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Forest floor chemistry and mineral soil ion exposure after surface application of alkaline-treated biosolids under two white spruce (*Picea glauca*) plantations in Nova Scotia, Canada

Kevin Keys[a,*], David L. Burton[b], G.W. Price[c], Peter N. Duinker[d]

[a] Nova Scotia Department of Natural Resources, Truro, Nova Scotia, Canada
[b] Department of Plant, Food, and Environmental Sciences, Dalhousie University, Truro, Nova Scotia, Canada
[c] Department of Engineering, Dalhousie University, Truro, Nova Scotia, Canada
[d] School for Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia, Canada

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ABSTRACT

Two field trials were established to evaluate the use of alkaline-treated biosolids (ATB) to offset current or predicted Ca deficits in Nova Scotia forest soils under juvenile white spruce (*Picea glauca*) plantations. At the rates applied (7.5 and 15 t ha^{-1} wet weight), ATB treatments led to significant increases in total and available Ca within the forest floor and surface mineral soil, significant increases in forest floor pH, significant or near-significant decreases in exchangeable forest floor Al^{3+} concentrations, and negligible leaching of metals (Cu, Cd, Pb, Zn) for the 2-year duration of study. Near-surface PO_4^{3-}-P availability was also slightly enhanced after an initial delay period. However, despite relatively high K concentrations in the ATB product used, there were no significant increases in forest floor K concentrations, suggesting a relatively rapid release and movement of K^+ to deeper soil layers compared to Ca^{2+}. There were also no significant increases in forest floor Mg concentrations, or in total and available N. Results suggest that ATB could be a good source of Ca in Ca-limited sites, but nutrient imbalances may be a problem on sites where K and Mg depletion has also occurred or where N is also limiting.

1. Introduction

Northeastern US and eastern Canadian forests have been affected by decades of acid deposition resulting in increased acidity, base cation depletion, and increased Al availability in many affected soils (Watmough and Ouimet, 2005; Lawrence et al., 2012). This has contributed to an overall reduction in potential site productivity in many areas, and an increased susceptibility to further environmental stresses (Schaberg et al., 2001; Duarte et al., 2013). Although acid deposition levels have decreased since adoption of the 1990 *Clean Air Act* (US) and 1991 *Air Quality Accord* (US and Canada) (CCME, 2013), the overall recovery of forests from decreased acid deposition has not progressed as quickly as hoped (e.g., Houle et al., 2006; Warby et al., 2009; Lawrence et al., 2012). Indeed, some projections suggest it could take several decades for many sites to recover naturally, due in part to (i) reduced acid neutralizing capacity in impacted soils, (ii) desorption of SO_4^{2-} that can continue to promote base cation depletion, and (iii) potential leaching impacts related to ongoing NO_3^- deposition (Driscoll et al., 2001). In addition to acid deposition, timber harvesting can also contribute to a decline in base cation nutrients (especially Ca) through periodic removal of stem wood and bark (e.g., Freedman et al., 1986; Federer et al., 1989; Adams et al., 2000; Huntington, 2005). Sustainable management in northeastern forests must therefore consider the balance between nutrient outputs via acid leaching and periodic harvesting, and nutrient inputs from soil weathering, atmospheric deposition, and (potentially) application of soil amendments (Keys et al., 2016).

Despite the well documented impacts of acid deposition, there has been little use of soil amendments to mitigate the effects of increased acidity and base cation depletion in northeastern forest soils (Moore et al., 2015). In contrast, lime has been used in some European countries since the 1980s to mitigate the impacts of acid deposition (e.g., Tomlinson, 1990; Nilsson et al., 2001), with wood ash also being used to offset both acid deposition and harvesting impacts (e.g., Levin and Eriksson, 2010). In addition to lime and wood ash, alkaline-treated biosolids (ATB) are also considered a liming amendment and nutrient supplement, but their use in forests has been minimal to date (Banaitis et al., 2009).

