1998 ICE STORM EFFECTS ON THE HEALTH AND PRODUCTIVITY OF SUGAR BUSHES OF EASTERN ONTARIO

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SUMMARY

In 1998, fifteen managed sugar bush blocks with 7% to 72% ice-induced crown damage were established in eastern Ontario. All blocks received dolomitic lime (Ca, Mg) and P and K treatments in June 1999. Initial crown damage, fall root starch, sap production and sweetness, and tap hole closure rate were measured. Syrup production was calculated. Trees with >50% (severe) crown damage had reduced root starch content in 1998 and 2000, but not in 1999. Sap produced per tap and sap sweetness were reduced by damage, but not consistently in all years. Syrup production per tap tended to increase as the number of branches per tree increased in all three years. Syrup production per tap was consistently reduced in damaged trees in all three years, usually in trees with > 50% damage. The lime and P and K treatments did not significantly affect syrup production. Results suggest that severe ice storm damage to crowns resulted in reduced fall root starch levels and less sap production, and/or sap sweetness, and therefore lowered the syrup producing capacity of sugar maple.

INTRODUCTION

The ice storm of January 5-10, 1998 was unprecedented in its duration, severity, and area affected (Chapeskie 1999). Perhaps the most unusual part of this weather event was the extended length of time the icing conditions persisted. At its peak, freezing precipitation extended from the Muskoka region in central Ontario to Kitchener in southern Ontario and eastward to New Brunswick in Canada. In the United States it covered northern sections of New York and the New England states (Van Dyke 1999; Irland 1998). The most severely affected area had ice accumulations of 50 to 100 mm, which were caused by three icing episodes over 5 days (Proulx and Greene 2001). It was one of the worst weather disasters ever recorded in Canadian history (Milton and Bourque 1999).

Sugar maple trees suffered extensive crown damage throughout the ice storm damage region of eastern Ontario. The number of sugar maple taps in Ontario lost due to ice storm damage has been estimated to be 12.5% of the provincial total of 1.3 million taps or about 33% of 500,000 taps in eastern Ontario (Irland 1998). Critical research needs identified by Ontario maple syrup producers included the impact of crown damage on tree health as measured by fall root starch level and on the rate of recovery or mortality for damaged sugar bushes, and on tree productivity as measured by sap production and sweetness (Chapeskie and Nielsen 1998). To address those needs the objective of this project was to determine whether ice storm damage to the crowns of sugar maple trees in working sugar bushes affected their health and productivity (but not mortality). This was assessed by measuring the amount of starch stored in the roots, the volume and sweetness of the sap produced, and the rate of taphole closure. In addition, this study examined the effect of lime and fertilizer treatments to accelerate the recovery process of sugar bush health and productivity.

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METHODS

Plot Network

In 1998, 15 one-hectare blocks were established throughout the heavily ice-damaged area of eastern Ontario in privately owned sugar bushes. Each block was rated for ice damage by visually estimating the percentage of branches in each tree's crown that were removed by ice damage (Lautenschlager and Winters 2001). Each block was divided into four, 0.25-ha plots that were treated (except the non-tapped block) with either: i) 2 tonnes of dolomitic lime/ha; ii) 200 kgs of P and K/ha; iii) lime plus P and K, or iv) nothing (control) in June 1999. At the time of establishment, 6 focus trees per plot (24 per block) were chosen to represent the average damage in the block and were marked for use in the study. At establishment, the following parameters were measured: I) tree damage, II) focus tree diameter at breast height (DBH), III) basal area m2 ha-1, IV) and root diameter of two roots sampled per tree for starch. Soil data (such as soil pH, Ca, K, Mg, and P, plus soil clay, silt, and sand content) were obtained from a companion maple project (Timmer et al. 2003) and total branch counts were conducted as described in Lautenschlager and Winters (2001).

Root Starch and Sap Sampling

Root starch samples were collected by taking late fall (Nov. or early Dec.) (Wargo 1979) increment cores, 2-3 (0.75-1.25") cm long, from two surface roots (mean diameter = 10.5 cm (4"), range 5-18 (2-7") cm) per tree of three focus trees per treatment plot (12 trees per block). Trees were tapped using standard 11.1 mm (7/16") diameter spiles with a taphole 6.35 cm (2.5") deep using conservative tapping guidelines: a maximum of two taps per tree (Chapeskie and Nielsen 1998). Sap was collected using a tube and bucket system. The buckets had 19-litre capacity with plastic lids to pre-

vent rain or snow dilution. Sap collection was made from the same 3 focus trees per plot as root starch. Fifteen blocks had sap collections made in the spring of 1999, 2000, and 2001. Sap volume production was determined by weighing buckets about every second day during sap runs. Twenty ml sap samples for sugar content analyses were taken periodically (4-12 times, except in the short sap run season of 1998 when 2 blocks had 3 collections and 1 block had 2 collections) through the season, depending on length of sap run. Syrup production was calculated two different ways: 1) total seasonal sap volume and seasonal average sugar concentration, and 2) the periodic sap sugar samples and sap production data corresponding to that period, with both using the rule of 86 (N. B. the appropriate value is now 87) to calculate syrup production (Walters 1982). Because no real differences were detected between the two methods the data presented is from the seasonal average method.

