Long-term leaching of nutrients from drained peatland after ash fertilisation

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Summary

The increased use of forest-based biofuels for energy production stresses also the utilisation of wood ash as a forest fertiliser. Wood ash contains considerable amounts of mineral nutrients, especially phosphorus (P) and potassium (K) that are usable by the ground vegetation and tree stands. On the other hand, wood ash does not contain any nitrogen (N). Therefore, N rich and simultaneously P and K poor drained peatlands are the best suitable sites for ash fertilisation. However, the concern about element leaching to watercourses has prevented any large-scale fertilisation. The objective of this study was to determine the leaching of nutrients and heavy metals from drained peatland catchments over a 10-year period following wood and peat ash applications. Both loose and granulated ashes were used. After 10 years, the concentrations of sulphur compounds accompanied by B, K, Cl, Ca, and Mg in drainage water were still slightly higher at wood ash treatments compared to the control. No increased leaching of P or N compounds was observed during the entire study period. The leaching of heavy metals was very low and not affected by ash treatments.

Key index words: drainage water, heavy metals, nitrogen, phosphorus

Introduction

As a member of the EU, Finland has committed to increase the share of renewable energy up to 38 % of the total energy consumption. This also means that utilisation of wood as a bioenergy source will increase. One avenue to achieve this is to enhance the use of chopped firewood, whose consumption is estimated to increase from 3.4 million m^3 in 2006 to 8-12 million m^3 by 2015 (Kansallinen metsäohjelma). In 2004 the energy and pulp industry produced 100 000-150 000 tons of wood ash (Korpilahti, 2004). If the scenario of forest-based bioenergy comes true, the amount of wood ash produced will be doubled. One suitable purpose of wood ash is to use it as a fertiliser on forested peatlands.

Peatland forests very often suffer from potassium (K) and phosphorus (P) deficiency and less fertile sites also from nitrogen (N) deficiency. Nitrogen is missing from wood ash, but the contents of K and P are high. Tree growth enhancing effects of wood ash are fast (Solla-Gullon *et al.*, 2006) and the influence is long-lasting (Moilanen *et al.*, 2005). Nutrient concentrations in the peat soil also increase for several years (Silfverberg, 1996). These observations indicate that the leaching of nutrients from wood ash is low. Wood ash contains also metals which do not affect tree growth or vigour, but they can be taken up passively by the vegetation. However, any accumulation of heavy metals in forest berries or mushrooms (Moilanen *et al.* 2006; Omil *et al.*, 2007), tree foliage (Solla-Gullon *et al.*, 2006; Saarsalmi *et al.*, 2006) or ground vegetation (Omil *et al.*, 2007; Ozolincius *et al.*, 2007a) has not been observed in ash fertilised areas so far. The reason for this low uptake by the vegetation is probably the increased soil pH decreasing the solubility of metals after ash fertilisation. Thus the leaching of heavy metals to watercourses will be low too. However, their leaching may increase once the liming influence of ash has vanished (McBride, 2003). The increased soil pH can also improve the mineralization of organic matter (Fritze *et al.*, 1994; Perkiömäki and Fritze, 2002) and the release of nutrients from the peat including N. Increased N concentrations in tree needles have been observed after ash fertilisation indicating improved N supply (Solla-Gullon *et al.*, 2006). However, in most studies the N concentrations in needles were not affected (Saarsalmi *et al.*, 2006; Ozolincius *et al.*, 2007b) or they even decreased (Moilanen *et al.*, 2005).

The objective of this study was to examine the leaching of nutrients (Ca, Mg, K, S, P, N, Mn, Al, Fe) and heavy metals (Cd, Cr, Ni) via drainage water from boreal catchments having different peat types and amounts of tree stock for 10 years after treatments with wood or peat ash.

Materials and methods

The study was carried out at 15 artificial peatland subcatchments. Twelve of them were at Pelso and Utajärvi in central Finland (64° N, 26° E) and three at Taavetti in southern Finland (60° N, 27° E). The subcatchments were formed by isolating an area of drained peatland by digging a surrounding ditch in August 1996 at Taavetti or in June–July 1997 at Utajärvi and Pelso. The Pelso site had been originally drained for forestry purposes in the 1930s and ditch cleaning was carried out in 1993. The Utajärvi site was drained for forestry in 1980–1981. The Taavetti site was drained for forestry in the 1960s and ditch cleaning was done in 1995. The Pelso site was dominated by *Carex* peat and the Utajärvi and Taavetti sites by *Sphagnum* peat. The tree stands were dominated by naturally regenerated Scots pine (*Pinus sylvestris* L.) at all sites. In the beginning of the study the stem volume was on average 52 m^3ha^{-1} at Pelso, 127 $m^3 ha^{-1}$ at Taavetti and 8 $m^3 ha^{-1}$ at Utajärvi.

