Variation in Sugar Content of Maple Sap

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IN A GENERAL WAY every sugarmaker recognizes variation in the sugar content of sap produced by the trees in his bush. He makes a point of pausing at a "sweet tree" for a drink of sap. He knows that a certain number of "turns" with the gathering tank in one part of his stand will give him more syrup than the same number in another part. He is aware that, after firing up on certain days, he must boil longer than usual before finished syrup can be drawn off.

This variation is important in a direct practical way. A standard gallon of maple syrup contains eight pounds of sugar plus water and traces of other materials, which bring its total weight to the required 11 pounds. A standard gallon, therefore, is not only defined by its sugar content but also has sugar as its principal constituent. Hence, a substantial saving in time, fuel, man and horse labor is the good fortune of the farmer with a high-yielding stand. Such a man spends much less time working up sugar wood, hauling sap, and boiling it down to the proper density than his less fortunate neighbor, and from the same number of trees his annual return is greater.

A knowledge of variation in sugar content is significant in any program aiming at improvement of existing maple stands. Certainly a factor which cannot be overlooked in making thinning recommendations for a producing stand is the sap quality of the maple trees under consideration. Respective yields, which are related to sugar content of sap as well as to amount of sap produced, must be taken into account.

Any program for replacing old stands or planting on new sites likewise depends on an understanding of sugar content and how it varies. A cause for growing concern in the maple industry today is the elimination of bushes through age and cutting. A hopeful sign for the future is the desire of farmers not only to replace former stands but also to establish new ones in favorable locations on their property. For either of these purposes the

1 The author gratefully acknowledges the continued interest and generous aid of James W. Marvin who has been closely associated with this project from the very beginning. He wishes to thank numerous associates who, through the years, have become expert sap testers. Thanks are also due Kenneth E. Boyden for help in setting up the original survey and Mary T. Greene for technical assistance.

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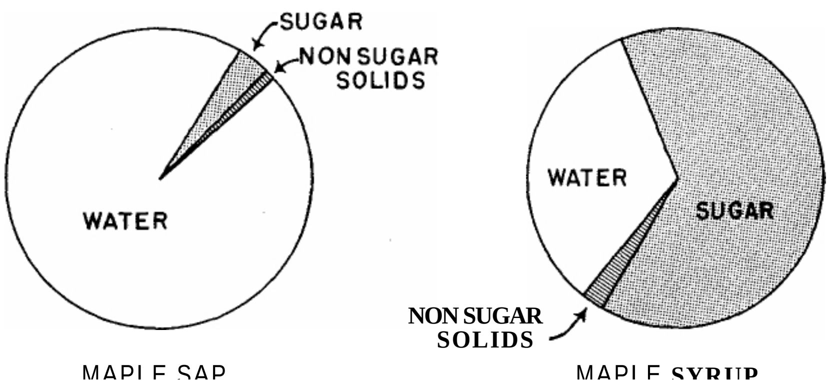
best available planting stock should be used, and a knowledge of variation in sugar content is a necessary preliminary to the production or selection of this stock. For example, individual trees of known performance are absolutely essential to the genetical studies of a maple improvement project. Then, too, the first step in propagation by vegetative means is the careful selection of plants whose characteristics are those desired in the clonal material. Certainly high sugar content is one of these characteristics.

Furthermore, the understanding of variation in sugar content is likely to have bearing on certain aspects of research in processing. Flavor development and evaluation, as well as other features of quality control, are concerned with the solids fraction of maple sap of which sugar is a major constituent. The fact of variation in sugar content points up the possibility of tree-to-tree variation in other important constituents as well.

Fig. 1. Boiling down maple sap to syrup means increasing the proportion of sugar



by eliminating great quantities of water.

Maple sap is a dilute solution of water and sugar, along with traces of other compounds. The proportions are variable but usually fall within the following limits: 95 to 99 percent water and 1 to 5 percent sugar. In addition sap contains minute quantities of organic acids, nitrogen-containing compounds, inorganic salts, and other substances, as yet undetermined.

The manufacture of syrup from maple sap is essentially a boiling process whereby water is removed and the solids fraction of the sap is increased (Figure 1). The boiling is continued until the resulting syrup contains 35 percent water and 65 percent solids, which are principally sugar and small quantities of other materials generally referred to as nonsugar solids. This proportion of water and total solids brings the resulting syrup up to the 11-pound weight required by law.

Of course, sap that already has a high sugar content[2] can be brought to the syrup stage with an expenditure of less time and effort than is required for less sweet sap. This difference in time is also important because the shorter the boiling period in present evaporators, the lighter the color and the more delicate the flavor of the syrup. Then, too, sap with high sugar content will bring the same return as sap which is more dilute, with less effort in gathering and hauling, both important items in times of high labor costs.

What, then, is the exact relation in volume between saps varying in sugar content and what bearing does this relation have on the processing into syrup? Eighty-six gallons of sap containing 1 percent sugar are required to make 1 gallon of syrup. Sap with a sugar content of 2 percent requires 43 gallons, or just half as much, to make a gallon of standard syrup. A gallon of syrup can be made from only 22 gallons of sap containing 4 percent sugar. In short, each time the sugar content of sap is doubled, the amount of sap necessary to produce a gallon of syrup is reduced by one-half.

Figure 2 shows the relationship graphically. Compare the bars for saps containing 5 and 2.5 percent sugar and assume that they represent sap gathered in two sugarbushes on the same day. Only 17 gallons of sap must be boiled down to produce a gallon of syrup from the trees yielding 5 percent sap. On the other hand, the farmer whose sap tests 2.5 percent must gather, haul, and store 34 gallons (or twice as much) to make a similar quantity. To put it another way, the second man must already have provided fuel and labor for boiling off 17 gallons of water before his sap contains as much sugar as his neighbor's did when it dripped into the buckets.

One other feature is obvious from Figure 2. As sap increases in sugar content, the advantage, always apparent in such cases, nevertheless decreases in degree. That is, an increase from 1 to 2 percent decreases the necessary amount of sap from 86 to 43 (a difference of 43 gallons), whereas an increase from 2.5 to 5 amounts to a difference of only 17 gallons. Yet, an earlier statement, that as sugar content is doubled the amount of sap required is cut in half, still holds, and its economic significance is unmistakable.

The chances are good that anyone studying variability in the sugar content of sap hopes to solve one or more of the following problems:

1. The degree to which inheritance influences the sugar content of sap.

2 Solids other than sugar comprise only a minute fraction of all the solids present in maple sap. For all practical purposes, then, "total solids," which include both sugar and nonsugar solids (Figure 1), is the equivalent of "sugar content." From this point on, total solids, measurable either by refractometer or sap hydrometer, will be called the "sugar content" of the sap.

2. The relation of sap flow and total yield of sap to sugar content.
3. The relation of the leaf-bearing capacity and the storage capacity of the tree to the sugar content of the sap.
4. The long-term and short-term relations of environmental conditions, such as light, altitude, exposure, range of temperature, nature and fertility of the soil, and availability of water, to the sugar content of the sap.

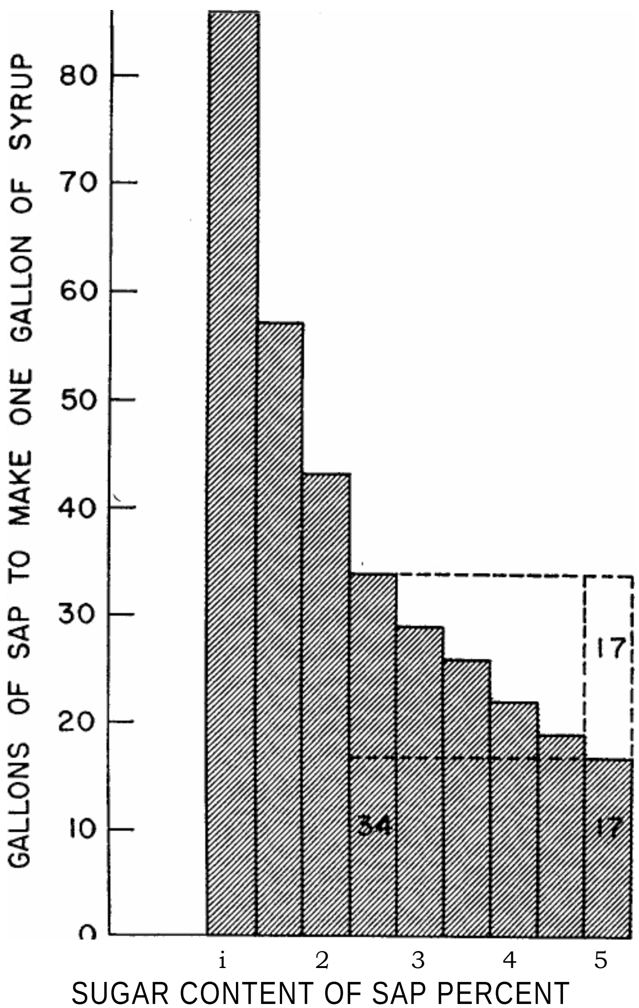


Fig. 2. An increase in sugar content reduces markedly the amount of sap needed to produce a gallon of syrup.

Yet, the investigator who would measure the sugar content of maple sap cannot go out into the sugarbush, make tests on a few trees, and immediately utilize these data with confidence. In our first experience at testing we ran head on into a series of variables which, for all we knew, might affect the worth of the data we had set out to accumulate. After some preliminary measurements, we realized that in dealing with a tree crop, exploited as it occurs in nature, there are no such things as controlled conditions. Maple trees, having been sowed naturally, show little uniformity. Furthermore, climatic conditions, so important in this industry, only rarely, if ever, duplicate themselves. In other words, numerous varying factors, each one potentially able to influence sugar content, are operative among maples in natural stands. The situation is further complicated by a sampling problem involving not only questions of how and where to make tests but also others with regard to time.

Obviously tests should be made in a practical sugar operation (or under conditions simulating one), but they should be so made as to provide information that can be used in a variety of ways some of these perhaps not even apparent at the time the measurements are made. The investigator, therefore, must rule out as many variables as possible. He must sooner or later answer or at least deal intelligently with the following questions:

1. Where on the tree should the test be made?
2. Should sap be tested at the spout or in the bucket?
3. At what time of day should the record be taken?
4. Does it make a difference at what time during a run the test is made? If so, are two trees necessarily at the same stage of a run at the same time by the clock?
5. Should readings be taken during a slow run or a fast one?
6. How many times must a tree be tested to obtain a reliable measure of seasonal performance?
7. During how many seasons must a tree be checked to eliminate seasonal irregularities?
8. How soon in the life of a tree can its sugar-producing potential be determined?
9. Can the saps of young and old trees be directly compared as to sugar content?
10. How many trees must be studied to get a measure of the relative performance of a single tree?
11. Can trees tested on different days be compared?

