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Reexamination of Effects of Paraformaldehyde on Tissues Around Tapholes in Sugar Maple Trees

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Abstract

Pellets containing paraformaldehyde (PFA) are sometimes placed behind spouts in tapped sugar maples to prolong sapflow and increase the yield of sap used to make maple syrup. The practice is controversial because the chemical has been shown experimentally to promote decay and is reported to cause cambial dieback around tapholes. This study reexamined the effects of PFA on tapped sugar maple and determined how these effects also are influenced by the time of tapping and spout removal, and by taphole flushing. A survey of sugarbushes in Wisconsin revealed no relationship between PFA use and cambial dieback and rate of taphole closure. Other factors including poor tapping techniques and practices, drought, and old age affected these taphole attributes more than PFA. A trial conducted in eastern New York using young, vigorous sugar maple trees showed that PFA increased the size of discoloration columns associated with taphole wounds. Discoloration columns were smaller around the PFA tapholes made at onset of sapflow. Decay incidence around PFA taps was 60 to 75 percent compared to 25 percent for controls. The presence of decay columns increased the size of discoloration columns. Tapholes from which PFA residues were flushed with water when spouts were pulled had the most and largest decay columns; columns were especially large around tapholes made prior to sapflow (January). Tapholes with spouts pulled just before growth resumed (May) had fewer and smaller decay columns than those removed earlier (April).

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Introduction

Sap from sugar maple (*Acer saccharum* Marsh.) trees can be collected and concentrated by boiling to produce maple syrup. The use of pellets containing paraformaldehyde (trioxymethylene) (PFA) to prolong the period of sapflow and thus increase the yield of sap from tapped trees is controversial. Development of the PFA pill to be placed behind spouts in tapholes followed research to determine why seasonal sapflows often stopped prematurely, especially during periods of warm weather. This research suggested that microorganisms present in tapholes in some way caused flows to stop (Sheneman et al. 1959; Ching and Mericle 1960). PFA inhibited the growth of these organisms in the laboratory, and its influence on sapflow seemed confirmed by trials which showed reduced microbial populations in sap, and significantly increased sap yields and prolonged sap flows when PFA was used (e.g., MacArthur and Blackwood 1966; Sheneman et al. 1959). Pellets containing 250 mg PFA became widely accepted as a means to sanitize tapholes (Costilow et al. 1962; Sheneman and Costilow 1959; Sheneman et al. 1959).

With time, reports (by sugarbush owners and operators) of tapholes not closing, of cambial dieback around tapholes, and of unusual amounts of decay in wood surrounding tapholes treated with PFA suggested the possibility that the chemical was injuring tree tissues. A series of studies comparing PFA-treated tapholes with untreated tapholes on the same tree suggested that PFA was toxic to tree tissues (Shigo and Laing 1970; Walters and Shigo 1978, 1979). In these studies, some treated trees were dissected after 2 months and others at intervals thereafter over the next 5 years. While the rate of taphole closure and incidence of cambial dieback were not affected, the incidence and extent of discoloration and especially of decay were significantly greater in wood around tapholes treated with PFA. Walters and Shigo (1978) concluded that PFA prolonged sapflow not because it inhibited microorganisms but because it inhibited the development of gums and other changes that comprise the protective barrier zones which normally develop in healthy tissues around wounds.

Despite this evidence, proponents of its use maintain that PFA is more beneficial (economically) than harmful (biologically) (e.g., Reynolds 1989), and many sugarbush operators have reported no observed (external) damage to trees even where PFA has been used for many years.

The seemingly variable damage attributable to PFA may result from differences in inherent or stress-induced responses to the chemical or to wounding, seasonal patterns of growth, tree condition, or tapping practices that affect when and how long tissues are exposed to PFA relative to the period of sapflow or the resumption of cambial activity.

The objectives of this study were to: (1) reexamine the effects of PFA on taphole closure, and on the development over time of discoloration and decay associated with tapholes; and (2) determine whether these variables are influenced by dates of tapping and spout removal, or by flushing PFA from tapholes. Preliminary reports have been published (Houston 1996; Houston and Fagan 1996).

Materials and Methods

The study consisted of two parts: a survey of taphole conditions in Wisconsin sugarbushes with and without histories of PFA use, and an experiment that compared both taphole closure and the development over time of discoloration and decay around tapholes treated or not treated with PFA.

Survey of Wisconsin Sugarbushes

In June 1991, 16 sugarbushes (50 trees in each sugarbush) in Wisconsin (Fig. 1) in which PFA had (9) or had not (7) been used in recent years were surveyed for external evidence of damage by PFA. Each owner was interviewed to determine the history of PFA use, method of sap collection, and other possible stress factors. Measurements were made of tree diameter at 1.4 m (d.b.h.); crown canopy position (dominant, codominant, intermediate, overtopped); crown condition (healthy, <10 percent dead upper and outer crown branches; fair, 10 to 50 percent dead upper and outer crown branches; poor, >50 percent upper crown branches dead); number of tapholes that were open and oozing (an indication of microbial infection); and amount of cambial dieback, if present, that occurred around (up to) three open tapholes. Outer bark around open tapholes was removed carefully to reveal the extent of cambial dieback.

Experimental Effects of PFA

Trees. In all, 162 sugar maples growing on a 10-acre (4-ha) portion of Bear Swamp State Forest near Dorloo, New York, were used. The trees, 20 to 25 cm in diameter at 1.4 m, were intermediate to codominant crown class, 43 to 47 years old, and part of a relatively pure stand of sugar maples that had colonized an old farm field that sloped 5 to 20 percent to the east.

In each tree, two standard tapholes 1.1 cm in diameter and 5.1 cm deep were drilled opposite each other on the west and east sides at 1.2 m above ground line. Standard plastic spouts were inserted into each hole. Care was taken to avoid drilling into frozen bark or to set the spouts too deeply. Each tree was assigned randomly to a group of three trees, and received two treatments assigned systematically so that there were two replicates of each treatment for each tree group.

Figure 1.—Locations of 16 Wisconsin sugarbushes surveyed for external evidence of damage caused by PFA (sugarbush 6 was not used). The encircled areas encompass those sugarbushes affected severely by drought in 1988-89. Sugarbushes in the central area were affected most severely.

