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Effects of two types of Ca fertilizer on sugar maple nutrition, vigor and growth after 7 years

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ABSTRACT

Sugar maple (*Acer saccharum* Marsh., hereafter SM) dieback has been of concern in many stands of northeastern North America for decades. In acidic, base-poor forest soils, this phenomenon has often been attributed to calcium (Ca) deficiency. Corrective measures such as dolomitic lime addition ($CaMg(CO_3)_2$) have been tested to restore SM vitality in these ecosystems. However, few studies have evaluated the effect of Ca addition alone on SM. Furthermore, liming experiments have showed that the Mg content of lime could induce a nutritional antagonism which hinders potassium (K) uptake. This may have limited the response of SM to dolomitic lime application. To address these issues, two calcium fertilizers with negligible Mg content ($CaCO_3$ and $CaSO_4{\cdot}2H_2O$) were applied at rates of 1, 2 and 4 t Ca ha^{-1} on SM trees. After 7 years, foliar Ca nutrient concentrations of treated trees increased in both Ca treatments, reaching published concentration ranges for healthy SM trees. These increases were greater than those observed after a similar period in two nearby experiments in which $CaMg(CO_3)_2$ and $CaCO_3$ were used at comparable or lower doses. Also, no nutrient antagonism was detected in the present study. Tree crown vigor and basal area growth were improved by the Ca treatments, but the magnitude of the growth response for trees treated with the $CaCO_3$ fertilizer was far less than in the other nearby experiment where $CaCO_3$ was also used. This strongly suggests that Mg nutrition is not a limiting factor in this ecosystem. The comparatively lower growth response of trees to Ca treatments in this study is unclear, but better growth conditions at the studied site, compared to the two other nearby experiments, may have played a role in this phenomenon. Long-term monitoring of these experiments seems warranted to clarify these issues.

1. Introduction

Over the last decades, evidence of base cation depletion in soils with a low acid-buffering capacity has been reported in forests of northeastern North America (Houle et al., 1997; Likens et al., 1998; Johnson et al., 2008). This phenomenon has been attributed, at least in part, to acid deposition (Houle et al., 1997; Likens et al., 1998; McLaughlin, 1998; Sharpe, 2002; Bailey et al., 2005; Long et al., 2009).

Sugar maple (*Acer saccharum* Marsh., hereafter SM) is known to be very sensitive to soil acidity, aluminum toxicity, and poor soil Ca availabilty (Wilmot et al., 1995; Bailey et al., 2004; Long et al., 2011; Moore et al., 2012). In Quebec, Duchesne et al. (2002) have shown that SM decline and the associated growth reduction could be related, at least in part, to soil acidification and increased acid deposition. In this context, several base cation fertilization experiments were established on sites with acidic, base-poor soils (e.g.: Wilmot et al., 1996; Long et al., 2011; Ouimet et al., 2008; Moore et al., 2012). Improved SM nutrition, growth and vigor after base cation addition demonstrated the link between base cation deficiency and SM vitality. However, relatively few studies have evaluated the effect of Ca addition alone on SM (Juice et al., 2006; Huggett et al., 2007; Ouimet et al., 2008). Moreover, improvement of SM vitality in liming studies occurred despite declines in foliar K (Long et al., 2011; Moore et al., 2012) below the sufficiency threshold established for this element (see Moore and Ouimet, 2010 for a review). This decrease in foliar K in these liming studies is likely due to the high Mg content of dolomitic lime (12%) used in these experiments, which caused a K–Mg antagonism. This phenomenon is well known for SM and appears when the availability is much greater for Mg than for K (Mengel and Kirkby, 1980; Ouimet and Camiré, 1995; Ouimet et al., 1996).

In this study, we tested the hypothesis that Ca fertilizers with a negligible Mg content (<1% Mg for $CaSO_4{\cdot}2H_2O$ and $CaCO_3$) could improve SM nutrition, vigor and growth without causing foliar K deficiency in the longer term (7 years). In the short term (⩽3 years), Ca and Mg nutrition, crown vigor and basal area growth

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had increased for both Ca treatments, and no nutrient antagonism had been observed (Moore and Ouimet, 2010). However, the growth response was of smaller magnitude than in two Ca addition experiments established nearby ($CaMg(CO_3)_2$: Moore and Ouimet, 2006; $CaCO_3$: Ouimet et al., 2008; Table 1). This study should help to verify the longer-term effect of these Ca fertilizers on SM nutrition, vigor and growth.

2. Material and methods

2.1. Site description

The experimental stand (46°57′N, 71°40′W) is located in the Duchesnay Experimental Forest, approximately 50 km northwest of Quebec City (Quebec, Canada), bordering the Lake Clair experimental Watershed (LCW). Site elevation varies between 270 and 390 m and the average slope is approximately 10%. Mean annual temperature is 3.4 °C and annual precipitation (1971–2000) totals 1300 mm. Forest stands are mainly uneven-aged, with vegetation dominated by SM, yellow birch (*Betula alleghaniensis* Britt.) and American beech (AB) (*Fagus grandifolia* Ehrh.) (basal areas of 21, 3, and 3 $m^2\ ha^{-1}$, respectively). Dominant and codominant SM trees are 85–130 years old, with an average height of 20 m and average diameter at breast height (DBH) of 28 cm. According to the *Canadian System of Soil Classification* (Canada Soil Survey Committee, 1998), the soil is classified as a stony, sandy loam Orthic Ferro-Humic Podzol. The humus type is of moder, and the surface deposit is a very acidic (Houle et al., 1997, 2002) and stony glacial till derived from the granitic gneiss bedrock of the Canadian Shield.