It soon became apparent that the answers to the intriguing fundamental problems, vital in improving existing stands and in establishing new, high-yielding ones, could not be sought until this series of intermediate technical ones had been disposed of. And it seemed equally evident that neither the fundamental nor the technical problems could be solved without a thorough understanding of how much variation actually exists.

Nowhere in the literature is there reported a survey which could be used as a broad base for studies on variation in maple sap. In fact by 1943, when this project was begun, only Jones *et at*. (3, 4) and McIntyre (7) had published any extensive data on sugar content of sap, and even these data had been presented in support of or in combination with other findings. In their studies, however, these investigators had substantiated the fact of variation among maples, reported as early as 1885 by Wiley 17

It seemed, therefore, that the first step in the current project should be to determine once and for all the degree of variation among maples of tapping size. Next, it was decided that an ambitious study of age, form, exposure, spacing, and climatic conditions could not properly be undertaken without knowing how much trees vary in the sugar content of their sap, how they vary in relation to other trees, how they vary within a season, and how they vary from season to season. It seemed futile, for example, to set up a state-wide project to study the influence of tree form on the sugar content of sap if day-to-day fluctuations might be so great as to obscure the results. In other words, the immediate goal of this project would not be to determine the roles of various environmental factors on the quality of the sap; nor would it be to study those characteristics of the tree which, likewise, might have direct bearing on sugar content. Instead, the aim would be to provide a basis of reference from which to make preliminary generalizations as to patterns of variation. A knowledge of these patterns would not only go far toward eliminating error but would also reduce the number of variables to be sorted out when the time came for studying single factors.

Review of Literature

From time to time information on the sugar content of maple sap has appeared in the literature. Nevertheless, when this project was started there were no detailed reports involving large numbers of trees and an observation period of several years. In most cases past studies were related to the larger problem of maple production or were undertaken in at-tempts to solve related problems. Few have been directed at this aspect of sap quality for its own sake. Consequently, most of the information on sugar percentage is presented along with sap flow records, tree dimensions, or measurable features of the environment and usually appears in the rather abbreviated form of extremes or averages.

More than 75 years ago, Clark (2) recognized the importance of possible variation in this constituent of maple sap. In a paper on the circulation of sap in trees and shrubs he said: "In regard to the amount of sap yielded by the sugar maple and its percentage of sugar, further observations are needed."

In 1884 William Frear was sent to Lunenburg, Vermont, by the United States Department of Agriculture to make chemical studies on maple sap (Wiley, 17). Over the period, April 7-28, he made observations on 15 trees, including two swamp, four white, two black, one striped, and six rock (sugar) maples. He noted variation in sugar content not only by sap-yielding trees of different species but also in individual trees during the course of his study. He also determined sugar percentages from the storage tanks of six different sugar places to demonstrate variations by groves of trees.

Morse (12) followed the fluctuations in sugar percent of two New Hampshire trees from March 13 to April 12, 1895. He comments on a gradual decrease in sugar content of sap until near the end of the season when there was a rise. Included also is an interesting comment to the effect that with an increase in flow there is a concomitant decrease in sugar percentage and vice versa.

"Trees with many branches, and exposed to the full effect of the sun, have been found to give the richest saps," stated Morse and Wood (13). According to their work, however, no one compass position for tapholes shows an advantage in sugar content of sap.

In their monumental work, "The Maple Sap Flow," Jones *et at*. (4) also give figures on the amount of sugar in maple sap. While studying the problems of the sugar orchard they accumulated and published data on sugar content in relation to location of taphole on trunk, position of taphole relative to sunlight, position of taphole with regard to branches, tapping at different heights, tapping at different depths, and tapping at different compass points. Furthermore, they measured sugar content of sap at different times during the day. They, too, present data on variation between stands of maples, finding that samples from five storage tanks varied from 2.08 to 3.44 percent sugar.

The significant contribution to this subject by McIntyre (7), although only one page in length, sets forth conclusions based on the testing of over 500 sap samples. The samples were measured in the field by hydrometer and checked in the laboratory by chemical methods. In addition to substantiating the conclusions of earlier investigators that there is seasonal variation and that sugar content decreases as the season progresses, he states that, although readings from tapholes taken at different times during the day vary slightly, still the relative ranking remains the same. Without elaborating he also notes, ". . . . neither did advance in season change the relative ranking of the taps." With regard to different "taps" on the same tree he says that there is considerable variation. On the basis of differences in sugar content he concludes, ".... the sugar maple is twice as valuable as the red or silver maple."

A year later, in 1933, Jones and Bradlee (3) published a table in which the total solids and sucrose, hexose, and ash contents of 50 sap samples are included. Since these samples were selected at random from many hundreds, the authors conclude that the average sucrose content of 2.93 percent "should be reasonably typical."

Following a study of 19 half-acre plots, Stevenson and Bartoo (14) presented statistical evidence for concluding that open-grown trees are sweeter than forest-grown ones and, further, that roadside trees produce sweeter sap than other open-grown trees.

Consistent performance by maple trees from year to year was reported by Taylor (15), following the testing of over 1,800 trees for two consecutive seasons. From a study of these trees, most of which were tested three times and many of them six times, he states, ". . . . the majority of the `sweet' trees in 1944 were again `sweet' trees in 1945."

In a 1949 report Anderson *et at.* (1) summarized a three-year study of maple yields and costs in Ohio. On 23 fifth-acre plots they found average sugar percentages for the 1948 season to vary from 0.8 to 2.3. Storage tanks of farmer-cooperators ranged from 1.4 to 2.1 percent sugar, with an average of 1.6. The latter figure is 0.2 percent below a comparable figure for 1947.

A progress report in 1950 (Taylor, 16), covering seven years of testing by the Vermont Agricultural Experiment Station, emphasized variation in sugar content of maple sap and presented data to show consistent patterns of variation by individual trees. Trees were found to maintain their positions relative to their neighbors, not only during a single maple season but over a period of years as well. The sugarbushes of nine producers, whose trees were numbered and individually tested on three occasions, showed the same tendency for within-season variation as did single maples.

Ohio Research Bulletin 781 (Moore *et* at., 8), dealing with "some physical and economic factors related to the production of maple syrup," presents the final results (for four years) of the project mentioned above (Anderson *et at.*, 1). Sugar content of sap, usually along with volume of sap, appears in many of the bar graphs presented by the authors. The latter present most of their results graphically and conclude therefrom that high sugar content is related to the following:

1. Species of tree (sugar maples superior to other maples)
2. Position in stand (exposed trees superior)
3. D. B. H. (trees with large trunks productive of more sugar)
4. Foliage density ("good" trees in this respect desirable)
5. Growth rate (trees with wide growth rings sweeter)

Morrow (9) emphasized the same consistency of seasonal variation as did Taylor, with figures for New York State, gathered by the Geneva Experiment Station. Taking this characteristic of maples into account, he suggests testing the sap, in an area to be thinned, twice a season for three seasons. In this way he feels the forester will be better equipped for recommending removal of surplus trees for stand improvement than he would be with visible features of tree and site alone.

"Early Tapping for More Quality Syrup" by Morrow (10) features a recommendation based on the observed decrease in sugar content of sap as the maple season progresses. The author states that in New York over the period 1951-54, February sap was as sweet as that of March and early April taken together but was not always as sweet as that of March sap alone.

The same author (11) in a detailed study of tree crowns and sap production concludes, "Crown diameter, then, seems to influence sugar percentage in all kinds of sugar bushes, while live crown ratio exerts influence mainly in more open stands."

Kriebel (5) found no significant difference in sugar content of sap between sugar and black maples. Some trees in each species were consistently sweeter than others.

Methods

This project of testing the sugar content of maple sap has had two phases:

1. An extensive survey involving several sugarbushes with trees of varying age, exposure, and spacing.
2. An intensive study of a smaller number of the same trees.

Prior to the maple 'season of 1944 more than 3,400 trees in nine sugarbushes were marked by numbered metal tags. A series of percentage figures could then be accumulated over a period of years for each tree and later used in relation to observations on tree and environmental characteristics.

Accordingly, during the season of 1944, over 8,000 sugar percentage readings were taken. Eight of the stands were measured at least three times and the ninth tested twice. During the short season of 1945 four of the sugarbushes were tested at least once for a total of 2,800 sugar percentage figures. Again in 1946 all nine were visited at least once, with nearly 3,500 samples being tested (Figure 3).

For one of these stands sugar percentage records have been kept for 12 consecutive seasons, and for another continuously for the same period except for the season of 1953.

An additional stand of 1,100 maples was added in 1946 with the acquisition of the Proctor Maple Research Farm by the University of Vermont and State Agricultural College. These trees have also been numbered and utilized in the extensive survey.

Trees from the two stands that have been tested regularly from 1944 to 1955 have been under scrutiny in the intensive study. Other trees ob-

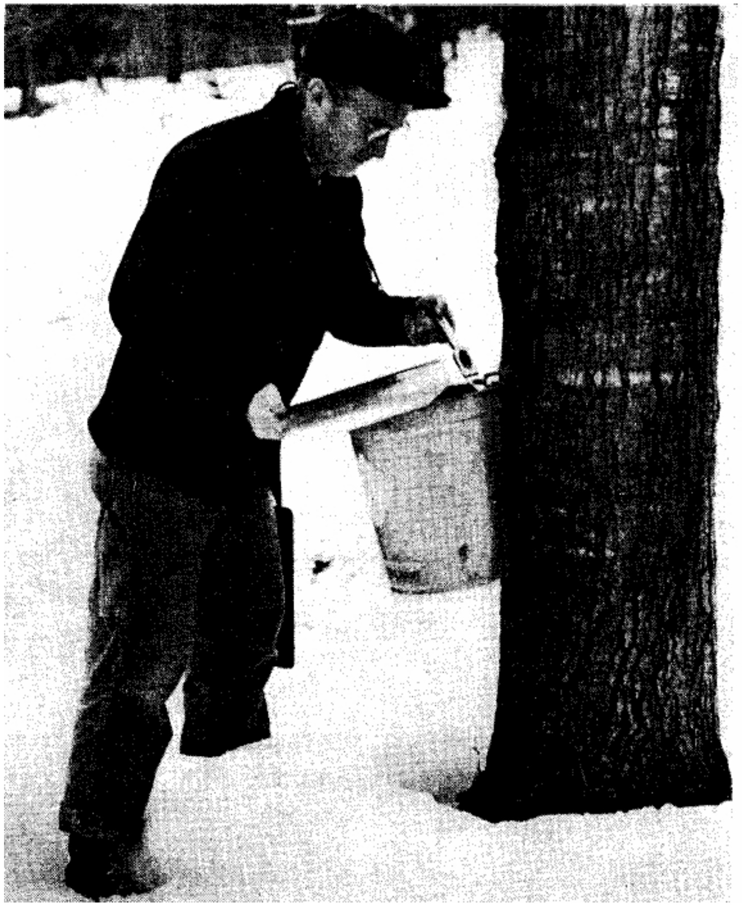


Fig. 3. The author takes a sample of maple sap direct from the spout to test for the sugar content.

served at the Proctor Farm since 1949 have also contributed to an understanding of how sugar content of sap varies during a season and from season to season. Sugar-content records on these Proctor Farm trees have been taken daily when sap ran enough to make testing feasible. The tests number at least 10 per year, with the exception of 1953, when six tests were made, and 1954, when nine were made. These same Proctor Farm

trees are also on record as to total yield of sap, and, in some cases, rate of sap flow.

