Ten-year effect of dolomitic lime on the nutrition, crown vigor, and growth of sugar maple

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Abstract: In a base-poor northern hardwood stand in Quebec, subjected to high acid deposition, sugar maple (*Acer saccharum* Marsh.) nutrition, growth, and crown vigor were evaluated 10 years after application of 0–50 t·ha^{-1} of $CaMg(CO_3)_2$ in 1994. One decade after treatment, foliar calcium and magnesium concentrations of sugar maple were still higher for treated than for control trees. The analysis of foliar nutrient indices showed that liming improved the nutrition of nitrogen and calcium, but caused imbalance of phosphorus, potassium, and magnesium. In 2004, crown dieback was much lower for limed trees (0.5%–4.5%) as compared to unlimed trees (23.7%). When compared with crown dieback before treatment, dieback of limed trees generally had decreased by 2004, while dieback of untreated maple trees increased over the 1994–2004 period. In 2004, basal area increment for limed trees was nearly double that of unlimed trees. However, no difference was detectable among trees limed at different rates. Midterm efficacy of liming in this study was demonstrated by the improvement of sugar maple calcium nutrition, crown vigor, and stem growth 10 years following treatment. This confirms the potential of liming to limit damage caused by acid deposition in base-poor and declining northern hardwood stands.

Résumé : La vigueur, la croissance et la nutrition de l'érable à sucre (*Acer saccharum* Marsh.) ont été évaluées dans un peuplement de feuillus nordiques pauvre en bases, situé au Québec et exposé à des dépôts acides élevés, 10 ans après l'application de 0 à 50 t·ha^{-1} de $CaMg(CO_3)_2$ en 1994. Les concentrations en calcium et magnésium du feuillage de l'érable à sucre étaient encore plus élevées chez les arbres traités que chez les arbres non traités 10 ans après le traitement. L'analyse des indices nutritionnels du feuillage montre que le chaulage a amélioré la nutrition en azote et calcium mais a causé un déséquilibre en phosphore, potassium et magnésium. En 2004, le dépérissement de la cime était beaucoup plus faible chez les arbres chaulés (0,5 % à 4,5 %) que chez les arbres non chaulés (23,7 %). Comparativement à la situation qui prévalait avant le traitement, le dépérissement de la cime des arbres traités avait généralement diminué en 2004 tandis que celui des arbres non traités a augmenté durant la période 1994–2004. En 2004, l'accroissement en surface terrière des arbres traités était près du double de celui des arbres non traités. Toutefois, aucune différence n'a été détectée entre les arbres traités avec différentes doses de chaux. L'efficacité à moyen terme du chaulage chez l'érable à sucre a été démontrée dans cette étude par l'amélioration de la nutrition en calcium, de la vigueur de la cime et de la croissance de la tige 10 ans après le traitement. Cela confirme que le chaulage peut limiter les dommages causés par les dépôts acides dans les peuplements de feuillus nordiques dépérissant sur les sites pauvres en bases.

[Traduit par la Rédaction]

Introduction

Over the last decade, many studies of sugar maple (*Acer saccharum* Marsh.) dieback in northeastern North American forests suggested that base cation deficiency, and particularly calcium (Ca) deficiency, was a cause of tree growth reduction or decline (Kolb and McCormick 1993; Heisey 1995; Ouimet and Camiré 1995; Sharpe and Sunderland 1995; Wilmot et al. 1995; Long et al. 1997; Moore et al. 2000; Bailey et al. 2004). A positive growth and vigor response of sugar maple to liming in base-poor northern hardwood stands demonstrated that Ca deficiency was linked to sugar maple decline in these ecosystems (Wilmot et al. 1996; Long et al. 1997; Moore et al. 2000).

Although the majority of northern hardwood forests recovered from forest dieback that occurred in the 1980s, the health of sugar maple forests remains a major concern in some areas, including Pennsylvania (Horsley et al. 2002) and Vermont (Wilmot et al. 1995, 1996) in the United States, and Quebec (Duchesne et al. 2002) and Ontario (Watmough and Dillon 2003) in Canada. Several hypotheses have been proposed to explain sugar maple dieback, including acid deposition (Ouimet et al. 2001; Duchesne et al. 2002), insect defoliation, and extreme climatic events (Bernier et al. 1989; Payette et al. 1996). It has been well established that sugar maple is very sensitive to soil acidity (Thornton et al. 1986; Ouimet et al. 1996*a*). In survey plots in Vermont, Wilmot et al. (1995) observed a strong correlation between soil pH and

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sugar maple dieback. Other studies suggested that acid deposition has accelerated the loss of available Ca from soils with a low acid-buffering capacity in northern hardwood stands (Likens et al. 1998; Houle et al. 1997; Sharpe 2002; Bailey et al. 2005). Duchesne et al. (2002) showed that the appearance of the sugar maple decline phenomenon and associated growth reduction in Quebec can be attributed, at least partially, to soil acidification and acid deposition levels.

