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Identifying Sustainable Practices for Tapping and Sap Collection from Birch Trees: Optimum Timing of Tapping Initiation and the Volume of Nonconductive Wood Associated with Taphole Wounds

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Abstract

Experiments were conducted to determine two pieces of information essential to identify practices necessary to ensure tapping trees for birch sap collection is both sustainable and profitable—the selection of the time to initiate tapping birch trees to obtain maximum yields, and the volume of nonconductive wood (NCW) associated with taphole wounds in birch trees. The yields obtained from various timing treatments varied between sapflow seasons, but indicate that using test tapholes to choose the appropriate time to initiate tapping is likely to result in optimum yields from birch trees. The volume of NCW associated with taphole wounds in birch trees was highly variable and generally quite large, averaging 220 times the volume of the taphole drilled, and requiring relatively high radial growth rates to maintain NCW at sustainable levels over the long-term. However, more conservative tapping practices, including reduced taphole depth and increased dropline length, as well as thinning and other stand management practices, can be used to reduce the minimum growth rates required. Producers can use this information to ensure that they use tapping practices that will result in sustainable outcomes and obtain the maximum possible sap yields from their trees.

Keywords

Birch Sap, Birch Syrup, Maple Syrup, Tapping, Compartmentalization

1. Introduction

Tapping and collecting sap from birch trees (*Betula*, sp.) for the production of beverages and syrup is gaining increased levels of interest in the maple-producing region of North America [1]. Although the practice of tapping birch trees and collecting sap has been ongoing for millennia across the world [2], there remain some critical data needed in order to make science-based decisions about the production practices required to optimize yields and ensure sustainable outcomes are achieved in the long-term.

First, there are limited data available on production practices required to ensure optimum yields are obtained from birch trees tapped for sap collection. In particular, a key information shortfall is with respect to the optimum timing of tapping birch trees each year—there is currently no scientific information on which to base decisions of when birch trees should be tapped to achieve the best sap yields. Currently, birch producers rely on a wide variety of informal techniques and indicators to determine when trees should be tapped, including tapping based on the rate of sap flow from test trees, or tapping when puddles first appear in the woods [1]. None of these methods has been investigated or demonstrated to effectively predict a time to tap birch trees that results in optimum sap yields. With a short production season (3 - 5 wks) and the high value of the birch syrup crop [1], producers risk substantially reduced yields and profits by tapping at suboptimal points during the sapflow period. Thus, the first objective of this study was to determine the optimum timing for tapping birch trees to achieve maximum yields.

Also, each year, tapping a tree for sap collection permanently removes a small portion of wood where the taphole is drilled and the spout inserted [3] [4]. The tree's response to the taphole wound also results in a column of wood extending above and below the taphole that remains permanently nonconductive to water and thus unavailable for future sap collection (**Figure 1**) [3] [4] [5]. However, stem growth also adds new conductive wood to the outside of the tree each year. Thus, for annual sap collection to be sustainable, generally, the volume of this nonconductive wood (NCW) generated by tapping shouldn't exceed the volume of new, conductive wood that can be added by annual radial growth [3]. To establish the practices required to meet these conditions of sustainability for birch sap collection, the volume of the column of NCW generated by taphole wounds in birch trees must thus be known, and the second objective of this study was to determine the volume of NCW generated in response to taphole wounds in birch trees. Together, these data can be used to inform birch sap collection practices used by producers to ensure that optimum yields and sustainable outcomes are achieved.

2. Materials and Methods

2.1. Timing of Tapping

Twenty-six healthy paper birch (*Betula papyrifera*) trees at the University of Vermont Proctor Maple Research Center (UVM-PMRC) in Underhill, Vermont (USA) were assigned to one of three timing of tapping treatments:

Figure 1. Illustration of the upper portion of a column of nonconductive wood (NCW) associated with a taphole in a paper birch stem, viewed transversely in stem cross-sections. The lower portion of the NCW column is not shown; it would be of similar size and length, and extend downward from the taphole (Photograph courtesy of Mark Isselhardt).

- Early: Trees were tapped before stem pressure development was observed or test taps were exuding sap.
- Test taps: Trees were tapped after test tapholes in nearby trees began exuding sap at a substantial rate, >1 drop per second.
- End of maple season: Trees were tapped immediately after the maple production season at UVM-PMRC ended.