Testing of sap was done with a Zeiss hand refractometer. This instrument can be adjusted for temperature, an important point of technique when the refractometer is used throughout an early spring day or from day to day when marked temperature fluctuations are the rule. The refractometer, whose scale has divisions at 0.2 percent intervals, can be read to 0.1 percent. In making sap tests, readings have been made to 0.1 percent. Nevertheless, since percentages must be determined by establishing a dividing line between gray and light areas superimposed on a scale of closely drawn black lines, little confidence can be placed in individual readings differing by less than 0.2 percent. In addition, individual differences between observers make conclusions based on seemingly more exact readings of doubtful value.

Drops of sap to be tested with the refractometer were taken at the spout and not from the bucket. This approach was used, especially in producer-owned stands, for four reasons:

1. To get around the problem of stratification. In testing large numbers of trees much time can be saved if each stop does not involve removal of bucket cover and stirring of sap before sample can be taken.
2. To make testing possible on good sap days which follow periods of freezing. Sizable chunks of ice often remain unmelted in the buckets. Stirring under these conditions is impossible and, even if it could be done, the presence of water in solid form would make for deceptively high readings.
3. To avoid collecting irregularities. In testing sap from buckets the presence of buckets missed or only partially emptied from run to run would prevent evaluation of comparable sap samples. The same difficulty would be encountered if, on the day of an extensive test, sap had been collected from buckets in one part of the bush and not in another.
4. To avoid errors traceable to accidental removal of bucket covers. Occasional high winds sometimes blow off bucket covers. Rain, accompanying or following the windy period, would lead to low readings in unprotected buckets.

In the extensive survey sap was tested at the south taphole if possible; otherwise at the southwest or southeast positions. These positions are most frequently tapped in a practical operation, and therefore most likely to be encountered in a survey. If sap from a southerly taphole was not available the sample was taken from some other taphole, but in all cases the position was marked alongside the sugar percentage reading for future reference. The identification of the taphole also served an important purpose in the testing operation, that of insuring that later tests, made in the same season, would be made, insofar as possible, at the same position.

The trees at the Proctor Farm, studied intensively over a period of years, were tapped mostly in southerly positions and, with one exception, always within an arc extending around the trunk from east through south to west. In 1954 all trees were tapped on the north side.

In order to get comparable samples and eliminate another possible variable, the following procedure was adopted early in the course of the project. Before starting tests on a given day a preliminary survey was made to make sure sap was running freely. The first drops of sap to leave the spout at the beginning of a run could give erratic readings due to melting of ice in the taphole or flushing out of "syrup" formed by evaporation during the previous rest period. Then, too, in the course of testing a stand of trees, an effort was made to test only those spouts which were dripping. In other words, the testing of hanging drops, which could have lost water by evaporation, was avoided. This situation is usually encountered late in the season when tapholes are beginning to dry out, although it may also occur toward the end of an early or midseason run.

Methods of presenting numerical data in the discussion which follows require explanation. In the tables listing averages for trees studied in detail, care has been taken that each tree is represented on every date for which data are given. The omission in the field records of one or more readings for a tree has eliminated that tree from consideration because daily differences might be great enough to affect averages. In addition, a gap for one tree would prevent its being ranked relative to others and this, in turn, would affect the rankings of the entire series. Consequently, in-stead of the approximately 30 trees which were observed on numerous days per season, only the 16 with complete records for the greatest number of dates are cited. It is believed, however, that these trees are representative of the entire group and Vermont maples in general, and that the dates are likewise typical for the seasons they represent. On the other hand, this procedure was not followed in computing averages for large numbers of trees as, for example, in an entire bush. Under such conditions it is assumed that the large numbers involved will smooth out the effects of individual records lacking for one reason or another.

Admittedly, an average percentage figure does not give an exact picture of the total sugar-producing potential of a group of trees because it assumes equal yields from all trees. Yet, it seems the most accurate method avail-able for the comparison of bushes, in the absence of a truly composite sample, in which sugar percentages would be weighted by respective yields. In its favor is the fact that it represents large numbers of individual trees whose sap varies not only in sugar content but also in quantity, with the

relationship between the two certainly not a simple direct one (Taylor, 16; Morrow, 9, 10). Furthermore, it undoubtedly tends to be a more constant figure, since it rules out the following weak points of storage tank testing:

1. Difficulty of stirring thoroughly.
2. Problem of ice, not only in buckets but in storage tank.
3. Danger of testing sap from different flow periods due to irregularities in gathering.
4. Problem of rain water from uncovered buckets.
5. Difficulty of obtaining comparable samples, since the tank can accommodate sap from only a fraction of the total number of trees at one time. And, rarely, if ever, is the same group of trees represented in the tank on two separate occasions.

As will be pointed out later, however, whenever differences between bushes are large, average sugar content provides a reliable figure for comparison as to relative costs of producing a gallon of syrup.

It should be pointed out, too, that in rating the sugar content of a tree in relation to a bush in studies involving hereditary considerations, the average figure for the bush is superior to sugar content of a composite sample because it is not affected by differing volume yields.

Variation in Sugar Content of Maples in Natural Stands

Maples growing on Vermont hillsides vary widely in the sugar content of their sap. This statement is made without taking into consideration such variables as age, location, or condition. The trees upon which this con-clusion is based, however, are alike in that all are of tapping size and are representative of maples found in Vermont sugarbushes. In other words, trees capable of being tapped in a practical operation do not yield sap that is uniform in its proportion of sugar and water (Table 1).

To be specific, on March 26, 1944, trees testing 8.4 and 3.2 percent sugar were discovered in the same sugarbush. In another bush, on the same day and in the same town, the high tree tested 3.8 percent while the low was 1.8. This variation, while usually not as striking (8.4 to 1.8), is constantly observed by those who study maple trees in large numbers.

Records kept over long periods show that this marked variation between trees is not the exception (Table 2). Twice in 1944 tree 1 tested over 7 per-cent sugar, with the two records averaging 7.4. This latter figure is just double that of tree 5, whose readings of 4.2 and 3.2 on the same dates average 3.7. In subsequent seasons, 1945-1955, the spread between the two trees is even more noticeable. The bush average, representing a grove of 227 trees, indicates that tree 1 is an exceptionally sweet one whereas tree 5 consistently produces sap low in sugar content.

A graphical presentation of records for the 10 seasons emphasizes the variation among maples in a more striking fashion (Figure 4). Not only is the variation among these five trees apparent, but it is also evident that variation within the group follows a definite pattern, to be discussed later.

Table 1. Variation in Sugar Content of Maple Sap
(350 samples from trees of seven bushes-all tested the same day)

Bush A	Bush B	Bush D	Bush F	Bush H	Bush I	Bush J
			Percent			
6.0	3.0	2.2	2.2	2.2	2.3	2.2
5.6	3.1	1.9	1.8	2.4	2.2	1.7
3.9	1.9	2.6	2.5	2.1	2.2	1.8
3.9	1.8	3.0	3.8	3.0	2.4	2.7
6.0	3.7	2.3	3.0	2.3	2.0	3.0
4.4	2.4	2.8	2.4	2.0	2.4	3.0
4.9	2.9	2.0	2.9	2.0	2.0	2.8
4.6	2.3	2.4	2.8	1.9	2.0	3.2
4.2	2.4	1.6	2.4	1.8	1.9	2.9
3.9	2.4	3.0	2.0	2.0	2.0	2.3
4.1	2.3	3.2	2.4	1.5	1.9	2.3
5.0	3.2	2.2	2.9	1.9	2.1	3.1
3.4	3.4	2.6	2.6	2.0	1.7	3.2
4.3	2.6	2.6	3.6	2.2	1.9	3.0
4.0	3.2	2.8	2.3	2.0	2.0	2.6
3.0	2.7	3.2	2.7	2.3	2.0	2.6
3.6	2.6	2.5	2.1	1.6	2.6	2.4
4.4	3.1	2.4	3.1	1.4	2.3	2.3
3.7	3.2	2.4	2.7	2.6	2.0	3.0
3.6	3.2	2.4	2.8	1.8	2.0	2.5
4.3	4.0	3.0	3.1	2.1	2.0	2.2
3.8	3.1	2.9	3.8	1.9	2.2	2.4
3.4	3.4	2.2	2.9	2.3	2.2	2.3
3.3	4.1	2.8	2.8	2.0	3.0	2.0
2.5	3.8	2.4	2.1	2.3	2.8	2.8
3.2	3.0	2.6	3.8	1.2	2.0	3.4
3.7	3.1	2.6	3.6	1.7	2.1	2.0
4.0	3.1	2.3	3.0	1.8	2.0	3.2
3.6	2.8	2.6	2.7	2.5	1.8	3.1
3.4	3.0	2.1	4.6	2.4	2.6	2.2
4.6	3.0	2.4	3.8	2.1	2.0	2.4
5.0	2.3	2.0	3.1	2.7	1.9	2.3
3.0	1.7	2.8	4.7	2.0	2.8	2.2
4.1	2.3	3.3	3.7	1.9	2.0	2.2
2.9	2.6	1.9	3.0	1.7	3.0	2.4
4.0	3.0	2.8	4.3	2.4	2.6	2.7
3.0	2.5	2.0	2.5	1.7	2.6	3.1
3.4	3.0	2.2	3.0	2.4	2.6	2.4
3.7	2.4	2.0	3.0	2.1	2.4	2.1
3.2	2.0	2.1	2.5	1.3	2.0	2.8
2.9	2.9	3.0	3.0	1.9	2.6	3.9
3.6	2.4	3.0	2.2	1.5	2.2	2.4
3.4	3.9	2.9	2.6	2.0	2.2	2.4
4.6	2.5	2.2	2.2	2.0	2.1	2.0
3.1	2.5	2.1	3.4	2.5	2.3	2.0
3.4	3.5	2.0	3.6	2.4	2.0	2.8
3.0	2.5	2.0	2.7	2.2	2.0	2.0
3.9	4.2	2.8	2.3	2.2	2.6	2.6
3.1	4.7	2.5	2.2	1.9	2.6	2.2
4.2	3.1	2.1	2.9	2.1	2.2	2.2

