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Initial effects of wood ash application to soil and soil solution chemistry in a small, boreal catchment

Sara H. Norström [a,*], Dan Bylund [a], Jenny L.K. Vestin [a,b], Ulla S. Lundström [a]

[a] *Department of Natural Sciences, Engineering and Mathematics, Mid Sweden University, SE-851 70 Sundsvall, Sweden*
[b] *Swedish Geotechnical Institute, Universitetsallén 32, SE-851 71 Sundsvall, Sweden*

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ABSTRACT

With the conception that whole tree harvesting leads to an impoverishment of forest soils wood ash application is recommended, with the foremost benefits being increased pH in soil and subsequent surface waters, and recycling of nutrients from the wood ash.

In this investigation a small boreal catchment in central Sweden was studied for 2 years before and 2 years after treatment with the maximum recommended dose, 3 tonnes/ha, of crushed, self-hardened wood ash. The sampling area was situated in a slope towards a stream, to include the effect on both recharge- and discharge areas with different soil constitutions. The soil solution chemistry, exchangeable pool of cations and potential heavy metal accumulation in berries were studied. Temporary increases in soil solution concentration were found for K in the recharge area and Ca and SO_4 in the discharge area when comparing ashed and control areas. No change in exchangeable cations was observed during the study period, and no increase of heavy metals in bilberries did occur. These small changes in the constitution of the soil solution do not suggest wood ash application as a method to improve soil quality in an initial phase.

1. Introduction

The use of whole tree harvesting (WTH) in Swedish forestry has increased in recent years due to increased interest in renewable energy sources. Previously, only stem wood was recovered at harvest while branches, tips and needles/foliage—parts of the trees that contain a large part of the mineral nutrients—were left to decompose at the harvest site, thereby contributing to the recycling of mineral nutrients to the forest soils. Compared with conventional stem harvest, WTH has been shown to significantly decrease the cation exchange capacity and total amount of exchangeable base cations in the uppermost soil layers 15 years after harvest (Olsson et al., 1996) and to increase soil acidity and reduce base saturation 28 years after harvest (Vanguelova et al., 2010). It has also been shown that leaving slash after forest harvest has a positive effect on the nutrient status in foliage for successive forest stands (Olsson et al., 2000) while WTH can have a negative effect on tree growth already in the second rotation (Proe et al., 1996; Walmsley et al., 2009). However it has been shown that site sensitivity towards WTH can vary along gradients of climate and microclimate, mineral soil texture and organic C content and soil mineralogy among others (Thiffault et al., 2011).

Increased usage of forestry products as bio-energy also gives rise to by-products in the form of wood ash. Wood ash is a highly alkaline material with a high content of base cations that until recently has been dumped in landfills. To counteract the concerns that a depletion of nutrients in forest soil will arise with expanded use of WTH, the Swedish Forest Agency now recommend wood ash application (WAA) to recycle the nutrients in these forests. The main aim of this application is to counteract acidification in soil and subsequent runoff from forests subjected to WTH. Positive side effects of WAA include the provision of an alternative disposal route for by-products from the forest industry and possibly also increased growth rates in treated forests. Wood ash has, however, been shown to increase forest growth only at nutrient rich sites or when added together with N-rich fertilizers, that is, not in forests with N-limited soils (Jacobson, 2003).

WAA is sometimes referred to as fertilization, due to the high content of base cations in the ash. Increased growth rate of soil microorganisms and increased respiration at the soil surface has been observed after adding 8 tonnes/ha of loose wood ash to an acidic Norway spruce forest (Zimmermann and Frey, 2002). Similarly, Perkiömäki and Fritze (2002) found that applying loose or hardened WA caused increased microbial activity and changes within the community structure in the mor layer. These effects seemed to be independent of the fertility of the site; rather the response was dependent on dose and type of ash applied.

Investigations of soil solution chemistry have demonstrated increased concentrations of Ca and Mg, and a change in dissolved organic carbon (DOC) quality 4 years after application of 4.28 tonnes

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* Corresponding author. Tel.: +46 60 148478; fax: +46 60 148820.
E-mail address: Sara.Norstrom@miun.se (S.H. Norström).

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wood ash/ha to a forested site in southern Sweden (Geibe et al., 2003; Holmström et al., 2003). In a similar investigation where 3 tonnes/ha crushed wood ash were applied K, Na, SO_4 and total organic carbon (TOC) all increased at 50 cm depth (Ring et al., 2006).

The soil solution in a pine stand in Northern Germany that received 2.4 tonnes/ha of sieved wood ash showed an initial decrease in pH and large increases in K and Ca that leveled out within a year at the mineral soil surface (Rumpf et al., 2001). These increases nonetheless persisted throughout the study, and were seen in deeper mineral soil after 24 months. Increases in Mg and NO_3 were also observed while no changes were detected in Al or DOC concentrations.