Wood or peat ashes were applied in winter (March 1998) or in summer (June 1998) at Pelso and Utajärvi. Powdered ash (5000 kg ha^{-1}) and granulated ash (6500 kg ha^{-1}), prepared with the self-hardening process, were used. The treatments were: 1) powdered wood ash applied in summer (US), 2) granulated wood ash applied in summer (GS), 3) powdered wood ash applied in winter (UW), 4) granulated wood ash applied in winter (GW), 5) powdered peat ash applied in summer (UPS) and 6) control, no ash (C). At the Taavetti site the treatments were done in August-September 1997 and they were 1) granulated wood ash, 5000 kg ha^{-1}, prepared with self-hardening process (GS1), 2) granulated wood ash prepared in a rolling drum, 5000 kg ha^{-1} (GS2) and 3) control, no ash. The amounts of nutrients added to the site with each treatment are presented in Table 1.

Drainage water from the outlet of the isolating ditch was collected weekly or biweekly from 1997 to 2007 during the periods from May–October, with the exceptions of 2003 and 2006 when no sampling was done. Upon collection the samples were kept cold and transported to the laboratory the day after sampling. Samples were filtered through a Schleiche & Schuell ME 25 membrane filter (0.45 µm) and the filtrates were stored at -18 °C until analysed. Nitrate, $PO_4^{3-}$and SO_4^{2-}concentrations were determined by ion chromatography and NH_4 and total N concentrations were determined by flow injection analysis. Calcium, Mg, K, P, S, Al, Fe, Mn, Cd, Cr and Ni concentrations were determined with ICP/AES.

The monitoring of the study sites had started one year before the fertilisation and it has been continued for 10 years now. The weakness of this study was the missing treatment replicates at each study site. We assumed that after ten years the differences between the wood ash treatments would have been disappeared since the differences were small throughout the study period (Piirainen and Domisch, 2004). For this report the wood ash fertilised catchments were combined for wood ash treatment (WA) and control (C) and peat ash (PA) fertilisation. Mixed linear models were used to evaluate the annual differences between treatments. The statistical analyses were made with SPSS 11.5-15.0 for Windows.

Results

The differences in nutrient and heavy metal annual average concentrations between the control and ash fertilised treatments were small after ten years. The annual average of total N concentrations in drainage water were smaller at the fertilised catchments compared to the control at Pelso site but not at other sites (Fig. 1). Also drainage water NH_4-N concentrations were smaller at the fertilised catchments compared to the control at Pelso site and also at Utajärvi site. No differences were observed in NO_3-N or organic N concentrations (data not shown). Total P concentrations in drainage water were small at all sites and no influence of ash fertilisation was observed after 10 years (Fig. 1). Total S, SO_4-S (Fig. 1) and B annual concentrations in drainage water were slightly higher at the fertilised catchments compared to the control and also Na at wood ash fertilised catchments at Taavetti and Utajärvi sites (data not shown). Calcium, Mn and K concentrations were higher at wood ash fertilised catchments at Pelso and Utajärvi sites and Mg at Pelso and Taavetti sites after 10 years (Fig. 1). No increased heavy metal concentrations in drainage water were observed after ash fertilisation (data not shown).

Discussion and conclusion

At the Pelso site the annual average total N concentrations in drainage water have always been highest at the control catchment during the study period and also before ash

Table 1. Amounts of elements (kg ha^{-1}) added by ash treatment (US=powdered wood ash spread at summer, UW=powdered wood ash spread at winter, GS=granulated wood ash spread at summer and GW=granulated wood ash spread at winter, UPS=powdered peat ash at summer, GS1= granulated wood ash at summer and GS2=granulated (drum) wood ash at summer).

Treatment	P	K	B	Ca	Mg	S	Fe	Al	Cd	Cr
US & UW	45	120	0.98	1785	85	65	50	65	0.08	0.25
GS & GW	40	110	0.97	1755	80	60	50	85	0.08	0.30
UPS	40	20	0.16	435	55	25	405	130	0.02	0.40
GS1	30	55	0.51	595	45	30	40	165	0.02	0.15
GS2	20	60	0.38	465	30	35	30	130	0.01	0.15

