USDA FOREST SERVICE RESEARCH NOTE NE-213
1975

Northeastern Forest Experiment Station

FOREST SERVICE, U.S. DEPT. OF AGRICULTURE, 6816 MARKET STREET, UPPER DARBY, PA. 19082

ODC 892.68

SUGAR MAPLE SAP VOLUME INCREASES AS VACUUM LEVEL IS INCREASED

by RUSSELL S. WALTERS and H. CLAY SMITH[1]
Research Foresters
U.S. Department of Agriculture, Forest Service
Northeastern Forest Experiment Station

Abstract.—Maple sap yields collected by using plastic tubing with a vacuum pump increased as the vacuum level was increased. Sap volumes collected at the 10- and 15-inch mercury vacuum levels were statistically significantly higher than volumes collected at the 5-inch level. Although the 15-inch vacuum yielded more sap than the 10-inch vacuum, the difference was not statistically significant. An efficient vacuum system should have a vacuum level of at least 10 inches of mercury at the taphole.

Sugar maple sap yields are known to be greater when sap is collected on a hillside by gravity in a closed plastic pipeline than when a vented system is used *(Blum 1967)*. This is because a natural vacuum is created by the weight of the sap flowing through the closed tubing line. A vacuum pump connected to an unvented tubing system can also increase sap yields. However, we did not know how much vacuum is needed to get the greatest sap yield.

Collecting sugar maple sap at three different levels of artificial vacuum—5, 10, and 15 inches of mercury—we found greater yields from the higher vacuum levels.

Study Methods

In late February 1971, 15 trees located in a northwestern Vermont sugarbush were selected and tapped. Three tapholes were drilled in each tree. All the tapholes were drilled to the same dimension: 7/16 inch in diameter and 3 inches deep inside the bark. A gasoline-powered tapper was used to make the holes.

Each of the three tapholes per tree was

[1] At the time this study was made, both authors were at the Northeastern Forest Experiment Station's laboratory at Burlington, Vermont. H. Clay Smith is now at the Experiment Station's laboratory at Parsons, West Virginia.

Figure 1.—Sap from each taphole was collected in individually sealed 55-gallon steel drums.

assigned, at random, to one of three different vacuum levels—5, 10, or 15 inches of mercury. Each taphole was connected by 5/16-inch plastic tubing to a separate 55-gallon steel drum, in which the sap from the taphole was collected (fig. 1).

In each system, vacuum was developed in a central tank by a vacuum pump and transferred through plastic tubing to the individual collection drums located at each tree. The desired vacuum levels were maintained in each system by regulating pressure-control valves. Vacuum levels were monitored by gages located at the ends of the tubing systems farthest from the pumps.

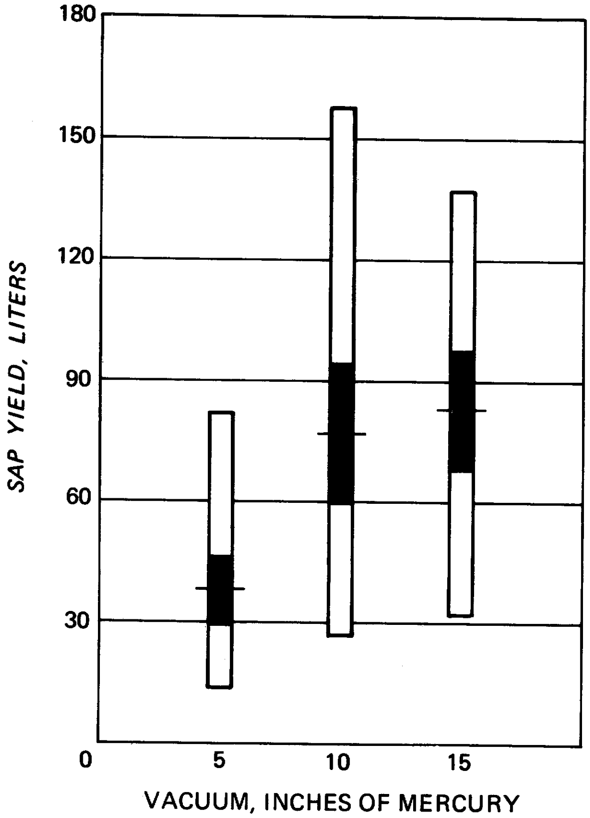
Vacuum was applied to the systems for approximately 130 hours during the sugaring season from March 19 to April 18. At the end of the sugaring season, the sap in each drum was measured to the nearest ½ liter.

Results

The results of this study indicated that the average sap-yield volumes per taphole varied positively with the vacuum levels. The greater the vacuum level, the greater the average sap yield. The average volumes were 37.8, 76.8, and 82.7 liters (40.0, 81.2, and 87.4 quarts) for the 5-, 10-, and 15-inch vacuum levels respectively. The sap volumes collected at the 10- and 15-inch vacuum levels were statistically significantly greater than the amount of sap collected at the 5-inch vacuum level. Sap volumes between the 10- and 15-inch vacuum levels were not statistically significantly different. Significant differences were determined at the 1-percent level.

These results are illustrated graphically in figure 2. The range of total per-taphole sap yields for each vacuum level is represented by the unshaded boxes. The average per-

Figure 2.—Average sap yield per tap for each vacuum level is indicated by the crossbar. The shaded areas indicate ±2 standard errors of the means. The total length of the unshaded boxes represents the total range of individual taphole yields.



taphole yield is indicated by a crossbar, and the shaded boxes represent ±2 standard errors of the mean *(Dice and Leraas 1936)*. A summary of the basic data is presented in table 1.