Results from investigations of WAA effects on soil and soil solution are far from concordant, often due to differences in location, ash dose, site fertility and time span of the investigation. The number of studies on the changes of the exchangeable pool of cations and pH of the soil are far more plentiful than investigations of soil solution. Saarsalmi et al. (2001) found increased pH in the mor layer in four sites of differing fertility forested with pine or spruce 7 years after application of 3 tonnes/ha of loose wood ash. The increase was largest at the most nutrient-poor site. After 16 years a pH increase was also found in the mineral soil for the most fertile sites. Decreases in exchangeable acidity and exchangeable Al were seen at all four sites after 16 years. Only temporary increases were seen for exchangeable K and Mg while Ca was still increased 16 years after treatment. The WAA increased cation exchange capacity (CEC) and base saturation (BS) at all sites and levelled out the differences in BS between sites with different fertility. Jacobson et al. (2004) found that 3 tonnes/ha of crushed wood ash which were applied in a Scots pine stand and in a mixed stand with Scots pine and Norway spruce resulted in increases in pH and exchangeable Ca in the mor layer in the pine site, but not in the mixed stand. No increase of K was seen in the mor layer. The mobility of the substances differed: Ca and Mg were for the most part recovered in the humus layer while K was recovered deeper in the soil horizon. This difference in mobility was also found by Kahl et al. (1996) when investigating application of high doses of moist wood ash to acidic forest soils in Maine, USA. Arvidsson and Lundkvist (2003) found that an application of 3 tonnes/ha crushed wood ash to four young Norway spruce stands resulted in modest but significant increases of pH, base saturation, exchangeable Ca, Mg and K and CEC in the top soil layer 6 years after application. Similar results was generated by Eriksson (1998) who, 2 years after the application of 3 tonnes/ha of granulated wood ash to two forest stands, noted decreased exchangeable acidity and increased pH, exchangeable Ca, Mg and/or K.

An important question when investigating WAA to forests is the potential effects on berries. Forest berries are consumed by both humans and animals and also have a commercial value in Sweden. In an investigation of berries exposed to WAA in Finland, no heavy metal accumulation in cloudberry (*Rubus chamaemorus*), cowberry (*Vaccinium vitis-idaea*) and bog whortleberry (*Vaccinium uliginosum*) 4 months to 2 years after application of different doses of powdered, non-granulated ash was reported by Moilanen et al. (2006). Similar results were observed for lingonberries (*Vaccinium vitis-idaea* L.) by Levula et al. (2000) two and seven growing seasons after application of 1, 2.5 and 5 tonnes/ha of wood ash from bark.

The present study explored the initial effects of WAA to the soil in a recharge area, podzol, and a discharge area, arenosol. The effects were investigated by lysimeter sampling of soil solution, content of exchangeable cations and investigation of potential heavy metal accumulation in bilberries (*Vaccinium myrtillus* L.).

The study was conducted on a slope toward a stream in a boreal catchment in central Sweden. Wood ash was applied in the fall of 2004 at a dose of 3 tonnes DS/ha. Earlier investigations of the interaction between soil solution and stream water in the same catchment thoroughly examined the seasonal variations of nutrients and metals in a recharge- and discharge area (Vestin et al., 2008b) and associations of cations and metals to organic matter in soil solution (Vestin et al., 2008a) and in stream water (Norström et al., 2010). Aronsson and Ekelund (2008) reported elevated concentrations of K in aquatic moss (*Fontinalis antipyretica*) and leaves from alder (*Alnus incana*) when investigating the limnological effects after WAA in the same catchment, and Norström et al. (2011) observed increased concentration of foremost DOC, K, and Ca when investigating the effect of WAA on stream water chemistry.

2. Materials and methods

2.1. Site description

The study took place in a small, 50 ha forested catchment in Bispgården (63°07N, 16°70E), central Sweden. The catchment was drained by a first order forest stream, Fanbergsbäcken, and the forest consisted mainly of 50 to 80 year-old Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) with a site productivity of 4.5 m^3 per ha and year. The catchment was located at an altitude of 258 m above sea level, which is above the highest coastline in this area, and the parent material in the area consists of gneiss and granite, with mainly podzolised soils except for the parts nearby the stream where the soil was classified as arenosol (FAO, 1990). In a slope towards the stream a 1 ha area was prepared for intensive sampling (Fig. 1). The area was divided into two parts, of which one was maintained as a control area. Each of the areas was furthermore divided into six squares. Between the areas and towards the stream, two 10 m wide untreated buffers strips were kept. A more detailed description of the catchment is available in Vestin et al. (2008a).

2.2. Wood ash application

The wood ash originated from the sawmill Jämtlamell located in Stugun in the county of Jämtland, Sweden, and consisted of bottom ash with a small part of fly ash. The ash was left outside to self-harden for three summer months and was then crushed, no sieving was considered necessary. 3 tonnes DS/ha was applied to the catchment in the beginning of October 2004.

The application was made by a tractor equipped with a rotating disc, except for the near-stream zone and for the study area, where the ash was spread manually so as not to destroy installations and disturb the sampling site more than necessary. No ash was spread in the control area and a 10 m buffer zone surrounding it (Fig. 1).

The water content of the wood ash was approximately 50%, and 3 tonnes DS/ha for a 50 ha catchment hence involved the spreading of 300 tonnes of wood ash.

The quality of the ash applied followed the recommendations of the Swedish Forest Agency for minimum and maximum concentrations of elements for ash products intended for use in forestry (Table 1, Anonymous, 2008).

2.3. Lysimeter soil solution sampling

Suction lysimeters (Rhizon MOM, Rhizosphere, Wageningen, Netherlands) were installed at three pits in the recharge area, podzol, at four horizons: O (lower mor layer), E, B1 (upper B-horizon) and C and at three pits in the discharge area, arenosol, at O (lower mor layer), 0–5 cm, 10–15 cm and 45–50 cm depth. Three lysimeters were installed at each horizon in each pit and were used to sample the percolating soil solution. After sampling, the soil solutions from the triplicate lysimeters were mixed to obtain a composite sample from each horizon and pit. The sampling season lasted from April to November in 2003, 2004, 2005 and 2006, and the lysimeters were sampled every month.