



Wood ash and N fertilization in the Canadian boreal forest: Soil properties and response of jack pine and black spruce



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ABSTRACT

Wood ash fertilization has yet to be investigated in Canadian boreal forests. Ash often improves soil acid–base status, but without N addition it seldom increases tree growth on poor mineral soils. We report results of a large scale experiment conducted in a boreal jack pine (*Pinus banksiana* Lamb) stand growing on sandy acidic soil in Northeastern Canada. The experiment was completely random with four replications (1 ha each) of five treatments (0, 1, 2, 4 and 8 dry Mg ha⁻¹) of loose fly ash with and without urea (280 kg N ha⁻¹). Soils were sampled in the 0, 2, and 8 Mg ha⁻¹ treatment up to eight years after application. Foliar nutrition and stand growth were assessed in all treatments one and two years and five years after treatment, respectively.

Even under low ash loading, forest floor exchangeable base cations, pH, and base saturation increased within a year of application. Ash application also resulted in a swift decrease in forest floor organic C and an increase in N potential net mineralization rate. The initial dominant pattern of upper mineral soil properties in relation to ash loading was a curvilinear relationship with the highest values observed in the 2 Mg ha⁻¹ treatment. Eight years after ash application, significant linear relationships were found between ash loading and base cations and base saturation in the forest floor and mineral soil (0–10 cm, 10–20 cm). Contrary to N fertilization, ash had no effect on jack pine foliar nutrition and on its five-year growth. However, a decrease of 30% in relative growth rate was observed between the control and the 8 Mg ha⁻¹ ash treatment for large (≥ 10 cm DBH) black spruces (*Picea mariana* (Mill.) BSP). Black spruce is the dominant commercial species of Canadian eastern boreal forests and thus, additional studies are needed to validate the deleterious effect of ash on spruce growth and to elucidate the mechanisms involved.

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1. Introduction

Interest in bioenergy, including the use of forest biomass as a fuel, is increasing in response to concerns over climate change, growing oil prices and energy security (EU, 2009; Titus et al., 2010). As a result, an increased production of ash from forest biomass combustion is predicted (James et al., 2012). Wood ash is recycled as a fertilizer by the farming industry, but this represents only a small portion of the total ash produced and thus, most is buried in landfills (Hébert and Breton, 2008; James et al., 2012). Because of the limited availability of landfills in close proximity of wood-fired power plants and in turn, the large handling and

transporting costs, recycling options in the vicinity of these power plants need to be considered.

Wood ash fertilization in Canadian boreal forests has yet to be investigated. Nonetheless, the use of ash as a fertilizer in forest ecosystems has been researched for more than eighty years in Fennoscandia (Lundström et al., 2003; Pitman, 2006; Huotari et al., 2015). Ashes generated from wood products contain variable amounts of most nutrients required for tree growth, with the exception of nitrogen (N) because of its low heat of vaporization. The acid neutralizing capacity of ash stems from its high content of calcium (Ca), magnesium (Mg) and potassium (K) hydroxides (Saarsalmi et al., 2001). Early benefits of ash application on the soil acid–base status, when they occurred, are observed in the forest floor and involve exchanges of protons (H⁺) by the mobile monovalent cations K and sodium (Na), while effects on the mineral soil often take place more gradually (Augusto et al., 2008; Pitman,

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2006; Reid and Watmough, 2014). The effects of ash application on forest soil acidity have been shown to last for as much as 30 years (Saarsalmi et al., 2012). Besides macro- and micro-nutrients present as oxides or hydroxides, wood ash also contains low amounts of transition metals and metalloids such as cadmium (Cd), barium (Ba), manganese (Mn) and arsenic (As) (Dahl et al., 2010) that may become phytotoxic (St-Clair and Lynch, 2005). The chemical composition of ash depends on tree species, fuel composition (wood, bark, branches, etc.), boiler type (Pugliese et al., 2014), heat of combustion and possible sources of contamination (e.g. construction and demolition wood, bottom vs fly ash) (Pitman, 2006).

Wood ash has the potential to affect soil N availability through different mechanisms, but mostly by increasing soil pH and dissolved organic carbon (DOC) (Jokinen et al., 2006; Molina et al., 2007). Changes in soil acidity affect microbial communities and activity, generally resulting in more N mineralization (Bååth and Arnebrant, 1993; Mahmood et al., 2003; Perkiömäki and Fritze, 2002). However, neither the increase in soil mineral forms of N or increases in foliar concentrations of P, K and Ca following ash application (Augusto et al., 2008) led to improved tree growth on poor mineral soils (Jacobson, 2003; Saarsalmi et al., 2004). Yet, the limited number of long-term studies precludes any definitive conclusions regarding tree response to improved soil conditions on these sites (Reid and Watmough, 2014). However, increased growth was reported following wood ash application on N-rich but K and P deficient drained peatlands (Huotari et al., 2015).