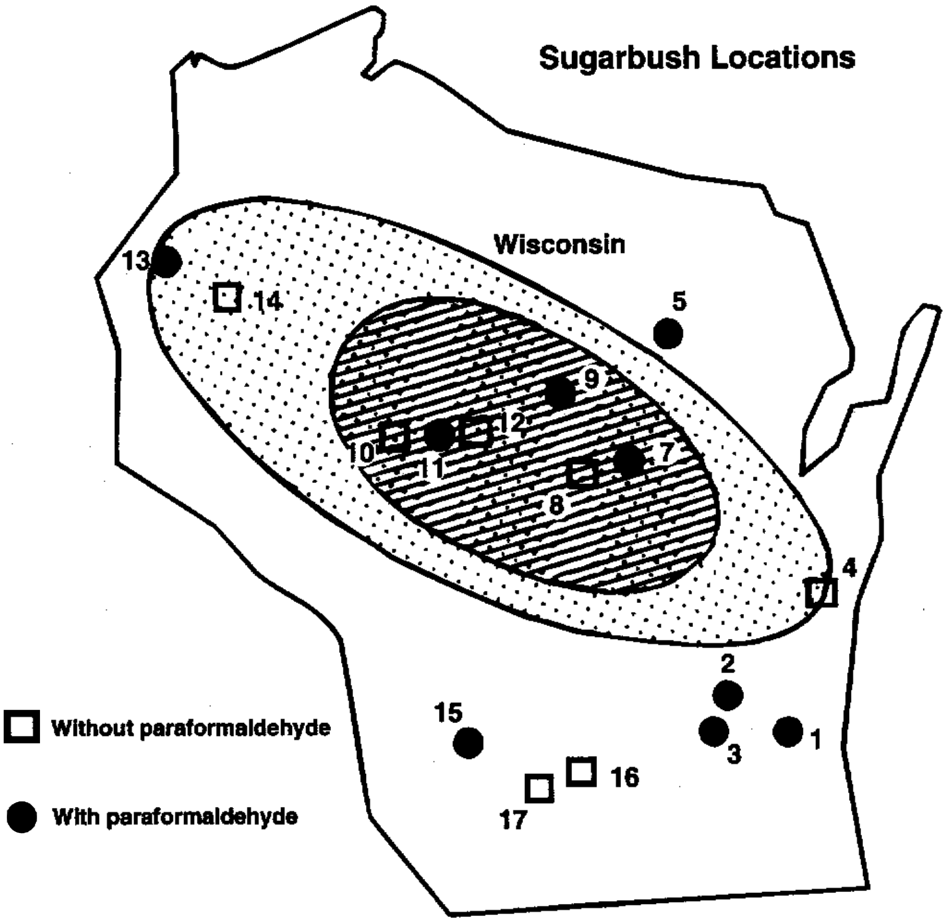
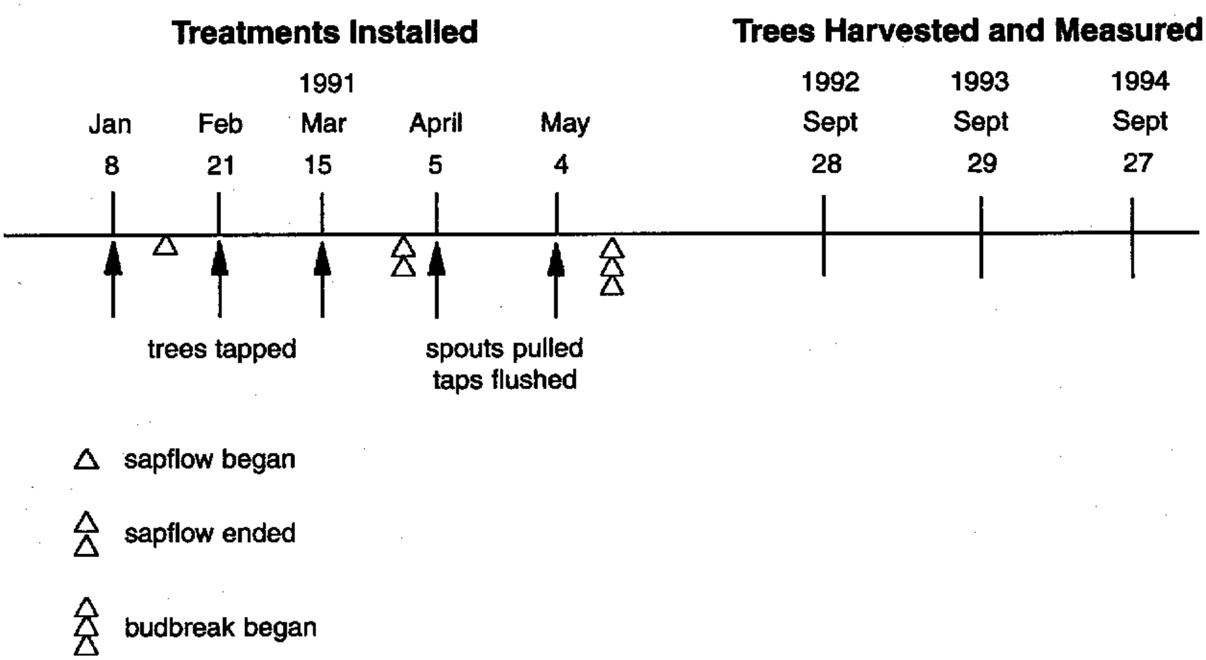


Figure 2.—Schedule of taphole treatments and tree harvests.



Treatments. The three main treatments were: 1) no PFA placed in the tapholes (controls), 2) a 250-mg pellet of PFA placed in tapholes behind the spouts, 3) same as treatment 2 except that the tapholes were flushed with sterile water after spouts were removed. All spouts were fitted with a 1-foot (30.5-cm) length of open plastic tubing that was curled upward and held in place by a spout clip. This simulated a closed tubing-collection system. While sap could flow out of the open tubing, the sap-filled loop restricted the entrance of air and microbes into the taphole.

Trees were tapped at three times selected to bracket the 1991 sapflow period in the stand (Fig. 2). Different groups of 54 trees (18 of the three-tree groups) were tapped on 8 January (before), 21 February (at), and 15 March (well after) the onset of sapflow.

Spouts from half of the trees in each treatment were carefully pulled "early" on April 5 (soon after sapflow ceased) or "late" on May 4 (just prior to cambial activity and budbreak) (Fig. 2). At the time spouts were removed, half of the PFA-treated tapholes were flushed with sterile water to remove all traces of the PFA pellet.

Harvests and Measurements

Groups of 54 trees each (18 of the three-tree groups selected randomly) were felled in September of 1992, 1993, and 1994 (18 to 20, 30 to 32, and 42 to 44 months after treatment hereinafter noted as two, three, and four growing seasons after treatment) to assess the influence of time on the development of discoloration and decay. A 2-m-long bolt centered about the tapholes was cut from each tree and returned to the laboratory where it was dissected and measured after its tapholes were examined for closure and any cambial dieback measured. Intact bolts were first cross sectioned through each taphole and a disk was removed. Measurements of the width and depth of the discoloration columns and of the decay columns if present around the tapholes were made on the faces of disks (Fig. 3a). Bolts were then split longitudinally through the opposing taphole columns and overall lengths of the discoloration and decay columns were measured (Fig. 3b). Small, narrow streaks of discolored wood extending beyond the main columns were not included in the measurements of column length. For this study, discolored wood was wood altered in color without a loss of strength; decayed wood was wood altered in color and determined to be softer or weaker than surrounding tissues when probed with a sharp scalpel.