Initial use of soil amendments in northeastern forests would seem most appropriate in areas under intensive management (such as

* Corresponding author.
E-mail address: kevin.keys@novascotia.ca (K. Keys).

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plantations) where the goal is to increase fibre yields over time through a combination of silviculture treatments and shorter rotation lengths. For example, typical productivity in spruce plantations in Nova Scotia, Canada, is estimated to be about 6 $m^3\ ha^{-1}\ yr^{-1}$ which equates to a doubling of predicted harvest volume at peak mean annual increment (approx. 300 $m^3\ ha^{-1}$) compared to extensively managed stands (NSDNR, 2011). However, based on outputs from a new steady-state nutrient budget model described by Keys et al. (2016), many plantation sites in Nova Scotia may not be able to continuously meet desired yield targets over time without the use of soil amendments, with Ca identified as a main limiting nutrient.

To evaluate the potential for ATB to offset current or predicted Ca deficits in Nova Scotia forest soils, two field trials were established to measure impacts of surface-applied ATB on white spruce (*Picea glauca*) plantation soils and vegetation. To our knowledge, this is the first time ATB has been applied to conifer plantations in northeastern North America to assess its potential role in plantation nutrient management. This paper describes field study design and discusses ATB treatment effects on plantation forest floor chemistry and surface soil ion exposure. The main objectives were to determine ATB treatment impacts on: (i) forest floor base cation (Ca, Mg, K) concentrations and movement; (ii) forest floor pH; (iii) forest floor Al, Mn, and trace metal concentrations and movement; and (iv) near-surface soil N and P availability.

2. Methods

An ATB product manufactured by N-Viro Systems Canada and trademarked as Halifax Soil Amendment™ was used in this study. The product is categorized as a Class A biosolid under Nova Scotia Department of Environment regulations (NSE, 2010) and is sold commercially under an approved fertilizer label. The patented N-Viro process is known as Advanced Alkaline Stabilization with Subsequent Accelerated Drying. In this process, an alkaline admixture (e.g., cement kiln dust) is added to dewatered biosolids, mixed, heated, and dried. This process eliminates almost all pathogens found in the untreated sludge (based on regular testing results) and produces an agriculture-grade liming material and fertilizer.

Two 10–15-year old upland white spruce plantations were selected for independent field trials in central Nova Scotia, Canada (Fig. 1). Sites were chosen to be broadly representative of two dominant soil types in the province. Site 1 was moderately well to imperfectly drained and underlain by a shaly loam soil derived from slate till. Site 2 was well to rapidly drained and underlain by a gravelly/cobbly sandy loam soil derived from granitic till. Both sites had originally supported shade-tolerant hardwood or mixed wood stands that were converted to spruce plantations after harvest.

Treatments compared at each site were a one-time surface application of 7.5 and 15 $t\ ha^{-1}$ ATB (wet weight), referred to as low (L) and high (H) rates respectively, along with an untreated control (C). Treatments were applied to Site 1 in September 2012, and to Site 2 in June 2013, with post-treatment measurements at both sites taken until November 2014. Target application rates were based on typical ATB product values for Ca (20%) and moisture content (33%) (N-Viro Systems Canada, pers. comm.) which corresponded to Ca applications of about 1000 and 2000 $kg\ ha^{-1}$. These rates were in the same range as Ca amendment studies conducted in the past (e.g., Matzner et al., 1985; Long et al., 1997; Juice et al., 2006), as well as a more recent ATB forestry trial in Maine, USA (Banaitis et al., 2009).

Nine 40 m × 40 m plots were established at each location allowing for three replicates of each treatment. Site conditions required different plot layouts at each location, with a Latin square design employed at Site 1 and a linear plot design (with dispersion) employed at Site 2. Plots receiving ATB applications were divided into square quadrats measuring 3.7 m × 3.7 m in low rate plots and 2.6 m × 2.6 m in high rate plots with each quadrat receiving approximately 10 kg of ATB. Treatments were applied manually in each quadrat, including under crop trees, taking care to ensure a uniform distribution (Fig. 2).