2.2. Stand conditions and disturbance history

The LCW is among the catchments in northeastern North America where acid deposition continues to acidify soils, leading to relatively high net soil Ca losses (Watmough et al., 2005). Over the period 1994–2009, atmospheric NO_3^-, NH_4^+, SO_4^{2-}, and H^+ loads in bulk deposition were estimated at 19, 5, 20 and 0.4 kg $ha^{-1}\ year^{-1}$, respectively. Neither severe insect defoliation nor frost or ice damage was observed in the area recently. Relatively short summer drought episodes did occur in 1995 and in 2002, but they did not cause lasting growth reductions. The last forest cutting in the experimental area was a thinning in the 1940s.

At Duchesnay, SM poor nutrition (Ca and Mg), vigor, and growth have been reported over the last decade (Duchesne et al., 2002; Ouimet et al., 2008; Moore and Ouimet, 2010; Moore et al., 2012). The low Ca availability in this ecosystem is probably attributable to the combination of high levels of acid deposition, significant Ca leaching, and relatively low Ca replenishment through mineral weathering in the soil (Houle et al., 1997; Ouimet and Duchesne, 2005).

Before treatment application in 2002, mean (±sd) foliar concentrations of Ca (5500 ± 1600 mg kg^{-1}), Mg (1200 ± 300 mg kg^{-1}) and Mn (800 ± 300 mg kg^{-1}) of the 63 selected SM trees were considered low, according to SM nutritional values in other studies (Moore and Ouimet, 2010). At the same time, conspicuous signs of dieback remained prevalent at the LCW (Ouimet et al., 2008; Moore et al., 2012).

Table 1
Comparison of control trees for the three Ca addition studies at Duchesnay.

	This study (after 7 years)	Moore and Ouimet, 2006 (after 10 years)	Ouimet et al., 2008 (after 10 years)
Foliar concentrations			
Ca (mg kg^{-1})	5212	4604	4540
Mg (mg kg^{-1})	1119	1083	980
BAI (Fig. 3)	High	Low	Low
Crown dieback (%)	4	30	2

2.3. Experimental design

In a maple stand adjacent to the LCW, 63 SM trees were selected in June 2002. To ensure a long-lasting experimental trial, trees were chosen without major trunk defects or crown dieback. They also had to be at least 15 m apart. Mean (± standard deviation) DBH of these subjects was 33.2 ± 8.2 cm (2002), and their basal area increment (BAI) was 12.2 ± 1.6 $cm^2\ year^{-1}$ (1990–2002). Granulated calcium carbonate ($CaCO_3$) or gypsum ($CaSO_4 \cdot 2H_2O$) fertilizers (commercial grade) were applied manually in June 2002 in a 5-m radius around SM trees, at a rate of 1, 2 and 4 t ha^{-1} of Ca, that is, 2.8, 5.6 and 11.1 t ha^{-1} of $CaCO_3$ or 3.7, 7.4 and 14.8 t ha^{-1} of $CaSO_4$. On the acidic forest floors in the area (pH = 3.5 ± 0.5; Moore et al., 2012; Ouimet et al., 2008), gypsum (dissolution constant $\log K_{25\,°C} = -4.64$) should be more stable than calcium carbonate ($\log K_{25\,°C} = 9.74$) (Lindsay, 1979), but it should also dissolve more quickly because the compound is hydrated.

Each treatment was applied randomly to 9 replicate trees during the first week of September 2002, before leaf fall. This experimental setup was directly adjacent to a dolomitic liming trial implemented in 1994 (the "dolomitic lime experiment", Moore et al., 2000; Moore and Ouimet, 2006) and close to another fertilizer trial implemented in 1990 (the "acidification/alkalinization experiment" Ouimet et al., 2008).

2.4. Sampling

Foliage was sampled before treatment in early August 2002, then in August of 2003, 2004, 2005 and 2009. This time of year corresponds to a period of stable foliar concentration preceding foliar coloration (Duchesne et al., 2001). Foliage was collected from each tree with a telescopic pole pruner at mid-crown on two opposite branches. Crown dieback was assessed in 2002 and 2009 on the same day as foliage sampling, by estimating the percentage of missing crown foliage (5% class intervals) from careful visual inspection. Foliar nutrient concentrations were used to evaluate nutritional status.

In November 2009, two increment cores were taken from opposite sides of each tree at breast height to measure tree radial growth. Annual ring width was measured using WinDendro version 6.1D software (Régent Instruments Inc., 1998) and validated with signature rings. Ring width values were converted to BAI (in cm^2) using the following equation:

$$BAI_t = \pi(R_t^2 - R_{t-1}^2)$$

where *R* is the tree radius (cm), and *t* is the year of tree-ring formation. One of the two cores from two control trees were removed because of highly abnormal growth rings and associated wood discoloration in recent years, suggesting that these cores were taken near a stem flaw or a previous core sample.

2.5. Chemical analyses

For each tree, a foliage sample of approximately 40 leaves was dried at 65 °C, then ground to ⩽250 μm. Following Kjeldahl digestion of a 500 mg subsample, nitrogen (N) concentration was determined by colorimetry (Kjeltec Tecator 1030 autoanalyzer), and P, K, Ca, Mg, and Mn concentrations were measured by inductively-coupled plasma-atomic emission spectroscopy (Perkin Elmer Plasma Model 40). Standard reference material used for the