Analysis

The following variables measured on tapholes were evaluated:

1. Tapholes open or closed at time of harvest

2. Area of cambial dieback calculated as:

   length x width of the opening

3. Volume of discoloration columns calculated as:

   $\frac{\text{vertical length x tangential width}}{2}$ x radial depth of discolored column

4. Number of tapholes with decay

5. Volume of decay columns calculated as:

   $\frac{\text{vertical length x tangential width}}{2}$ x radial depth of decay columns

Results

Survey of Wisconsin Sugarbushes

The 16 sugarbushes surveyed were well distributed within the state (Fig. 1). Overall, there was no apparent relationship between the use of PFA and any of the taphole attributes measured (Table 1). Some sugarbushes with long histories of PFA use ranked among the lowest (least damage) for some attributes and among the highest for others, while several stands with high values had never been treated with PFA (Table 2). There was no correlation between these attributes and tree size (d.b.h., crown class), though there was a significant correlation ($p=0.02$, $R^2=0.28$) between the amount of cambial dieback and tree condition.

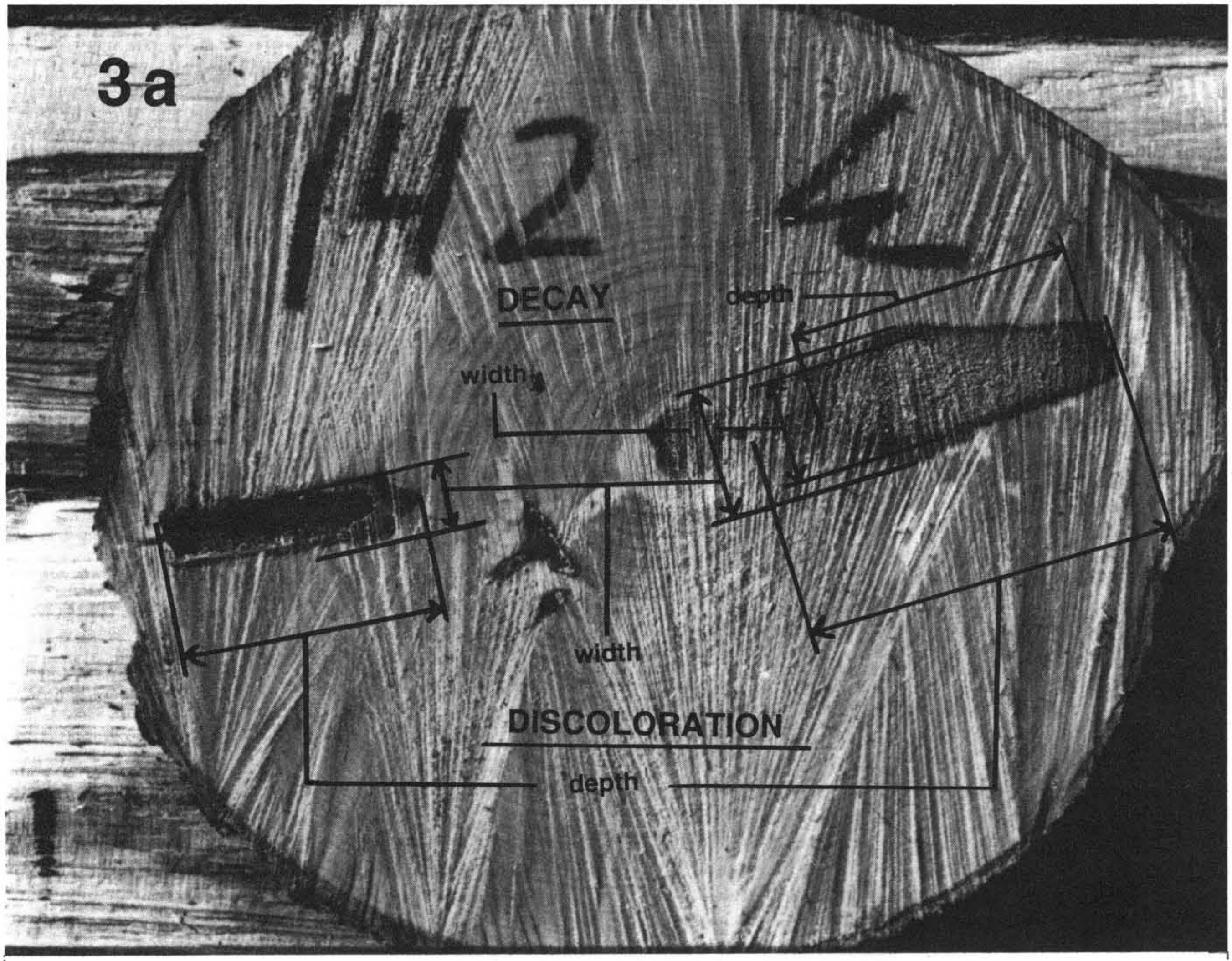
Interviews with sugarbush owners and personal observations revealed that other factors, often unique to individual sugarbushes, influenced the external taphole attributes more than PFA. Poor practices such as overtapping, tapping small trees in overly dense stands, and leaving spouts in trees were observed in some sugarbushes. Bark splits above and below tapholes, common in some sugarbushes, resulted from inserting spouts too deeply or from tapping into frozen bark.

The severe drought of 1988-89 in Wisconsin adversely affected the condition of trees in some sugarbushes, especially in the central part of the state. The approximate area where drought damage was most intense, as revealed through interviews with owners and others, is shown in Figure 1. The stress history and other stand data, together with mean tree condition and mean cambial dieback for eight representative sugarbushes, are listed in Table 3.

Experimental Effects of PFA

Taphole closure. Pearson's chi square used in 2x2 contingency table analyses revealed no simple correspondence between the use of PFA and taphole closure. After two growing seasons, about half of the controls and two-thirds of the PFA-treated taps had closed. By the third and fourth growing seasons, these percentages had risen to 95 percent and 97 percent, (controls) and 93 to 99 percent (PFA), respectively.

