The effect of XYLEM AGE on volume yield & sugar content of SUGAR MAPLE SAP

by Carter B. Gibbs

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RICHARD D. LANE, DIRECTOR

The Author

CARTER B. GIBBS, silviculturist, earned a bachelor's degree in 1950 and a master's degree in 1956 at the University of New Hampshire. In 1969 he received a Ph.D. degree from the New York State University College of Forestry at Syracuse. He has worked for private industry, the New Hampshire State Forestry Department, and the Bureau of Land Management of the U.S. Department of Interior. He joined the Forest Service in 1957 and has done research on the silviculture of southern pines in Texas, the silviculture of Appalachian hardwoods in West Virginia, and maple sap production techniques in Vermont, where he is now located at the Burlington research unit of the Northeastern Forest Experiment Station.

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THE QUESTION "How deep should a taphole be in a sugar maple tree to get the best production of sap and sugar?" has never been answered satisfactorily. Most studies of this question have been concerned mainly with volume of sap yield. Now the answer is being sought by looking at the age of the xylem—especially the outer layers where the greatest movement of sap and sugar occurs.

Studies of differences in sap flow from tapholes of various depths were made as early as 1895. Wood (*1895*) concluded that the then common practice of tapping to a depth of 1 inch, in the belief that most of the sap came from outer wood, was erroneous. He recommended tapping to depths of 4 or 5 inches. Morse (*1895*) found that deeper tapholes flowed longer than shallow tapholes. In more recent times, Cope (*1949*) used an instrument that separated yields from 2-inch and 4-inch depths in the same taphole; he showed that as much as one-third of the potential flow is lost by tapping to a 2-inch depth as opposed to tapping to a 4-inch depth. Morrow (*1963*), in a test of 2-inch and 3 1/2-inch holes, found that the deeper tapholes yielded significantly greater amounts of sap in two out of the seven seasons tested, and that there was a tendency toward more flow from the deeper taps in all years.

Although deep tapping apparently increases yields, there is a limit to the increases that can be obtained this way. Jones, Edson, and Morse (*1903*) showed that sap volume yields decreased after the optimum depth of 3 inches was reached. They also showed that sap-sugar content decreased as taphole depth increased. Herbert (*1923*) reported that nothing is gained by tapping more than 2 inches deep. In a comprehensive study of sap flow, Robbins (*1960*) compared yields from 2-, 4-, and 6-inch taps and found significantly greater yields from the 4-inch tapholes than from either of the other depths.

All this previous work was oriented toward yield as a function of taphole depth; none of it dealt with the basic problem of identifying the high-sap producing areas of the xylem. It is known that the sap-bearing tissue of the maple consists primarily of vessel cells in the xylem (*Marvin 1958*). However, the xylem gradually becomes functionless as the tissues age, thus limiting sap flow to the outer portions of the wood (*Jones, et al. 1903*). This functional area no doubt varies from tree to tree, depending on vigor, size, and age.

At the Burlington, Vermont, research unit of the Northeastern Forest Experiment Station, a study was begun in 1966 in an effort to identify the portions of the xylem that produce the most sap and the sap with the highest sugar content. The study revealed that the greatest volume of sap comes from xylem that is about 35 years old, and that the sweetest sap comes from the young xylem just beneath the bark.

STUDY METHODS

Thirty-six vigorous sugar maple trees larger than 16 inches d.b.h. were each tapped once. Taphole depths ranging from 1 to 6 inches were assigned to trees at random until there were six trees in each of the following taphole depth classes: (1) 0 to 1 inch; (2) 1 to 2 inches; (3) 2 to 3 inches; (4) 3 to 4 inches; (5) 4 to 5 inches; and (6) 5 to 6 inches.

All tapholes were drilled in two stages. In the first stage, the hole was drilled through the bark and approximately 1/2 inch into the tree. Bark thickness was measured and added to the depth to be drilled. The taphole was then drilled to the prescribed depth plus bark thickness.

Flow from sections of the taphole that were not sampled—for example, the 0-to-4-inch section of a taphole scheduled to be sampled in the 4-to-5-inch depth—was blocked by a copper tube of the same diameter as the taphole (fig. 1). These tubes were coated with wax and inserted to the prescribed depth, thus leaving an open 1-inch sampling segment in each tree.

