# CORRELATION BETWEEN SEVERAL TREE CHARACTERISTICS OF SUGAR MAPLE (*ACER SACCHARUM* MARSH.) AND THE MAPLE SAP AND SUGAR YIELDS

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ABSTRACT

CORRELATION BETWEEN SEVERAL TREE CHARACTERISTICS OF SUGAR MAPLE (<u>ACER</u> <u>SACCHARUM</u> MARSH.) AND THE MAPLE SAP AND SUGAR YIELDS

by Abdul Karim Toma

Of the numerous studies made in the general field of maple sap products, only a few are concerned with the relationship between the tree characteristics, on the one hand, and the sap and sugar yields, on the other. Furthermore, most of the publications concerned with this phase of maple sap products are based on inadequate sampling and, often, on unreliable statistical evidence.

This study, therefore, was devoted to determine the relationships which exist between several tree characteristics and the sap and sugar yields. The characteristics studied were: d.b.h., basal area, tree height, tree volume, crown length, live crown ratio, crown diameter, and crown area.

The experimental area is located in Baker Woodlot on the campus of Michigan State University. Tree measurements were made in the fall of 1952 for 52 trees and their yields of sap and sugar for the years 1953, 1954, and 1955 were recorded.

In order to obtain maximum information about the effect of the previously stated tree characteristics on the yields of sap and sugar, three distinct statistical procedures were conducted. These were: (1) analysis of variance, (2) simple correlation analysis, and (3) multiple correlation analysis. Calculations for these analyses were performed by MISTIC computer. This is a tape-input, digital, high-speed, electronic computer.

The results of this study were as follows:

1. Significant increases in the yields of sap and sugar are obtained from trees with larger diameters (d.b.h.). There are also indications that the increase in sugar production is not attributed only to the increase in the volume of sap produced, but also to the higher sugar percentage in the sap of trees with larger diameters.

2. The effect of basal area, which was found significantly favorable, on the yields of sap and sugar is none other than that already expressed by d.b.h.

3. Consistent negative correlation existed between tree height and the yields of sap and sugar in the three study years, but this correlation was not significant.

4. Significant increases in the yields of sap and sugar are expected by the increased tree volume.

5. No significant increases in sap and sugar yields are obtained by the increased crown length of a tree in this experimental area.

6. Live crown ratio was positively correlated with the yields of sap and sugar in all the study years, but this correlation was not significant except with sugar yield in 1955.

7. Significant increases in the yields of sap and sugar are obtained from trees with larger crown diameters. This experiment also shows that large crown diameter is equally effective in increasing sap and sugar yields.

8. Large crown area significantly increases the yields of sugar, but not that of sap.

9. The combined effect of d.b.h., height, crown diameter, and live crown ratio accounted for 19 percent of the sap and 32 percent of the sugar in this experimental woodlot. The correlation coefficient of the four tree characteristics with the sap was significant at the 1 percent level, and with the sugar at the .1 percent level of significance.

10. No significant improvement was achieved in predicting sap and sugar yields by a multiple correlation analysis involving four tree characteristics than by a simple correlation using d.b.h. data only.

11. Since the four visual tree characteristics, namely, d.b.h., height, crown diameter, and live crown ratio, determine only about one-fifth of the sap yield and about one-third of the sugar yield, the need for future research in genetic variability between trees and the effect of soil characteristics in determining sap and sugar production is stressed.

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By

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# INTRODUCTION

The maple syrup and sugar industry is confined to North America. Although some believe that early French settlers taught the American Indians the techniques of making maple syrup and sugar, the majority of writers (2, 14, 27, 32, 45)[1] believe that it was the Indians who taught the European pioneers. The writings of early American settlers dating as far back as the year 1521 (31) show that this industry was a well established practice among the Indian tribes.

Income from maple sap products constitutes a small portion of the national economy. The annual national income from maple sap products for the period between 1943 and 1954 averaged a little over 7,250,000 dollars (41). With its average annual production valued at approximately 400,000 dollars during that period, Michigan ranks fourth or fifth among the maple sap producing states. This contributes substantially to the income of many woodland and sugar grove owners.

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[1]The underlined numbers in parentheses refer to the literature cited.

Production of maple syrup and sugar in commercial quantities is confined to the eastern and northern United States and the neighboring southeastern part of Canada (3, 27, 45). There are only eleven states in the United States which produce syrup and sugar in commercial quantities. These states are, in descending order of the average number of trees tapped per year (1949-1958), Vermont, New York, Ohio, Michigan, Pennsylvania, Wisconsin, Maine, Minnesota, and Maryland (42).

