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A Correlation Between Sugar Concentration and Volume Yields In Sugar Maple An 18- Year Study

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Abstract. The sugar concentrations and the volume yields of Acer saccharum Marsh. sap from trees with single tapholes both show large variations from year to year and during sap flow seasons. Daily measurements of sugar concentration and volume yield from 29 trees for 18 years show consistent patterns. High sugar concentrations and high volume yields are characteristic of some trees; lower sugar concentrations and smaller volume yields are characteristic of other trees. A regression analysis shows a highly significant relationship between sugar concentration and volume yield in individual trees.

AN IMPORTANT OBJECTIVE of a program to domesticate sugar maples and increase the yield is to identify superior trees in nature. These should be individual trees with high sugar concentration and large sap volume yields as compared with the other trees in the same stand. That there is great variation in each of these two factors has long been known (Jones et al. 1903); individual trees are consistent as high or low sugar producers (Taylor 1956) and are also consistent in volume yields, as maple producers will testify.

The ideal condition would be to find a positive correlation between sugar concentration and volume yield in the same tree. Such a correlation cannot be assumed. It is assumed that sugar concentration is in part a function of total reserve carbohydrate and is correlated with the past summer's growth and metabolism, and also with the effect of winter temperatures on the relative amounts of soluble and insoluble carbohydrates (Jones et al. 1903). Volume yield is a function of the weather conditions during the maple sap flow season; the total yields are directly related to the vicissitudes of the diurnal temperature regime during that period. Individual trees differ quantitatively in their response to these environmental factors; it is these differences that are of interest here. The reasons for the differences are presumably both anatomical and physiological and appear to be the result of genetic factors.

The maximum yield of syrup from a stand of maple trees depends on sugar concentration and the volume of sap the trees produce. Taylor (1956) and others have determined that in a population where the high and low sugar

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concentration trees have been identified, they are, from year to year, the same individuals. A positive correlation between sugar concentration and volume for individual trees would identify the superior ones. Sugar concentrations can be easily measured in the field with hand refractometers. Volume measurements are much more time-consuming determinations.

Differences in the volume yield from individual sugar maples have been recognized from the beginning of the industry. Clark (1874) was one of the first to record differences in volumes from individual trees and correlate these with temperature. Jones (1903) was apparently the first to measure sugar concentration and volume yields simultaneously from each of several tapholes in the same tree and in different trees. The data on volume yields from groups of trees are extensive, but there are very few data comparing volume yields and sugar concentrations on individual trees.

Moore *et al.* (1951), in Ohio, observed in a group of trees over a four-year period that the volume and sugar concentration of the sap were related to crown depth, density and height. Morrow (1955), using his and Taylor's data, made similar observations on the in-creased sugar concentration in large-crowned trees.