Although the short-term beneficial effect of fertilization with base cations on sugar maple has been demonstrated (Ouimet and Fortin 1992; Wilmot et al. 1996; Moore et al. 2000), limited documentation on the longer term effect of this treatment is available (Long et al. 1997, 1999). The goal of this study was to make a contribution to filling this knowledge gap by documenting the midterm (10-year) effect of a 1994 liming experiment (Moore et al. 2000) on nutrition, crown dieback, and growth of sugar maple established on a very acid, base-poor forest soil in a northern hardwood stand with declining health in Quebec, Canada.

Material and methods

Site description

The experimental stand (46°57′N, 71°40′W) is located at the Duchesnay Experimental Forest, approximately 50 km northwest of the city of Québec (Quebec). The elevation varies between 270 and 390 m. The average slope is approximately 10%. The mean annual temperature and annual precipitation are 3.4 °C and 1300 mm, respectively. The vegetation is dominated by sugar maple in association with yellow birch (*Betula alleghaniensis* Britt.) and American beech (*Fagus grandifolia* Ehrh.). According to the *Canadian System of Soil Classification* (Canada Soil Survey Committee 1998), the soil is classified as Orthic Ferro-Humic Podzol. The humus is of moder type, and the surface deposit is a very acidic and stony glacial till derived from granitic gneiss bedrock. The Lake Clair Watershed, located beside the experimental liming site, is among the catchments in northeastern North America where acid deposition continues to acidify soils, with corresponding high losses of Ca (Watmough et al. 2005).

Over the 10-year period of the study (1994–2004), atmospheric NO_3^-, NH_4^+, SO_4^{2-}, and H^+ bulk deposition was 22, 5, 23 and 0.5 kg·ha^{-1}·year^{-1}, respectively. During this period, neither insect defoliation nor frost or ice damage was observed in this area. However, relatively short drought episodes occurred during the summers of 1995 and 2002.

Experimental design

In the stand, 98 sugar maple trees were selected and numbered, and treatments were randomly applied to each tree in the fall of 1994 (14 replicates for controls and 12 for the 7 other treatments; see below). Their diameter in 1994 was 30.9±5.6 cm (mean ± SE; range: 20.0–44.0 cm). Foliar sampling was carried out in mid-July, before treatment (1994), and in mid-August for the years following treatment (1995–1998, 2002, and 2004). Foliar nutrient concentrations and Diagnosis and Recommendation Integrated System (DRIS) indices were used to evaluate nutrient status. The DRIS technique, developed by Beaufils (1973) and described by Walworth and Sumner (1987), takes into account relationships among different nutrient concentrations. The index values, calculated from these ratios, can vary from negative to positive, but the sum is always equal to zero. For a given nutrient, negative values represent suboptimal nutrition, while positive values represent supraoptimal nutrition. The ideal balance is when the DRIS index for all nutrients and the sum of their absolute values (the so-called nutrient disequilibrium index (NDI)) approaches zero (Walworth and Sumner 1987). The DRIS standards developed by Lozano and Huynh (1989) for sugar maple were used in this study.

Lime spreading was done manually within a 5 m radius of each tree. Eight lime treatments were applied (0, 0.5, 1, 2, 5, 10, 20, and 50 t·ha^{-1}). After observing a nutritional imbalance that was attributed to liming, potassium sulphate (K_2SO_4) was applied in late August 1997 on half the replicates at a rate of 1% of the dolomitic lime (0, 5, 10, 20, 50, 100, 200, and 500 kg·ha^{-1}). More details on the experimental design can be found in Moore et al. (2000).

Two increment cores were taken from each tree in October 2004 to measure tree radial growth. Annual ring measurements were carried out using WinDendro version 6.1D software (Régent Instruments Inc. 1998) and validated with signature rings. Ring values were converted to basal area increment (BAI, cm^2) using the following equation:

$$\mathrm{BAI}_t = \pi(R_t^2 - R_{t-1}^2)$$

where R is the tree radius (cm) and t is the year of tree-ring formation.