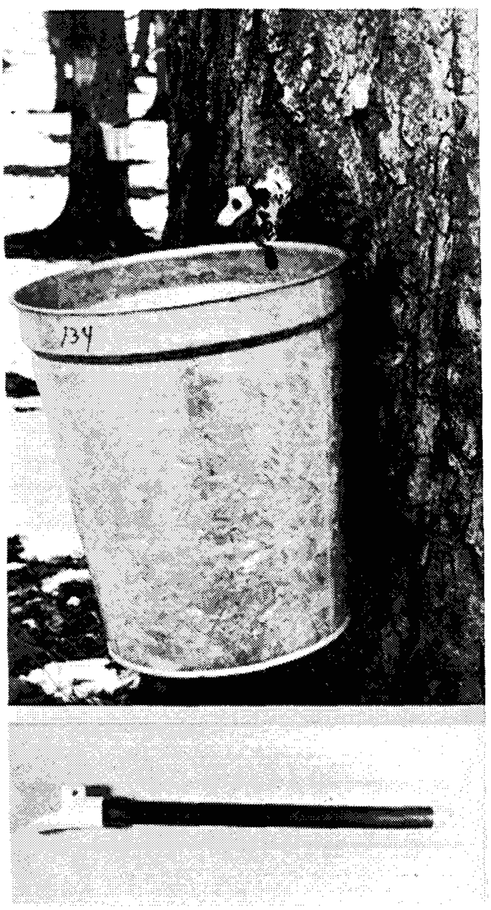


Figure 1.—For collecting sap flow from taphole depths greater than 1 inch, copper tubes were inserted into the taphole to stop the flow from lesser depths. Inset below shows the copper tube, fitted with a plastic spout.

For the 0-to-1-inch sampling depth, copper tubes larger than the taphole were placed over the taphole and driven through the bark to the wood (fig. 2). The bark at the bottom of the taphole was then sealed with hot wax to prevent sap leakage into the bark.

Drill shavings were removed from the taphole with a small wooden dowel, and a fresh paraformaldehyde pellet was placed in the 1-inch sampling segment. Metal buckets with covers were

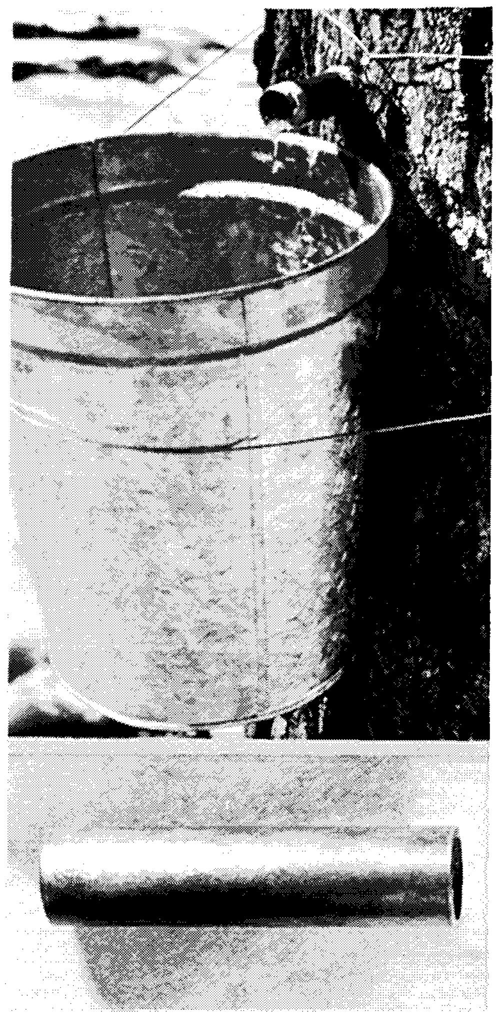


Figure 2.—For collecting flows from the 0- to 1-inch depth, copper tubes were driven through the bark to the wood.

hung on nails inserted below the taphole for the sampling segments deeper than 1 inch. For the 0-to-1-inch depth, buckets were secured to the trees by a plastic bucket hook on a stainless steel wire (fig. 2).

Sap volume was measured 16 times during the season. Yield was recorded to the nearest 10 milliliters when the sap was liquid, and to the nearest 4 ounces when the sap was frozen. The previously determined bucket weights were subtracted from the total weight of the bucket plus frozen sap, and the sap weight was then converted to milliliters. Total seasonal sap-volume yield was calculated for each taphole.

Sap-sugar concentrations were recorded eight times during periods of moderate to heavy flow. Readings were made with a standard sap refractometer to the nearest 1/10 percent sap-sugar concentration. Average seasonal sap-sugar percentage was calculated for each taphole segment.

After the sap season, the age of the xylem at each sample depth was determined from an increment core taken just above or below each taphole. An increment borer was inserted to a depth greater than the taphole depth plus bark thickness. The total depth of the taphole and the innermost inch, the sampled area, were than marked on the core. The core was stained with phloroglucinol in the laboratory, and the total age of the taphole and the age at the beginning of the 1-inch sampling segment were determined with a binocular microscope.

The average age of each 1-inch taphole segment was computed by adding the total age of the taphole to the age at the beginning of the sampling segment and dividing the sum by two.

