Wound Response to Taphole Rejuvenation Practices

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In response to injury from wounds such as tapholes, trees initiate processes to compartmentalize the affected area in order to prevent the spread of infection by disease- and decay-causing microorganisms beyond the wound, and to preserve the remaining sap conducting system (Shigo 1984). This results in the formation of a column of visibly stained wood above and below the wound, and the affected zone is rendered permanently nonconductive to water and nonproductive for sap collection. These processes, along with effects from microbial activity, are responsible for the gradual reduction in sap flow from tapholes over the course of the production season.

There has been recent renewed interest in strategies which attempt to extend the standard sapflow season or increase overall yields through the "rejuvenation" of tapholes. These strategies include reaming existing tapholes – made either early or during the standard spring sapflow season – to be slightly wider, deeper, or both. It is thought that by exposing new vessels these strategies might increase sapflow and yields by overcoming the tree's response to the taphole wound and microbial effects (Childs 2019).

There are numerous economic questions with respect to these taphole "longevity" strategies, including whether they actually result in an increase in yield relative to a standard spring taphole, or whether any resulting increase is sufficient to overcome the additional costs in labor and materials necessary to implement the practices. There are also numerous questions related to the sustainability of such strategies, including whether the amount of nonconductive wood (NCW) generated in response to longevity treatments is proportional to that from a single taphole, or whether they render the wound more susceptible to disease and decay. Ultimately, the net economic outcomes of these strategies are driven by their effects on both yields and NCW development – the accumulation of NCW within a tree's tapping zone over time will determine the likelihood of drilling into productive sapwood in the future. Thus, as part of a multi-year experiment to investigate the yields and net economic outcomes of several taphole longevity strategies, we conducted an experiment to investigate the volume of NCW generated in response to two of these strategies.

Materials and Methods

Twenty sugar maple trees (mean diameter at breast height = 11.0″ ± 0.25) located in the Forest Genetics Plantation at the University of Vermont Proctor Maple Research Center were selected. Each received a "Control" taphole – 5/16″-diameter, 1.5″-depth – during the standard spring sapflow period in 2018. Each tree also received one or both of the following taphole longevity treatments:

- Reamed Wider and Deeper (RWD) – For this treatment, ¼″-diameter, 1.5″-depth tapholes were drilled in early November 2017. On the same date Control tapholes were drilled in spring, these tapholes were reamed to 5/16″-diameter and 2.5″-depth.

- Second Taphole (ST) – For this treatment, 5/16″-diameter, 1.5″-depth tapholes were drilled in early November 2017. A second, 5/16″-diameter, 1.5″-depth taphole was drilled 2″ directly above the first taphole on the same date as spring Control tapholes were drilled. This treatment was selected for investigation because it was hypothesized that by drilling a second taphole within the column of NCW that would develop from the first taphole, the total amount of NCW generated by both tapholes might be minimized (while also potentially maximizing the additional sap yield by creating an entirely fresh taphole instead of enlarging an existing one).

Taphole depth was controlled using a plastic drill stop over the bit. Care was taken to place all treatment tapholes in locations not proximate to one another, old tapholes, or stem defects.

Trees were felled the following fall (October 2018), and portions of the stem that contained each taphole and associated NCW were cut and removed. Each stem portion was subsequently cut with a circular saw into 2″-wide segments beginning at the center of the taphole and moving up and down the stem until stain from the taphole was no longer visible. Each of these segments was then photographed with a scale using a digital camera. Tapholes for which the NCW intersected or interacted with existing wounds or the central column of discolored wood (and thus generated much larger amounts of new NCW) were not included in analyses. The resulting overall sample sizes were 16 Control, 12 RWD, and 11 ST treatment tapholes.

ImageJ image analysis software (https://imagej.nih.gov/ij/) was used to measure the area of NCW in the image of each segment of each tree. These data were then used with the segment widths to calculate the total volume of NCW generated in response to each taphole in each tree. To reduce the effect of the variation in NCW development between trees, the volume of NCW generated in response to longevity treatment tapholes were expressed as a percentage of the NCW volume of the Control tapholes in the same tree. In addition, the ratio of the volume of NCW generated to the final taphole volume was calculated for each taphole.

Statistical analyses were performed using JMP Pro 15.0 (SAS Institute, Cary NC). Normality of distributions was assessed with Andersson-Darling tests. Paired analyses with Wilcoxon Signed Rank tests were used to test the following hypotheses:

1) that the volume of NCW gen-

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erated in response to each longevity treatment was equal to the volume generated in response to Control tapholes within the same tree; and

2) that the ratio of the final taphole to NCW volume for each longevity treatment was equal to that of Control tapholes within the same tree.