Discoloration. Columns of discolored sapwood were associated with every taphole and were larger around the PFA-treated tapholes, especially the PFA-flushed tapholes, than in the controls (Fig. 4). However, analysis of variance



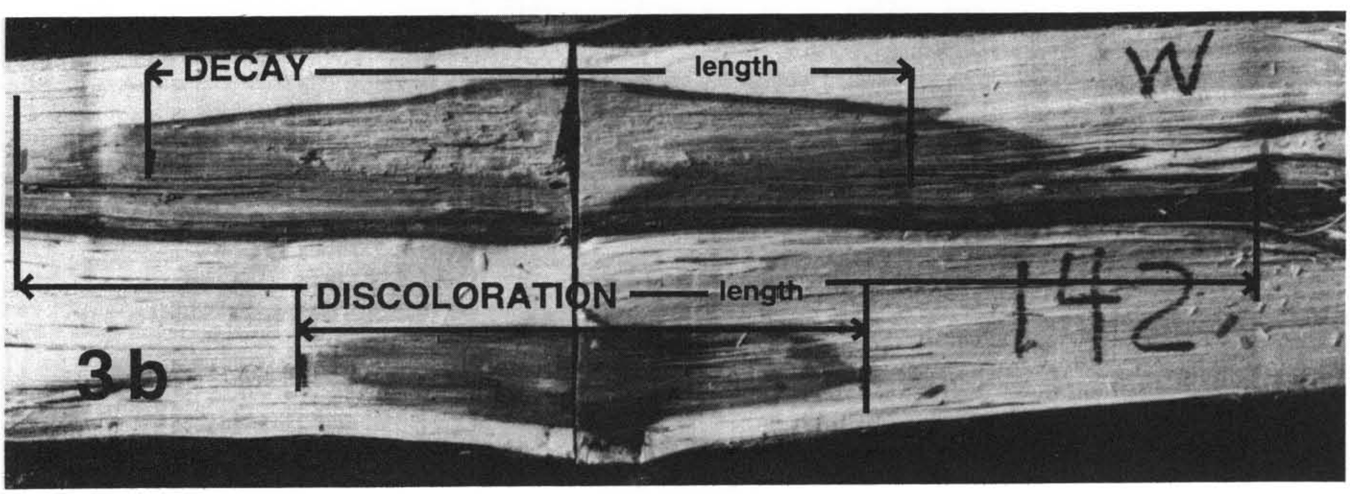


Figure 3.—(a) cross-sectional disk and (b) split bolts with typical discoloration and decay associated with the tapholes. Taphole "w" (with decay) received PFA; the other taphole did not.

indicated some high-order interactions between the independent variables, especially those related to timing of treatments. A classification tree model using all possible values of all possible variables was used to help identify the most important interactions.

Using PFA (flushed or not) always was the most important factor affecting column volume. However, columns associated with PFA-treated tapholes, made either before or well after sapflow began, were larger than those of tapholes made at onset of sapflow (Table 4). The largest columns were associated with PFA-flushed tapholes installed before sapflow with spouts pulled early (Tables 4-5). The smallest after four growing seasons were around control tapholes made at onset of sapflow with spouts pulled late (Tables 4-5). Regardless of when tapping was done, discoloration columns increased in size over the four growing seasons.

Decay. Decay incidence (number of tapholes with decay columns) was much higher for tapholes treated with PFA, especially those that were flushed, than for the controls (Table 6). Incidence increased over time for PFA-treated tapholes. After four growing seasons, 75 percent of the flushed and 60 percent of the nonflushed PFA tapholes had decay columns compared to less than 25 percent of the controls.

After two growing seasons (1992), there were no evident differences in decay incidence related to tapping dates. However, by the next year, significantly fewer PFA tapholes made at onset of sapflow had decay columns than PFA tapholes made either earlier or later (Fig. 5). This pattern occurred after four growing seasons as well.

When spouts were removed strongly influenced the occurrence of decay. For controls, while there were no

Table 1.—Average values (50 trees) for trees in 16 sugarbushes in Wisconsin where PFA had (9) or had not (7) been used

Item	Paraformaldehyde (+)	Paraformaldehyde (-)
D.b.h. (cm)	40.1	39.3
Crown class (1-4)[a]	2.1	2.3
Condition (1-3)[b]	1.3	1.3
Open taps (no.)	3.0	3.2
Taps with dieback (no.)	2.1	2.3
Dieback area (cm^2)	5.3	5.2
Taps		
Open, oozing (no.)	0.6	0.4
Closed, oozing (no.)	0.1	0.1

[a] 1 = dominant tree; 4 = overtopped, suppressed tree.
[b] 1 = healthy, full crowned tree; 3 = poor tree, > 50 percent upper crown branches dead.

Table 2.—Subarbushes ranked by mean values for taphole attributes for 50 trees in each of 16 Wisconsin sugarbushes where PFA had (9) or had not (7) been used; for each attribute, sugarbushes are ranked as high (left), moderate (center), or low (right) with range of mean values in parentheses

Attribute	High values	Moderate values	Low values
Open tapholes (no.)	14 11[a] 13[a] 8 (5.4 .... to .... 3.9)	15[a] 9[a] 2[a] 10 12 7[a] 17 16 (3.7 .... to ....2.2)	5[a] 1[a] 3[a] 4 (2.1 .... to ..... 1.6)
Tapholes with dieback (no.)	14 11[a] 13[a] 8 (4.8 .... to .... 2.9)	9 7[a] 17 15[a] 10 5[a] 12 16 (2.5 .... to ....1.7)	2[a] 1[a] 3[a] 4 (1.5 .... to ..... 0.9)
Dieback area (cm^2)	11[a] 14 9[a] 7[a] (8.7 .... to .... 5.7)	12 8 17 13[a] 5[a] 4 15[a] 10 (5.5 .... to ....3.8)	1[a] 2[a] 16 3[a] (3.5 .... to ..... 2.1)
Open tapholes oozing (no.)	11[a] 2[a] 7[a] 1[a] (0.89 .. to .. 0.80)	14 9[a] 12 8 5[a] 10 15[a] 17 (0.78 .... to ....0.30)	16 13[a] 3[a] 4 (0.26 .. to ... 0.02)

[a] Paraformaldehyde used.

Table 3.—Stress histories and other data for eight representative Wisconsin sugarbushes ranked from low to high based on their mean taphole dieback rankings (see Table 2)

Sugarbush (no. and rank)	Location	Collection method	Mean D.b.h.	Mean tree condition (1-4)	Mean taphole dieback	PFA history	Other stress
			cm		*cm²*		
3 (L)	Mayville	Tubing	34.0	1.18	2.12	10 years	Young, vigorous stand but "no syrup in 1989"
2 (L)	Lomira	Buckets	51.7	1.26	3.33	15 years but not in 1990 and 1991	No apparent drought
16 (L)	Rock Springs	Tubing	42.6	1.04	3.16	None	No drought effects; large, old trees left after logging
4 (L-M)	Cleveland	Buckets	41.4	1.38	4.09	10 of 15 years to 1987; no tapping in 1991	Some effects of 1988 drought; vigorous stand in good condition
8 (M-H)	Tigerton	Tubing (vacuum)	32.7	1.20	5.48	1-2 years, but not in past 5	Severe drought in 1988 and 1989; many small, suppressed tapped trees, overtapped, stand overstocked
12 (M)	Owen	Tubing	35.6	1.70	5.50	None	Severe drought 1988-89
11 (H)	Owen	Buckets	37.5	2.00	8.72	1989-91	Same location as stand (12), but trees have marked top dieback and are in poorer condition
14 (H)	Cumberland	Buckets	48.3	1.22	7.39	None for *last 10* years	No drought effects *"noticed"; trees are* old, long history of tapping