Of the 13 species of maple native to the United States, only sugar maple (*Acer saccharum* Marsh.)[2] and black maple (*Acer nigrum* Michx. f.) are of importance in the production of syrup and sugar in commercial quantities (1, 22, 45). These two species have approximately equal capacity for sap production. Because of its wider range of distribution and more frequent occurrence, sugar maple, however, contributes most of the sap produced.

For some time, plant physiologists have been aware that in several genera, including *Acer*, *Betula*, *Juglans*, *Ostrya*, and *Vitis*, transitory pressure is developed in the vessel sap of their stems (25). Upon wounding of the stem, exudation is formed which in *Acer spp*. is sap containing

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[2]Scientific names are according to Little (22).

varied amounts of sugar that may be converted into syrup or sugar by concentrating at boiling temperature.

Sugar in the maple sap comes from carbohydrates accumulated in the tree as starch during the previous summer. When the weather becomes cool, the starch is converted into sugar. This results in a relatively high concentration of sugar in the xylem sap. Sugar solution drains out of holes bored in the stem if conditions are favorable for the existence of pressure in the xylem (20).

The exact cause of maple sap flow is not yet determined in spite of numerous physiological studies. Marvin (25), conducted intensive study in an effort to determine the mechanism or mechanisms responsible for the flow of sap. He concluded:

> An explanation of the mechanism producing sap pressures and flows in maple stems based on a single physical phenomenon such as thermal expansion seems inadequate. A more acceptable point of view is that the sap flow results from the interaction of two or more factors . . . . During the cooling part of the temperature cycle there is an absorption of water or the vessel solution from the vessel by other xylem cells. This absorption is independent of the composition of the vessel solution and may be in part a physical phenomenon. It apparently does not depend entirely upon the activities of living cells. The vessel solution is then replaced by absorption from the roots. We have called this absorption on cooling the conditioning period. It appears to be quantitatively related to the volume of flow following warming . . . . After adequate conditioning, sap

> pressures and flow may occur on warming. There is evidence that living cells are necessary and the composition of the vessel solution is important. The mechanism may be osmotic and the pressures and flow depend on D.P.D. across the ray cells between the ultimate reservoirs and the vessel solution.

Whatever physiological activities may take place within the stem cells and vessels, however, it is now certain that the alternating freezing and thawing of the stem control sap flow (18, 23, 24, 25, 27, 37).

The effect of weather, prior to and during the flow, on sap and sugar production, is one of the most thoroughly discussed topics in maple sap products literature. This is expected because the flow of sap itself is dependent on the temperature. To substantiate this, severed stems of maple trees exuded sap upon proper control of temperature (18, 23, 25). Maple trees, therefore, will produce sap during the dormant season, each time a period of freezing is followed by a period of thawing (45).

A rise in temperature following a period of low, but not necessarily freezing temperature, is essential for the flow of sap. However, the volume of flow is greater when the preceding temperature drops below 32° F. than when the lowest temperature between the flows is above 32° F. (24). It has been found that the more often the temperature fluctuates between freezing and thawing the better the sap flow season (19). The best runs have been reported to occur after sudden and rapid thaws with temperatures above 40° F. following freezing nights (3, 33).

Reports on the effect of weather conditions during the growing season preceding the sap flow are somewhat contradictory. On the one hand, it is reported (18) that drought during the summer greatly reduced the subsequent sap yield. On the other hand, later investigators (1, 27) failed to report any significant correlation between the sap yield and weather conditions previous to the sap flow. Because of the statistical evidence presented by the latter group, the writer is of the opinion that no significant correlation exists between the volume of sap and weather conditions prior to sap flow.

The flow of sap is not a continuous process; that is, sap does not flow constantly all the time from the beginning of the season till the end. It only flows when atmospheric conditions are favorable during the season. Generally, there are 6 to 10 runs within each sap season. These are separated by non-flow periods ranging from one to several days.

The starting dates of sap flow vary from year to year and from one place to another, depending upon weather conditions and geographic locations. For instance, sap season in Maryland or Ohio starts a week or two earlier than in the more northerly states such as Maine or Minnesota. With the same latitude, the season starts earlier in lower elevations than in higher elevations. In any one area, sap season starts earlier in some years than in other years if the rise in temperature following the freezing period of the winter is unseasonably early. If, on the other hand, the day and night temperature stay at freezing mark or below until the spring, sap season is, consequently, delayed. The sap season therefore, may start at any time between late January and the middle of March. As the beginning of sap season is influenced by temperature, so is its termination. So long as the temperature during the day is preceded by freezing or near freezing temperatures at night, sap will continue to flow. If, however, the day and night temperatures continue to be above freezing, sap stops flowing and the season comes to an end. Sap season in northern states and in higher elevations lasts longer than in the more southerly states and in lower elevations by 10 to 15 days. In the region as a whole, sap season usually ends between the middle of March and the middle of April. Radio forecasts of the correct tapping dates are provided for sugar grove owners in several states including Massachusetts, Michigan, New York, Vermont, and Wisconsin (13, 32, 45).