Canadian and Fennoscandian boreal environments share numerous characteristics which should contribute to similar soils, including similar climates, geological formations (Vogel et al., 1998) and recent glacial history (Kleman and Hättestrand, 1999). However, variations between and within regions in tree species composition, forest management history (Östlund et al., 1997) and environmental stressors (Scheffer et al., 2012) preclude direct inference of research findings from one region to the other without proper investigation.

We report on a large scale replicated factorial experiment initiated in 2005 on a mature boreal jack pine stand subjected to increasing loads of wood ash with and without N fertilization. Our objective is to assess the initial response of forest stands to ash fertilization in the Canadian boreal forest. We hypothesized that: (1) soil base cation concentrations, pH and N net mineralization would increase with increasing ash loading, (2) increases in soil alkalinity would first take place in the forest floor and would later appear in the mineral soil, and (3) tree foliar nutrition and growth would respond positively within the first five years of wood ash application when being combined with N fertilization (Jacobson, 2003; Saarsalmi et al., 2006).

2. Approach and methods

2.1. Study area

The study was conducted in the Abitibi-Témiscamingue region of northwestern Québec, Canada (48°31'24"N, 76°37'42"W). The region is included in the Superior geologic province of the Canadian Precambrian Shield. The topography is relatively flat and the elevation ranges from 300 to 350 m. Most of the bedrock is covered by quaternary deposits (Veillette et al., 2000). The climate is continental with an average annual temperature of 0.5 °C and a mean annual precipitation of 973 mm, with 64% falling inclusively between May and October (Government of Canada, 2014). The region is part of the Canadian boreal forest (Rowe, 1972). It is located within the balsam fir (*Abies balsamea* L. Miller) – white birch (*Betula papyrifera* Marshall) bioclimatic domain (Saucier et al., 2011). Soils developed from well drained loamy sands to sandy

loams and consist of Dystric Eluviated Brunisols (Dystrochrepts, Cryochrepts) with a 10–15 cm organic layer (LFH) originating from feathermoss (Agriculture Canada Expert Committee on Soil Survey, 1998).

2.2. Experimental design and sampling

The 43 ha field trial was set up in October 2005 in a mature jack pine (*Pinus banksiana* Lamb) stand of fire origin (approximately 53 years) that had been commercially thinned in 1999. The stand had an average basal area of 22.3 m² ha⁻¹ with 20.0 m² ha⁻¹ of jack pine stems (average diameter = 16 cm) and the remainder composed of black spruce (*Picea mariana* (Mill.) BSP) stems (average diameter = 10 cm). The experiment was designed as completely random with four replications (1 ha each) of five ash treatments (0, 1, 2, 4 and 8 dry Mg ha⁻¹ of loose unstabilized fly ash; see Table 1 for ash elemental composition) with and without urea (CO(NH₂)₂) fertilization (280 kg N ha⁻¹) for a total of 40 experimental units. Ash and urea were applied with a farm spreader using harvesting trails.

Prior to ash and urea application and in each experimental unit, three permanent circular sampling plots (PSP) of 200 m² were delineated. All jack pine and black spruce stems greater than 5.0 cm of diameter at breast height (DBH) were tagged, identified by species, and measured for DBH. These were measured again five years later (2010) to obtain an estimate, for each stem, of the five-year relative growth rate:

$$\left[\frac{(DBH_{2010} - DBH_{2005})}{DBH_{2005}} \right]$$

In each PSP, soils were sampled one, two and five years (2006, 2007 and 2010, respectively) after application of 0, 2 and 8 Mg ha⁻¹ of ash with and without urea. Bulk soil samples were taken from the forest floor and the 0–10 cm mineral soil. Eight years (2013) following treatment application, the forest floor as well as the 0–10 cm and 10–20 cm mineral soils were sampled once more in three replications in the 0, 2 and 8 Mg ha⁻¹ ash treatments with and without urea.

One and two years (2006–2007) after treatments, current-year pine needles were collected within the same PSPs where soils were

Table 1

Characteristics of fly ash from Boralex wood residue thermal power plant during the year preceding field application (median, *n* = 8). The plant mostly uses softwood bark residues from nearby sawmills. Characteristics of fly ash (median, *n* = 4–10) of comparable origin published by the Wood ash database (WAD) (Swedish University of Agricultural Sciences, <http://woodash.slu.se/eng/>) are also provided.

	Boralex ^a	WAD	Boralex	WAD
Macroelements (mg g ⁻¹)			Microelements (µg g ⁻¹)	
N tot	<1		As	2
Ca	67	214	B	62
K total	9	74	Ba ^c	1300
Mg	4	20	Cd	3
Mn	2	12	Co	10
Na	2	14	Cr	11
P total	1	11	Cu	20
			Fe	1216
Physicochemical properties (%)			Hg	0
			Mo	4
CCE ^b	31		Ni	12
Fineness	92		Pb	10
OM (%)	22		Zn	286
				3300

^a Nitric acid (HNO₃) or HNO₃ and hydrochloric acid (HCl) extraction.

^b CCE = calcium carbonate equivalence, fineness = particles < 2 mm; OM = organic matter

^c Ba was estimated in 2011 on a single sample.

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