Tree diameter ranged from 8.8 - 14.0″, and was stratified across treatments so that it did not differ significantly between treatments ($p < 0.6200$, $\bar{Y}_{Early} = 11.2''$, $\bar{Y}_{Test\ taps} = 11.9''$, $\bar{Y}_{End\ of\ maple} = 11.5''$). At the appropriate time for each treatment, each tree was tapped with a standard 5/16″ maple spout and connected to a plastic chamber that enables the collection and quantification of sap from individual trees under vacuum. Vacuum was maintained throughout the duration of the experiment at standard maple industry levels (~25″ Hg). The volume and sugar content of sap produced by each tree was measured daily throughout the production season. Sap sugar content was measured with a Misco PA202X refractometer. (It should be noted that maple refractometers are calibrated for sucrose solutions; although birch sap is predominantly a solution of glucose and fructose, at concentrations below 10%, the difference between invert and sucrose refractometer scales is negligible [6].) At the end of the sapflow season, defined as when sap collected was too poor in quality to process into syrup, the total volume of syrup equivalent at 66.9% sugar produced by each tree was calculated and used to calculate the average total yield for each treatment. The experiment was repeated in the 2015 and 2016 sapflow seasons, using the same trees and timing treatments. The climate conditions during the sapflow periods of the two years of the study are illustrated in Figure 2.

All data were analyzed using JMP Pro software version 13.0 (SAS Institute, Cary, NC). Homogeneity of variance assumptions were verified using Levene's tests and normality assumptions were verified using Shapiro-Wilk tests. One-way analysis of variance was used to determine if significant differences existed between the overall mean syrup equivalent yields of the three treatments in 2015 and 2016, and Students *t*-tests were used to conduct pairwise comparisons between individual treatments within each year. Wilcoxon Rank Sums tests were used for data that were not normally distributed.

2.2. Volume of Nonconductive Wood from Taphole Wounds

Thirty-nine healthy paper birch trees with an average dbh of 9.6″ (range, 7.9 - 12.7″) growing in a stand in located in Underhill, VT (USA) were selected and tapped during the spring 2015 sapflow season following current standard maple tapping practices (5/16″ spout, 2″ tapping depth). Each tree was subsequently felled in late-autumn 2015, and a portion of the stem containing the taphole wound (approximately 4' above and below the taphole) was cut and removed (Figure 3).

Beginning at the center of the taphole, each stem segment was subsequently cut with a circular saw into 2″-wide segments (Figure 3). Each of these segments was then photographed with a scale using a digital camera (Figure 3). ImageJ image analysis software was used to measure the area of NCW (visible as