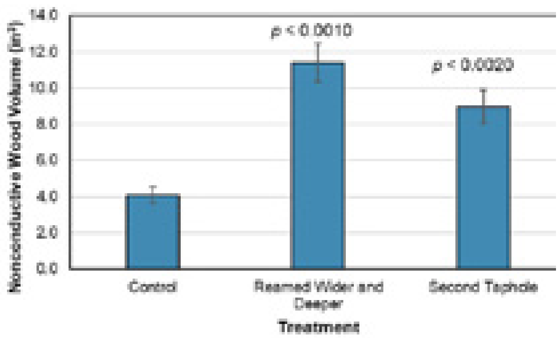

Figure 1. Overall mean (± standard error) volume of NCW generated in response to Control and longevity treatment tapholes (Control n = 16, Reamed Wider and Deeper n = 12, Second Taphole n = 11). p-values are for paired comparisons made with Wilcoxon Signed Rank tests to test the hypotheses that the volume of NCW generated in response to each longevity treatment was equal to that generated in response to Control tapholes within the same tree (n = 10 for paired comparisons).

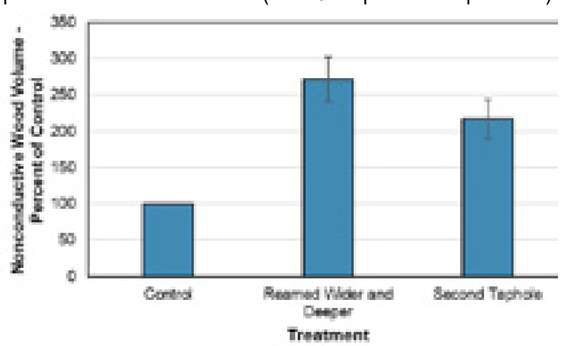

Figure 2. Overall mean (± standard error) volume of NCW generated in response to longevity treatment tapholes as a percentage of the Control taphole NCW volume within the same tree. n = 10 for each treatment.

For paired analyses (within the same tree), sample size was 10 for each treatment, because within the overall dataset only 10 trees had both Control and Reamed Wider and Deeper treatment tapholes, and both Control and Second Taphole treatment tapholes.

Results and Discussion

Both longevity treatments resulted in significantly more nonconductive wood than Control tapholes within the same tree (Figure 1). The average volume of NCW generated by Reamed Wider and Deeper tapholes was 271% (2.7 times) the volume of NCW from Control tapholes in the same tree (Figures 2 and 3). The average volume of NCW generated by the Second Taphole treatment was 217% the volume of NCW from Control tapholes in the same tree, or slightly more than double (Figures 2 and 4). This is not surprising, as the final taphole volumes for both longevity treatments were larger than that of the Control, and the general relationship between wound size and NCW volume is well established (Renaud 1998, Wilmot et al. 2007).

The relative amount of NCW generated in response to the different treatments can be compared more directly by examining the volume of NCW generated relative to that of the final taphole wound. The overall average volume of NCW from Control tapholes was 36 times the volume of the taphole (Figure 5). For the ST treatment, the overall average NCW volume was 39 times the size of the two tapholes (Figure 5). This indicates that the amount of NCW generated was proportionally more than 2 individual tapholes, although within the same trees the difference was not statistically significant. For the RWD Treatment, the overall volume of NCW averaged 59 times the size of the taphole, demonstrating that this treatment resulted in disproportionately more NCW relative to the size of the taphole than in Control tapholes. These results suggest that tapholes which are re-injured with a longevity treatment result in significantly more NCW than single, undisturbed tapholes of the same size.

Longevity treatments like those studied in the experiment involve drilling into areas in which the tree has already initiated a response to the original taphole wound. It is well established that tapholes drilled into pre-existing NCW from a previous taphole, branch scar, or the

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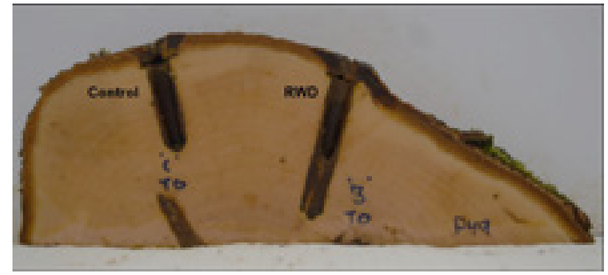

Figure 3. Stem segment with both Control and Reamed Wider and Deeper treatments; the cross-sectional cut was made through the center of each taphole.