The sap and sugar yields vary from year to year, from sugar bush to sugar bush, from tree to tree, and from day to day during the sap season (3, 7, 20, 26, 28, 32, 39). These variations are due to: (1) the difference in climatic conditions during the sap season from one year to another, (2) the difference in soil characteristics between different sugar bushes, (3) the inherent tree characteristics for sap production (genetic variation between trees), (4) the difference in the physical tree characteristics such as stem diameter, height, crown diameter and length, etc., and (5) unknown factors. The average sap produced per tree ranges from 10 to 40 gallons annually, but yields as high as 130 gallons have been reported.[3] Sugar concentration in the sap varies from .5 to as high as 7 and even 10 percent, but ordinarily it is between 2 and 3 percent (3, 20). With an individual tree, sugar concentration in the sap is low early in the season, rises quickly to a maximum, then gradually decreases as the season advances (40).

Maple sap is free from bacteria, yeasts or molds when in the tree (12). It becomes contaminated in the taphole, spout or in the bucket. As the season advances, infection becomes more severe and produces the so-called "buddy sap"

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[3] Unpublished data, Forestry Department, Michigan State University.

or sour sap. The growth of microorganisms in the maple tree taphole results in a decreased rate and often complete stoppage of sap flow (30, 34). Yields from trees tapped early in the season are much more likely to be affected by microbial growth, even in a relatively cold season, than trees tapped at later dates (34).

In an effort to determine the exact causes of premature stoppage of sugar maple sap production, intensive study was conducted by Ching and Mericle (4). They concluded:

> Histological findings indicate that premature stoppage of sap flow in normally tapped maple trees results from the combined effects of a bacterial invasion of the living tissue via pits along the cell walls, and an actual vessel blockage by microorganisms and/or gummy plugs produced by these microorganisms. Demonstration of pectolytic activity in the bacteria isolated from tapholes suggests a mechanism whereby these organisms penetrate the pit membranes.

The most promising method of combatting microorganisms which result in premature stoppage of sap flow has been found recently by Sheneman and his coworkers (34). It consists of inserting a pellet containing paraformaldehyde with agar into the taphole during the tapping operation.

The effect of grazing on the yields of sap and sugar is a matter of dispute among the writers. One group (10, 33) reported substantial decrease in the yields of sap and sugar as a result of grazing. However, no statistical evidence was presented. The other group (16, 27), with reliable statistical evidence, found that yields from grazed groves were as high or higher than from ungrazed areas, but the difference was not statistically significant. Consequently, the writer is convinced that grazing has no significant effect on the yields of sap and sugar. However, the harmful effect of grazing on the physical properties of soil and on the young reproduction is well realized (3, 9, 10, 16, 26, 32, 33).

In reviewing the literature, the writer noted several comments as to the effect that different types of soil may have upon sap yield and sugar percentage. They were mainly speculations with no statistical evidence of the superiority of one soil type over others in relation to maple sap and sugar yields.

Moore and others (27) failed to establish any significant difference between sap yields of several soil types, except as was related to drainage, depth of topsoil, and tilth. White and Robbins (43), using different combinations of nitrogen, phosphorus, and potassium, commercial fertilizer, found that trees receiving nitrogen and phosphorus gave significantly higher sap yields than the trees receiving other treatments. In the same experiment, they found that there are indications that potash depresses the yields.

Trees of similar growth rate, crown and diameter sizes, growing on the same soil, vary considerably in their capacity to produce sap and sugar. This, then, suggests that factors other than environmental, perhaps genetic, may be partly responsible for this variation. Genetic efforts to improve sap producing qualities of maple trees have been very scant. In fact, the few attempts made in this direction were to propagate trees of high sugar concentration by means of cuttings (11, 35, 36). The initial rooting was very poor. Later, with improved techniques and better care, rooting was increased to about 35 percent. Best results were obtained with cuttings taken from current season's growth. They were planted in indoor shaded beds and sprinkled frequently with water. Adaptation of the rooted cuttings to the field or to nursery conditions in tne open, however, was not encouraging.

Despite the numerous studies made in the general field of maple sap products, only a few are concerned with the relationship between tree characteristics such as d.b.h., height, crown width and length and the sap and sugar yields. In addition, most of the publications devoted to this phase of maple sap products are based on inadequate sampling and, often, on unreliable statistical procedures.

This study is an attempt to determine the relationships which exist between several tree characteristics and the sap and sugar yields.