Table 2. Variation in Sugar Content of Sap of Five Maples in a Producing Bush

Year	Date	Tree number 1	2	3	4	5	Average percent for bush
				Percent			
1944	Apr. 1	7.6	5.1	4.1	4.0	4.2	4.6
	Apr. 7	7.2	4.2	3.8	2.8	3.2	3.8
1945	Mar. 3	3.8	2.1	2.2	2.0	1.8	2.6
	Mar. 15	4.8	3.0	4.1	2.9	2.0	3.4
	Mar. 23	4.8	3.4	3.7	2.5	1.8	3.3
1946	Mar. 1	3.6	2.5	2.4	2.0	2.0	2.7
	Mar. 2	4.0	2.4	2.2	2.0	1.6	2.5
	Mar. 24	5.4	3.4	3.0	2.4	2.2	3.4
1947	Apr. 4	5.9	3.6	3.4	2.5	2.1	3.1
1948	Mar. 26	5.0	3.0	2.8	2.8	2.2	3.4
	Mar. 30	4.8	3.0	2.4	2.6	1.8	3.1
1949	Apr. 1	5.1	4.1	3.4	2.4	1.9	3.2
1950	Mar. 22	3.1	2.0	2.2	1.9	1.9	2.5
	Apr. 14	4.0	3.6	3.6	2.3	2.2	3.1
1951	Apr. 6	4.2	3.4	2.3	2.6	2.0	3.2
1952	Apr. 9	4.2	3.9	3.2	2.6	1.8	3.3
1954	Feb. 28	2.8	2.3	3.2	1.8	1.9	2.8
1955	Apr. 11	3.7	3.0	3.0	2.4	1.7	2.7

Numerous examples of similar nature may be demonstrated from the records of other trees in this bush. Table 3 gives the records of five additional trees. Each one is represented by a single measurement of the sugar in its sap in each of 10 maple seasons. The fact that trees vary widely in this characteristic can be seen by following the sugar content figures from left to right. In fact, the sugar content of the sap of tree 31 is at least twice that of tree 35 on several occasions and approaches doubling it on most of the remaining dates. Take March 30, 1948, for example. On this date tree 31 tested 4.0 and tree 35, 2.0. That this difference is significant can be determined by reference to Figure 2. Forty-three gallons of 2 percent sap

Table 3. Variation by Five Trees on One Sap Day in Each of 10 Seasons

Year	Date	Tree number 31	32	33	34	35
				Percent		
1944	April 1	6.6	4.5	3.8	3.3	2.0
1945	March 23	3.5	3.2	2.5	2.2	2.1
1946	March 24	3.2	3.2	2.6	2.6	2.0
1947	April 4	4.1	3.6	2.8	2.1	2.0
1948	March 30	4.0	3.4	2.4	2.4	2.0
1949	April 1	2.6	3.3	2.5	2.5	2.0
1950	April 14	3.3	2.8	2.7	2.3	2.2
1951	April 6	3.0	2.6	2.8	2.7	1.7
1952	April 9	4.0	2.7	2.8	2.3	2.2
1955	April 11	3.3	2.6	2.7	2.2	1.7

must be boiled down to yield a gallon of syrup, whereas only 22 gallons are required of 4 percent sap. It is not necessary to search far for illustrations of this sort. In fact, the five trees in this series grow within a radius of 150 feet.

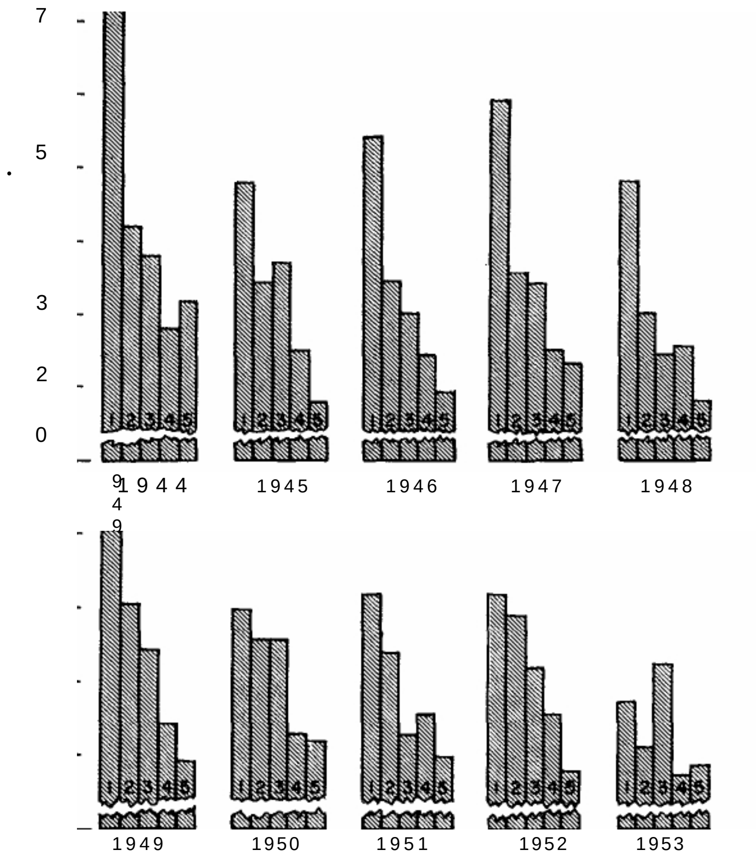


Fig. 4. How sugar content of sap varies-five maple trees from a sugarbush tested on one sap day for 10 seasons. (Records from Table 2.)

Furthermore, similar variation is shown by a group of five trees, selected from another stand, which has been studied annually from 1944 through 1955 (Table 4). The extremes in sugar content of sap may be observed in trees 26 and 30, whereas trees 27, 28, and 29 constitute the intermediates in what, on almost every sap day, amounts to a descending series.

Such variation in the chief component of finished syrup cannot be discounted in any consideration of the economics of the maple operation.

Table 4. Variation by Five Trees and the Bush of Which They Are a Part Over a 12-year Period

Year	Date	Tree number					Average for bush
		26	27	28	29	30	
		Percent					
1944	Mar. 31	6.4	5.6	5.0	4.0	3.6	4.8
	Apr. 7	5.5	5.0	3.7	3.4	3.0	4.0
1945	Mar. 23	5.0	3.8	4.0	3.6	2.8	3.5
1946	Mar. 16	4.8	3.8	4.3	3.7	3.0	4.0
	Mar. 24	4.0	3.4	3.9	3.0	2.6	3.6
1947	Apr. 14	3.7	3.8	3.0	3.4	2.7	3.4
1948	Mar. 26	4.9	4.3	3.7	3.6	2.4	3.5
	Mar. 30	4.5	4.1	3.4	3.8	2.4	3.3
1949	Apr. 1	3.7	4.0	3.2	3.0	2.3	3.3
1950	Mar. 22	4.3	3.0	3.0	3.0	1.7	3.1
	Apr. 14	4.0	3.2	2.9	2.8	2.3	3.2
1951	Apr. 6	4.0	4.3	3.7	32	3.1	3.8
1952	Apr. 9	4.7	4.3	3.8	2.9	2.4	3.7
1953	Apr. 3	3.8	2.9	2.8	2.5	2.7	3.1
1954	Feb. 26	3.8	3.8	3.2		2.3	3.2
1955	Apr. 12	4.2	3.1	3.2	2.8	2.8	3.1

Season-to-Season Variation in Sugar Content by Individual Trees

Individual maples show variation in the sugar content of their sap from season to season. A tree which produced sap containing a certain percentage of sugar in one season cannot be depended upon to yield sap of exactly the same quality the next (Table 5).

Tree 10, which produced sap with an average sugar content of 4.4 percent in 1949 and 1950, dropped to 3.7 in 1951 and rose to 4.0 in 1952. Its low season's average was 3.5 in 1953. Tree 11, after two seasons at 4.0,

Table **5. Variation in Sugar Content of Individual Trees from Year to Year**

Tree number	1949	1950	1951	1952	1953
	Average percent				
10	4.4	4.4	3.7	4.0	3.5
11	4.0	4.0	3.7	4.1	3.6
12	3.5	3.7	4.0	3.5	3.1
13	3.9	3.7	3.8	3.7	3.5
14	3.2	3.4	3.3	3.6	3.4
15	3.6	3.2	3.3	3.5	3.2
16	2.8	3.0	2.8	3.1	2.7
17	3.1	2.9	3.0	3.2	3.0
18	2.3	2.8	2.6	2.4	2.6
19	2.6	2.8	2.5	2.7	2.2
20	3.2	2.7	2.7	3.5	2.8
21	3.1	2.7	2.8	3.0	3.1
22	2.9	2.7	2.8	2.6	2.7
23	2.6	2.4	2.7	2.6	2.3
24	2.3	2.4	2.4	2.7	2.5
25	2.3	2.1	2.4	2.5	2.4

yielded sap of 3.7 percent sugar content in 1951. In 1952 tree 11 had its best record of 4.1 but it dropped to 3.6 in 1953. This seasonal fluctuation is also apparent in tree 12, as it is to a greater or less degree in all trees shown in Table 5. In other words, there is no such thing as a 3 percent tree or a 5 percent tree or any tree with an exact numerical tag from which predictions as to future sugar content can be made.

Season-to-season variation for a single tree, however, is not as great as at first might be assumed from reading down the columns of Table 2. It should be noted that the values listed are single daily records while those in Table 5 are averages of numerous daily readings. The figures for the 1950 column in Table 5 were computed from Table 6, which in turn is composed of the daily readings over an entire season. Table 6 shows that some readings for a given tree are high, while others for the very same tree are relatively low. For example, tree 11, which tested 3.0 percent on March 27, had a record of 4.6 on April 10. If, therefore, a single reading were taken as the measure of an entire season for season-to-season comparisons, a wholly erroneous impression would result. It would be equally invalid to use 3.0 or 4.6 for comparison with the performance of this tree in other seasons, because the average value for the entire season is 4.0. As illustrated in Table 2, such a mistake might have been made in 1946 if the only records for the year had been taken on March 24. The records of early March, however, show that those of March 24 were poor indicators of the true nature of the season.