Dieback was evaluated from 1994 to 1998, and in 2004, by estimating the percentage of missing crown foliage (5% class intervals) from careful visual inspection by the same two experienced observers. Crown assessment was carried out the same day as foliage sampling.

Chemical analyses

The collected leaves, approximately 40 from each tree, were initially dried at 65 °C and then ground to 250 µm. Nitrogen (N) was determined with Kjeldahl digestion (Kjeltec Tecator 1030). For phosphorus (P), K, Ca, magnesium (Mg), manganese (Mn), and aluminum (Al), 500 mg of foliage was microwave digested with HNO_3 in Teflon^{TM} bombs. Following digestion, element concentrations were measured by atomic emission spectrophotometry (Perkin Elmer Plasma Model 40). Foliar Al concentrations were always found to be under the detection threshold (0.03 mg·kg^{-1}).

Statistical analyses

Given that short-term results of this liming experiment were published previously (Moore et al. 2000), the main focus of this paper was to evaluate the 10-year response of sugar maple to liming. Potassium fertilization treatments conducted at the end of summer in 1997 on half the experimental design were first checked for the different parameters. Given that this treatment did not show global (all treatments together) significant effects for each of the parameters studied, data were analysed without consideration of K application.

Foliar concentrations, DRIS indices, crown dieback, and stem BAI were analysed for 2004 only, using a one-way analysis of variance (ANOVA), with liming rate as the main

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Table 1. Foliar nutrient concentrations and Diagnosis and Recommendation Integrated System (DRIS) indices for control and limed sugar maple trees, 10 years after liming.

	Dolomitic lime (t·ha^{-1})								*P* values			
Nutrient	0	0.5	1	2	5	10	20	50	Treatment effect	Unlimed vs. limed trees	Linear contrast	Quadratic contrast
Concentration (mg·kg^{-1})												
N	20 054	19 982	20 355	20 082	19 233	20 533	18 933	18 583	0.118	0.496	0.098	0.128
P	1 463	1 446	1 366	1 546	1520	1 525	1 558	1 743	0.114	0.441	0.003	0.989
K	6 592	6 591	6 400	6 291	5233	6 042	4 992	5 633	0.003	0.042	0.237	0.726
Ca	4 604	5 820	5 593	7 064	8129	8 181	9 424	9 578	<0.001	<0.001	<0.001	0.011
Mg	1 083	1 504	1 797	2 199	2568	2 728	3 178	3 416	<0.001	<0.001	<0.001	0.002
Mn	905	921	942	651	873	503	533	292	<0.001	0.008	<0.001	0.117
DRIS index												
N	36	29	30	24	25	25	24	19	<0.001	<0.001	<0.001	0.159
P	14	5	–2	–4	–8	–11	–12	–11	<0.001	<0.001	<0.001	<0.001
K	–12	–18	–23	–31	–48	–42	–64	–56	<0.001	<0.001	<0.001	0.098
Ca	–50	–42	–45	–37	–29	–35	–26	–30	<0.001	0.001	0.026	0.224
Mg	12	26	40	47	60	63	78	78	<0.001	<0.001	<0.001	0.004
NDI[a]	128	126	143	146	172	177	204	194	<0.001	0.012	0.003	0.223

[a]NDI, nutrient disequilibrium index.

treatment. BAI was also analysed for the 1995–2004 period by repeated-measures analysis. For foliar analyses, the corresponding 1994 covariate was used when applicable. Data for annual BAI (1995–2004 period and 2004 only) and crown dieback were transformed to square root and logarithm + 1, respectively, for statistical analysis.

To account for the variability of tree growth between treatments before liming, BAI for 1995–2004 and for 2004 only were adjusted with pretreatment BAI using the 1993–1994 and 1994 BAI as a covariate, respectively, to provide adjusted BAI means. Also, orthogonal polynomial contrasts were performed to separate the linear and quadratic components of the trend across treatments. All statistical analyses were carried out using the SAS MIXED procedure (SAS Software Inc. 2000).

Results

Effect of K treatment on limed sugar maple

When considering all treatments together after 10 years, the addition of lime plus K had the same effect on BAI ($P \geq 0.663$), crown dieback ($P = 0.644$), foliar concentrations ($P \geq 0.054$), and DRIS indices ($P \geq 0.403$) as liming only, except for N, K, Mg, and NDI DRIS indices ($P \leq 0.038$).