The characteristics studied are:

1. D.B.H. (diameter at breast height, approximately four and one-half feet from the ground) in inches.
2. $(D.B.H.)^2$ as an expression of the basal area in square inches.
3. Total tree height in feet.
4. $(D.B.H.)^2$ x height as an expression of volume in cubic feet.
5. Crown length in feet.
6. Live crown ratio in percent.
7. Crown diameter in feet.
8. $(\text{Crown diameter})^2$ as an expression of crown area in square feet.

# LITERATURE REVIEW

Several workers (5, 6, 15, 16, 26, 27, 28, 32, 45) anticipate an increase in the yield of sap by tapping additional holes in a tree. As a general rule, they recommend one taphole for a 10 to 15-inch (d.b.h.) tree, two tapholes for a 16- to 20-inch tree, three tapholes for a 21- to 25-inch tree, and four tapholes for trees over 25 inches in diameter. Other investigators (7, 17), on the other hand, failed to report any significant difference in the yields of sap due to the addition of more tapholes on trees of comparable diameter classes. Due to inadequate sampling reported by the latter group, the writer holds the conviction that the addition of more buckets to a tree, especially to those with larger diameter classes, will result in significantly higher sap yields.

Moore *et al*. (27), in a test based on four-year average of 35 plots, reported an increase in both the volume of sap and sugar percent due to increase of d.b.h. In another experiment, Lawrence (21) found significant increase in sap yield and sugar percent for those trees with bigger d.b.h. in comparison with those with smaller d.b.h.

Morrow (29), reports that significant correlation exists between live crown ratio and sugar percentage for trees in open stands. Others (8, 27) report that marked increases in the volume of sap and its sugar content are obtained from trees with larger live crown ratio.

That a large photosynthetic surface (leaf area) is a prerequisite for increased sugar production in maple trees is well recognized (3, 18, 20, 21, 27, 29). Significant increases in sap yield and sugar percent were reported for trees with larger crown diameter compared with those of smaller diameter (21, 27, 29). McIntyre (26), in an experiment including large numbers of trees, showed evidence of increased sap flow with the increase of crown size. Morrow (29) found that crown diameter was correlated with increased sap flow much more than with sugar percentage. He also found that the influence of crown diameter on sugar percentage was greater in a closed forest than that of the live crown ratio, although the latter had greater effect on sugar percent in open type sugar bush than the former. White (44) found that sugar percent in the sap yield of trees growing in open stands or along roadsides was significantly higher than that of forest grown trees. Roadside trees were reported (38) to yield sap with higher sugar percent than trees growing in open stands. In addition to their higher sugar contents, Willit (45) observes that open grown trees are excellent sap producers. This is explained (29) by more rapid fluctuation between freezing and thawing in the open than in the forest, which directly hastens or retards sap flow.

## LOCATION AND GENERAL DESCRIPTION OF THE EXPERIMENTAL AREA

The experimental area with which this study is concerned is about 6 acres in size and is located on the northeast corner of the 77-acre Baker Woodlot on the campus of Michigan State University, East Lansing, Michigan. This woodlot is a part of the initial land grant to this university which was established in 1855, then known as Michigan Agricultural College. It is located in Section 19, Township 4N, Range 1W, Ingham County, Michigan.

The experimental portion of the woodlot is a mixed hardwood stand containing a high proportion of sugar maple. Other species present are red oak (*Quercus rubra*, L.), basswood (*Tilia americana*, L.), black cherry (*Prunus serotina*, Ehrh.), and American elm (*Ulmus americana*, L.). The woodlot is well protected from fire and grazing. Some intermediate cuttings have been made since 1914, with major harvest cuts in 1938 and in 1947, and, in small portions of the woodlot, experimental wildlife cuttings were made in 1933 and 1950.

The site of the experimental area is well drained, with Miami and Hillsdale sandy loam soils on level to gently undulating terrain. Maple trees vary in size to over 30 inches in diameter, with ample reproduction in the understory.

The trees in this woodlot were tapped for this experiment for the first time, hence, the hazard from previous injuries due to tapping is eliminated.