Within-Season Variation in Sugar Content by Individual Trees

A given tree varies in sugar content within the limits of a single season. This fact has already been mentioned as contributing to a difficulty encountered in comparing trees from season to season (Table 6). It was observed that within-season fluctuations are so great that single records of sugar content of sap cannot be used in comparisons from one season to another. The dollars-and-cents importance of this characteristic, however, lies in the effect this variation has on seasonal yield.

A specific example of this kind of variation is seen in Table 7 in which detailed records for one tree are presented for nine seasons. In none of the nine is there anything like a single reading that can quickly be selected as typical for the tree. Instead there is a noticeable lack of uniformity. Among the records for 1949 only one (3.3) is repeated, while the others range all the way from a high of 3.7 to a low of 2.5. The same tendency of sugar content to vary is evident within each of the other seasons, the striking feature being that the spread between high and low records is not only sizable but also quite constant from year to year.

Further evidence of within-season variation is shown in the horizontal columns of Table 6. The sugar content of the sap for each tree was meas-

Table 6. Variation in Sugar Content of Sap from 16 Trees Tested During the 1950 Maple Season

Tree No.	Date tested 3/26	3/27	3/31	4/1	4/8	4/10	4/11	4/12	4/14	4/15	Avg.	Range	Spread between high & low
						Percent							
10	3.9	3.8	4.3	4.1	4.8	5.1	4.3	4.6	4.8	4.3	4.4	5.1-3.8	1.3
11	3.2	3.0	4.0	4.0	4.2	4.6	4.4	4.3	4.2	4.4	4.0	4.6-3.0	1.6
12	3.6	2.9	4.3	3.8	3.8	4.2	3.7	3.6	3.7	3.6	3.7	4.3-2.9	1.4
13	3.1	3.1	3.8	3.8	4.0	3.9	3.8	3.g	3.7	3.6	3.7	4.0-3.1	.9
14	3.3	3.1	4.0	3.6	3.4	3.2	3.1	3.3	3.4	3.1	3.4	4.0-3.1	.9
15	3.0	2.9	3.8	3.5	3.6	3.1	3.1	2.9	3.0	2.7	3.2	3.8-2.7	1.1
16	2.8	2.8	3.4	3.3	3.0	2.9	2.9	3.2	3.1	2.9	3.0	3.4-2.8	.6
17	2.7	2.5	3.0	3.0	3.0	3.1	3.0	3.1	2.9	3.0	2.9	3.4-2.5	.9
18	2.9	2.7	3.6	3.0	2.6	2.4	2.5	2.5	3.1	2.4	2.8	3.6-2.4	1.2
19	2.4	2.2	3.1	3.0	3.0	2.7	2.8	3.0	3.2	2.7	2.8	3.2-2.2	1.0
20	2.8	2.8	3.2	3.0	2.8	2.4	2.4	2.7	2.7	2.6	2.7	3.2-2.4	.8
21	2.4	2.8	3.2	3.0	2.8	2.7	2.5	2.8	2.7	2.3	2.7	3.2-2.3	.9
22	2.3	2.3	3.1	2.9	2.8	2.6	2.7	2.7	2.7	2.4	2.7	3.1-2.3	.8
23	2.2	2.4	2.8	2.4	2.6	2.4	2.3	2.4	2.3	2.2	2.4	2.8-2.1	.7
24	2.2	1.9	2.5	2.4	2.6	2.8	2.4	2.4	2.2	2.4	2.4	2.8-1.9	.9
25	2.1	2.3	2.7	2.1	2.2	2.0	1.9	2.2	2.1	1.8	2.1	2.7-1.8	.9
All												5.1-1.8	1.0

Table 7. Variation in Sugar Content of a Single Tree on the Sap Days of Nine Maple Seasons

1947	1948	1949	1950	1951	1952	1953	1954	1955
				Percent				
4.2	3.8	3.7	1.8	3.1	4.2	2.9	4.4	3.2
4.0	3.2	3.4	2.0	3.1	3.5	3.6	3.1	3.1
3.6	3.0	3.5	2.2	3.2	3.5	2.9	3.8	3.0
3.2	2.8	3.3	2.8	3.1	4.2	2.9	3.7	3.1
2.8	2.8	3.2	3.0	3.5	3.1	2.8	3.0	3.1
3.0	2.7	3.3	2.8	2.9	3.4	2.9	3.0	2.8
		3.1	2.9	3.1	3.9	2.4	2.8	2.8
		2.8	3.0	3.2	3.8		2.5	2.7
		2.9	3.2	3.0	3.8		2.4	2.6
		2.7	2.9	3.1	3.8		2.5	2.6
		2.5	3.1	2.5	3.3		2.0	2.3
			3.0	2.8	3.6		2.0	2.2
			3.0		3.7			2.5
			2.7		3.7			2.4
			2.5		3.5			2.4
			2.6		3.6			
			2.4		3.3			
			2.2		3.2			
			2.2					

ured on 10 different days, but all of the trees were tested on the same 10 days. The performance of tree 12 may be considered typical. This tree began the season with a reading of 3.6. On the next day its sugar content dropped to 2.9, but it reached a high of 4.3 four days later. After 10 days,

epresented by two readings of 3.8, it again rose over the 4.0 mark on represented by two readings of 3.8, it again rose over the 4.0 mark on April 10. The remaining readings fluctuated between 3.6 and 3.7 to give the tree an average of 3.7 for the season.

The difference between a tree's high and low readings for a given season is an appreciable quantity. For the 16 trees in Table 6 the average spread in sugar content is 1.0 percent, although in extreme cases it is as high as 1.6 (tree 11) or as low as 0.6 (tree 16).

The sugar content of sap is a percentage figure that indicates the amount of sugar present as compared to other constituents, principally water. In other words, 2 percent sap contains 2 pounds of sugar per 100 pounds of sap. The 1 percent variability figure (Table 6) on first consideration seems small. On the other hand, if this 1 percent is compared to the total amount of sugar present, it is apparent that the seemingly small 1 percent is actually a figure of considerable size. For example, if a tree's sap has a 1950 sugar content represented by a 2 percent average, and the difference between low and high readings is 1 percent sugar, then such a tree would vary during the season by half of its average figure. In the case of a tree with an average of 4.0 percent and a 1 percent spread, the variation would be smaller (25 percent) but still important.

Tree 18 in Table 6 provides a specific example. On March 31 the sap of this tree contained 3.6 percent sugar and on April 10, 2.4 percent. The difference of 1.2 percent indicates that on the last day of March the sap contained half again as much sugar as it did 10 days later. Given equal quantities of sap, it would take more time, labor, and fuel to reach the syruping-off stage on April 10 than on March 31. Or, producing a gallon of syrup on April 10 would require much more sap and, therefore, more time, labor, and fuel than on March 31.

Consistent Within-Season Performance by Individual Trees

In spite of the within-season variation just discussed, maple trees generally maintain their positions in sugar content, relative to their neighbors, throughout an entire season. Trees that are sweet at the beginning of a season are those that are sweet at the end; trees that, compared to others, produce less sugar at the beginning still do so at the end.

In Table 8 the records for the 16 trees listed in Table 6 are ranked from 1 to 16 on each day of the 1950 season. On most days in 1950 tree 10 is found in first position. On no occasion does it drop below second. Likewise, tree 25 is found consistently (eight of ten times) in last place. Trees 15, *16,* and 17 generally occupy the mid-positions in the series, with tree 16 being especially consistent by always placing sixth, seventh, or eighth.

It may be objected that a difference of only 0.1 percent sugar might separate trees in first or second positions or in any other pair of consecutive positions. A more realistic estimate of performance, therefore, may be obtained by dividing the trees into groups. On each sap day the 16 trees

Table 8. The 16 Trees of Table 6 Ranked as to Sugar Content on the Sap Days of 1950

Tree No.	3/26	3/27	3/31	4/	4/8	4/10	4/11	4/12	4/14	4/15
10	1	1	1.5*	1	1	1	2	1	1	2
11	4	4	3.5	2	2	2	1	2	2	1
12	2	5.5	1.5*	3.5	3	4	4	4	3.5	3.5
13	5	2.5	5.5	3.5	4	3	3	3	3.5	3.5
14	3	2.5	3.5	5	6	5	5.5	5	5	5
15	6	5.5	5.5	6	5	6.5	5.5	9	9	8.5
16	8.5	8	8	7	8	8	8	6	7.5	7
17	10	11	13	10	8	6.5	7	7	10	6
18	7	10	7	10	14	14	11.5	13	7.5	12
19	11.5	15	11.5	10	8	10.5	9	8	6	8.5
20	8.5	8	9.5	10	11	14	13.5	11.5	12	10
21	11.5	8	9.5	10	11	10.5	11.5	10	12	14
22	13	13.5	11.5	13	11	12	10	11.5	12	12
23	14.5	12	14	14.5	14	14	15	14.5	14	15
24	14.5	16	16	14.5	14	9	13.5	14.5	15	12
25	16	13.5	15	16	16	16	16	16	16	16

*If two trees have the same sugar content on a given day, each is given the average of two ranks or positions in the series. In Table 6 notice trees 10 and 12 on March 31. Both had a sugar content of 4.3 on that day. The two trees, being the highest in the group, would occupy positions 1 and 2 in the 16-tree series. Accordingly, the average is taken and each is given the rank of 1.5.

Table 9. Maple Trees Grouped on Basis of Rank in Sugar Content on Sap Days of 1950

Tree number	Days in 1st quarter*	Days in 2nd quarter	Days in 3rd quarter	Days in 4th quarter
10	10			
11	10			
12	9	1		
13	8	2		
14	3	7		
15		8	2	
16		10		
17		5	4	1
18		3	4	3
19		4	5	1
20		2	6	2
21		1	8	1
22			7	3
23			1	9
24			2	8
25				10

*Each time a tree ranks in one of the first four positions in the 16-tree series, it is placed in the first quarter, and so on.