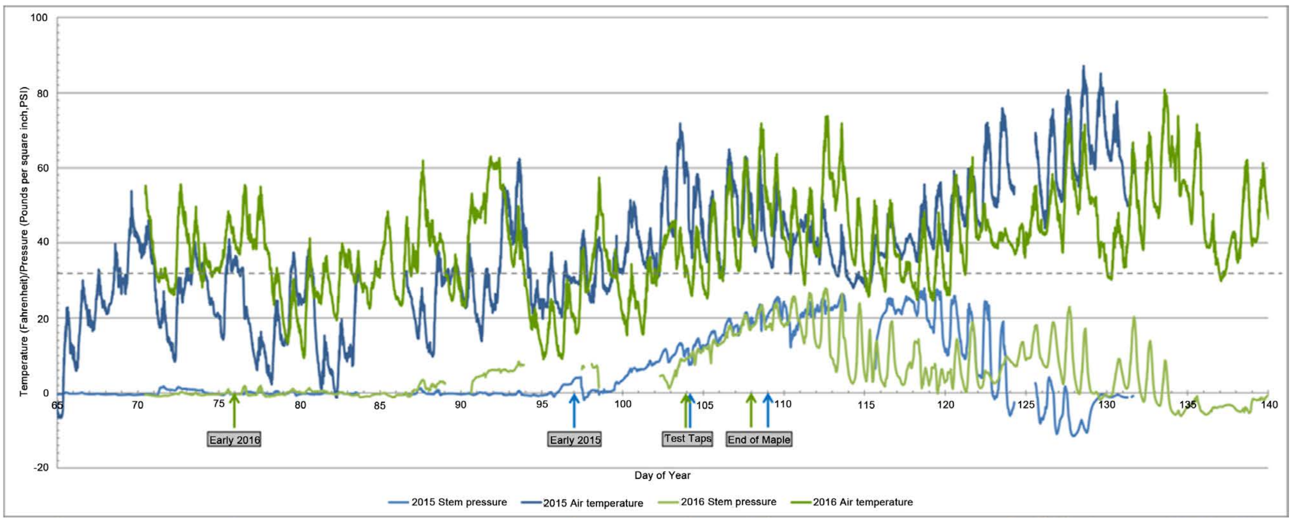

Figure 2. Air temperature (Fahrenheit) and stem pressure (PSI) in a paper birch tree during the birch sapflow periods of 2015 (blue lines) and 2016 (green lines). Pressure was measured with a pressure transducer (PX26-030GV, Omega Engineering, CT, USA) mounted in an inverted standard spout and dropline, and data recorded at 15-minute intervals with a datalogger (GL220, Graphtec Corp., Yokohama, Japan). Dashed lined indicates freezing point (32˚F); gaps in the pressure data are periods when sap in the pressure sensor tubing was frozen, resulting in spurious pressure gauge measurements.

Figure 3. Stem sections from paper birch trees felled for quantification of the volume of nonconductive wood (NCW) associated with taphole wounds. Each segment was cut into 2″—wide cross-sections, photographed, and the area of NCW measured with image analysis software and used to calculate the total volume of NCW associate with the taphole.

discoloration [3]) in the image of each segment of each tree [7]. These data were then used with the segment widths to calculate the total volume of NCW generated by the taphole in each tree, and the volume of NCW in proportion to the size of the taphole wound.

NCW volume data were then input into a mathematical model of the "tapping zone" of a tree, the portion of the stem available for tapping and sap collection [3]. The model estimates the proportion of NCW in the tapping zone of a tree over time based on inputs of radial growth rates, tapping practices (e.g. taphole diameter, tapping depth, and the length of the sap dropline), and using known values for the volume of NCW generated by each taphole [3]. The model was used to determine the minimum growth rates required to maintain NCW levels below 10% when using current conservative maple tapping guidelines (taphole/spout diameter = 5/16″, taphole depth = 1.5″, dropline length = 30″ [5]) with the average volume of NCW associated with taphole wounds in birch trees that had been determined in this study, and thus assess the tapping practices required for tapping birch trees to be sustainable in the long-term.

3. Results and Discussion

3.1. Timing of Tapping

The birch sapflow seasons of 2015 and 2016 were extremely different from one another (**Figure 2**), with 2016 marked by early warm temperatures, limited snow cover, and an approximately 2- to 3-fold reduction in overall yields relative to 2015 (**Table 1**). The yield results for each year were thus analyzed separately.

In 2015, there was an overall significant difference in total yield between the timing treatments ($p < 0.0138$), with pairwise comparisons indicating greater yields were obtained from both the Early ($p < 0.0062$) and Test Taps ($p < 0.0485$) treatments compared to yields from trees tapped at the End of the Maple season (**Table 1**). Indeed, both of these treatments had more than double the yields of trees tapped at the end of the maple season. There was no significant difference between the yields from the Early and Test Taps treatments ($p < 0.4705$) (**Table 1**). The end of the maple season is a practical time for maple producers engaged in birch sap collection to tap birch trees, as it enables a full transition from one practice to another, without an overlap in need for equipment or personnel. However, these data indicate that at least in some years, waiting for this time can result in substantial yield losses. It is also notable that although there was a 2-fold difference between the average yields of the Test Taps and End of Maple treatments, the time between these treatments was only 5 days. This suggests that even small differences in the time producers choose to tap birch trees can have significant impacts on overall yields in some years.

In contrast, in 2016 there was only a marginally significant overall difference in the yields between the three timing treatments ($p < 0.0829$) (**Table 1**). Although yields were much lower overall relative to 2015, in contrast to the results observed in 2015, tapping trees with the Test Taps ($p < 0.0745$) and End of Maple ($p < 0.0400$) treatments resulted in significantly greater yields than the Early treatment (although only marginally so for the Test Taps treatment). The

Table 1. Mean sap sugar content and total sap and syrup equivalent yield per tree (±standard error of the mean), and sapflow season length for paper birch trees tapped with three timing of tapping treatments in 2015 and 2016.