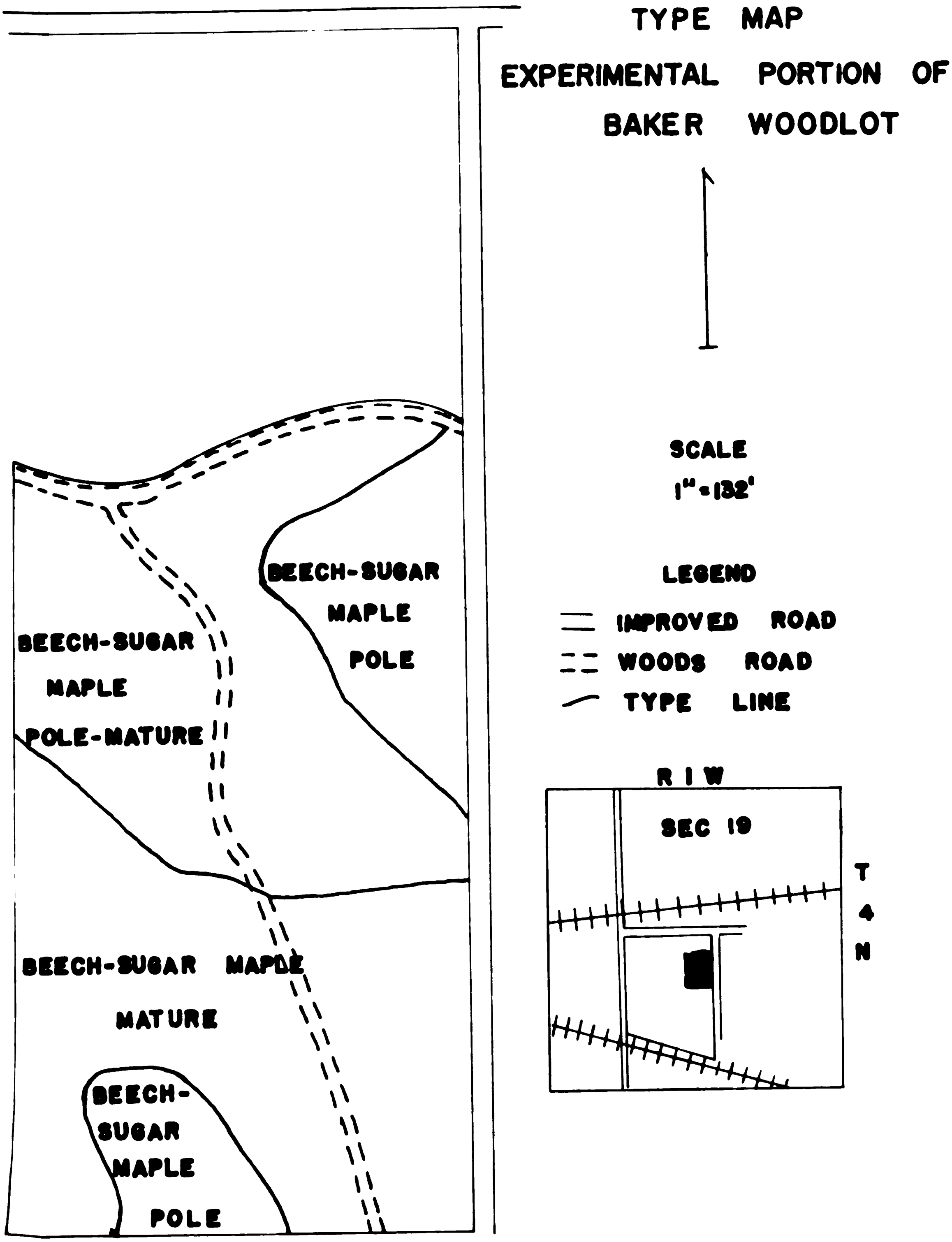

TYPE MAP
EXPERIMENTAL PORTION OF
BAKER WOODLOT
SCALE
1" = 132'
LEGEND
IMPROVED ROAD
WOODS ROAD
TYPE LINE
R I W
SEC 19
T 4 N
BEECH-SUGAR MAPLE POLE
BEECH-SUGAR MAPLE POLE-MATURE
BEECH-SUGAR MAPLE MATURE
BEECH-SUGAR MAPLE POLE

FIGURE 1

## EXPERIMENTAL PROCEDURE AND COLLECTION OF DATA

In the fall of 1952, the tappable maple trees, 10 inches and over, were selected and numbered with white paint on the west side of the trunk. The d.b.h. to the nearest tenth of an inch, total height in feet, and their crown length and diameter in feet were recorded.

In the winter of 1953, a study on maple sap and sugar production for 120 selected trees was initiated in Baker Woodlot. Some trees were assigned one bucket, others two, and some others three buckets. The study was aimed at determining the effect that some production techniques such as height, depth and diameter of the taphole, number of tapholes per tree, type of spout and container, several tree characteristics, as well as weather factors, may have on maple sap and sugar yields. This study is concerned only with the 52 trees that were assigned one bucket to determine the effect of d.b.h., basal area, height, volume, crown length, live crown ratio, crown diameter, and crown area on the yields of sap and sugar.