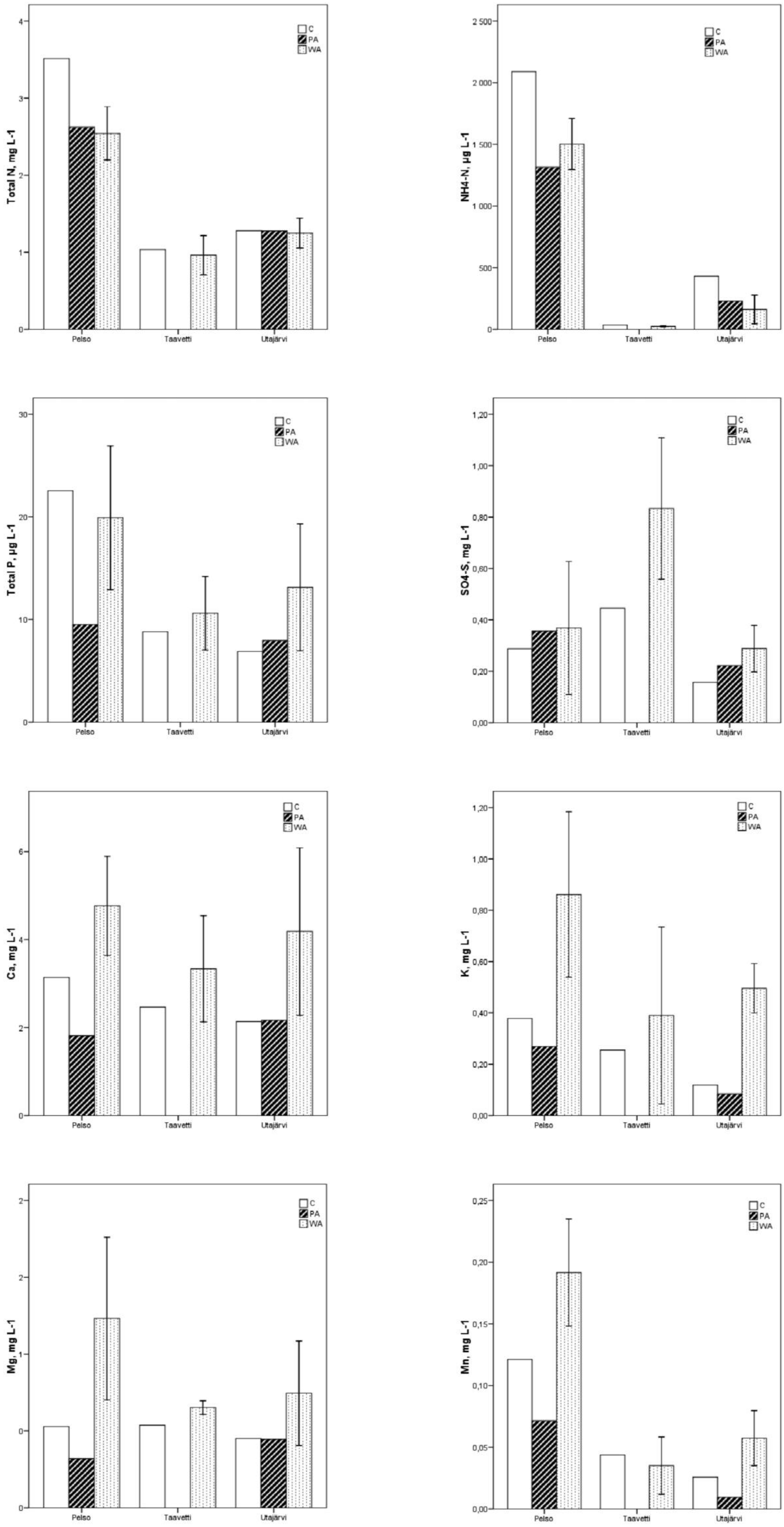

Figure 1. Nutrients concentrations in drainage water at ash treatments at different sites in 2007. Treatment abbreviations see text.

applications (Piirainen and Domisch, 2004). Thus it is uncertain that ash fertilisation has decreased N concentrations in drainage water. Both increased (Nilsson and Lundin, 1996) and decreased concentrations (Tulonen *et al.*, 2002) in streams and lakes after ash fertilisation have been reported earlier. At the Utajärvi site the N concentrations were much smaller than those at the Pelso site. However, the observed decrease of NH4-N concentrations in drainage water at both sites during the study period (data not shown) could indicate increased N uptake by vegetation or microbes. The recommended amount of P applied by fertilisation is 45 kg ha^{-1} (Vasander, 1996). The dose of P applied with the ash in this study varied from 20 to 45 kg ha^{-1}, and it exceeds the annual uptake rate manifoldly (e.g. Finér, 1991). The only increase of total P concentrations in drainage water was associated with the US treatment at the Utajärvi site in 1999-2002 (Piirainen and Domisch, 2004). At the other sites no increases were observed indicating a slow release of P from ash and an effective sorption of P by the peat soil. The very small concentrations of total P observed in drainage water in 2007 confirmed the previous results suggesting that the leaching of P from wood and peat ashes was small (Nilsson and Lundin, 1996; Tulonen *et al.*, 2002; Piirainen and Domisch, 2004).

Sulphur, Na, B, and K are the most easily released elements in ash fertilisers (Nieminen *et al.*, 2005) and increased concentrations of these elements have been observed soon after ash fertilisation (Nilsson and Lundin, 1996; Piirainen and Domisch, 2004). Although the leaching of these elements was very high (max. 20-50 %) during the first years after fertilisation (Piirainen and Domisch, 2004), the effect was long lasting since the concentrations were still high after 10 years. Ash fertilisation increased also the concentrations of Ca, Mg and Mn in drainage water in a long-term (Fig. 1), but no leaching of heavy metals after has been observed (Piirainen and Domisch, 2004). Heavy metals in ash are in non-soluble form because of the high alkalinity and are not easily released (Nieminen *et al.*, 2005). However, when the pH of the ash fertilised peat decreases, some leaching of heavy metals can occur.

Our results showed that nutrients and heavy metal released directly from the wood ash or from the peat as a result of increased decomposition due to the ash effects were mainly retained by the peat matrix. These findings support the conclusion that the nutrient release from wood ash is a rather slow process. However, peat type and tree stock also have an influence on the retention of released nutrients.

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