(Table 8) may be placed in four groups, on the basis of rank as to sap quality. Then, if these daily groupings are summarized for the season, a more satisfactory measure of performance and, incidentally, one which is just as significant to the sugarmaker is the result (Table 9). Actually it makes little difference to the farmer whether four trees with sugar per-

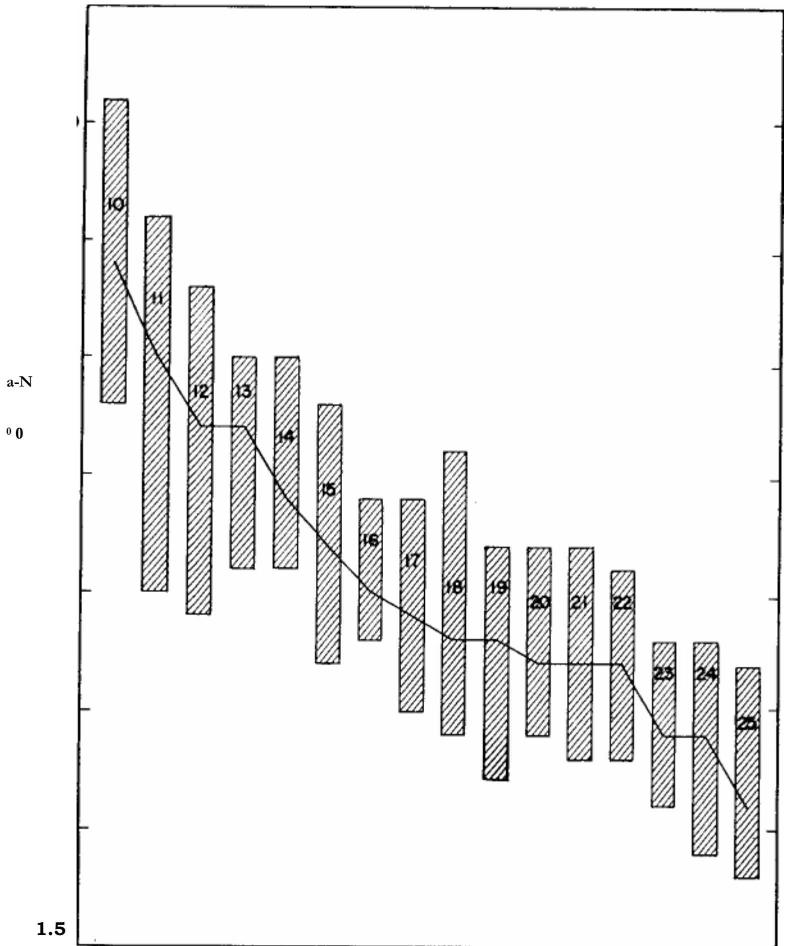


Fig. .5.
Sugar content of sap varies within a season. Bars represent ranges of variability for the trees in Table 6. Line connects the average sugar content for the 1950 season.

centages of 4.1, 4.0, 3.8, 3.8 (April 1 column in Table 6) are arranged in one order or another. The important fact for him is that these trees produce sweeter sap than another group of four trees with records of 2.9, 2.4, 2.4, 2.1, and that they do it consistently throughout the season. That this relationship holds true is apparent in Table 9.

Tree 10 falls in the first quarter, the group of trees with the highest sugar content, on every day recorded. Tree 11 is likewise in this select group all 10 times. Other trees ranking among the sweetest of the 16 on this basis are numbers 12 and 13. Tree 25 has a perfect record for appear-

ing in that group with lowest sugar content. Trees 23 and 24 also fall in the lowest quarter much more often than not. By occurring nearly always in the middle groups, trees 15, 16, and 17 might be termed average within the larger group of 16. Thus, by falling in the same group day after day, trees are shown to be consistent in their performance as to sugar content, and on this basis may readily be classified within a given season as excel-lent, poor, or just average producers.

Figure 5 shows the magnitude of the variation in sugar content for each of the trees ranked in Table 9. The average for each tree, indicated in the appropriate bar, relates the entire season's performance to this range of variability. Although the average range of variability for the 16 trees is 1.0 percent sugar, in no case is there overlapping between trees in the groups just designated excellent producers or poor producers. The contrast between trees 10, 11, 12, 13, on the one hand, and 23, 24, 25, on the other, is apparent at a glance. Not only are the average sugar concentrations for the season far apart, but the lowest reading for the former group (2.9) is higher than the highest record for the latter (2.8). It is apparent, then, that although daily performance in sugar content does vary, it does so only within the limits characteristic of a given tree.

Consistent Season-to-Season Performance by Individual Trees

Undoubtedly the most significant feature of variation in sugar content is the consistent pattern of season-to-season performance by individual trees. It has just been pointed out that a tree is consistent in its performance within the limits of a single season (Tables 8 and 9). That a tree is consistent in its relative sugar content from year to year is no less striking.

If the 16 trees of Table 5 are ranked as to average sugar content in each of the five seasons, 1949-1953, this consistency is apparent (Table 10).

Table 10. Maple Trees Ranked on Basis of Average Sugar Content, 1949-1953

Tree number	1949	1950	1951	1952	1953
10	1	1	3.5*	2	2.5
11	2	2	3.5*	1	1
12	5	3.5	1	6	6.5
13	3	3.5	2	3	2.5
14	6	5	5.5	4	4
15	4	6	5.5	6	5
16	11	7	9	9	10.5
17	7.5	8	7	8	8
18	15	9.5	13	16	12
19	12.5	9.5	14	11.5	16
20	9	12	11.5	6	9
21	7.5	12	9	10	6.5
22	10	12	9	13.5	10.5
23	12.5	14.5	11.5	13.5	15
24	15	14.5	15.5	11.5	13
25	15	16	15.5	15	14

*Indicates a tie for third place.

It is obvious that a sweet tree is a sweet tree year after year and that a tree which is low in sugar content, relative to its neighbors in one season, tends to stay in that position as the seasons come and go.

Tree 10 is in first place twice, second place once, tied for second once, and tied for third once (with tree 11). Actually there is little to choose between trees 10 and 11, for the latter is in first position in 1952 and 1953, in second position in 1949 and 1950, and tied for third in 1951. Tree 25 occupies one of the lowest positions in the scale each year, just as it did on the majority of sap days within the single season 1950. Tree 17 is, likewise, a consistent performer in what has previously been called the average group. Throughout the five-year period it always places in seventh or eighth position.

Once again it should be pointed out that by this system of ranking, a difference in position, such as fifteenth versus sixteenth, has little importance in itself even though each rank represents the seasonal average of numerous daily records. The real significance of this ranking lies in the fact that trees 10, 11, 12, and 13 are always near the top of the series, while trees 23,. 24, and 25 are invariably near the bottom.

In Figure 6 the tree position as to sugar content is summarized, not on the questionable 1, 2, 3 basis but by location in the top, second, third, or lowest quarters of the 16-tree series. Each upright bar shows the five-year

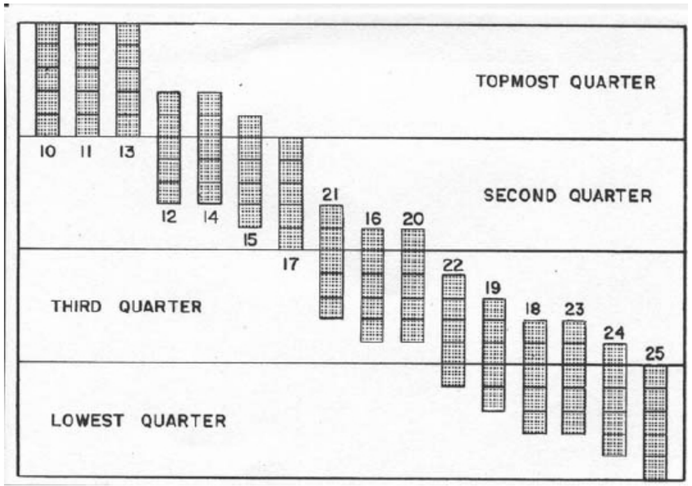
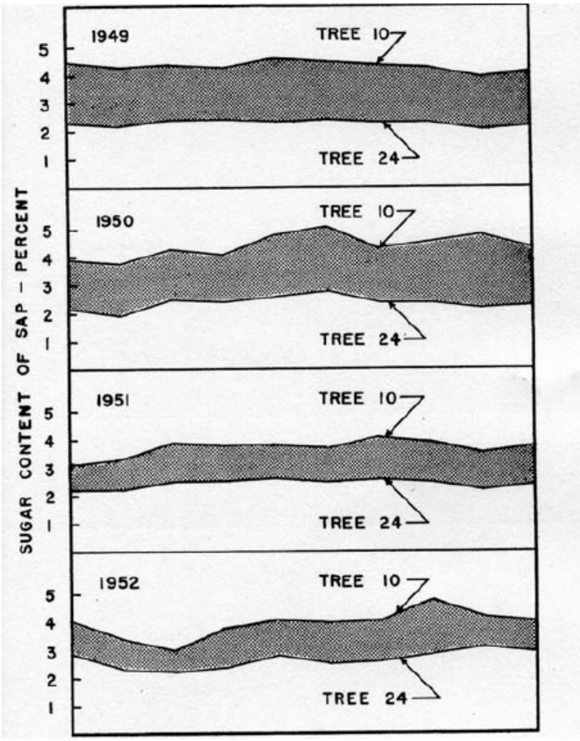


Fig. 6. Individual trees perform consistently from year to year. Each vertical bar represents the five-year record for one tree. Each square within a bar shows the rank of the same tree for one season.

position in sugar content for a given tree; each square within the bar and in the proper quarter represents the position for a single year.

Tree 10, represented by the left-hand bar, lies wholly within the top quarter. Tree 25, represented by the right-hand bar, lies wholly within the lowest quarter.



RECORDS FOR MAPLE SEASON

Fig. 7. Maple trees perform consistently within a season and from season to season.

It seems highly significant that no single tree ranks in all four quarters or even in three different ones during this five-year period. Only very rarely does a tree have an exceptionally high or unusually low season which would upset an alignment such as the one pictured here. For the most part, each tree occupies a position within a narrow relative range, which is characteristic of its performance, no matter what the season.

Two trees have been selected from the series to show this consistency graphically (Figure 7). In each section of the graph the upper border of the shaded area is determined by 10 sugar percentage readings for tree 10. The position of the lower boundary is similarly fixed by 10 readings for tree 24. The shaded area itself represents the difference in sugar content of sap produced by the two trees in each season. Two conclusions are unmistakable: (1) tree 10 produces sweeter sap than tree 24 throughout each of the seasons illustrated; (2) tree 10 is consistently sweeter than tree 24 year after year.

Variation in Sugar Content Among Sugarbushes

Stands of maple trees, growing on Vermont hillsides, vary in the sugar content of the sap they yield. As was the case with individual maples, sugarbushes, whose trees are used collectively as sources of sap, show wide variation in sugar percentage. Once again, in the making of this statement no classification and segregation of bushes on the basis of tree type, exposure, or age of stand have been attempted. The only point being made is that all producers, in using what nature has provided, do not start from scratch when they fire up under their evaporators. Some must expend considerable time, labor, and fuel just to bring their sap up to the sugar content of the untouched sap in a neighbor's buckets.