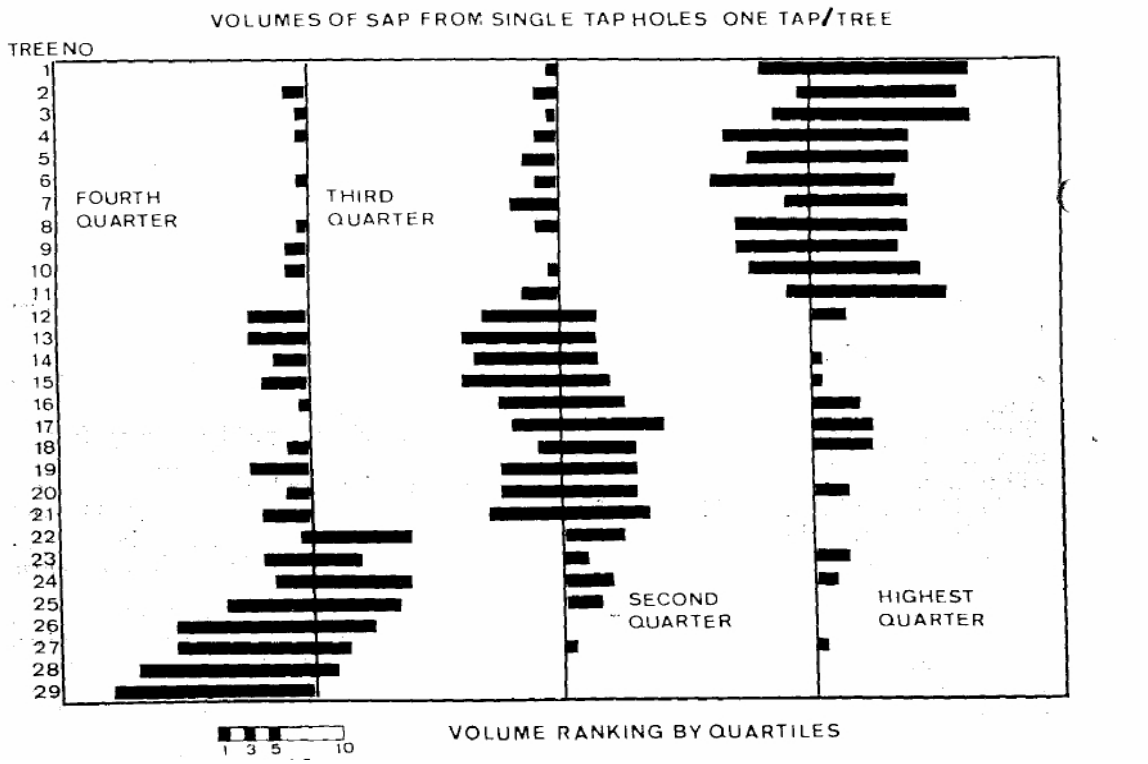

FIGURE 1. Quartile ranking of trees according to the volumes of sap per year from trees with one taphole per tree. The sum of the bar lengths represents 13—18 years.

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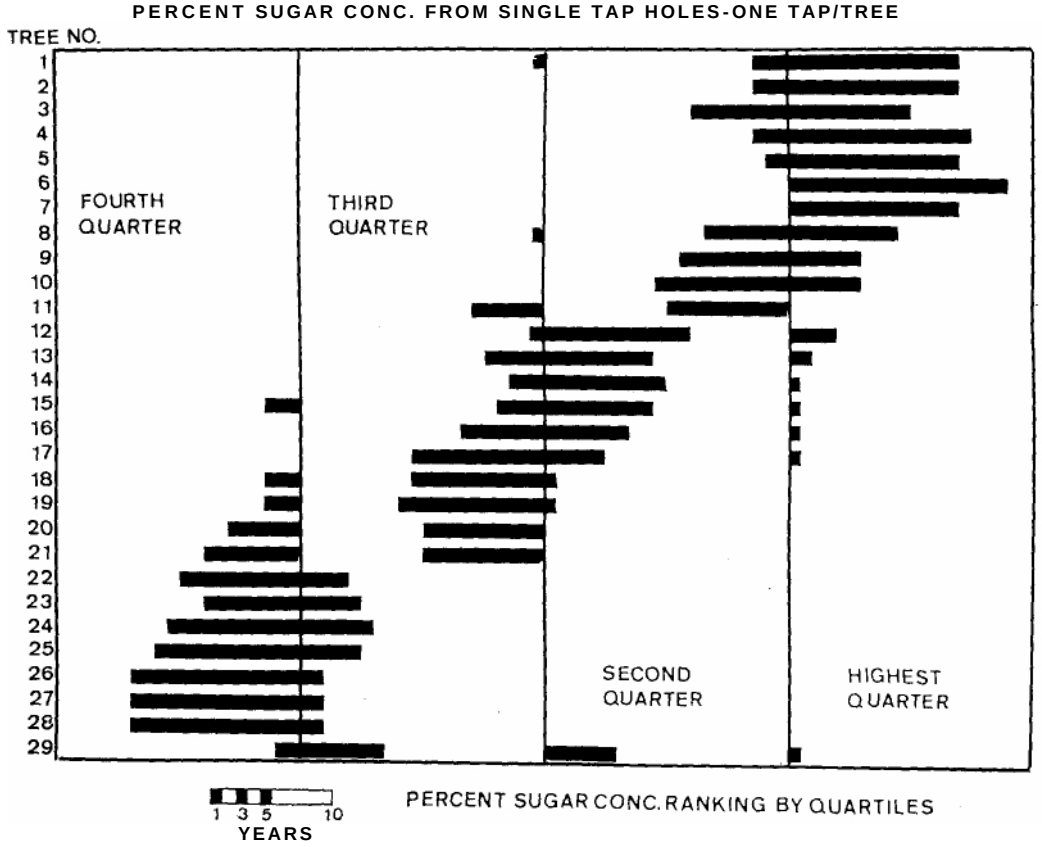
Tressler and Zimmerman (1942) reported on observations in a New York sugarbush over a three-year period. They measured the sugar concentration and volume yields from individual tapholes, but unfortunately did not publish their data in this form. They did find a positive correlation between sap volume and sugar content (weight of sugar) from similar tapholes—that is, trees with one, two or three taps. Morrow (1952), commenting on Tressler's work, observed that the data did not show a correlation between sugar concentration and volume yield in the same taphole (tree).