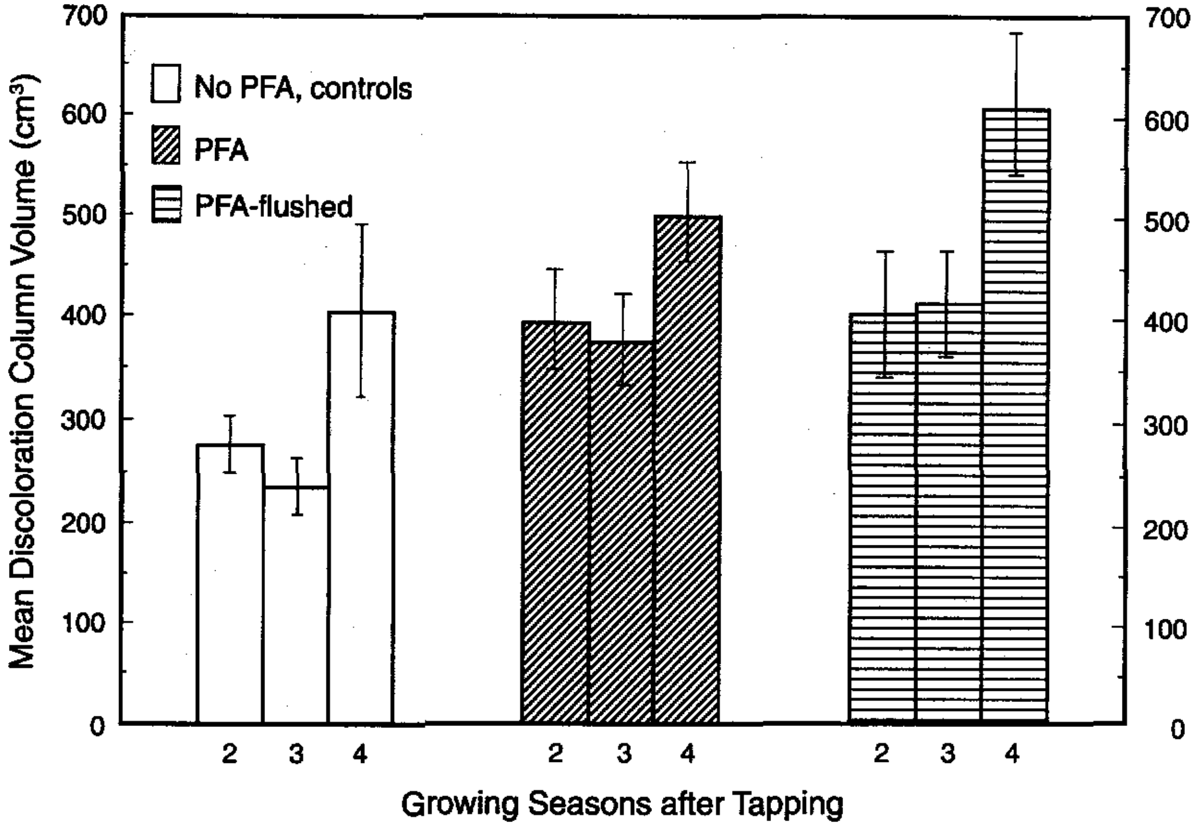


Figure 4.—Mean volume of discoloration columns by treatment over time. Columns were measured in September of 1992, 1993, or 1994 two, three, or four growing seasons after tapping in 1991.

Table 4.—Mean volume (cm³) of discoloration columns around tapholes treated or not treated with PFA before (January), at (February), or after (March) the onset of sapflow in 1991 in trees harvested two, three, or four growing seasons after tapping

	Growing seasons after tapping								
	2			3			4		
Treatment	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
No PFA	306	253[b]	264[b]	303	190[b]	209	345	332	537
PFA	437	260[b]	506	393	368	362	552	379	537
PFA-flushed	555	299	348	555	259[b]	440	722[a]	597	508

Note: Means followed by "a" are significantly different ($p < 0.05$) from those followed by "b" as determined by Tukey's Studentized Range Test.

differences after two growing seasons, about 40 percent more of the tapholes with spouts pulled late had decay columns after three and four growing seasons (Table 6). By contrast, the proportion of PFA tapholes with decay columns was much higher in all three harvest years when spouts were pulled early.

Decay severity. Decay severity (volume of decayed wood) can be expressed as the average for all tapholes in a given treatement, whether or not a taphole had a decay column (the treatment means), or as the average amount for only those tapholes that were decayed.

The average volumes of decay for the two PFA treatments were consistently and markedly greater than for controls. For the latter, mean decay volume was greatest about those tapholes with spouts pulled late (Table 7). For PFA tapholes, decay volumes were greatest for two of the three harvest years when spouts were removed early (Table 7) from tapholes installed before or after sapflow (Table 8). There were no differences related to time of installation for the controls (Table 8).

Except for the PFA tapholes that were examined after three growing seasons (where average decay columns were about

Table 5.—Mean volume (cm^3) of discoloration columns around tapholes treated or not treated with PFA and where spouts were pulled early (April) or late (May) two, three, or four growing seasons after tapping in 1991

	Growing seasons after tapping					
	2		3		4	
Treatment	Early	Late	Early	Late	Early	Late
No PFA	277[b]	272[b]	199[b,c]	289[b]	474[b]	349[b]
PFA	440	343	356[b]	399	559[d]	450
PFA-flushed	484	322[b]	407	422	711[a]	527[d]

Note: Means followed by "a" are significantly different ($p < 0.05$) from those followed by "b"; those followed by "c" are significantly different from those followed by "d" as determined by Tukey's Studentized Range Test.

Table 6.—Percentage of tapholes treated or not with PFA and whose spouts were pulled early (April) or late (May) with decay two, three, or four growing seasons after tapping in 1991 (number of observations in parentheses)

	Growing seasons after tapping					
	2		3		4	
Treatment	Early	Late	Early	Late	Early	Late
No PFA	29 (17)	32 (19)	14 (22)	40 (15)	13 (16)	33 (21)
PFA and PFA-flushed	59 (37)	43 (35)	65 (40)	14 (29)	81 (32)	56 (39)

one-third the size of their corresponding discoloration columns), decay columns were 20 to 24 percent the size of their associated discoloration columns regardless of treatment or time after tapping (Table 9). Regression of the mean discoloration volumes against mean decay volumes (Fig. 6) revealed a highly significant relationship ($P=0.01$, $R^2=0.54$).