Each year during the sap seasons of 1953 through 1955, the trees were tapped at randomly selected compass positions at a height 2 to 3 feet from the ground. The holes were drilled with a brace and an ordinary tapping bit. Two different types of spouts with three-eighths and seven-sixteenths of an inch in diameter were used to lead the sap from the tree to the collecting container. The container was either a metal bucket with snap-on cover or a plastic bag with a flap on top to prevent rain and other materials from falling into the sap.

It has been reported by Cool (7) covering other phases of this study that no significant difference was detected between yields of sap and sugar due to: (1) height of taphole from the ground; (2) depth of taphole, ranging from 2 to 6 inches; (3) diameter of taphole, ranging from three-eighths to fifteen-sixteenths of an inch; (4) type of spout design; and (5) type of receiving container.

At the beginning of each sap season, the trees were tapped 24 to 48 hours ahead of the first sap flow predicted by the Office of the United States Weather Bureau at East Lansing and the Michigan State University Forestry Department cooperating. Tapping just shortly before the sap starts flowing is very important, since, as it has been pointed out earlier, too early a tapping may reduce the yield substantially due to the infection by bacteria and other microorganisms even in a relatively cold season.

For the 1953 sap season, the first sap collection was made on February 20 and the last on April 8, with eight major runs separated by non-flow periods ranging from one to several days. The total sap produced by the 52 trees was 6,522 pounds for an average of 125.4 pounds (or 15 gallons) per tree. The first run of sap during the 1954 season was collected on February 15 and the last on April 7, with 9 major runs. It gave a total sap yield of 10,916 pounds and an average of 210.0 pounds (or 25 gallons) per tree. In 1955, the sap started flowing on February 20 and it stopped on April 5, with 8 major runs in between. Total sap yield was 10,530 pounds for an average of 202.5 pounds (or 24 gallons) per tree.

During each day, when a major run occurred, the sap was collected in the afternoon. The contents of the bucket or the bag were poured into a pail on which a standard dairy milk scale was attached, and the weight was recorded to the nearest tenth of a pound. The percent sugar was determined by placing a few drops of fresh sap in the Bausch and Lomb Hand Refractometer. The refractometer actually measures the density of the sap expressed in percent of total solids (Brix scale). These solids contain, along with sugar, minute quantities of proteins and minerals, but the scale corresponds very closely with total sugar in the sap (2, 7, 28).

Tree measurements as well as the collection of sap and sugar data for the 1953 and 1954 seasons were made by J. G. Williams, a graduate assistant at Michigan State University (Forestry Department). The sap and sugar data for the 1955 season were collected by B. M. Cool, also a graduate assistant in the same department. The entire field work for this project was under the guidance of P. W. Robbins, Associate Professor of Forestry, Michigan State University.

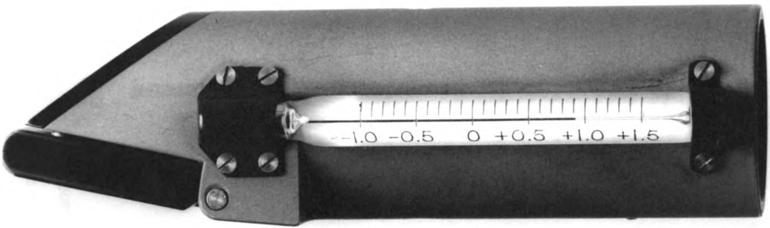
Sugar yield was calculated by multiplying the daily sap reading for each tree by its corresponding sugar percent and the yield of sugar for that tree and day was recorded to the nearest one-hundredth of a pound. At the end of each season, the sugar yields for all the 52 trees were added to determine total sugar production for that season. The total sap yields for the three seasons are presented graphically in figure 5.