When lime only versus lime plus K treatments were compared pair by pair, the effect of the 1997 K treatment was observed only for the 50 t·ha^{-1} lime treatment rate, which reduced foliar Ca (by 23%) and Mg (by 29%) concentrations ($P \leq 0.042$) and changed foliar K, Mg, and NDI DRIS indices (increase in K, decrease in Mg, and decrease in NDI indices by 41%, 29%, and 26%, respectively; $P \leq 0.038$). However, *t* values were low ($t \leq 2.59$). Consequently, further analyses were carried out without regard to the K treatment.

Effect of liming on sugar maple

Foliar concentrations and DRIS indices

Ten years after treatment, foliar Ca and Mg concentrations increased linearly with the liming rate, while foliar Mn concentrations decreased (Table 1). Foliar K concentrations for limed-only trees were lower than that for control trees 10 years after treatment. No effect of liming was observed on foliar N concentrations after 10 years. However, according to DRIS indices (Table 1), liming positively influenced foliar N and Ca status, but negatively influenced foliar P, K, and Mg status. Liming increased NDI, indicating that dolomitic lime negatively influenced the overall nutritional status of sugar maple after 10 years. However, NDI increase was mainly due to changes in K and Mg DRIS indices (Table 1).

Basal area growth

Over the 10 years following liming, BAI was higher for limed maple trees than for unlimed trees ($P < 0.001$; weak linear effect: $P = 0.038$; see Fig. 1). However, no linear trend in BAI was detected for liming rates in the repeated-measures analysis ($P = 0.287$) or by year ($P = 0.144$).

In 2004, 10 years after liming, BAI for limed maple trees was still higher than for unlimed trees ($P < 0.001$; Fig. 2), but no difference in BAI was detectable among liming rates ($P \geq 0.150$).

Crown dieback

Ten years after treatment, a beneficial effect of liming on preventing dieback was observed ($P < 0.001$; Fig. 3). Mean crown dieback for limed trees ranged from 0.5% to 4.5%, compared to 23.7% for unlimed sugar maple trees. In 2004, 8 of the 10 trees with the greatest crown decline were among the controls (crown dieback of 10%–90%; $n = 6$) or had the lowest lime treatment rate (0.5 t·ha^{-1}, crown dieback of 15% and 20%; $n = 2$). Crown dieback of all trees in the liming treatments was ≤7%, except for four individuals, two in the 0.5 t·ha^{-1} lime treatment rate and two in the 2 t·ha^{-1} lime treatment rate (crown dieback of 10% and 25%).

Discussion

Sugar maple nutrition

Foliar concentrations and DRIS indices of sugar maple

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Fig. 1. Adjusted total basal area increment (BAI) of sugar maple at Duchesnay, Quebec, over the 10 years (1995–2004) following liming. Bars represent ±2 SE.