Discussion

Taphole Closure

Treating tapholes with PFA did not cause dieback of cambium around tapholes nor prevent or slow taphole closure in this or previous experiments (Walters and Shigo 1978, 1979). Factors other than the use of PFA appear responsible for these effects, for example, cambial dieback and slow closure have been attributed to stressors such as defoliation (Wargo 1977).

Discoloration

Wounds in trees invariably result in the development of discoloration columns whose size and shape are delimited by the tree's inherent ability to establish barriers against both the inroads of air and the invasion of microorganisms (Shigo 1984; Shortle 1979). With respect to discoloration, the questions addressed in this study are: To what extent does the use of PFA alter the natural ability of the tree to set and maintain its defensive barriers around tapholes? And to what extent are these defenses influenced by when the wounds are made and when spouts are removed?

For some time after tapping, complex interactions among timing of tapping and spout removal as well as treatment influenced the processes of discoloration. With time, though, the time of spout removal became less important. By the fourth growing season, the use of PFA and to a lesser extent the timing of tapping relative to the onset of sapflow were the principal factors influencing discoloration column size.

That PFA strongly increases the volumn of discoloration columns is an important finding where sap production is concerned. Columns of discolored tissues neither store sugars nor transport sap. Consequently, their presence determines the availability of future tapping sites. Also, their size and shape establishes the potential limits of subsequent decay columns (Shigo and Hillis 1973). The complex interactions between discoloration and decay was further demonstrated by Shortle et al. (1995) and by our findings, which indicate that the spatial limits of discoloration (column sizes) are increased by the presence of decay fungi. Yet the question remains: Are these effects important to the tree or to the sugarbush?

One way to address this question is to project our results over time—given certain assumptions of practice and tree

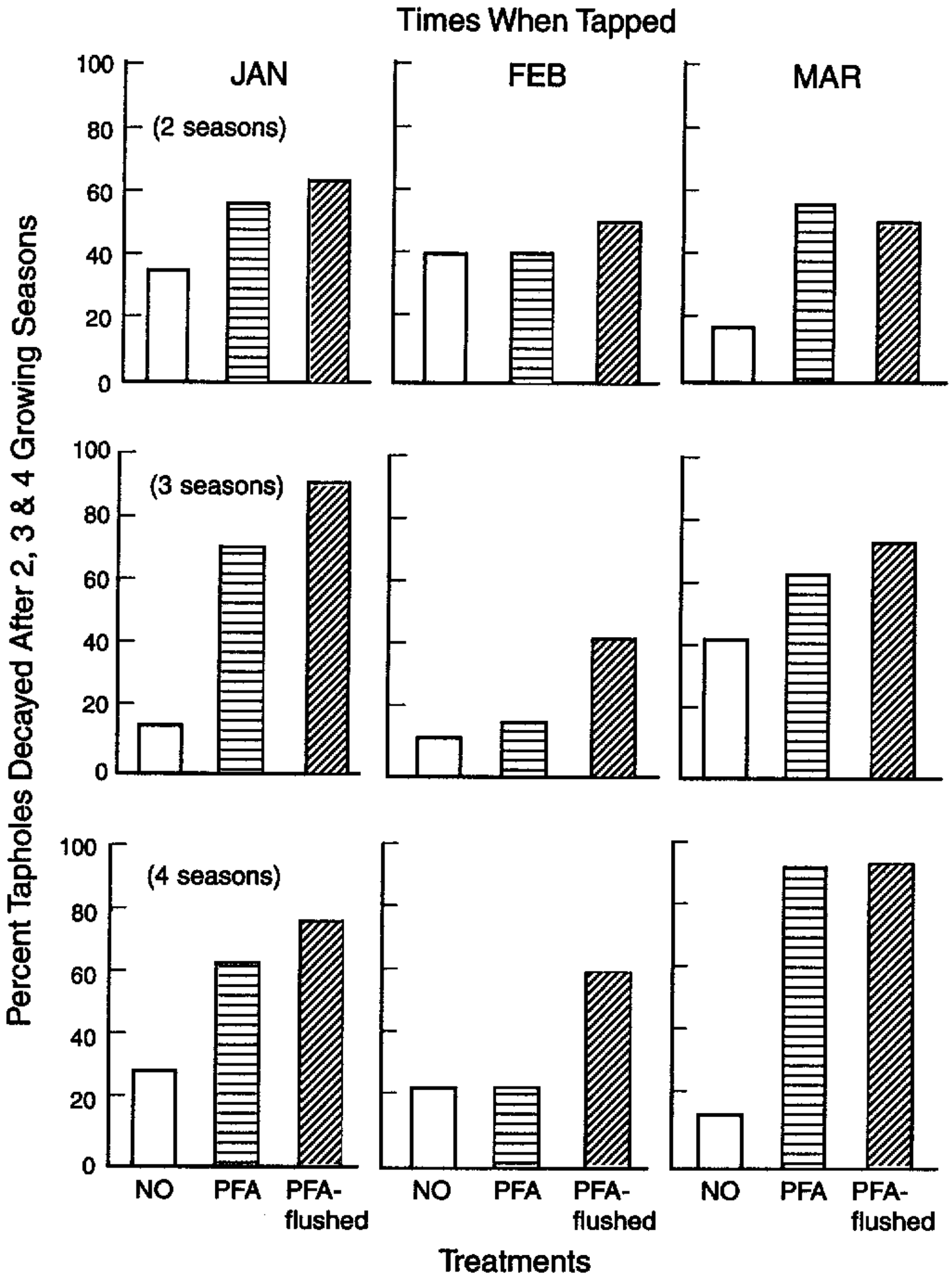


Figure 5.—Percentage of tapholes decayed by treatment over time in relation to time of tapping (January, February, or March) in 1991. Tapholes were examined in September of 1992, 1993, or 1994.

condition. Thus, if we assume that a tree will be tapped only after reaching 12 inches (30.5 cm) in diameter, that there will be two taps per year, that tapping and its effects will be limited to a 4-foot (1.2 m) section of stem, and that the tree will grow 1 inch in diameter every 10 years, we project the following:

1) Without PFA, about 9 percent of the outer 3 inches of wood in the tapped section will be discolored in 10 years and about 15 percent of the outer 4 inches will be discolored after 20 years.

2) With PFA, these values will be about 15 percent (10 years) and 23 percent (20 years), and thus, in this hypothetical tree, represent an increase of 6 to 8 percent (compared to no PFA) in sapwood rendered unsuitable for tapping by the presence of discoloration.