Taylor (1956) reported the results of an extensive study of 4,500 trees undertaken over a period of several years. He found that, although the sugar concentration in the sap of individual trees varies during the day, from day to day and from season to season, individual trees maintain their relative position in a population. The sweetest trees are always the same individuals.

Materials and Methods

The trees used in this study are part of a stand of mature maples (Acer saccharum Marsh.) growing at an elevation of 1,400 feet on a site with a gently sloping southwest exposure at the Proctor Maple



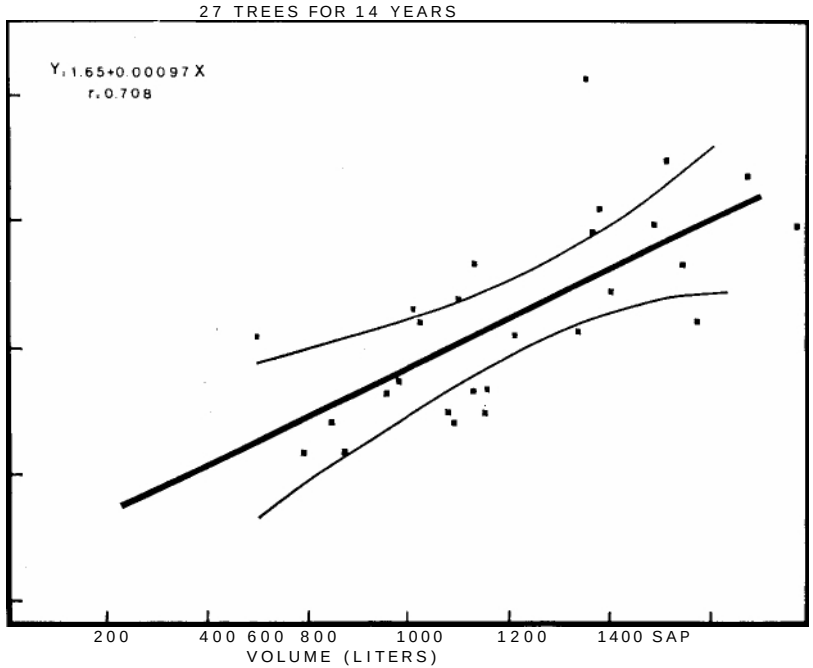


FIGURE 3. *Average percent sugar concentration and total sap volume from 27 trees for 11 years with the regression line, the regression formula, the correlation coefficient and the 99 percent confidence bands for the mean percent sugar.*

Research Farm in Underhill, Vermont. The trees, widely spaced in a parklike stand, range from 15 to 32 inches dbh and have from one-third to two-thirds of their height in live crown.

