT + SITE + SITE \times TREAT + SITE(BLOCK)$$

The interaction factor SITE x TREAT was included to explain the variation relating to the fact that the effect of a certain treatment may differ between sites. As well, a certain treatment may have different effects in different parts of an experimental site. Therefore, also the factor SITE(BLOCK) was used in the model. The collected data were compiled in EXCEL 2010 and the statistical analyses were made with the SYSTAT 13.1 software.

RESULTS

Ground water analyses

The wood ash fertilization effects on groundwater, 3 years after the amendment, were very weak (Table 2). The only significant effects showed in the contents of ammonium (NH_4), sulphate (SO_4) and potassium (K) (Figure 1). The ammonium concentrations on plots treated with 5 or 10 tons ash per hectare were significantly lower than on control plots ($p = 0.039$ and 0.025, respectively). The sulphate concentration increased with increasing ash dose (10 t > 0 t; $p = 0.042$). Similar to ammonium, the variation between sites was large and the statistical support for higher sulphate concentration with increased ash dose did not exist for all sites. Also the potassium concentration in groundwater was higher on plots that received the highest ash dose compared to control plots ($p = 0.048$). Total organic carbon, pH and calculated ANC did not show any effect of ash treatment (Table 2). The main cause of variation within these variables, similar to most other variables in Table 2, was the variation between sites (not shown).

The mean concentrations of methyl mercury ranged between 0.05 and 0.20 ng L^{-1}, varying mainly between sites. There were no systematic differences between ash treatments.

Table 2: Mean (m) and mean error (m. e.) for analyzed groundwater variables 3 years after ash treatments of 0, 5 or 10 tons ha^{-1}.
"ANC" denotes the calculated Acid Neutralizing Capacity. (N = 12-13).

	0 t ha^{-1}		**5 t ha^{-1}**		**10 t ha^{-1}**	
	m	*m.e.*	m	*m.e.*	m	*m.e.*
TOC, mg L^{-1}	66,71	*11,74*	54,19	*8,73*	62,49	*11,70*
pH	4,86	*0,23*	4,93	*0,22*	4,81	*0,23*
ANC, µmol L^{-1}	265	*54*	257	*36*	236	*21*
Al^{n+}, mg L^{-1}	1,24	*0,27*	1,16	*0,20*	1,29	*0,22*
Ca^{2+}, mg L^{-1}	3,52	*0,63*	3,14	*0,41*	2,73	*0,30*
K^{+}, mg L^{-1}	0,46	*0,13*	0,78	*0,30*	1,17	*0,17*
Mg^{2+}, mg L^{-1}	0,91	*0,18*	0,81	*0,12*	0,72	*0,09*
Na^{+}, mg L^{-1}	1,14	*0,31*	1,35	*0,18*	1,55	*0,15*
N-NH_4^{+}, mg L^{-1}	0,67	*0,17*	0,49	*0,15*	0,36	*0,16*
N-NO_3^{-}, µg L^{-1}	21,79	*3,29*	29,54	*11,03*	25,15	*3,98*
P-PO_4^{3-}, µg L^{-1}	11,08	*4,42*	18,35	*11,99*	6,39	*0,86*
S-SO_4^{2-}, mg L^{-1}	0,38	*0,21*	0,45	*0,22*	0,80	*0,32*
MeHg, ng L^{-1}	0,09	*0,02*	0,09	*0,02*	0,11	*0,02*