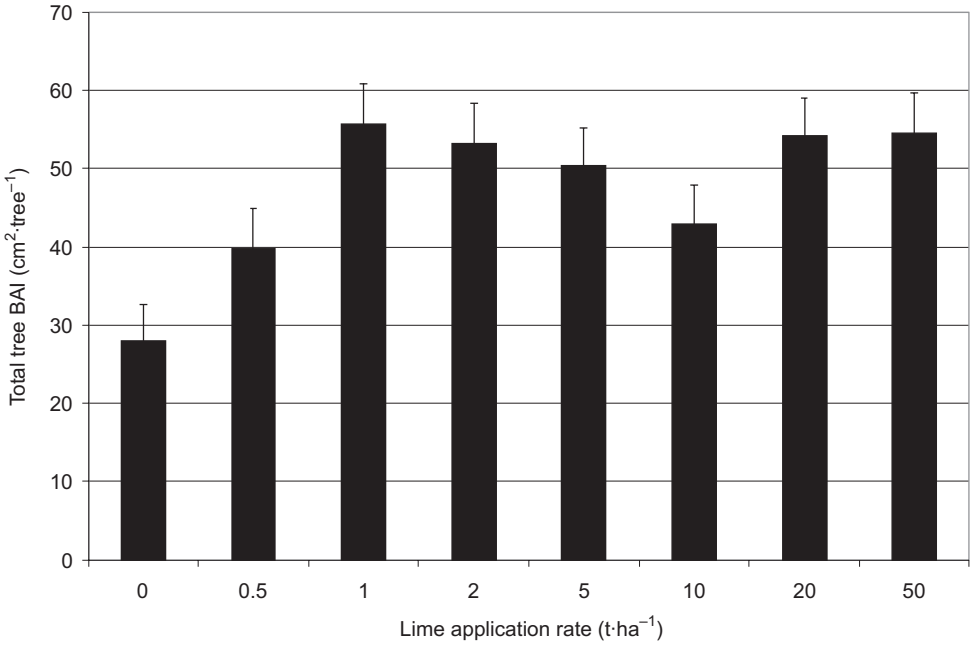
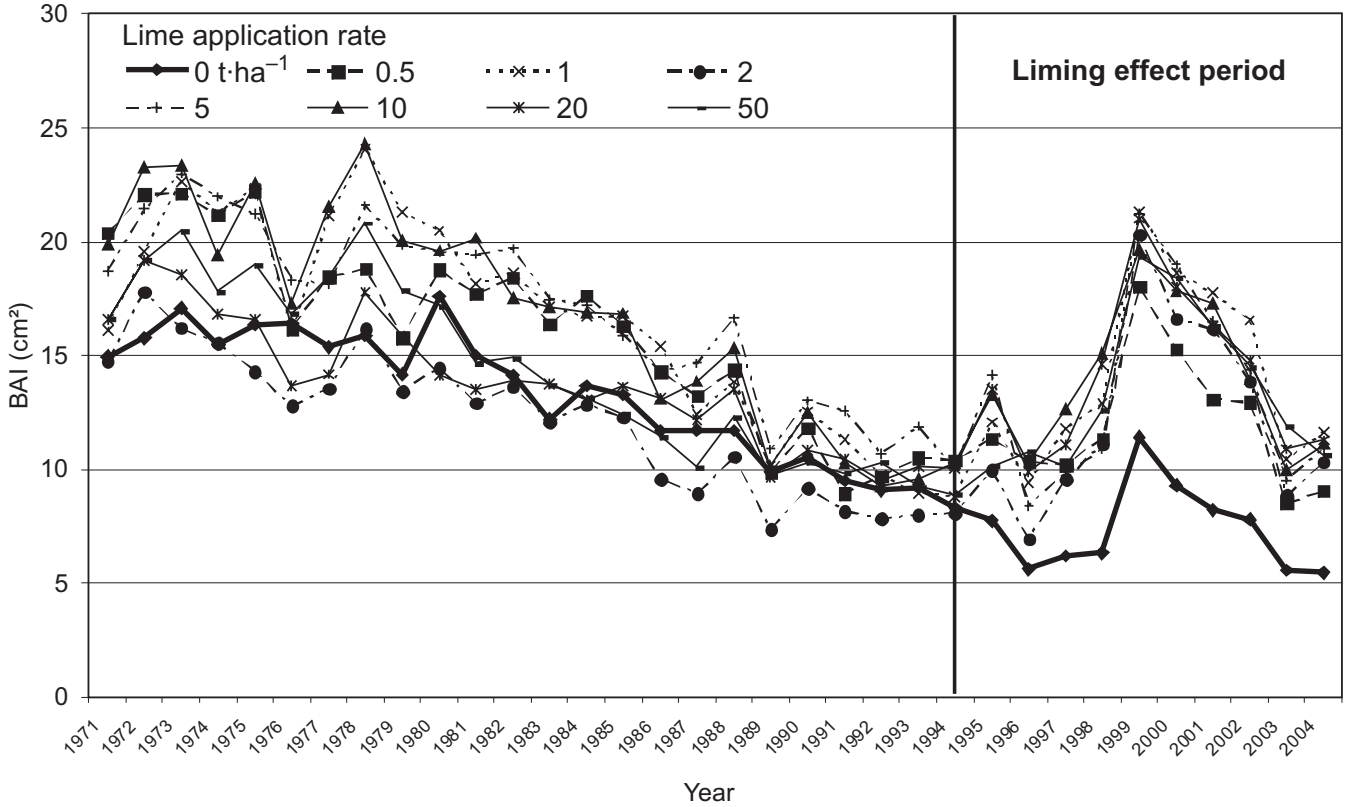