Sugar concentrations were determined as total solids with Zeiss hand refractometers from a drop of sap when the spout was dripping. Volumes were measured either from individual buckets or by an automatic volume recorder previously described (Marvin and Erickson 1956). Measurements of sugar concentration and sap volume were taken simultaneously whenever a flow period occurred, frequently although each of the trees was not used every year. Thus 4 of the trees were used every year (trees 1, 3, 4 and 6), 9 trees were used for 17 years, 9 trees for 16 years, 3 trees for 15 years, 3 trees for 14 years, and 1 tree for 13 years (tree 23). In Figures 1 and 2 all the available data were used for 29 trees. In Figure 3 and Table 1 the data are for the 27 trees used each year for 14 years. The volumes compared were the totals for each tree for each year, and the sugar concentrations were the averages for each tree for each year. Over 10,000 observations were recorded during the 18-year period. The data were analyzed both manually and by

and separated into quartiles with the largest volumes and highest sugar concentrations on the right. The trees are listed in the same order in both figures The bar length represents the number of years for which data were available.

The consistent pattern observed by Taylor (1956) in sugar concentrations is apparent here. High sugar content trees and low sugar content trees remain in the same quartile year after year. A similar consistent pattern occurs in the volume yields of individual trees. Trees with high volume yield and high sugar concentration are nearly always the same individuals.

Tree 1 ranked in the top quartile in volume for 13 years, in the second quartile for 4 years and in the third quartile 1 year. Similarly, this tree ranked in the top quartile in sugar concentration for 14 years, in the second quartile for 3 years and in the third quartile for 1 year. Ten trees ranked in the first and second quartiles, 8 trees are ranked in the third and fourth quartiles; other trees with average sugar concentrations and volume yields are in the second. and third quartiles. Tree 28 was in the lowest quartile for 14 of 16 years in both sugar concentration and volume yield. Tree 29 was unusual in that it was consistently low in volume yield, but its sugar concentration varied widely.

It appears that quite apart from whether average sugar concentrations are high or low in a particular year, or whether the volumes are large or small, trees maintain their relative position in a population both in sugar concentration and volume yield. Furthermore, the highest sugar concentrations and the largest volume yields are found in the same trees and the lowest sugar concentrations and lowest volume yields are found in other individual trees.

The apparent relation between sugar concentration and volume yield was tested statistically (Snedecor 1957, pp. 138-139). Figure 3 is a plot of the average sugar concentration for each tree for all years against its total volume yield. Statistically speaking, the probability of this distribution occurring by chance is less than one-tenth of one percent.

Discussion

The analysis of data strongly suggests a positive correlation between sugar concentration and the volume of sap from the same taphole on the same tree. Thus, high sugar concentration and a large volume of sap are correlated.

There was no reason to assume that such a correlation would be found. Jones

TABLE 1. The percent average sugar concentration and the total sap volume for *27 trees for 14 years.*

Tree no.[1]	Ave. percent sugar concentration	Total volume (liters)
1	2.98	157
2	3.18	1474
3	2.99	129
4	3.05	118
5	3.24	131
6	3.57	115
8	2.96	116
9	2.72	120
10	2.83	134
11	2.61	137
12	2.83	934
13	2.65	812
14	2.69	902
15	2.60	823
16	2.55	101
17	2.56	113
18	2.34	958
19	2.37	780
20	2.2S	953
21	2.33	928
22	2.21	888
24	2.25	878
25	2.32	757
26	2.09	677
27	2.21	645
28	2.09	592
29	2.54	499

[1] Trees No. 7 and No. 23 were not considered in this analysis because their data were not recorded for a total of 14 years.

(1903) noted that the sugar concentration in maple bark and wood depended upon winter temperatures. He recorded the highest sugar concentration in January, February and early March when the temperatures were lowest for the year. Volume yield depends on the weather and diurnal temperatures during the sap flow period of March and early April in northern Vermont.

Crown size, anatomical differences and genetical as well as environmental factors all influence sugar concentration and volume yield. However, the results of this study demonstrate a strong positive correlation between sugar concentration in the sap and the volume yield of sap from individual trees regardless of the absolute values for these two dependent variables. When the data from individual trees were tested for correlations year by year, there were positive correlations some years and poor correlations in other years. Therefore, it was necessary to use many years' data before a convincing correlation was found.

The data in Table 1 and Figure 3 should not be used to predict volume yield from observed sugar concentrations measured from individual trees. The significance of the data presented here is, rather, that some of the complex of factors determining sugar concentrations also determine sap volumes, and thus trees identified as high sugar concentration trees can be expected to be high volume trees also.

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