Sugar and Starch Analysis

Extraction of starch used 1.5 ml of methanol: chloroform: water mixture (12:5:3 by volume) (Haissig and Dickson 1979) and was done 3 times on each 25 mg DM (freeze-dried mass) root tissue sample (ground with size 20 mesh). Root starch was analyzed using a Waters' HPLC system as described in Noland et al. (1997).

Experimental Design and Statistical Approach

The experiment is a split-plot completely randomized block design with 3 crown damage levels:

i) Light (0 - 25%),
ii) Moderate (26%-50%), and
iii) Severe (51% +).

The split for each 1 ha. block is the following treatments: fertilizer, liming, fertilizer+liming, and control applied randomly to one of the 4 subplots. The initial design called for 3 blocks (replications) of each damage level to be established in each physiographic region for a total of 36 plots. However, because of the pattern of ice storm-induced damage, 3 replications of each damage level (especially light damage) were not always possible in each region. This study was one of many using the same plot network to investigate the impact of the 1998 ice storm on the sugar bushes of eastern Ontario (Lautenschlager and Nielsen 1999).

Relationships between each response variable (i.e. root starch and sugars, sap volume and sugar content, and calculated syrup production) and the explanatory variables were examined using regression and ANOVA techniques (SAS 1996).

RESULTS

Root Starch and Total Sugars

Ice storm damage definitely affected root starch levels in sugar maple trees (Figure 1). Severely damaged trees had less (P£0.05) starch in their roots in 1998 and 2000 than did light or moderately damaged trees, but the difference was not significant in 1999. Comparisons among years show the average root starch content of all tapped trees was similar in 1998 (1.87% ± 0.09) and 1999 (1.84% ± 0.07), but lower levels in 2000 (1.43% ± 0.05, P £ 0.05).

Live branch numbers and soil K content were positively correlated with root starch content in 1998 and 1999, respectively, but not in the other years. Fall root starch levels were not correlated with sap production or sweetness in the following spring (data not shown).

Sap Volume and Sweetness

Sap volume was reduced by ice storm damage but not consistently every year (Figure 2). In 1999, affects of ice storm damage were not apparent when comparing sap production from the light, moderate and severe damage levels. However, if you group the damage levels differently, trees with 0-20% crown damage produced 45.1 liters of sap per tap in 1999, more than the 38.7 liters per tap produced by the trees

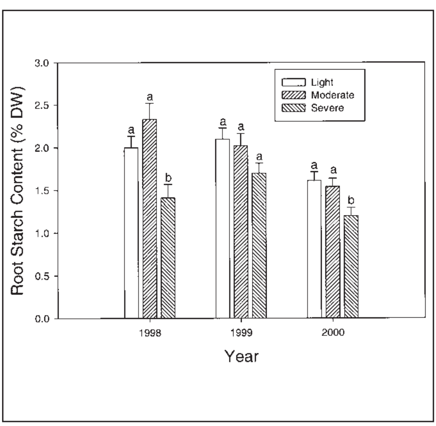

Figure 1. *Effect of ice storm damage on fall root starch levels in sugar maple trees from 15 tapped and 1 non-tapped maple stands in Eastern Ontario (Mean + Std. Error). Any columns within a year topped by different letters are significantly different (p£0.05).*

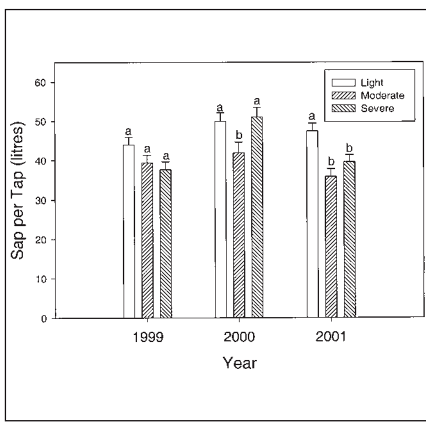

Figure 2. *Ice storm damage impact on seasonal sap volume production in sugar maple trees from 15 tapped stands in Eastern Ontario (Mean + Std. Error). Any columns within a year topped by different letters are significantly different (p£0.05).*

Table 1. *Ice storm damage impact on seasonal average sap total sugar content in sugar maple trees in Eastern Ontario (Mean ± Std. Error). Any mean in a column followed by the same letter is not significantly different (p£0.05).*