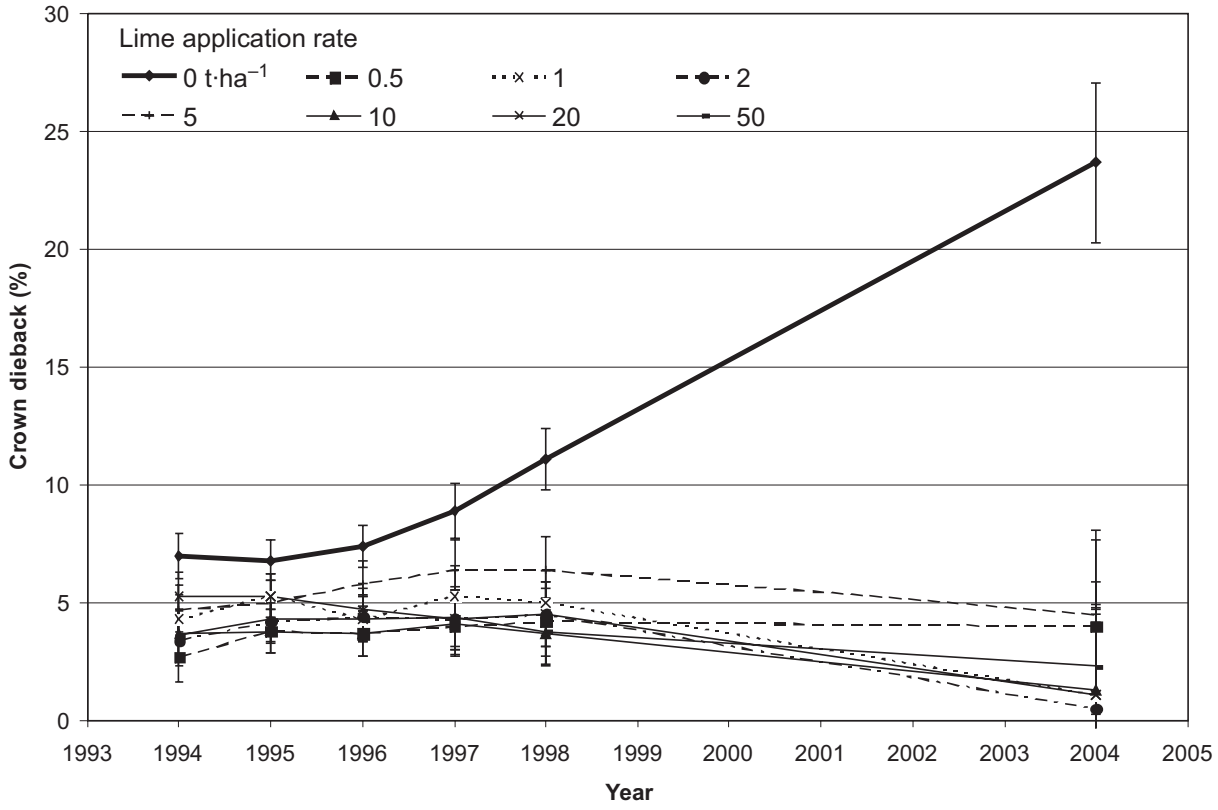
Fig. 2. Unadjusted basal area increment (BAI) of sugar maple at Duchesnay, Quebec, before and during the 10 years following liming.



control trees from 1995 to 1998 (Moore et al. 2000) and in 2004 (Table 1) strongly suggest that Ca availability was low at Duchesnay during this period. The lack of Ca 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). Short-term results showed that liming significantly improved Ca nutrition of these sugar maples (Moore et al. 2000). Ten years after liming, the dolomitic lime effect was still evident in the foliage of these trees (Table 1). Foliar concentrations of Ca and Mg were higher for limed trees than for control

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Fig. 3. Unadjusted crown dieback of sugar maple at Duchesnay, Quebec, before and 10 years after liming. Bars represent ±2 SE.



trees by 21%–108% and 39%–215%, respectively (Table 1). Similar increases were also reported by Long et al. (1997) in Pennsylvania for Ca and Mg, 9 years following the application of 22.4 t·ha^{-1} of dolomitic lime. In 2004, the Ca DRIS index value still indicated suboptimal Ca levels in foliage, but its value increased linearly with the liming rate, corroborating the beneficial effect of liming on Ca nutrition of these trees. Foliar concentrations of sugar maple trees in 2004, particularly for P, K, Ca, and Mg, were higher than those found by Moore et al. (2000) in 1998. These differences were observed for both limed and control trees, suggesting that interannual variation can be the cause. From 1994 to 1998 (Moore et al. 2000), foliar concentrations of P, K, Ca, and Mg in control trees varied by 31%, 21%, 15%, and 19%, respectively. These variations compare relatively well with differences of 48%, 22%, 30%, and 14% between 1998 and 2004 for the same elements. It is known that the availability of each nutrient can be affected differently by reductions in soil water content (Schulze 1991), suggesting that the interannual variation of leaf nutrient concentrations observed in this study could be the result of interannual variation in precipitation.