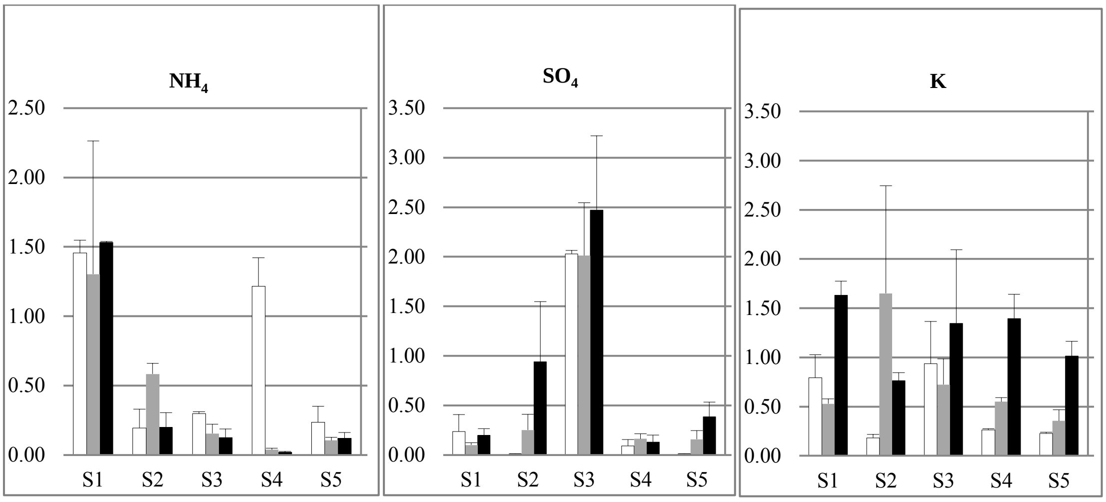

Figure 1: The concentrations (mg L^{-1}) of potassium (K), sulphate (SO_4) and ammonium (NH_4), in groundwater from sites S1 – S5, 3 years after amendments of 0, 5 or 10 t ha^{-1} (white, grey and black bars, respectively). Error bars indicate the error of the mean. (N = 2-3).

Needle analyses

The current-year needles of some trees on ash treated plots had a darker green colour compared to needles from trees on control plots, but differences between treatments were not consistent. Similarly, the 100-needle weight for some of the sites showed a nearly significant increase with ash dose, but the overall treatment means were not significantly different (Figure 2). The treatment mean 100-needle weight and mean error on control plots and on plots treated with 5 and 10 t ash ha^{-1} were 2.67 (0.12), 2.72 (0.16) and 3.06 (0.19), respectively.

The needle concentration of the macronutrients phosphorus, potassium and sulphur increased after the ash amendments of 5 and 10 t ha^{-1} (P: $p_{5t} = 0.001$, $p_{10t} < 0.000$: K: $p_{5t} < 0.000$, $p_{10t} < 0.000$: S: $p_{10t} = 0.018$), whereas the concentration of magnesium became lower (Mg: $p_{10t} = 0.014$) (Fig. 4). Nitrogen and calcium were not affected by the ash fertilization. Among the micronutrients, boron concentration was ca. 50% higher on plots that received 5 or 10 tons of ash per ha (B: $p_{5t} < 0.000$, $p_{10t} < 0.000$), and an increase also showed for silicon (Si: $p_{5t} = 0.010$, $p_{10t} = 0.002$) (Fig. 4).

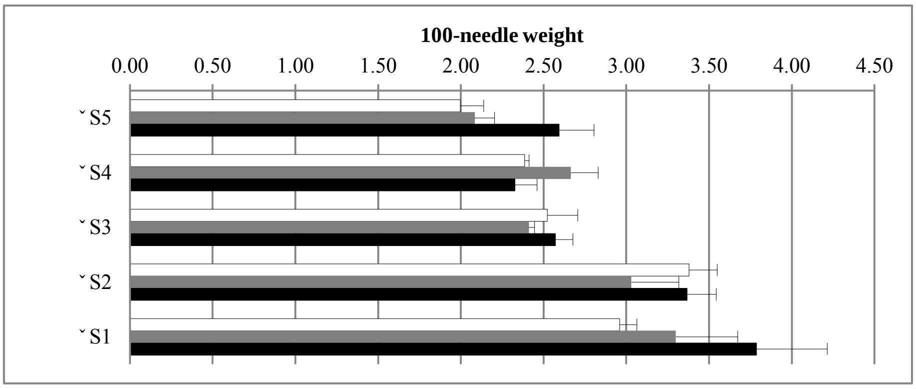

Figure 2: Mean and mean error for the dry weight (g) of 100 pine needle-pairs, by site and treatment, 3 years after ash treatments of 0, 5 or 10 tons/ha. (N = 2-6).