Damage Level	1999 Sap Sugar Content (%)	2000 Sap Sugar Content (%)	2001 Sap Sugar Content (%)
Light	1.74 ± 0.11 ab	2.25 ± 0.12 a	1.73± 0.41 b
Moderate	2.00 ± 0.12 a	1.97 ± 0.04 b	1.73 ± 0.05 b
Severe	1.57 ± 0.12 b	1.94 ± 0.06 b	1.93 ± 0.04 a

with greater than 20% crown loss. Although only moderately damaged trees produced less sap in 2000, in 2001 both moderately and severely damaged trees had significantly lower yields of sap per tap.

The impact of ice storm damage on sap sweetness was variable (Table 1). In 1999, the moderately damaged trees had the sweetest sap, while the moderately and severely damaged trees produced sap with about 15% less sugar in the 2000 sap run. In 2001, the severely damaged trees produced the sweetest sap.

Syrup Production

Potential syrup production was reduced by ice storm damage (Figure 3). For example, in 1999 the syrup production of severely damaged trees was calculated to be about 25% less than in lightly or moderately damaged trees. Compared to lightly damage trees, moderately and severely damaged trees had a similar reduction in calculated syrup production in 2000. In 2001, the moderately damaged trees had less potential syrup production than lightly or severely damaged trees. Overall mean calculated syrup production per tap for maples of all damage levels was higher in 2000 (1.11 l/tap) than in 1999 (0.82 l/tap) or 2001 (0.85 l/tap).

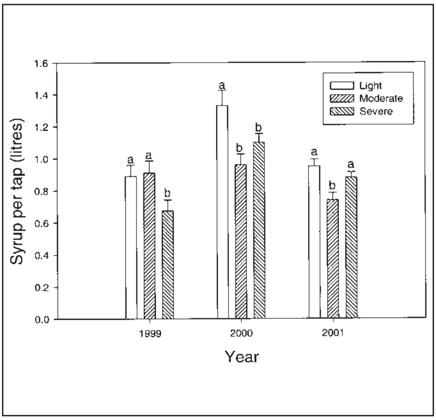

Figure 3. *Ice storm damage impact on calculated syrup production in sugar maple trees from 15 tapped stands in Eastern Ontario (Mean + Std. Error). Any columns within a year topped by different letters are significantly different (p£0.05).*

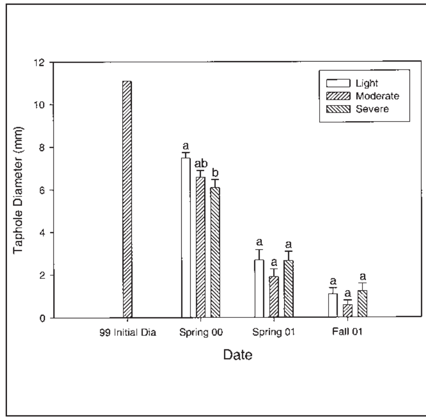

Figure 4. *Initial 1999 taphole diameter and diameter after one, two, and three growing seasons as affected by crown damage in 15 tapped stands in Eastern Ontario (Mean + Std. Error). Any columns within a group topped by different letters are significantly different (p£0.05).*

Total Branch Count

The total number of branches per tree was positively correlated with sap production in all three years, but was only correlated with sap sugar concentration and syrup production in 1999 (data not shown). However, if one block (an outlier) that had trees with the highest branch counts and low sap production in 2000 and 2001 is removed from the analysis, the relationship usually becomes significant for both sap sugar content and syrup/tap in both years (data not shown).

Taphole Closure

The effect of crown damage on taphole closure rate varied from year to year with no clear relationship evident (Figure 4). For example, after one year, tapholes closed faster in severely damaged trees for 1999 tapholes, then faster in moderately damaged trees for 2000 tapholes, while 2001 tapholes showed no rate of closure differences related to damage. Although tapholes for all levels of damage were significantly smaller than the initial diameter after one year, they were still less than 50% closed after one year. After two to three growing seasons, there were no damage-related significant differences in taphole closure rate.

Dolomitic lime and fertilizer treatments did not have a significant affect on anything measured in this project (data not shown). However, the P and K fertilizer treatments did stimulate diameter growth of ice storm damaged maple trees (Lautenschlager et al. 2003; Timmer et al. 2003).