The fact that columns of discoloration continued to increase in size for at least four growing seasons after tapping, and especially about tapholes that had contained PFA, indicates that the chemical's influence is long lasting. Yet the largest columns were about tapholes that had been both made and

Table 7.—Mean volumes (cm³) of decay in tapholes treated or not treated with PFA two, three, or four growing seasons after tapping in 1991, and whose spouts were removed early (April) or late (May)

	Growing seasons after tapping					
	2		3		4	
Treatment	Early	Late	Early	Late	Early	Late
No PFA	18[b]	23[b]	2[b,d]	22[b]	2[b,d]	42[b]
PFA	78[b]	55[b]	60[b]	75	111[c]	53[b]
PFA-flushed	54[b]	36[b]	70[b]	84	171[a]	79

Note: Means followed by "a" are significantly different from those followed by "b" ($p < 0.05$); those followed by "c" are significantly different ($p < 0.05$) from those followed by "d" as determined by Tukey's Studentized Range Test.

Table 8.—Mean volume (cm³) of decay around tapholes treated or not treated with PFA before (January), at (February), or after (March) the onset of sapflow in 1991 in trees harvested two, three, or four growing seasons after tapping

	Growing seasons after tapping								
	2			3			4		
Treatment	Jan	Feb	Mar	Jan	Feb	Mar	Jan	Feb	Mar
No PFA	23	27	10[b]	6[b]	3[b]	21	37	20	16
PFA	104	39	62	85	41	72	67	46	125
PFA-flushed	46	63	27	102	55	72	141[a]	96	124

Note: *Means followed by "a" are significantly different* ($p < 0.05$) from those followed by "b" as determined by Tukey's Studentized Range Test.

Table 9.—Mean volumes (cm³) of the decay columns that occurred and associated discoloration columns, by growing seasons after tapping and treatment

Treatment	Decay Growing seasons after tapping			Discoloration Growing seasons after tapping		
	2	3	4	2	3	4
No PFA (SE=11.7-87.7)	73.9 n=10	51.3 n=7	101.6 n=9	338.2 (21.8)[a]	251.8 (20.4)	509.9 (19.9)
PFA (SE=17.7-88.7)	112.4 n=16	165.2 n=15	132.6 n=21	472.0 (23.8)	484.0 (34.0)	638.2 (20.8)
PFA-flushed (SE=19.9-108.2)	98.4 n=17	143.0 n=18	172.7 n=25	461.0 (21.3)	432.9 (33.0)	711.5 (24.3)

[a] *Numbers in parentheses are the relative proportion of the discoloration columns occupied* by the decay columns.

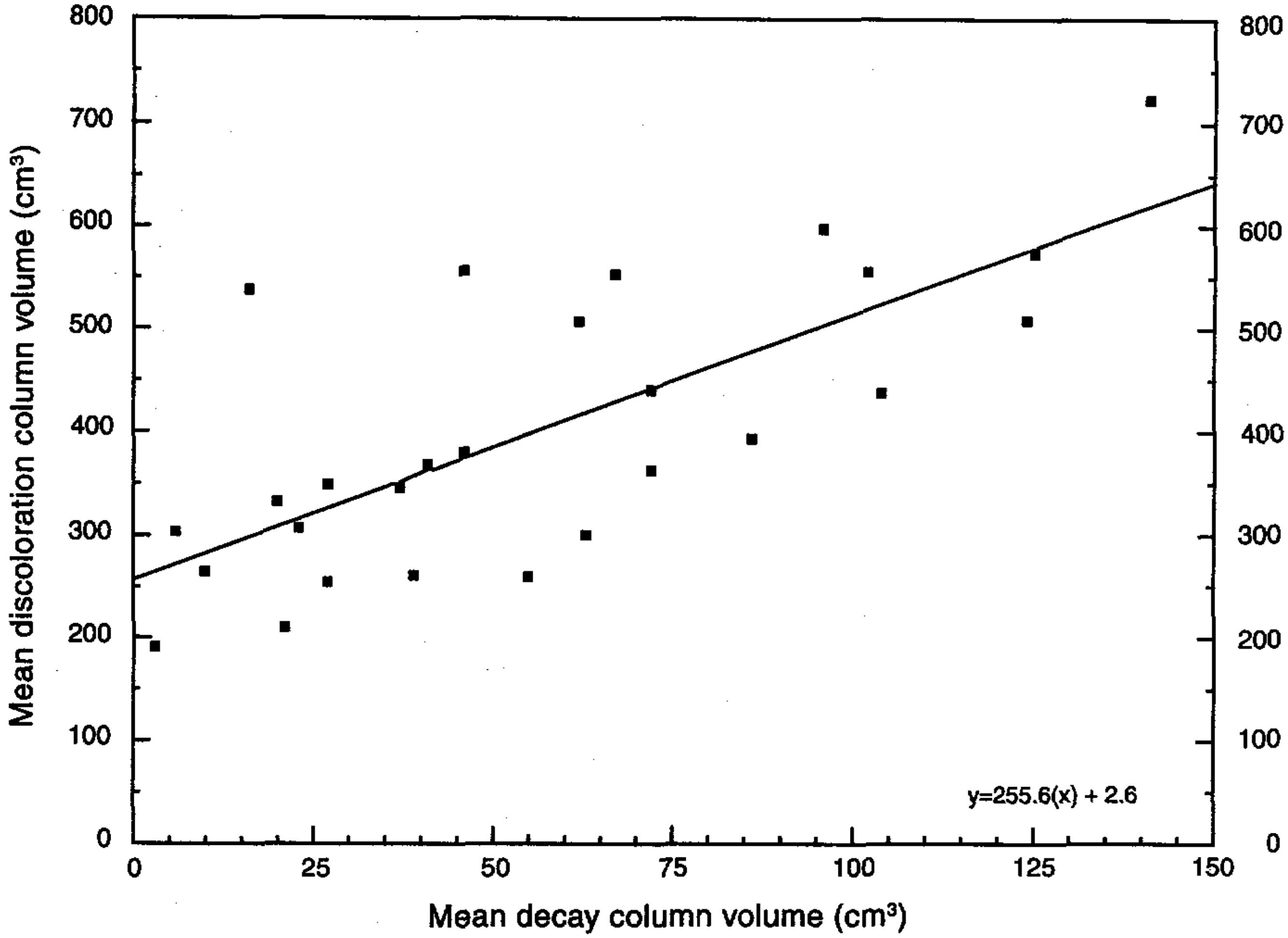


Figure 6.—Regression of mean discoloration column volumes on means of decay column volumes (R^2=0.54, P=0.01); discoloration data from Table 4, decay values from Table 8.

flushed of PFA residues the earliest. This suggests that PFA may influence the discoloration process in two ways: 1) through an initial and rapid effect on surrounding wood tissues that impairs the formation of anatomical or chemical defense barriers, and 2) through a biocidal effect on invading stain-causing and decay-causing microorganisms. It has been suggested that PFA inactivates defense-plugging mechanisms and chemicals, including oxidized phenols (Walters and Shigo 1978; Morselli 1995). The microbiocidal or sanitizing effects of PFA might be reduced if "still active" residues were flushed from tapholes, particularly if done early to allow a longer period for organisms to invade and grow in "defenseless" tissues prior to the tree's resumption of active spring growth.