DRIS indices clearly showed a negative effect of dolomitic lime application on K nutrition, resulting in highly unbalanced Mg and K DRIS indices. This Mg–K (and also Ca–K) antagonistic effect with sugar maple has already been demonstrated experimentally by Ouimet et al. (1996*b*). Similar reductions in foliar K concentration in sugar maple and other species after the application of dolomitic lime were also observed in other studies (Côté et al. 1995; Huettl and Zoettl 1993; Ouimet and Camiré 1995; Long et al. 1997). Even though K nutrition was negatively affected, the results suggest that liming caused an overall improvement in crown vigor and growth at Duchesnay. In this context, it would seem that K was not the limiting factor for sugar maple in this ecosystem and would explain the absence of a midterm response of sugar maple to K applications. This interpretation contrasts with the results of Wilmot et al. (1995), who found that foliar K was significantly correlated with dieback in Vermont. Also, Ouimet and Fortin (1992) showed that low foliar K concentration was associated with low growth and vigor of sugar maple in the Quebec Appalachian range. These contrasting findings underline the importance of determining which nutrients limit sugar maple growth and health in a given ecosystem before applying fertilizer amendments.

After 10 years, liming improved N nutrition by slightly decreasing its DRIS index from higher positive values to lower ones (Table 1). Similar results were reported by Moore et al. (2000) after 4 years. The relatively high atmospheric N deposition rate at the site (more than 9 kg N·ha^{-1}·year^{-1}) makes this nutrient nonlimiting for maple growth and vigor. Since no decrease in foliar N concentrations was noted in 2004, it appears that the decrease in the foliar N index is due to the change in concentrations of the other nutrients (namely K, Ca, and Mg).

The reduction in foliar Mn concentrations with increasing liming rates was still observed after 10 years. This result is consistent with short-term observations of lower Mn foliar concentrations in limed trees (Moore et al. 2000) and with the decrease in xylem Mn concentrations and reduced soil acidity following liming in this experiment (Houle et al. 2002). Long et al. (1997) also observed a decrease of foliar

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Mn concentrations in sugar maple, 9 years after lime application.

Crown dieback

In the absence of lime, the crown dieback of untreated sugar maple trees increased by a magnitude of approximately two since the last measurement in 1998 and by nearly four after 10 years (Fig. 3). This increase in dieback cannot be explained by insect defoliation or frost or ice damage, given that none of these phenomena were observed or reported at Duchesnay over the 10-year period. Moreover, although two drought episodes occurred during that time (1995 and 2002), these episodes were not of high intensity and did not significantly affect stem growth in those years (Fig. 2). The evidence suggests that the long-lasting predisposing factors prevailing at Duchesnay (low soil base cation saturation, Ca-poor soil, high acid deposition) can lead to sugar maple dieback without the presence of strong triggering factors. Duchesne et al. (2003) have shown that a constant decrease in BAI growth rate for 30 years would clearly lead to visual symptoms of crown dieback. According to their results, the level of declining BAI growth rate (average of -0.35 ± 0.03 $cm^2 \cdot year^{-1}$) of control trees observed over the last 34 years in our experiment would sooner or later lead to the appearance of noticeable visual symptoms of dieback. It seems likely that these symptoms appeared during this experiment.

In lime-treated plots, it appears that lime application prevented the progression of decline symptoms. In the same experiment, Moore et al. (2000) observed, 4 years after treatment, only a slight beneficial effect of lime on sugar maple dieback. This reversing trend can also be noted in the increased BAI growth rate of the limed trees. Our results support observations made in four very acidified sugar maple stands in Pennsylvania by Long et al. (1999), who showed that sugar maple in limed plots had better vigor and lower mortality than those in unlimed plots, 12 years after the application of 22.4 $t \cdot ha^{-1}$ of dolomitic lime.

Basal area growth

After a decade, liming had a very strong positive effect on sugar maple BAI at Duchesnay (Fig. 1, 2). From 1995 to 2004, mean total BAI nearly doubled for limed sugar maple trees relative to that of control trees (Fig. 2). Similar results were noted by Long et al. (1999) over a 13-year period following application of 22.4 $t \cdot ha^{-1}$ of dolomitic lime in Pennsylvania. They found that the mean annual BAI of limed sugar maples increased by 125% relative to that of unlimed trees. Increase in leaf photosynthesis from higher leaf biomass (resulting from increasing vigor) and higher photosynthetic rates following base cation addition (Ellsworth and Liu 1994) may explain the positive effect of liming on sugar maple BAI observed in this study.