RESULTS AND DISCUSSION

General

Scatter diagrams of the data indicated that both relationships – volume yield over mean xylem age and sap-sugar percentage over mean xylem age – were curvilinear; and the data were subjected to computer analysis for curvilinear regression.

The relationship of number of annual rings in the 1-inch sampling segment to the volume yield and sugar percentage variables was also considered. However, scatter diagrams indicated an unpatterned distribution of the variation in both variables.

Volume Yield – Mean Xylem Age Relationship

The regression model for volume yield-mean xylem age relationship followed a third-degree parabola

$$Y = b_oX + b_1X^2 + b_2X^3$$

where $\hat{Y} = 6296X - 129.21X^2 + 0.7056X^3$

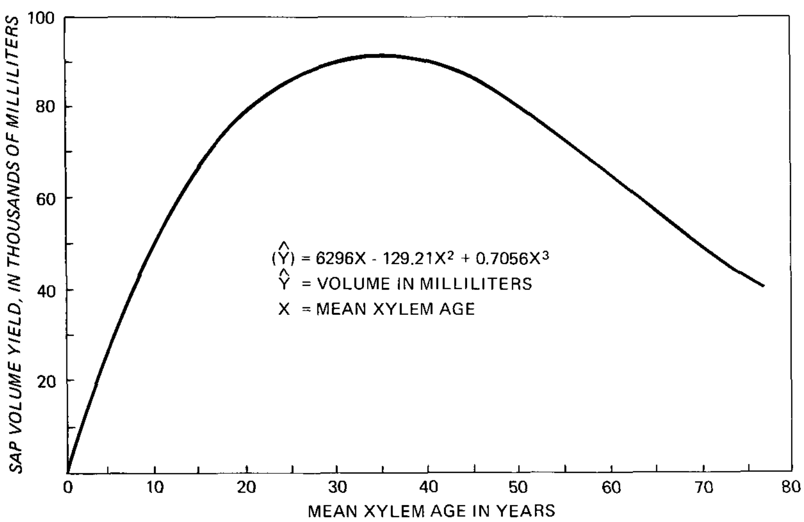
$\hat{Y}$ = Sap volume yield in milliliters.

X = Mean age of a 1-inch segment of xylem.

The multiple correlation coefficient (R^2) was 0.93, and the regression was significant at the 1-percent level. A graph of the computed curve is given in figure 3.

The curve indicates that the major area of sap movement during the sap season is in segments of the xylem that average 35 years old. Since no anatomical analysis was made of the

Figure 3.—Relationship of mean xylem age to sap volume yield.



xylem we can only postulate the reasons for this area of high productivity. It seems that chemical and morphological changes affecting sap movement must occur as the xylem increases in age. In the early years there may be a period of maturation before these tissues attain maximum transport efficiency. As the xylem ages, this efficiency apparently drops off, perhaps due to deposition of amorphous inorganic matter. Such obstruction is particularly true in sugar maple, according to Kramer and Kozlowski (*1960*).

To be useful to the average maple producer, mean xylem age must be related to taphole depth. To obtain an estimate of this relationship for the sugarbush used in this study, mean xylem age, total sap volume yield, and mean sap-sugar percentage were calculated for each depth sampled.

As expected, the high-yield areas bridged the 35-year average xylem age, indicating that tapholes at least 3 inches deep are needed to insure high productivity. Also, the accumulated volume yield (table 1) appear to make it worthwhile to drill tapholes as deep as 6 inches for maximum productivity.

However, the accumulated mean yields must be interpreted cautiously in view of previous studies that have shown that yield decreases with taphole depth greater than about 4 inches (*Robbins 1960*). A major difference between our study and previous studies is that copper tubes were used to block flow in certain taphole segments. Most investigators feel that some sap

Table 1.—Mean xylem ages, sap volume yields, and sap-sugar percentages, by 1-inch sampling depths

Segment depth	Mean xylem tissue age	Sap-sugar concentration	Sap volume yield	Cumulative yield totals
Inches	*Years*	*Percent*	*Gals.*	*Gals.*
0 to 1	6	3.9	8.5	8.5
1 to 2	16	3.2	20.0	28.5
2 to 3	27	2.9	23.5	52.0
3 to 4	37	3.1	20.9	72.9
4 to 5	54	3.5	18.4	91.3
5 to 6	64	2.8	14.6	105.9

absorption normally takes place in deep tapholes as a result of differences in temperature between inner and outer segments. Inner tissues react more slowly to temperature changes, either warming or cooling. Jones, Edson, and Morse (*1903*) concluded that the time of flow is associated with depth: outer segments of tissue flow first, then successively deeper tissues. Thus, the deeper tissues may absorb some of the sap flow from the outer tissues at certain times, and vice versa. Studies by Marvin (*1946*) have illustrated this absorption of sap by cold xylem tissue. In our study, sections of the taphole that might have absorbed sap were blocked by the copper tubes.