Discussion

It has long been known that maple sap will exude from a taphole or wound in dormant sugar maples when the internal pressure of the tree becomes greater than the external, or atmospheric, pressure *(Jones and others 1903; Marvin 1958)*. This is a function of changes in temperature. Cold nights induce a negative pressure within a tree, resulting in moisture being absorbed through the roots. Warm days provide a positive internal pressure, forcing sap from the tree at tapholes or wounds. The volume of flow is not related to the temperature rise on the day of the flow, but rather to the length of the preceding cooling period.

A theory developed by Sauter[2] suggests that the mechanism of the sap-flow phenomenon is due to gas (mainly CO_2) expanding and contracting in response to temperature changes. Under cooling conditions, CO_2 contracts and dissolves in the sap, causing negative tree pressure. During warm daylight hours, CO_2 is produced by living cells. Also, warming of tree drives the CO_2 out of sap solution. The gas accumulates in spaces of the fibrous tissue and expands, creating positive tree pressure on the vessel, causing sap to flow out through the taphole.

Maple sap cannot be pulled or sucked from a taphole. Rather, it is forced out by a positive pressure differential when the pressure inside the tree is greater than the atmospher-

[2] Sauter, Jörg. 1971. A new hypothesis for the mechanism of sap flow in sugar maple. Botany Seminar, University of Vermont, 10 May 1971.

Table 1.—Summary on analyses for comparing yields and vacuum levels

Vacuum level	Average sap volume/taphole	Standard error of mean	Analyses comparisons: Vacuum level	Analyses comparisons: F. value
Inches of Mercury	*Liters*	*Liters*	*Inches of Mercury*	
5	37.8	±4.1	5 vs. 10	44.4**
10	76.8	±8.5	5 vs. 15	50.5**
15	82.7	±7.3	10 vs. 15	0.5NS

** Significant at 1-percent level.
NS Nonsignificant.

ic pressure outside. Applying vacuum to a taphole has the effect of artificially reducing the external pressure, thus creating the pressure differential necessary to allow sap to flow from the tree.

In each sap season there are a number of days when conditions are almost right for a sap run. That is, the tree's internal pressure is about equal to the atmospheric pressure. This situation also occurs for a period at the beginning and end of each sap run. It is during these times that a sap flow can be induced or prolonged by vacuum pumping to create a pressure differential. During periods of good sap-flow conditions, even heavier flows may be induced by vacuum.

The use of vacuum has raised questions about its effect on the composition of the sap collected. Maple sap is a very complex solution of sucrose, other sugars, minerals, and organic compounds. A large amount—about 98 percent of the dissolved solids—is sucrose. For the most part, these solutes diffuse from the living ray and parenchyma cells into the sap in the vessels. Because of the complexity of the constituents in maple sap and the mechanism whereby sap enters the vessels, concern developed that vacuum might possibly increase the amount of water in the sap, resulting in diluted sap.

Maybe various sap constituents respond selectively to the exertion of vacuum at the taphole, and maybe sap composition is altered by extracting more or less of the individual solutes. Vacuum may even cause the extraction of substances that do not normally appear in sap flowing from the taphole. Laing and others *(1971)* considered these possibilities and concluded that, under normal conditions of gravity flow, only a small volume of the available vessel sap reaches the taphole, and that vacuum pumping (as high as 25 inches of mercury) simply removes additional unaltered vessel sap.

Conclusions and Recommendations

We found that the higher the vacuum level generated within an unvented tubing system, the greater the sap yield will be. A vacuum level of at least 10 inches of mercury should be mainained at the taphole. The sap volume yielded by both the 10- and 15-inch vacuum levels was significantly greater than that yielded by the 5-inch level. However, the 15-inch volume was not significantly greater than that of the 10-inch level.

Further, results of this study and from other research strongly emphasized the importance of maintaining high vacuum at each taphole. To check the effectiveness of the vacuum system, gage readings should be made at the ends of the pipeline system farthest from the pump. There is, of course, a loss of vacuum through friction in long tubing lines. This means that a vacuum level higher than 10 to 15 inches should be maintained at the pump, perhaps as high as 20 to 25 inches, in order to achieve the desired level at the taphole. Maintaining high vacuum requires constant inspection and maintenance of the tubing system.

Literature Cited

Blum, Barton M.
1967. PLASTIC TUBING FOR COLLECTING MAPLE SAP: COMPARISON OF SUSPENDED VENTED AND UNVENTED INSTALLATIONS. USDA For. Serv. Res. Pap. NE-90. 13 p.

Dice, Lee R., and Harold J. Leraas.
1936. A GRAPHIC METHOD FOR COMPARING SEVERAL SETS OF MEASUREMENTS. Univ. Mich. Lab. Vertebrate Genet. Contrib. 3. 3 p.

Jones, C. H., A. W. Edson, and W. J. Morse.
1903. THE MAPLE SAP FLOW. Vt. Agric. Exp. Stn. Bull. 103. 184 p.

Laing, F. M., J. W. Marvin, Mariafranca Morselli, David W. Racusen, E. L. Arnold, and Elizabeth G. Malcolm.
1971. EFFECT OF HIGH-VACUUM PUMPING ON VOLUME YIELDS AND COMPOSITION OF MAPLE SAP. Vt. Agric. Exp. Stn. Res. Rep. MP 65. 11 p.

Marvin, J. W.
1958. THE PHYSIOLOGY OF MAPLE SAP FLOW. *IN* THE PHYSIOLOGY OF FOREST TREES: 95-124. Ronald Press, New York.

MANUSCRIPT RECEIVED FOR PUBLICATION 3 MARCH 1975