However, the lack of differences in BAI response to a very wide gradient of liming rates in our study is somewhat surprising. This contrasts with the short-term results of this experimental design (Moore et al. 2000), in which the positive effect of lime on stem growth was noted with rate gradients in 1998. This effect was, however, for diameter growth, which is a less representative value than BAI for evaluating stem growth and was mainly attributable to the two higher lime treatments (20 and 50 $t \cdot ha^{-1}$). For comparison purposes, reanalysis of the Moore et al. (2000) data was conducted. Results of BAI in 1998 suggest that, although the BAI of control trees was lower than for limed trees ($P < 0.001$) at that time, only a small difference existed among the lime treatments (linear effect; $P = 0.043$).

The absence of a growth response to liming dose is not uncommon. In Europe, Huettl and Zoettl (1993) reported that many liming trials did not show any growth response to lime owing to the substantial changes in the chemical properties of the mineral soil. In the present study, although major changes were noted in the chemical properties of the forest floor 5 years after applying increasing liming doses, the upper mineral soil did not display great changes (Houle et al. 2002). It will be interesting to see how soil chemical properties evolved in response to these liming treatments after 10 years.

The mean BAI gain of 8.6 $cm^2 \cdot year^{-1}$ (14.0 $cm^2 \cdot year^{-1}$ (limed trees) to 5.4 $cm^2 \cdot year^{-1}$ (control trees)) observed for limed sugar maples between 1995 and 2004 compares well with the gain of 6.1 $cm^2 \cdot year^{-1}$ (14.1 $cm^2 \cdot year^{-1}$ (treated trees) to 8.0 $cm^2 \cdot year^{-1}$ (control trees)) noted during the same period in a selective-cutting experiment located near the liming trial (Bédard and Majcen 2001). A previous study in Pennsylvania demonstrated the positive response of sugar maple to the combination of selective cutting and liming (Long et al. 1997). It would therefore be interesting to evaluate the effect of this approach on sugar maple trees at Duchesnay.

Duration of the liming effect: a perspective

A recent study conducted in a sugar maple stand in Connecticut showed that most Ca cycling occurs in the surface soil and that a relatively small amount of Ca uptake in the deep soil beneath sugar maple is able to sustain high amounts of available Ca in the surface soil (Dijkstra and Smits 2002). Also, the soil study of our experiment 5 years after treatment indicated that Ca moved very slowly from the forest floor to the underlying mineral soil (Houle et al. 2002). According to the 10-year results of this study, and given that liming rates were far greater than the current reservoir of exchangeable Ca (~200 $kg \cdot ha^{-1}$), atmospheric deposition (~2 $kg \cdot ha^{-1} \cdot year^{-1}$), mineral weathering (2.4–6.1 $kg \cdot ha^{-1} \cdot year^{-1}$), and leaching (4.4–7.3 $kg \cdot ha^{-1} \cdot year^{-1}$) in this ecosystem (Houle et al. 1997; Ouimet and Duchesne 2005; Watmough et al. 2005), it is anticipated that the beneficial effect of lime on sugar maple will be effective for many years. Old liming trials in Europe showed that liming mainly caused chemical and biological improvements of acidic topsoil layers. In the long term, there was an increase in soil pH and a reduction in forest floor thickness (Huettl and Zoettl 1993), which indicated an improvement of the ecosystem biogeochemical nutrient cycle.

Forest composition considerations

Recent studies suggest that acid deposition and subsequent depletion of base cations and acidification of soils, combined with sugar maple dieback in some areas, are the most likely reasons explaining the large increase of pole-sized beech trees observed in recent decades in northeastern North America (Jenkins 1997; Duchesne et al. 2005). Con-

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trary to that observed for sugar maple, the absence of a growth response by beech to liming, as noted by Long et al. (1997), suggested that American beech was not limited by Ca in base-poor acid soils. Moreover, it has been demonstrated that soil-exchangeable Ca depletion and its influence on seedling dynamics could lead to substantial decreases in sugar maple canopy dominance within a single forest generation (Kobe et al. 2002). This suggests that the proportion of beech at Duchesnay could increase at the expense of sugar maple if no action is taken to prevent Ca deficiency.

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