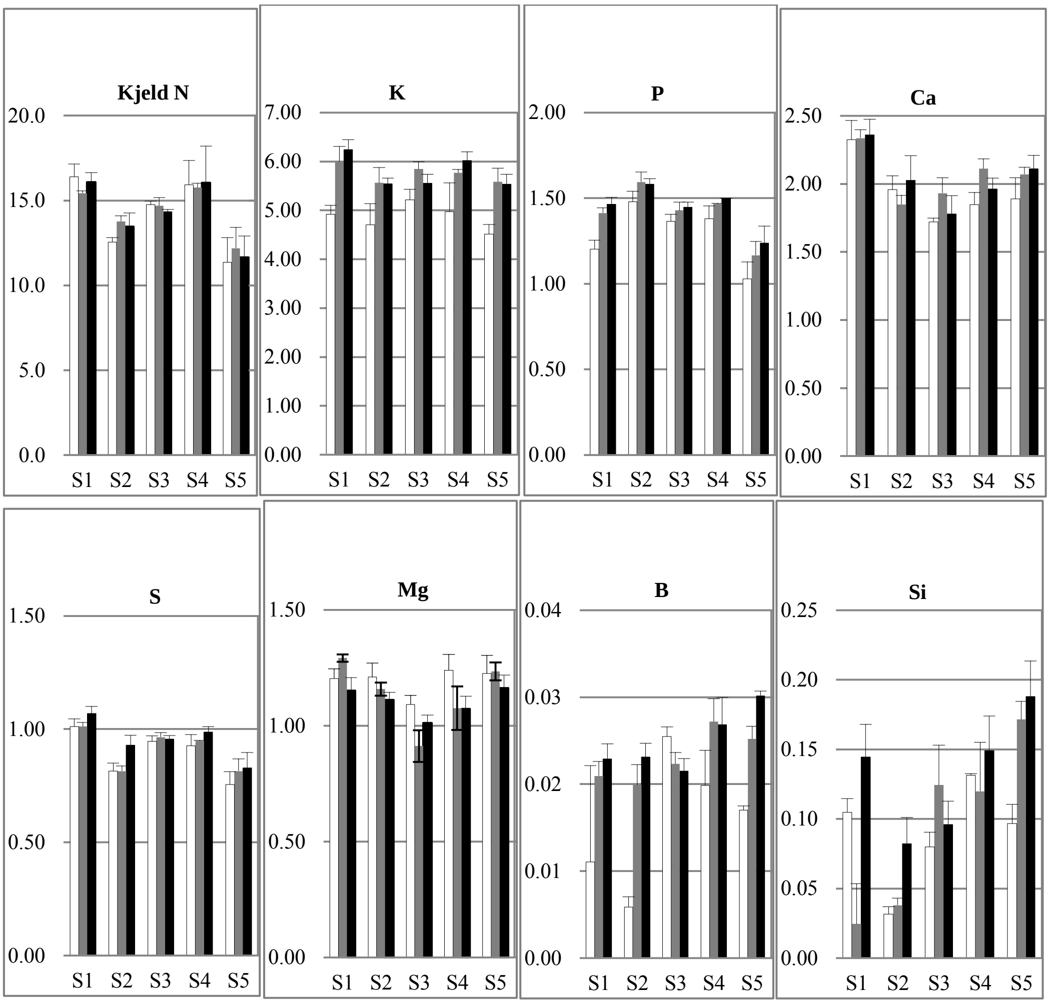

Figure 3: Total concentration (mg g^{-1}) of nitrogen (Kjeldahl), potassium, phosphorus, calcium, sulphur, magnesium, boron and silicon in pine needles, 3 years after ash treatments of 0, 5 or 10 tons/ha. Error bars indicate the error of the mean. (N = 2-6).

DISCUSSION

The wood ash amendment did not increase pH or the Acid Neutralizing Capacity (ANC) in the peat groundwater. Analyses of pH and ANC in runoff water from drains have often shown increases, but not always (Piiranen *et al.,* 2013). The fact that groundwater - not water from drains - was sampled in this study, may be an important difference. The cation exchange capacity of the unsaturated peat layer above the groundwater level is several times greater than the liming effect of 10 tons of ash ha $^{-1}$. The groundwater concentration of K and S increased significantly after an ash dose of 10 t per ha. Neither the eutrophying substances NO_3 and PO_4, nor the organic matter content (TOC), showed increases. These results are, in brief, similar to earlier reports by e.g. Nieminen *et al.* (2005), Piiranen *et al.* (2013) and Ring *et al.* (2011). At several sites, the NH_4 concentration in groundwater was lower on ash treated plots than on control plots. This could possibly be related to improved nutrient status, growth and thus increased assimilation of ammonium from the soil. Another reason may be enhanced nitrification that would intensify competition for mineralised ammonium.