SAP RECEIVING CONTAINER

FIGURE 2


WEIGHING OF SAP AND DETERMINING SUGAR PERCENT

FIGURE 3




REFRACTOMETER FOR DETERMINING SUGAR PERCENT

FIGURE 4

AVERAGE SAP PER TREE

BY YEARS

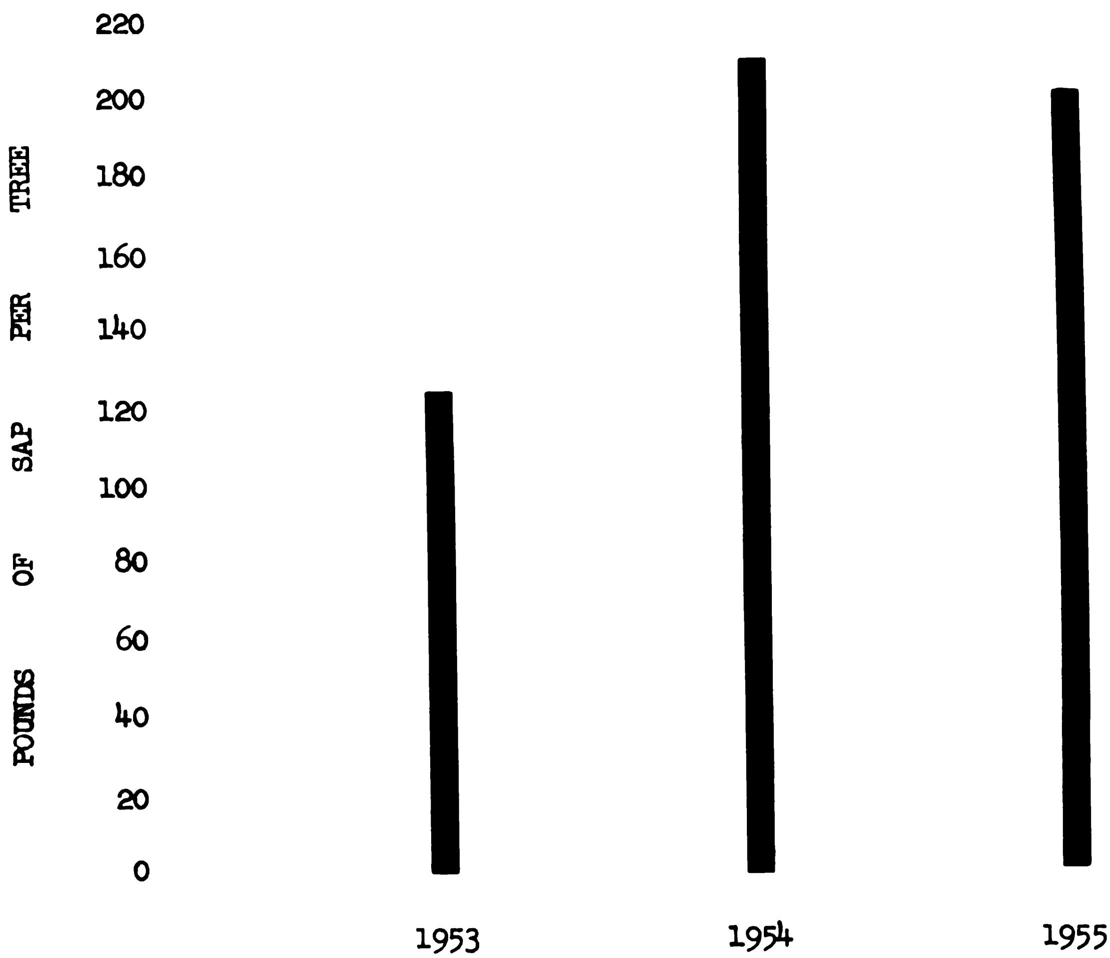



FIGURE 5

# STATISTICAL PROCEDURE

Three different statistical analyses were performed in this study. They are:

1. Analysis of Variance

This analysis was performed to test differences in sap and sugar yields between different classes of d.b.h. and crown diameter. Separate analyses were performed for each season, and a fourth analysis was devoted to the combined total yield of the 3-year period. Differences between classes means were tested, using the Studentized Range Test procedure. The summary for this analysis is shown in Tables 3, 4, 5, and 6. The step by step details for the analysis of variance are shown in the appendix.

2. Simple Correlation

This analysis included sap and sugar data for 52 trees for three sap seasons (1953-1955) and their combined total. The aim was to determine the extent and the level of correlation between sap and sugar yields and the tree characteristics studied, namely d.b.h., basal area, height, volume,crown length, live crown ratio, crown diameter, and crown area. The results of this analysis appear in Tables 1 and 2.

3. Multiple Correlation

Two analyses, one for sap and the other for sugar, were conducted using combined yields for the 3-year period for 52 trees, and the values pertaining to d.b.h., tree height, live crown ratio, and crown diameter. The objectives were as follows:

A. Do these four tree characteristics significantly affect the yields of sap and sugar? The answer to this question lies in the magnitude of the multiple correlation coefficient (R).

B. What percentage of sap and sugar yield is determined by the four characteristics studied? This is expressed by the value of the coefficient of determination ($R^2$).

C. How accurate can we predict the yields of sap and sugar from the four characteristics studied? The prediction, or the multiple regression equation is:

$$\dot{Y} = A + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \pm S_{\bar{y}}$$

D. To determine whether a multiple correlation analysis, involving four true characteristics, is a worthwhile venture in predicting the yields of sap and sugar instead of a simple correlation involving only one character such as d.b.h.