DISCUSSION

The crown of a sugar maple tree is its photosynthetic factory for producing sugar. By removing a significant portion of this crown, the ice storm of 1998 reduced the capacity of the tree to produce energy (sugar) needed for growth and development. Storm damage was assessed as the percentage of live crown removed. Although this provides a rough assessment of the ice storm impact on the tree's ability to produce energy, it does not account for differences in initial crown size between trees and the differing ability with age (Kramer and Kozlowski 1979) and crown classification (Meating et al. 2000) to sprout new epicormic branches to replace lost ones. Therefore, the impact of 50% damage on one tree that initially had 50 tertiary branches may not have been as great as on a second tree that had 20 such branches before the storm. This led to the effort to quantify the number of live and epicormic branches on the focus trees used for this experiment (Lautenschlager and Winters 2001). In addition, the age of the tree and its condition prior to the storm (Proulx and Greene 2001) also will influence the degree to which it will be affected by ice storm damage. The combination of these factors and weather patterns in the eastern Ontario region during the growing seasons (Parker 2003) after the storm are likely reasons why response to the ice storm was variable from stand to stand; these factors have been considered when interpreting the results.

The severe level of damage (>50 %) reduced fall root starch. To my knowledge, this is the first time ice storm induced crown damage has been shown to reduce root starch content. Reductions in autumn root starch levels have been reported for sugar maple trees where crown dieback equaled or exceeded 50% (Renaud and Mauffette 1991). However, they also found that the same trees had elevated levels of fall root sugars (glucose and fructose). Mortality of sugar maple has been associated with shoot and root starch depletion in artificially defoliated trees (Gregory and Wargo 1986). Severe insect defoliation reduced fall root starch levels in sugar maple (Kolb et al. 1992). Other ice storm studies estimated that, for hardwoods, a 40-50% crown loss was the critical level above which tree death tended to increase rapidly with increased damage (Proulx and Greene 2001, Boulet et al. 2000). The 50% crown damage threshold for root starch depletion found in this study tends to support this critical crown damage threshold for mortality. However, these studies and others found a wide range of projected or measured mortality with crown loss; in general, mortality was proportional to damage (Proulx and Greene 2001).

Root starch levels of severely damaged trees were not significantly affected by crown damage in 1999. This suggests that variable growing conditions during the different years (Parker 2003) also may affect the fall root starch levels. Other factors correlated with and possibly influencing autumn root starch content appear to be of little or no importance.

Ice storm damage effects on sap production, sap sweetness, and syrup production were usually negative; but variable. Sap volume was significantly reduced by crown damage in two of the three years measured. However, damage effects on sap sugar content were more variable and that variability may have been due to inherent natural variability and the effects of other environmental factors. Syrup production was significantly reduced by damage in all three years, but only in moderately damaged trees in 2001. In his review, Coons (1999) could not find any previous literature documenting the effect of ice storms on sugar maple sap and syrup production. This study and that of Campbell et al. (2001) are, to my knowledge, the first evidence that ice storm induced damage to sugar maple crowns reduces sap sweetness, sap volume, and syrup production. Insect defoliation has been shown to lower sap production and sweetness in Pennsylvania (Kolb et al. 1992). The higher sap sugar content in the severely damaged trees in 2001 is similar to Kolb et al.'s (1992) finding that the second year after insect defoliation, sap sweetness was highest in the heavily (60-90% foliage damage) damaged maples.

Total branch count was consistently and positively correlated with sap per tap production in all three years, which suggests that ice storm removal of branches is one mechanism that reduces sap production. This finding is consistent with evidence on how the colder temperatures at night freeze the sap in the outer branches first causing sap flow up the tree to replace the frozen sap (Tyree 1983; Tyree 1984).

Lime and fertilizer treatments did not have a significant effect on anything measured in this study. The P and K treatments were found to enhance the recovery of sugar maple from crown damage by stimulating diameter growth (Lautenschlager et al. 2003; Timmer et al. 2003). It is possible that such treatments could be used in the future to speed recovery of trees from crown damage. However, sugar maple response to liming treatments is a long term process (Long et al. 1997) and it is too early to make any definitive conclusions on liming treatment effects.

The maple tree's ability to heal wounds did not seem to be affected much by the level of crown damage. Other studies have reported that wound healing usually progresses slower in defoliated maples (Wargo 1977), so the lack of an effect of crown damage on taphole closure rate was somewhat unexpected. It is likely that natural variability in wound healing response obscured any tendency for damage to inhibit the tap wound closure process. It is also possible that tap hole wounds were too small to detect any effects of degree of damage on the wound healing process.

In conclusion, ice storm damaged sugar maple crowns tended to have less syrup productive capacity and lower root starch levels, especially in trees with more than 50% crown damage. The effect of the damage lasted up to three years after the ice storm.

Future plans (dependent on new funding) for this project are to do follow up measurements of growth, sap production and sweetness, and fall root starch levels at year 5 (post treatment) and possibly year 10 to track longer term effects of the ice storm. In addition, any effects of the lime and fertilizer treatments on sugar maple health and productivity would also be measured.

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