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Reduced global warming potential after wood ash application in drained Northern peatland forests

Tobias Rütting [a,*], Robert G. Björk [a], Astrid Meyer [a], Leif Klemedtsson [a], Ulf Sikström [b]

[a] *Department of Earth Sciences, University of Gothenburg, Box 460, 405 30 Gothenburg, Sweden*
[b] *The Forestry Research Institute of Sweden, Uppsala Science Park, 751 83 Uppsala, Sweden*

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ABSTRACT

Past land use change has converted vast areas of Northern peatland by drainage to agricultural or forested land. This change often reduces the greenhouse gas (GHG) sink strength of peatlands or turns them even from sinks to sources, which affects the global climate. Therefore, there is a need for suitable mitigation options for GHG emissions from drained peatlands. Addition of wood ash to peatland forests has been suggested as such a measure, but the overall effect on the global warming potential (GWP) of these ecosystems is still unclear. In order to fill this knowledge gap, we investigated three drained peatland forests in Sweden that had been fertilized with wood ash and monitored stand growth as well as the GHG emissions from soil, i.e. net effluxes of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Our results show that over the first five to eight years after wood ash application, tree growth was enhanced at all sites. This was accompanied by generally little changes in the GHG emissions. Overall, we found that wood ash application reduced the GWP of drained peatland forests. Even though that our study was limited to eight years after wood ash application, we can conclude that in the short term wood ash application may be a suitable mitigation option for GHG emissions from Northern drained peatland forests.

1. Introduction

Northern peatlands have accumulated large amounts of carbon (C) as peat from the atmosphere since the last glaciation (Yu et al., 2010). However, past and present land use have altered their greenhouse gas (GHG) balance, resulting in high emissions of carbon dioxide (CO_2) and nitrous oxide (N_2O) after drainage (Maljanen et al., 2010). Forestation of drained peatlands may be a mitigation option for increased GHG emissions due to accumulation of C in the aboveground and belowground tree biomass. However, reviewing existing studies, Maljanen et al. (2010) concluded that there is a lack of data and that, hence, large uncertainties exist regarding the potential of different land-use options to mitigate GHG emissions from drained peatlands.

On drained peatlands with sufficient aeration in the (hemi-)boreal zone, tree growth is commonly limited by nutrient availability, especially by phosphorus (P) or potassium (K), but sometimes also by nitrogen (N) or boron (B) (Ferm et al., 1992; Moilanen et al., 2010). Wood ash contains all essential elements for plant growth, although only trace amounts of N (Demeyer et al., 2001). Provided that the drainage and supply of N from mineralization is sufficient, wood ash application has proved beneficial for tree growth on drained peatlands (Hökkä et al., 2012; Moilanen et al., 2005; Sikström et al., 2010). However, previous studies have mostly been conducted in low- to medium-productive peatland sites forested with Scots pine (*Pinus sylvestris* L.). Hence, there is a lack of studies on high-productive drained peatlands and of peatlands forested with other tree species. As fertile afforested peatlands have been identified as hot spots for GHG emissions (Alm et al., 2007; Ernfors et al., 2007; Klemedtsson et al., 2005), there is a particular need to evaluate the potential of wood ash application to mitigate GHG emissions from these forests.

Apart from increasing tree growth, wood ash application may also affect the exchange of GHGs between the soil and atmosphere. An increased tree growth can lower the ground water table (Hökkä et al., 2008) and thereby affect the decomposition of organic matter, leading to increased CO_2 emissions. Wood ash usually increases the soil pH, which can stimulate both soil microbial activity (Fritze et al., 1994; Zimmermann and Frey, 2002) and decomposition rates (Moilanen et al., 2002, 2012), but see Björk et al. (2010). However, increased pH may also affect the product ratio of denitrification, hence reducing N_2O emission (Šimek and Cooper, 2002). The few studies that investigated the effect of wood ash application on soil GHG emissions are inconsistent, suggesting either unaffected (Ernfors et al., 2010; Maljanen et al., 2006),

* Corresponding author. Tel.: +46 31 786 1874.
E-mail address: tobias.rutting@gu.se (T. Rütting).

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increased (Moilanen et al., 2012) or reduced (Klemedtsson et al., 2010) CO_2 and N_2O emissions for up to five years after wood ash application. Methane (CH_4) fluxes have been found to be unaffected in these studies. However, in the long-term the effects of wood ash on GHG emissions may differ from the short-term responses. Indeed, 14–50 years after wood ash application to three Finnish pine forests, the soil CO_2 emissions increased, while decreased CH_4 and no consistent effect on N_2O emission was observed (Maljanen et al., 2006).

Application of wood ash on drained peat soil usually contributes to increased C sequestration in terms of increased tree growth (as referred to above) and can additionally be a profitable silvicultural investment (Väätäinen et al., 2011). However, a pertinent question is the overall effect on the global warming potential (GWP), i.e. if the increased forest growth can offset the increased GHG emissions. Therefore, in the present study we evaluated the effects of wood ash application on tree growth and soil-atmosphere GHG exchange (CO_2, CH_4 and N_2O) in drained peatland forests, by combining new and earlier published data (Ernfors et al., 2010; Klemedtsson et al., 2010). The overall aim was to quantify how wood ash application alters the total GWP of drained peatland forests.