According to diagnostic limit values for mineral nutrient content in pine needles published by Braekke (1994), the concentrations on control plots were within the class ”Optimal” for all elements, except N, K, P and Fe (Classes: Optimal, Sub-optimal, Deficient, Strongly deficient). The status for N, P and K were classified as ”Deficient”, whereas Fe was ”Sub-optimal”. After ash amendments, the macronutrients K, P, and S, and the micronutrients B and Si, all increased. The increase of K and B agrees with most of earlier reports on ash fertilization effects on needle nutrient status, e.g. Ferm *et al.* (1992) and Moilanen *et al.* (2005). These nutrients are commonly sub-optimal or deficient in peatlands and plant uptake is facilitated by the fact that K and B are mainly bound to easily soluble compounds in the ash. Phosphorus, besides K, is the most critical element limiting plant growth on peatlands. The P compounds in the ash are however poorly soluble, which may retard the increase of the needle P content. Still, in our study a significant increase of P in needles showed after three years. This agrees well with the earlier reports from Ferm *et al.* (1992) and Moilanen *et al.* (2005). The nitrogen content in needles was not affected by the ash amendments. This is in accordance with earlier experiences, which varies between increased, indifferent and somewhat lowered N content after ash fertilization (Silfverberg and Huikari, 1985, Moilanen *et al.,* 2002, Huotari *et al.,* 2015). The ash does not add any N at all. Therefore, increased N content in needles following ash amendments is an indirect effect, caused by gradually enhanced microbial turnover of the existing (organically fixed) nitrogen in the peat substrate.

REFERENCES

1. Braekke F H, 1994. Diagnostiske grenseverdier for naeringselementer i gran- og furunåler. NISK. Aktuellt fra Skogforsk Nr 15 -94, 11 pp.
2. Ernfors M, Sikström U, Nilsson M & Klemedtsson L, 2010. Effects of wood ash fertilization on forest floor greenhouse gas emissions and tree growth in nutrient poor peatland forests. Science of the total environment 408, pp. 4580-4590.
3. Ferm, A, Hokkanen, T, Moilanen, M & Issakainen, J, 1992. Effects of wood bark ash on the growth and nutrition of a Scots pine afforestation in central Finland. Plant Soil 147, pp. 305–316.
4. Huotari N, Tillman-Sutela E, Moilanen M & Laiho R, 2015. Recycling of ash – For the good of the environment? Forest Ecology and Management 348, pp. 226-240.
5. Klemedtsson L, Ernfors M, Björk R G, Weslien P & Rütting T, 2010. Reduction of greenhouse gas emissions by wood ash application to a Picea abies (L.) Karst. forest on a drained organic soil. European Journal of Soil Science 61, pp. 734-744.
6. Lukkala, O J, 1955. Maanparannusaineet ja väkilannoitteet metsäojituksen tukena II (Soil amelioration agents and fertilizers in the peatland forestry). Metsätaloudellinen Aikakauslehti 6–8, 273–276.
7. Malmström C, 1935. Om näringsförhållandenas betydelse för torvmarkers skogsproduktiva förmåga. Meddelanden från Statens skogsförsöksanstalt häfte 28 N:r 6, pp. 571-650.
8. Moilanen M, Silfverberg K, Hokkanen T J, 2002. Effects of wood-ash on the growth, vegetation and substrate quality of a drained mire: a case study. Forest Ecology and Management 171, 321–338.
9. Moilanen M, Silfverberg K, Hökkä H & Issakainen J, 2005. Wood ash as a fertilizer on drained mires growth and foliar nutrients of Scots pine. Canadian Journal of Forest Research. 35, pp. 2734–2742.
10. Nieminen M, Piirainen S & Moilanen M, 2005. Release of mineral nutrients and heavy metals from wood and peat ash fertilizers: field studies in Finnish forest soils. Scandinavian Journal of Forest Research. 20, pp. 146–153.
11. Piirainen S, Domisch T, Moilanen M & Nieminen M, 2013. Long-term effects of ash fertilization on runoff water quality from drained peatland forests. Forest Ecology and Management 287, pp.53-66.
12. Ring E, von Brömssen C, Losjö K & Sikström U, 2011. Water chemistry following wood-ash application to a Scots pine stand on a drained peatland in Sweden. Institute of Forestry and Rural Engineering, Estonian Agricultural University, Tartu, Estonia, Forestry Studies / Metsanduslikud Uurimused, 2011, 54, pp 54-70.
13. Rütting T, Björk R G, Meyer A, Klemedtsson L, Sikström U, 2014. Reduced global warming potential after wood ash application in drained Northern peatland forests. Forest Ecology and Management 328, pp. 159-166.
14. Sikström U, Björk R G & Klemedtsson L, 2012. Wood ash application reduced global warming potential over the five years after application in two drained peatland forests in Sweden. Proceedings of The International Peat Congress, Stockholm, Sweden, 3-8 June 2012.
15. Silfverberg K & Huikari O, 1985. Wood-ash fertilization on drained peatlands. Folia Forestalia 633. 25 pp.

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