Treatment	No. of trees	Mean total sap yield (gal)	Mean total syrup yield (gal)	Mean sap sugar content (%)	Tap date	Season end date	Season length (days)	Overall mean†	Pairwise comparisons Early	Pairwise comparisons Test Taps
2015										
Early	9	40.5 ± 10.0	0.37 ± 0.08	0.8 ± 0.04	4/7/15		27	0.0138*‡	---	---
Test Taps	8	33.8 ± 9.1	0.36 ± 0.10	1.0 ± 0.05	4/14/15		20		0.4705‡	---
End of Maple	9	14.9 ± 2.6	0.16 ± 0.03	0.9 ± 0.06	4/19/15	5/3/15	15		0.0062*‡	0.0485*‡
2016										
Early	8	12.3 ± 2.7	0.11 ± 0.03	0.8 ± 0.02	3/16/16		50	0.0829	---	---
Test Taps	7	15.8 ± 1.7	0.19 ± 0.02	1.0 ± 0.02	4/13/16		22		0.0745	---
End of Maple	9	17.9 ± 2.4	0.19 ± 0.03	0.9 ± 0.02	4/17/16	5/4/16	18		0.0400*	0.8557

†p-values are for one-way analysis of variance comparing overall mean syrup yields between the treatments, and individual Students t-tests between each timing treatment. ‡indicates comparison made with nonparametric Wilcoxon Rank Sums test. *denotes statistically significant differences ($p \le 0.05$). One tree each in the Test Taps and End of Maple treatments was lost to mortality after the 2015 season.

Early treatment in 2016 was initiated much earlier than in 2015, after several consecutive days with temperatures above 50˚F (**Figure 2**) and observations of no snow cover and sap dripping from some test tapholes. The lower yields observed in the Early treatment compared to the later timing treatments provides some support for anecdotal reports that birch trees can be tapped too early [1], ultimately resulting in reduced yields, even when conditions appear appropriate for birch sap flow to occur. However, the data from 2015 indicate that there is likely an appropriate balance that can be achieved, as earlier tapping in that year resulted in the largest yields of the three timing treatments (**Table 1**). Also unlike 2015, there was no significant difference in yields between the Test Taps and End of Maple treatments in 2016 ($p < 0.8557$), suggesting that waiting to tap birch trees until the maple season has concluded does not always result in significant yield losses.

Taken together, these results indicate that inherent variability in sap yields between years might sometimes confound impacts of the selection of the time to tap birch trees. However, despite the variability observed, the data do indicate an optimum timing of tapping that producers can use to obtain optimum yields. In both years, the Test Taps treatment resulted in yields that were equal to or not significantly different from the highest-yielding treatments. Thus, tapping trees based on observations of when test tapholes begin running at a substantial rate (>1 drop per second) appears to be an effective strategy to ensure optimum yields are obtained. In addition, the results indicate that 1) waiting to tap birch trees until the maple season concludes could result in significantly lower yields in some years, 2) tapping slightly early and before test taps are observed to be exuding sap (when using vacuum) is not likely to significantly negatively impact yields, and 3) tapping very early in response to aberrantly early warm temperatures like those observed in 2016 may result in yield reductions compared to tapping at later times closer to the "standard" birch sapflow season.

3.2. Volume of Nonconductive Wood from Taphole Wounds

The volume of NCW columns was highly variable between trees (**Table 2**), ranging from 65 to 2275 cm^3 (±92). Some of this variability appeared to be driven by instances where the NCW column generated in response to the taphole intersected and interacted with areas of existing NCW (the central column of discolored wood, branch scars, etc.), which resulted in much larger or longer NCW columns (**Figure 4**). The volume of NCW was on average 222 times the volume of the taphole that was drilled (**Table 2**). These volumes were much greater than those observed previously for maple trees, which have NCW columns that average only 49.2 (±5.1) times the volume of taphole wounds (van den Berg *unpublished*). This difference between NCW column size in birch and maple is consistent with observations in previous studies [8] [9] [10].