2. Materials and methods

The present study was conducted at two experimental sites, an oligotrophic (Anderstorp) and a mesotrophic drained peatland (Skogaryd), and at one catchment study with oligotrophic peatlands (Bredaryd) (Table 1). Tree growth and GHG emissions following wood ash application for the first five years at Anderstorp and for the first two years at Skogaryd have been reported previously (Ernfors et al., 2010; Klemedtsson et al., 2010). Here, we monitored tree growth in Anderstorp, and both tree growth and GHG emissions in Skogaryd over three additional years and compiled a total GWP for these sites. In addition, data on tree growth over seven years following wood ash application are reported for Bredaryd (Table 1).

2.1. Sites, experimental designs and treatments

The experiments at Anderstorp (Ernfors et al., 2010) and Skogaryd (Klemedtsson et al., 2010) were designed as randomized blocks, with four respectively three replicates (blocks). At Bredaryd two small catchments were investigated without replication on wood ash application (Ring et al., 2011).

The Anderstorp site is a former bog, which was drained in the late 1980s and has a naturally generated tree stand dominated by Scots pine. The Skogaryd site is a former fen, which was drained in the 1870s and used for agriculture until 1951, when it was planted with Norway spruce (*Picea abies* L. Karst.). Both experiments included three treatments; a control and application of crushed wood ash at a rate of 3.3 and 6.6 t d.w. ha^{-1} (hereafter referred to as low and high wood ash treatment). The wood ash applications were conducted in September 2003 (Anderstorp) and in August 2006 (Skogaryd). Although the doses were the same in both experiments, the amounts of added nutrients varied due to differences in element concentrations in the wood ashes (Ernfors et al., 2010; Klemedtsson et al., 2010). Chemical and physical soil characteristics, microbial community structure and biomass in the peat, as well as some microbial processes at the two sites are reported by Björk et al. (2010).

The Bredaryd site consists of two small catchments, both containing drained peatland, referred to as "Bredaryd North" and "Bredaryd South". Both peatlands were originally bogs that were drained in the late 1980s. The peatlands were about 400 m apart and forested by naturally generated tree stands dominated by Scots pine. In October 2004, Bredaryd North was treated with 3.1 t d.w. ha^{-1} of crushed wood ash, while the southern peatland was left as control (Ernfors et al., 2010). On each of the two peatlands, nine permanent measurement plots were arranged in a grid-based pattern within 3.5 ha (Bredaryd North) and 6 ha (Bredaryd South), respectively. The plots were located halfway between two ditches.

2.2. Tree growth

In Anderstorp and Skogaryd, biomass data of all trees in each plot were collected before wood ash application (September 2003 and June 2006, respectively) and at the time of revision (September 2011). Stem diameters at breast height (1.3 m above the ground) were measured with callipers in two perpendicular directions. Tree heights were measured using a hypsometer (Vertex III, Haglöf Scandinavia AB, Avesta, Sweden). In addition, increment cores were sampled in September 2011 from each tree at all three

Table 1
Basic site and soil properties for three Swedish peatland forests (control plots). Data are presented as means ± standard error.

	Anderstorp	Skogaryd	Bredaryd	
			North	South
Coordinates	57°15′N, 13°35′E	58°23′N, 12°09′E	57°11′N, 13°44′E	
Stand properties				
Tree species[a]	98% *P. sylvestris* 2% *P. abies*	3% *P. sylvestris* 95% *P. abies* 3% *B. pubescens*	99% *P. sylvestris* 1% *P. abies*	90% *P. sylvestris* 9% *P. abies* 1% *B. pubescens*
No. stems (ha^{-1})	742 ± 32	797 ± 55	722 ± 38	757 ± 76
Tree height (m)	13.3 ± 0.3	22.3 ± 0.8	14.8 ± 0.2	15.1 ± 0.2
Tree stem volume (m^3 ha^{-1})	109 ± 5	404 ± 20	131 ± 6	132 ± 13
Monitoring period	September 2003–September 2011	June 2006–September 2011	October 2004–September 2011	
Soil properties (0–0.05 m)[b]				
pH	4.9 ± 0.3	4.5 ± 0.1	4.4 ± 0.0	
SOM (%)	96.2 ± 0.2	79.4 ± 9.6	n.d.	
C/N	23.4 ± 1.0	23.1 ± 1.0	33 ± 3[c]	

[a] By stem volume.
[b] Data from Björk et al. (2010) for Anderstorp and Skogaryd and from Ernfors et al. (2010) for Bredaryd. pH measured in 1:10 water extract; SOM is soil organic matter content measured by loss on ignition; C/N is carbon to nitrogen ratio of bulk soil.
[c] 0.05–0.15 m soil depth.