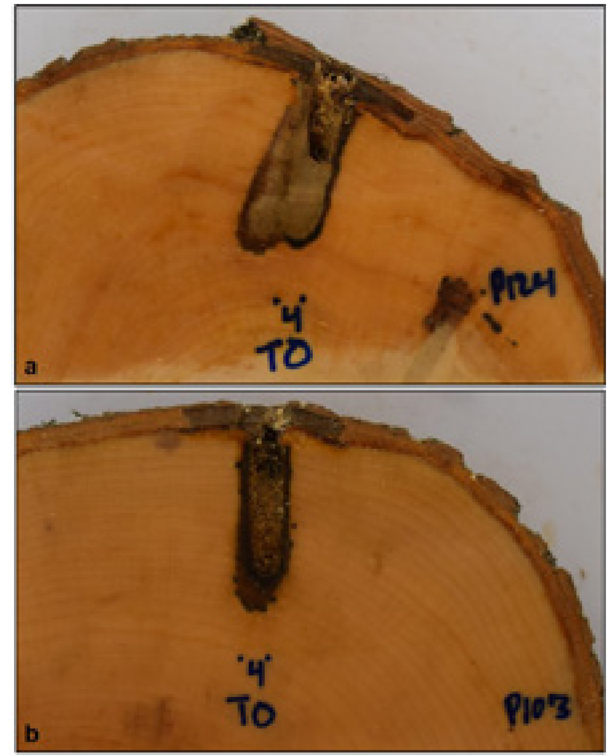

Figure 4. Two examples of stem segments cut through the center of Second Taphole treatments. If the two tapholes were not perfectly horizontally aligned (a), it is easier to see two more distinct areas of NCW development. However even when the two tapholes were well-aligned (b), the volume of NCW generated was still more than double that from a single Control taphole of the same size.

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central column of discolored wood, result in the generation of much more NCW than a wound made in clear, conductive sapwood (Shigo and Marx 1977, Shigo 1984). This is likely due in part to the cells in the pre-existing area of NCW being less capable of signaling or mounting a defense response to the new wound. Compartmentalization of that new, additional injury is thus likely to be less rapid, robust, or complete. The results of this study suggest a similar outcome occurs when a longevity treatment is used within the same sapflow season. The tree's response to the initial taphole wound has already begun (Figure 6). Reaming, re-drilling the same hole, or making a new taphole within or nearby the initial wound response column creates an injury in tissue already less able to respond, resulting in less complete compartmentalization of both wounds, and, ultimately more NCW than a single taphole.

The accumulation of NCW in the tapping zone of a tree is directly linked to future, long-term yields (van den Berg and Perkins 2014, Isselhardt 2019). The greater the amount of NCW in the tapping zone, the higher the chances of drilling into it when tapping, resulting in much lower yields than a taphole drilled into clear, conductive sapwood. Thus, any tapping practice which increases the amount of NCW, particularly by large amounts like those observed from the longevity treatments in this study, increases the likelihood of diminished yields and economic returns in the future. Moreover, excessive accumulation

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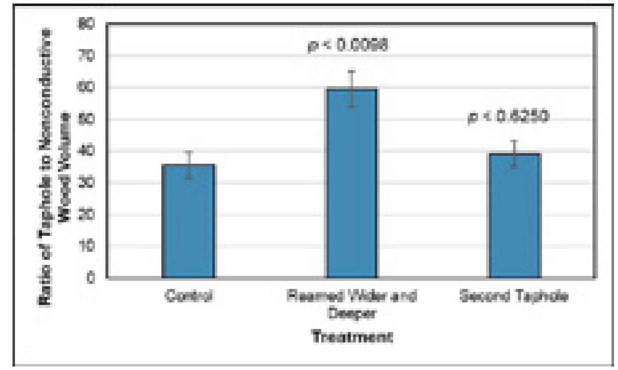

Figure 5. Overall mean (± standard error) ratio of taphole to NCW volume in Control and longevity treatment tapholes (Control n = 16, Reamed Wider and Deeper n = 12, Second Taphole n = 11). p-values are for paired comparisons made with Wilcoxon Signed Rank tests to test the hypotheses that the ratio of taphole to NCW volume for each longevity treatment was equal to that of Control tapholes within the same tree (n = 10 for paired comparisons).

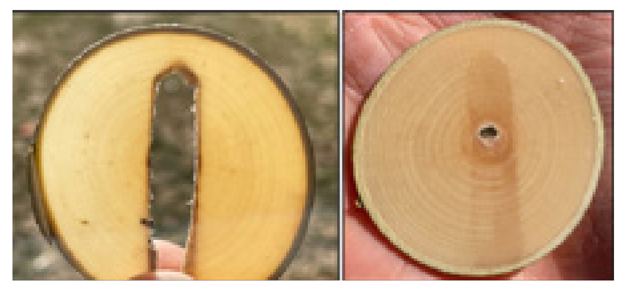

Figure 6. The tree's response to the taphole wound begins immediately. In these stem segments made through (left) and 0.5" above the taphole (right), substantial discoloration from the wound response is already visible 2 weeks after the taphole was drilled.

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of NCW can increase the risk of disease and decay.

The results of this study indicate that longevity treatments not only result in more NCW due to the larger size of the final tapholes, but also due to an increased development of NCW from the re-injury of the initial wound in proportions far exceeding a single, undisturbed taphole. In our corresponding study of yields from longevity treatments, neither of the treatments examined in this study resulted in a gain in yield relative to a single standard spring taphole (these data will be reported in a forthcoming article). However, regardless of any potential gain in yield, based on the significant impacts of these treatments on the amount of NCW generated - both the total amount and the disproportionate increase relative to a single taphole – we strongly advise against the use of these practices in any circumstances. The costs in terms of increased NCW, potential harm to tree health, and impacts on future sap yields, are simply too great to offset any short-term gains.

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