The accumulated mean volume yield of 1-inch segments was 105 gallons (table 1). This is much higher than would be expected from a single 6-inch taphole, which tends to support the theory that the copper tubes prevented absorption of sap in sections of the taphole at certain times. The high cumulative yield of 105 gallons may also be due partly to incomplete blocking of the unsampled taphole section by the copper tubes. Some sap may have moved along the copper tube from the blocked area into the sampling segment, thus inflating the yield of some or even all segments.

Another factor that must be considered in evaluating the results is that pressure and flows may be directional at any time during a sap-flow period. Sap moves either from below or from above the taphole as the result of the buildup of pressures in the tree roots or crowns (*Jones et al. 1903*). When the flows are from above, there is a possibility that the sap may pass through the taphole into tissues below and may be lost as yield. This condition may be less serious in short xylem segments than in deep tapholes where the range in temperatures and pressures are much greater.

All the factors of temperature, pressure, and directional flow appear to be closely interrelated; and they may affect yield from deep tapholes much more than yield from short segments of xylem or from shallow tapholes.

Sap-Sugar Percentage — Mean Xylem Age Relationship

The regression model for the sap-sugar percentage-mean xylem age relationship followed the logarithmic form

$$Y = b_o + \log_{10}(\frac{1}{X})$$

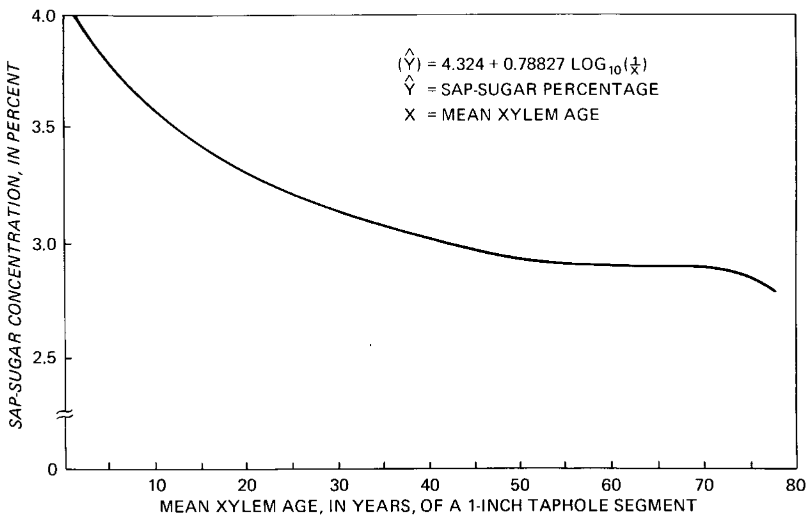
where $Y = 4.324 + 0.78827 \log_{10}(\frac{1}{X})$

$\hat{Y}$ = Mean seasonal sap-sugar percentage.

$\hat{X}$ = Mean age of a 1-inch segment of xylem.

The multiple correlation coefficient (R^2) was low—0.43—but the regression was significant at the 1-percent level. The computed curve is shown in figure 4. The general shape of the curve indicates that either starch-to-sugar conversion or sugar transport is greatest near the bark—and perhaps both are greatest there. This seems logical because sucrose is utilized in metabolism as well as in growth processes concentrated in the cambial area. However, after a sharp initial drop, sap-sugar percentage declines

Figure 4.—Relationship of mean xylem age to sap sugar percentage.



slowly with increasing xylem age. Although their methods were strictly observational, Jones, Edson, and Morse (*1903*) found the same general trend.

The sap-sugar percentage curve has practical significance when sap-sugar percentage is to be used as a basis for breeding or thinning. Tapholes for tree-to-tree comparisons of sap-sugar concentrations should cover the same range of xylem age, or depth, because random taphole depths could mean differences in sap-sugar percentage resulting from xylem age affects rather than from inherited variations.

CONCLUSIONS

Seasonal sap volume yield and mean seasonal sap-sugar percentage are both correlated with the mean age of 1-inch segments of the xylem, and the relationships confirm the findings of others who worked solely with taphole depth.

Evaluation of the sap volume yield-xylem age relationship indicates that the accumulated mean yields of 1-inch segments are not a realistic expression of the total yield that could be expected from a single deep taphole. Other investigators have found that total yield from deep tapholes is less than that from average depths. In deep tapholes, where ranges in temperature and pressure can occur, parts of the xylem may be absorbing while other parts may be flowing. However, more research is needed before we can have an adequate understanding of the sap-flow process in the taphole.

Until further research more clearly identifies the depth of taphole that gives highest net yields, I recommend that tapholes be drilled just deep enough to include the area of maximum yield, which occurs in xylem aged 30 to 45 years. On most trees, this means that taphole depth should be 3 to 4 inches. This recommendation agrees with most of the conclusions from previous investigations.

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