The magnitude of the differences between stands is shown in Table 11. This table gives average sugar percentages for nine bushes, tested on two occasions during the 1944 season. Early midseason records show bushes A and B to be more than twice as sweet as bush I, on the basis of refractometer tests of individual trees. Later in the season both still have a sugar content at least double that of I. Bushes C, D, E, F, and G seem to be intermediate. They are noticeably less sweet than A or B, yet produce sap with higher sugar content than H and I.

This comparison might be objected to because "early midseason records" cover a period from March 25 through April 1 and "late-season records," a period from April 13 through April 23. It will be recalled that sizable variations in sugar percentage occur in individual trees from day to day during the course of a maple season (Tables 6, 7, 8). This characteristic of single trees might conceivably make a comparison of groups of trees, tested on different days, of questionable value. In this connection it should be pointed out that, in obtaining the midseason records, bushes A, D, and G were all tested on March 31. Among the late-season records, bushes A, C, F, and G were likewise sampled on the same day. The positions of these bushes relative to one another, then, are firmly established. Furthermore, a look at the third column in Table 12 indicates that the alignment in Table 11 is a valid one and that the differences in average sugar content are reasonable. Six of the nine bushes under consideration were tested on a single day in 1951, and they appear in essentially the same positions in the series as in 1944.

Apparently the nine bushes fall into three classes, superior (Bushes A and B), average (Bushes C, D, E, F, and G), and poor (Bushes H and I), in terms of sweetness of sap. Within a class daily fluctuation might be great enough to throw an average up or down and, therefore, the order of bushes within a class has little significance. On the other hand, differences between classes are large enough so that daily fluctuations do not shift a bush from one class to another. Records taken in 1945 and 1946 bear out this conclusion (Table 18).

Further insight into variation by bushes can be gained from Table 12. In this table the trees of six bushes, tested on a single day, have been grouped by sugar content to show the pattern of variability. For example, all of the trees in bush I test between 1.1 and 3.0 percent. Within this range, however, 1 percent of the trees fall between 1.1 and 1.5, 41 percent between 1.6 and 2.0, 41 percent between 2.1 and 2.5, and the remaining

Table 11. Sugar Content of Nine Bushes at Two Stages in the 1944 Maple Season

Bush	Early midseason records: No. of trees	Early midseason records: Average sugar %	Late season records: No. of trees	Late season records: Average sugar %
A	87	4.8	85	3.4
B	216	4.6	180	3.5
C	200	3.4	166	2.7
D	552	3.0	519	2.6
E	673	3.0	756	2.5
F	235	3.0	164	2.4
G	313	2.9	256	2.4
H	103	2.6	51	2.1
I	778	2.2	631	1.7
	3,157	2.8	2,808	2.4

Table 12. Comparison of Six Bushes on Basis of Proportion of Trees in Sugar Percentage Classes, All Tested April'6, 1951

Bush	No. of trees	Average sugar %	Sugar content: 6.0 to 5.6	5.5 to 5.1	5.0 to 4.6	4.5 to 4.1	4.0 to 3.6	3.5 to 3.1	3.0 to 2.6	2.5 to 2.1	2.0 to 1.6	1.5 to 1.1
			Percent of trees									
A	86	3.8	3*	2*	8	14	38	24	8	1		
B	160	3.2		1	2	7	2!	31	22	12	4	
D	195	3.1		1	4	6	18	19	24.5	20.5	7	
F	139	2.7			1	4	9	20	37	25	4	
H	59	2.1						2	5	41	44	8
I	195	2.3							17	41	41	1

*Three percent of the 86 trees in bush A produced sap falling between 5.6 and 6.0 percent sugar. Two percent of the 86 trees tested between 5.1 and 5.5 percent, etc.

17 percent between 2.6 and 3.0. Other bushes have been similarly analyzed. Approximately 90 percent of the trees in each bush fall within the limits of five classes, representing a spread of only 2.5 percent sugar.

This pattern of distribution of trees by sugar content classes is not only interesting but important as well. In fact, when differences between bush averages are large enough to have real significance (Figure 2), bush averages constitute a sound basis for comparison as to efficiency of operation a basis which rules out the necessity for information on volume of sap produced. The truth of this statement is evident in Table 12. When bushes A and I are compared, it can be seen that only 8 plus 1 or 9 per-cent of the A trees fall within the same classes as do those of I which in no case test higher than 3 percent. Conversely, 91 percent of the trees in bush A have sweeter sap than the sweetest tree of bush I, and the trees in that 91 percent are bound to account for most of the sap produced. So, even if the owner of bush I could have the same yield per bucket as the operator of A (which is doubtful), his cost of producing a gallon of syrup would be higher for labor in gathering and for fuel and labor in boiling.

This example is not an isolated one because a similar situation can be demonstrated using bushes B and H. By reading the columns for B and H horizontally one can see that 1 plus 2 plus 7 plus 21 plus 31 plus 22 or 84 percent of the trees in B are sweeter than 41 plus 44 plus 8 or 93 percent of those in H. With such a distribution it really makes little difference whether or not some trees within a given bush produce more sap than others. Under such conditions average sugar content provides a well-grounded criterion for predicting discrepancies in costs per gallon of syrup.

Season-to-Season Variation by Groups of Maple Trees

The group of trees tapped by the sugarmaker cannot be counted on to produce sap with the same sugar content year after year. Since individual trees vary from season to season in this respect it is to be expected that the larger unit will vary as well.

The subject of season-to-season variation by groups of trees, however, is a difficult one to get at. Certainly the degree of variation is not as great as might at first be suspected from reading down the columns of Table 13. Bush A has a high record of 4.8 in 1944 and a low of 3.0 in 1949. Bush B shows a difference of as much as 2.5 percent in average sugar content between the 1944 and 1950 seasons. Yet, it cannot be concluded that yearly variations are so great. It must be remembered that each of these figures is an average for a bush for a single day and, therefore, does not represent the entire season. Even if the averages available should be for the same date in successive years, there is still no guarantee as to their reliability for comparative purposes. The maple season is not pegged to the calendar. A record for April 1, 1944 may reflect an entirely different set of physiological and environmental conditions than subsequent April 1 averages.

The problem, then, is to find comparable figures for the same group of trees year after year. Much of the data accumulated in the extensive survey cannot be used with confidence because single-day averages in different seasons may not reflect the influence of within-season variation to the same degree. This eliminates the use of bushes as such. Annual averages of a smaller group of trees have been substituted (Table 14). The sap of these maples has been tested for sugar content as often as possible during seven maple seasons. It is believed that this method of testing provides more reliable measurements for comparative purposes than tests of numerous trees restricted to one, or at best, a few days per season.

Table 13. Twelve-year Records of Sugar Content of Sap of Two Maple Stands

	Bush A		Bush B	
Year	Date	Average sugar percent	Date	Average sugar percent
1944	Mar. 31	4.8	Mar. 26	5.0
	Apr. 7	4.0	Apr. 1	4.6
	Apr. 19	3.4	Apr. 7	3.8
			Apr. 20	3.5
1945	Mar. 15	4.0	Mar. 3	2.6
	Mar. 23	4.0	Mar. 15	3.4
			Mar. 23	3.3
1946	Mar. 16	4.1	Mar. 1	2.7
	Mar. 24	3.6	Mar. 2	2.4
	Mar. 28	3.6	Mar. 24	3.4
1947	Arr. 14	3.5	Apr. 14	3.3
1948	Mar. 26	3.9	Mar. 26	3.4
	Mar. 30	3.8	Mar. 30	3.1
	Apr. 7	3.2	Apr. 7	2.7
1949	Apr. 1	3.3	Apr. 1	3.2
	Apr. 11	3.0	Apr. 11	2.9
1950	Mar. 22	3.1	Mar. 22	2.5
	Apr. 4	3.6	Apr. 14	3.1
	Apr. 12	3.3		
	Apr. 14	3.2		
1951	Arr. 6	3.8	Apr. 6	3.2
1952	Apr. 9	3.7	Apr. 9	3.3
1953	Apr. 3	3.1		
1954	Feb. 26	3.2	Feb. 28	2.8
1955	Apr. 12	3.1	Apr. 11	2.7

Table 14. Season-to-Season Variation by a Group of 16 Maple Trees

Year	Number of tests during season	Average sugar %	Year	Number of tests during season	Average sugar %
1949	10	3.0	1953	6	2.9
1950	10	3.1	1954	9	2.6
1951	12	3.0	1955	12	2.5
1952	17	3.2			

When tests on the trees of a group are made at every reasonable opportunity, the annual averages do not show striking variation (Table 14). On the other hand, day-to-day variation by individual trees (Tables 6. 7) and within-season variation by individual bushes (Table 13) are marked. Further study, then, may reveal that the greater yields per bucket of certain seasons are due as much to climatic conditions which favor runs on "sweet days" as to inherent yearly differences in sugar content.

Within-Season Variation by Single Maple Bushes

Maple trees, considered collectively, produce sap which varies in sugar content throughout the season.

Table 13 shows that on different days during the 1944 season bush A tested 4.8, 4.0, and 3.4 percent. In 1946 tests for bush A were 4.1, 3.6, and 3.6, and in 1948 sap from this stand averaged 3.9, 3.8, and 3.2 percent sugar. Tests of 3.1, 3.6, 3.3, and 3.2 were recorded for this group of trees in 1950.

This within-season variation in sugar content is seen in records from bush B which has also been observed over a period of years. The extent of the variation, determined by subtracting the season's low average from the high, was 1.5 percent in 1944, 0.8 in 1945, 1.0 in 1946, 0.7 in 1948, 0.3 in 1949, and 0.6 in 1950.

In 1946, when the difference was 1.0 percent sugar, there would be a substantial difference in the quantity of sap required to make one gallon of syrup on the two days in question. Keeping in mind that average sugar percent is a good substitute for the sugar percent of a composite sample, but that it is still a substitute, one can calculate that on March 2, 1946, when the test was 2.4 percent, 36 gallons of sap would be required to produce one of syrup. Three weeks later, on the other hand, the ratio would be only 26 to 1 ______a saving of nearly one-third in the volume of sap to be handled in bush and sugarhouse.

In addition to the fact that there is marked variation, the pattern of this variation is of both scientific and practical interest. In the columns for bushes A and B (Table 13) it can be seen that late-season sugar percent-ages are generally lower than those of the early part of the season. Note bush A for 1944. In this instance there is a decrease from 4.8 percent through 4.0 to 3.4. Even in those years in which the daily averages do not show a progressive decrease, as in 1950 (3.1, 3.6, 3.3, 3.2), the pattern of reduction in sugar content toward the end of the season is still evident. This same tendency can be observed in the midseason and late-season records of Table 11.

Still another trend is noticeable in the data available for some years (Table 13). The trees of bush B show an average sugar content of 2.6 on March 3, 1945 and a rise to 3.4 on March 15, followed by a small decrease

to 3.3 on March 23. In 1946 there was a rise from an early season low of 2.4 to a later average of 3.4 and in 1950 from 2.5 to 3.1.