The data on the average volume of NCW generated by taphole wounds in birch trees were next used to estimate the practices required for tapping and sap

Table 2. Mean total volume and volume in proportion to that of the taphole (±standard error of the mean) of nonconductive wood (NCW) columns associated with taphole wounds in paper birch trees.

	n	Mean	Minimum	Maximum
Total NCW volume (cm^3)	39	557.2 ± 91.9	65.4	2275.3
NCW volume in proportion to taphole volume		221.6 ± 36.6	26.0	905.1

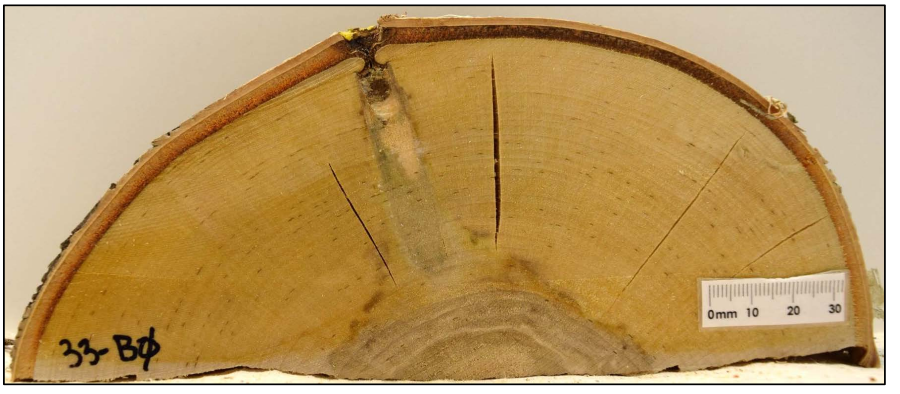

Figure 4. Example stem cross-section in which nonconductive wood (NCW) associated with the taphole has merged with NCW from a pre-existing central column of discolored wood.

collection from birch trees to be sustainable in the long-term. To do this, the NCW volume data were used with a model of the tapping zone of a tree [3] to calculate the minimum radial growth rates required to maintain the volume of NCW at less than 10% of the tapping zone for 60 years when following current maple tapping guidelines. This level is equivalent to a <10% chance of encountering NCW when tapping a tree each year, and was selected through consultations with researchers, maple producers, and extension personnel as the maximum amount of NCW acceptable for sustainable outcomes [3]. The results of this analysis indicate that relatively high radial growth rates, from 24.9 - 56.4 cm^2 BAI annually, are required to ensure an adequate replenishment of conductive wood and prevent an excessive accumulation of NCW in the tapping zone when using the specified tapping practices (**Table 3**). It is possible to adjust tapping practices to help reduce the growth rates required for sustainable outcomes, for example, using longer droplines (36″) reduces the required radial growth rates to between 20.1 and 32.5 cm^2 (**Table 3**). However, these results suggest that producers must be very aware of the growth and vigor of birch trees used for birch sap collection, and use tapping practices (taphole depth, spout size, and dropline length) as conservative as possible in order to ensure sustainable outcomes are achieved.

4. Conclusion

The results of this study indicate that test tapholes can be a reliable indicator that producers can use to determine the appropriate time to tap birch trees to obtain

Table 3. Minimum growth rates required for nonconductive wood (NCW) in paper birch trees to remain below 10% of the tapping zone volume for 60 years when tapped following current conservative maple tapping guidelines (spout size = 5/16″, tapping depth = 1.5″, dropline length = 30″), and with increased dropline length (spout size = 5/16″, tapping depth = 1.5″, dropline length = 36″).

Tapping Practices				
Tapping Depth (in.)	1.5		1.5	
Spout size (in.)	5/16		5/16	
Dropline length (in.)	30		36	
DBH (in.)	BAI (cm^2)	Ring width (cm)	BAI (cm^2)	Ring width (cm)
8	24.9	0.38	20.1	0.31
10	29.3	0.36	20.1	0.25
12	33.8	0.35	20.3	0.21
14	38.3	0.34	20.4	0.18
16	42.8	0.33	23.3	0.18
18	47.3	0.33	26.4	0.18
20	51.9	0.32	29.4	0.18
22	56.4	0.32	32.5	0.19

optimum yields. In addition, the results indicate that the volume of NCW associated with taphole wounds in birch trees is generally quite large, and that vigorous radial growth rates are required to ensure NCW does not accumulate excessively in the tapping zone. Producers should evaluate the growth rates of birch trees to be tapped for sap collection to ensure sustainability of tapping practices, and, if necessary, modify tapping practices to increase the likelihood of sustainability—increasing dropline length and reducing tapping depth can reduce the accumulation of NCW [3]. Stand management practices, particularly thinning, can also be used to increase radial growth rates and enhance sustainability of tapping for sap collection. Producers can use this information to implement birch sap collection practices that will ensure that optimum yields and sustainable outcomes are achieved.

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