Ca concentrations in ATB samples collected at both trial sites were in the expected 20% range and relatively consistent (coefficient of variation 6–12%) (Appendix A). Most other elements also showed consistent concentrations (coefficient of variation less than 10%), but some variability in ATB batches was observed. Based on field assessments and quarterly N-Viro analysis data, ATB moisture content during application at both sites averaged about 38% rather than the typical value of 33%. After adjusting for moisture content and average Ca concentration, estimated Ca application rates were 957 $kg\ ha^{-1}$ and 1914 $kg\ ha^{-1}$ (Site 1), and 935 $kg\ ha^{-1}$ and 1870 $kg\ ha^{-1}$ (Site 2), for the low and high ATB rates respectively (Appendix A). Due to analytical problems, cadmium (Cd) and lead (Pb) concentrations and calculated loading rates were determined using average quarterly chemical analysis data obtained from N-Viro Systems Canada (Appendix A).

A systematic sampling scheme was used to assess soil and vegetation parameters in each plot (Fig. 3). Since the focus of this paper is on forest floor chemistry and surface soil ion exposure, only details related to these assessments are presented here. Pre- and post-treatment forest floor samples (combined F and H horizons) were collected in summer and late fall of each year for chemical analysis. Samples consisted of pooled sub-samples from three systematically located points in each plot (Fig. 3) and were analyzed for pH, total Ca, total magnesium (Mg), total potassium (K), total phosphorous (P), total nitrogen (N), total sulphur (S), total carbon (C), total manganese (Mn), and total zinc (Zn). Exchangeable aluminum (Al^{3+}) was also assessed in pre-treatment and late fall forest floor samples.

Ion exposure was assessed using PRS™-probes (Western Ag Innovations Inc., Saskatoon, SK, Canada). A PRS™ (Plant Root Simulator) probe is an ion exchange membrane encased in plastic that provides a dynamic measure of ion flux to a quantifiable surface area and represents plant nutrient supply rates for the duration of burial (Western Ag, 2010). Although more commonly used in agriculture, PRS™-probes have also been used in forest soil assessments (e.g., Harrison and Maynard, 2013; Johnson et al., 2014). In this study, we refer to the cumulative capture of ions by PRS™-probes as a measure of ion exposure rather than flux because probes were used year-round and capture levels reflected more than just short-term plant nutrient supply rates.

Eight sets of cation and anion probes were used in each plot with probes inserted at an approximate angle of 15 degrees until tops were flush with surface mineral soil immediately below the forest floor. This resulted in probe membranes being centred around 10 cm from the surface. Probes were installed just before plots were treated, with post-treatment sampling taking place approximately bi-weekly for the first six weeks after ATB application (to avoid overloading the probes), then monthly for most of the remaining study period (when soils were not frozen or snow covered). Burial duration was approximately two months per sampling period for the last year of assessment. Probes were replaced after each sampling period to allow for continuous monitoring (15 sampling events at Site 1 and 10 events at Site 2). All probes were cleaned with de-ionized water shortly after retrieval and shipped to Western Ag Innovations Inc. for extraction and analysis. Probes were extracted in batches of four to give two average cation (Ca^{2+}, Mg^{2+}, K^+, NH_4^+-N, Mn^{2+}, Al^{3+}, Cd^{2+}, Cu^{2+}, Pb^{2+}, Zn^{2+}) and anion (NO_3^--N, SO_4^{2-}-S, PO_4^{3-}-P) measurements per plot per assessment period. This equated to a sample size of six for each ion for each treatment. Randomly selected blank probes handled in the same manner as others (except not deployed in the field) were also submitted for analysis on a periodic basis to check for potential contamination, with no contamination problems found.