These figures indicate that, although there is a downward trend in sugar content toward the end of the maple season, there is an earlier period when sugar content is low relative to the situation on later dates. Why does this tendency appear in the records of certain years and not in others (in bush A in 1950 but not in earlier seasons; in bush B in 1945, 1946, and 1950 but not in 1944, 1948, and 1949)? Is this characteristic of certain seasons only or does it occur annually, being obscured in the above records by gaps in the data?

The fact that, during the course of a single season (1946), bushes A and B show different patterns discounts the former explanation. While the more commonly encountered decrease is exhibited by A, an increase in average sugar content is shown by B. Furthermore, the first tests on B were made two weeks before the 1946 study of bush A was begun, another indication that the early season low is a distinct possibility in every bush in all seasons.

In checking on this possibility it is obvious that a definition of "early season" is essential. It should be remembered that, in spite of the fact that the Vermont maple season can be expected within the general limits of March and April of the calendar year, there is no such thing as exact correspondence between the maple month of March in two different years. The first run of sap may come during the first week of March in one year and it may come a week or 10 days later in the next. Before events occurring in the sugarbush in different years can be judged in relation to one another, a point of reference must be established.

With the information available an exact starting point for the season cannot be established. On the other hand, a point of reference not far from the start of the season can be chosen with reasonable accuracy. The first accumulation of sap in the buckets does not mark the start of the maple season, but it does indicate that a certain degree of progress into the season has been made. That combination of weather conditions which signified to the sugarmaker that it was time to tap has passed. That combination of conditions that led to the running of sap in appreciable quantity from taphole into bucket has passed. If changing environmental conditions at this time of year have an effect on tree physiology, these too have been brought to bear during the first few days of "sugar weather." It seems, then, that here at the time of first gathering there is a point for making comparisons between maple seasons; a point at which, regardless of date, maple seasons from year to year have much in common.

This point has been used in the preparation of Table 15 which presents an analysis of the data for bushes A and B in those seasons in which each bush was tested more than once. Dates of first gathering of sap in these

Table 15. Relation of Progress of Maple Season to Sugar Content of Sap

Year	Days between first gathering and first test	Bush average first test	Bush average later test	Difference
			Percent	
		BUSH A		
1944	14	4.8	4.0	-0.8
1945	12	4.0	4.0	0.0
1946	12	4.1	3.6	-0.5
1948	9	3.9	3.8	-0.1
1949	27	3.3	3.0	-0.3
1950	2	3.1	3.6	+0.5
		BUSH B		
1944	9	5.0	4.6	-0.4
1945	0	2.6	3.4	+0.8
1946	- *	2.7	3.4	+0.7
1948	9	3.4	3.1	-0.3
1949	27	3.2	2.9	-0.3
1950	2	2.5	3.2	+0.7

*Trees of bush tested during first run before first gathering of sap.

bushes are available and have been used to place testing records in proper perspective, relative to the progress of maple seasons from 1944-50. It will be noted that only in' 1950 was bush A tested close to the time of first gathering and then it had an average sugar content 0.5 percent less than a subsequent figure of 3.6. In all other seasons, with an interval of more than a week elapsing between gathering and first test, there was a decrease in sugar content between first and second tests.

Records for bush B show the same phenomenon in operation. When tests were made early in the season, they showed relatively low sugar content, whereas relatively high percentages were uniformly encountered when the first test was made more than a week after the date of first gathering. Of course, the exact number of days presented in the column headed "days between first gathering and first test" has little significance. Measuring the progress of the maple season in daily intervals beyond the date of first gathering is as unreliable a procedure as trying to relate other events to the calendar. The number of days merely indicates that a test was made close to the time of first gathering or at some time distant from this gathering date, as the case may be.

In support of the foregoing, records for the intensively studied 16-tree series are presented in Table 16. In every season except 1949 the first daily average is less than the season's maximum, which comes at a later date. In the 1950, 1951, and 1952 seasons, daily averages even lower than the first average came between this first record and the maximum.

The evidence indicates that there is a period early in the season when sap is low in sugar content. Some time later, sugar content of sap reaches

Table 16. Comparison of Early-Season Averages with Maximum Averages of a Group of 16 Trees

Year	1st record of season	Max. record of season	Difference
		Average percent	
1949	3.2	3.2	0.0
1950	2.8	3.4	+0.6
1951	2.8	3.3	+0.5
1952	3.1	3.4	+0.3
1953	2.3	3.4	+1.1
1954	2.7	3.1	+ 0.4
1955	2.4	2.7	+0.3

a maximum and then decreases as the season progresses. The early-season pattern is suggestive of a conditioning process, perhaps similar to the one reported for maple sap flow by Marvin and Erickson (6). At any rate the fundamental and practical implications of the pattern are being checked in detailed records of sugar content, and studied in relation to temperature, weather conditions, and volume yield of sap.

Consistent Within-Season Performance by Maple Bushes

The average sugar content of a single maple bush may vary widely during a given season, yet throughout the season it remains remarkably constant in position relative to the averages of other bushes.

On the same day bushes A and B were tested two or more times in four different seasons (Table 17). In each of these seasons bush A surpassed B in average sugar percentage on every occasion, whatever the date of the test.

Further evidence for consistent within-season performance is apparent in Table 18. The 1944 figures include two sets of average percentages, calculated from tests made at different stages during the season. The averages in the right-hand column run anywhere from 0.4 to 1.4 percent

Table 17. Comparison of Two Sugarbushes Tested on the Same Day During Four Sap Seasons

Year	Date	Bush A Average sugar percent	Bush B Average sugar percent
1945	Mar. 15	4.0	3.4
	Mar. 23	4.0	3.3
1948	Mar. 26	3.9	3.4
	Mar. 30	3.8	3.1
	Apr. 7	3.2	2.7
1949	Apr. 1	3.3	3.2
	Apr. 11	3.0	2.9
1950	Mar. 22	3.1	2.5
	Apr. 14	3.2	3.1

Table 18. Sugar Content of Sap of Nine Bushes in Four Seasons

Bush	1944		1945	1946	1951
			Percent		
A	4.8	3.4	4.0	4.0	3.8
B	4.6	3.5	3.3	3.4	3.2
C	3.4	2.7		3.0	
D	3.0	2.6		3.0	3.1
E	3.0	2.5	2.2	2.6	
F	3.0	2.4		3.1	2.7
G	2.9	2.4		3.0	
H	2.6	2.1		1.8	2.1
I	2.2	1.7	1.9	2.0	2.3

less than the corresponding ones to the left. In spite of the over-all reduction in sugar content, bushes A and B are at the top of the series in both in-stances and H and I remain at the bottom. Bushes C, D, E, F, and G form a homogeneous, middle group at both stages in the season.

Consistent Season-to-Season Performance by Maple Bushes

When maple bushes are compared to one another, each one is consistent in its performance as to sugar content of sap year after year. This fact, recognized to a certain extent by producers themselves, is clearly apparent in Table 18.

The extremes in the series, bushes A and I, are far apart in sugar content in five different tests representing four different years. The same is true of B and I. In a comparison of bushes B and E and again of E and I the differences, although not so great, are too uniform and too regular in occurrence to be coincidental. Even records of A and B, if compared on all of those days when both were tested (Table 17), show A to surpass B in sugar content, and by a significant margin.

Earlier, in the discussion of variation in general, it was suggested that the maple bushes under observation could be classed as "superior," "average," and "poor," in terms of sugar content of sap. Table 18 shows these classes with bushes A and B together at the top of the scale, H and I at the bottom, and the larger "average" class coming in between. Differences between classes are of such size and bushes perform so consistently that, in spite of changing seasons, there is no reason to move a group of trees from one class to another anywhere in the table.

Summary

Variation in sugar content concerns the maple producer who must gather, haul, store, and boil great quantities of sap to manufacture each gallon of syrup. Variation in sugar content concerns the economist who must deal with cost and profit in the maple operation and evaluate its place in the over-all farm economy. Variation in sugar content concerns the forester who must recommend removal of trees in producing bushes and thinning practices for immature maple stands. Variation in sugar content concerns other plant scientists who, in their breeding, selection, and propagation programs, aim at high-yielding trees.

This detailed study provides a foundation upon which specific recommendations and suggestions for the above interested parties can be based. Furthermore, it constitutes a point of departure for intensive investigations of maple problems involving yield of sap and rate of flow, as well as sugar content.

The extensive survey of 4,500 trees and the intensive study of a smaller number have led to the following conclusions :

1. Sugar maples vary widely in the sugar content of their sap. Trees varying by as much as 2 to 3 percent sugar may often be found in the same bush. If, at first sight, this figure seems small, nevertheless it may mean that one tree has twice as much sugar in its sap as another.
2. A single tree shows variation in the sugar content of its sap from season to season. A tree which produced sap with a certain percentage of sugar in one season cannot be depended upon to yield sap with exactly the same proportion of sugar and water in the next.
3. The most significant feature of variation in sugar content is the consistent pattern of season-to-season variation by individual trees. A sweet tree is a sweet tree year after year, and a tree that is low in sugar content relative to its neighbors in one season tends to remain in that position as the seasons come and go.
4. A given tree varies in sugar content within the limits of a single season. Variations of as much as 1.0 percent sugar by single trees are common.
5. In spite of this within-season variation, maple trees maintain their positions in sugar content, relative to their neighbors, throughout an entire season. Trees that are sweet at the beginning of a season are those that are sweet at the end; trees that, in comparison to others, produce less sugar at the beginning still do so at the end.
6. Maple bushes, which after all are simply individual trees dealt with collectively, show great variation in the sugar content of sap.

Average sugar percentages for bushes, tested on the same day, are on record as differing by nearly 2.0 percent.

7. The sugarbush tapped by the producer cannot be counted on to produce sap with the same sugar content year after year. The degree of variation is probably not as great as might be suspected from an examination of daily average percentages. One small group of trees tested intensively over a seven-year period had yearly averages varying only within the limits of 2.5 to 3.2 percent.
8. When maple bushes are compared to one another, each one is consistent in its performance as to sugar content of sap year after year. Bushes whose average sugar percentages differ to a significant degree in one season will be found in the same, relative positions in later seasons.
9. A given sugarbush produces sap which varies in sugar percentage throughout the course of a single maple season. There is evidence that sap is low in sugar content early in the season. Later the sugar content quickly rises to a maximum and then decreases as the season progresses.
10. The average sugar content of a single maple bush may vary widely during a given season; yet, throughout the season, it remains remarkably constant in position relative to other bushes.

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