It is not known whether discoloration columns will continue to increase in size or at the same rate as they did during the study period. Walters and Shigo (1978) found that such columns associated with tapholes increased in length through 44 months (four growing seasons) but ceased thereafter.

Decay

Decay develops in trees that are wounded, i.e., within tissues that have become discolored. However, unlike discoloration, decay after wounding is not inevitable. With respect to decay, therefore, the questions of concern are: To what extent does PFA increase the likelihood of decay? To what extent does it facilitate the decay process? And to what extent does the presence of decay increase the size of the associated discoloration columns? Most decay-causing fungi succeed only in wound-altered woody tissues, and then usually only after such tissues have been altered further by earlier colonizers including bacteria and stain fungi (Shigo and Hillis 1973).

Using PFA resulted in more than twice as many decayed tapholes and, correspondingly, twice as much volume of decay compared to the controls. However, we found that the volume of decayed wood around tapholes was relatively small. Using our results and the tapping assumptions given previously, we project that when PFA is used, about 2.2 percent (10 years) to 3.4 percent (20 years) of the tapable sapwood will be decayed compared to 0.6 and 0.9 percent with no PFA. In practice, tapholes often are concentrated in stem sections much shorter than 1.2 m long. In such cases, the proportion decayed, especially of cross-sectional areas, would be much greater—perhaps more than twice that calculated here. That our data and the findings of Shortle et al. (1995) clearly show that discoloration columns increase in size when invaded by decay organisms reveals an additional and perhaps even more important effect of decay on sap production.

Practices and factors that could alter these values even more adversely include tapping slow-growing trees stressed by inadequate light, moisture, or nutrients (overly dense sugarbush), external stress factors that slow growth and prevent rapid taphole closure (e.g., drought and insect defoliation), and overtapping (increased tapping intensity or tapping undersize trees). While trees in this study were smaller than recommended (e.g., Houston et al. 1990) for operational sugarbushes, they were young and vigorous, closed taphole wounds quickly, and probably established internal compartment barriers rapidly. It is likely that decay volumes would be larger in old trees or trees under stress.

An important factor is the distribution of tapholes with discoloration and decay. Thus, in a tree 12 to 14 inches in diameter, even 23 percent of the tapable wood with discoloration distributed as many separate columns would be damaging, particularly if they were concentrated in a limited area. Decay rapidly spreads outward into the tissues around new tapholes that penetrate into preexisting decay columns. Of course, this volume of decay will be a significantly larger proportion of the available sapwood in trees smaller than 12 inches in diameter and in trees tapped for longer periods.

Literature Cited

Ching, T. M.; Mericle, L. W. 1960. **Some evidence of premature stoppage of sugar maple sap production.** Forest Science. 6: 270-275.

Costilow, R. N.; Robbins, P. M.; Simmons, R. J.; Willits, C. O. 1962. **The efficiency and practicability of different types of paraformaldehyde pellets for controlling microbial growth in maple tree tapholes.** Q. Bull. East Lansing, MI: Michigan State University Agricultural Experiment Station. 44(3): 559-579.

Houston, D. R. 1996. **A reexamination of the effects of paraformaldehyde on tapped sugar maples.** I. Survey of some Wisconsin sugarbushes. Maple Syrup Digest. 8A(2): 12-16.

Houston, D. R.; Allen, D. C.; Lachance, D. 1990. **Sugarbush Management: a guide to maintaining tree health.** Gen. Tech. Rep. NE-129. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Houston, D. R.; Fagan, J. C. 1996. **A reexamination of the effects of paraformaldehyde on tapped sugar maples.** II. Development of discoloration and decay around tapholes. Maple Syrup Digest. 8A(3): 20-30.

MacArthur, J. D.; Blackwood, A. C. 1966. **Taphole sanitation pellets and sugar maple sap yields.** Forestry Chronicle. 42(4): 380-386.

Morselli, M. 1995. **Effects of the use of paraformaldehyde sterilising pellets on sugar maple health: a review.** In: Caring for the forest: research in a changing world: abstracts of invited papers; 1995 August 6-12; Tampere, Finland. Tampere, Finland: IUFRO XX World Congress: 410. Abstract.

Reynolds, L. 1989. **Editorial.** Maple Syrup Digest. 1A(1): 16-17.

Sheneman, J. M.; Costilow, R. N. 1959. **Identification of microorganisms from maple tree tapholes.** Food Research. 24: 146-151.

Sheneman, J. M.; Costilow, R. N.; Robbins, P. W.; Douglass, J. E. 1959. **Correlation between microbial populations and sap yields from maple trees.** Food Research 24: 152-159.

Shigo, A. L. 1984. **Compartmentalization: a conceptual framework for understanding how trees grow and defend themselves.** Annual Review of Phytopathology. 22: 189-214.

Shigo, A. L.; Hillis, W. E. 1973. **Heartwood discolored wood, and microorganisms in living trees.** Annual Review of Phytopathology. 11: 197-222.

Shigo, A. L.; Laing, F. M. 1970. **Some effects of paraformaldehyde on wood surrounding tapholes in sugar maple trees.** Res. Pap. NE-161. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Shortle, W. C. 1979. **Compartmentalization of decay in red maple and hybrid poplar trees.** Phytopathology. 69: 410-413.

Shortle, W. C.; Smith, K. T.; Dudzik, K. R.; Parker, S. 1995. **Response of maple sapwood to injury and infection.** European Journal of Forest Pathology. 25: 241-252.

Walters, R. S.; Shigo, A. L. 1978. **Discoloration and decay associated with paraformaldehyde-treated tapholes in sugar maple.** Canadian Journal of Forest Research. 8(1): 54-60.

Walters, R. S.; Shigo, A. L. 1979. **Paraformaldehyde-treated tapholes: effects on wood.** National Maple Syrup Digest. 12(2): 13-18.

Wargo, P. M. 1977. **Wound closure in sugar maple: adverse effects of defoliation.** Canadian Journal of Forest Research. 7: 410-414.

Houston, David R.; Fagan, J. Chris. 1997. **Reexamination of effects of paraformaldehyde on tissues around tapholes in sugar maple trees.** Res. Pap. NE-706. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Pellets containing paraformaldehyde (PFA) are sometimes placed behind spouts in tapped sugar maples to prolong sapflow and increase the yield of sap used to make maple syrup. The practice is controversial because the chemical has been shown to promote decay and is reported to cause cambial dieback around tapholes. This study reexamined the effects of PFA on tapped sugar maple and determined how these effects also are influenced by time of tapping and spout removal, and by taphole flushing. A survey of sugarbushes in Wisconsin revealed no relationship between PFA use and cambial dieback and rate of taphole closure. Other factors including poor tapping techniques and practices, drought, and old age affected these taphole attributes more than PFA.

Keywords: sugar maple, paraformaldehyde, tapholes, discoloration, decay

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