Calculations for the three analyses discussed above were performed by the MISTIC computer (operated by the Electrical Engineering Department of Michigan State University). This is a tape-input, digital, high-speed, electronic computer.

# EFFECT OF D.B.H. ON THE MAPLE SAP AND SUGAR YIELDS

In an attempt to determine the degree of correlation between d.b.h. and the yields of sap and sugar, a simple correlation analysis was carried out. It included sap and sugar yields for three separate seasons and their combined total pertaining to 52 trees of different diameters. Tables 1 and 2 show that significant correlation exists between d.b.h. and the sap and sugar yields in the 1953 and 1955 seasons. Although positive, the correlation was not significant in 1954 for either the sap or the sugar. Analysis of data (see Tables 1 and 2) concerning the three-year total shows that significant correlation exists, but more so with sugar production than with the sap.

A glance at Tables 1 through 6 as well as at the analysis of variance in the appendix shows that the yields of sap and sugar for the 1954 season did not lend themselves readily to analysis. It seems that the climatic conditions during that year obscured the effect of tree characteristics on the yields of sap and sugar. This conclusion was also reached by Cool (7).

Analysis of variance was performed to determine the degree of variation in the yields of sap and sugar for trees

TABLE 1. Correlation coefficients between tree characteristics and maple sap and sugar yields

| Tree characteristics | D.b.h. in inches /10 | Basal area in square feet | Height in feet | Volume in cubic feet | Crown length in feet | Live crown ratio in percent | Crown diameter in feet | Crown area in square feet |
|---|---|---|---|---|---|---|---|---|
| D.b.h. | 1.000 | ----- | .008 | ----- | .161 | .187 | .545 | ----- |
| Basal area | ----- | 1.000 | ----- | .915 | ----- | ----- | ----- | .499 |
| Height | .008 | ----- | 1.000 | ----- | .451 | -.161 | .000 | ----- |
| Volume | ----- | .915 | ----- | 1.000 | ----- | ----- | ----- | .461 |
| Crown height | .161 | ----- | .451 | ----- | 1.000 | .796 | .167 | ----- |
| L.c.r. | .187 | ----- | .161 | ----- | .796 | 1.000 | .187 | ----- |
| Crown diameter | .545 | ----- | .008 | ----- | .167 | .187 | 1.000 | ----- |
| Crown area | ----- | .499 | ----- | .461 | ----- | ----- | ----- | 1.000 |
| Sap yield 1953 | .529 | .520 | -.084 | .481 | .037 | .122 | .269 | .241 |
| Sap yield 1954 | .122 | .135 | -.123 | .050 | .072 | .019 | .121 | .111 |
| Sap yield 1955 | .560 | .568 | -.148 | .461 | .152 | .268 | .298 | .255 |
| Sap yield 1953-55 | .419 | .428 | -.155 | .310 | .023 | .142 | .255 | .226 |
| Sugar yield 1953 | .583 | .574 | -.125 | .444 | .064 | .199 | .337 | .305 |
| Sugar yield 1954 | .196 | .213 | -.174 | .100 | .040 | .092 | .147 | .136 |
| Sugar yield 1955 | .624 | .236 | -.263 | .471 | .115 | .326 | .377 | .339 |
| Sugar yield 1953-55 | .499 | .512 | -.234 | .349 | .038 | .231 | .315 | .286 |

TABLE 2. Significance levels for correlations between tree characteristics and the yields of sap and sugar

| Tree characteristics | D.b.h. in inches /10 | Basal area in square feet | Height in feet | Volume in cubic feet | Crown length in feet | Live crown ratio in percent | Crown diameter in feet | Crown area in square feet |
|---|---|---|---|---|---|---|---|---|
| D.b.h. | .001 | ----- | ----- | ----- | ----- | ----- | .001 | ----- |
| Basal area | ----- | .001 | ----- | .001 | ----- | ----- | ----- | .001 |
| Height | ----- | ----- | .001 | ----- | .001 | ----- | ----- | ----- |
| Volume | ----- | .001 | ----- | .001 | ----- | ----- | ----- | .001 |
| Crown length | ----- | ----- | .001 | ----- | .001 | .001 | ----- | ----- |
| Live crown percent | ----- | ----- | ----- | ----- | .001 | .001 | ----- | ----- |
| Crown diameter | .001 | ----- | ----- | ----- | ----- | ----- | .001 | ----- |
| Crown area | ----- | .001 | ----- | .001 | ----- | ----- | ----- | .001 |
| Sap 1953 | .001 | .001 | ----- | .01 | ----- | ----- | ----- | ----- |
| Sap 1954 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| Sap 1955 | .001 | .001 | ----- | .001 | ----- | ----- | .05 | ----- |
| Sap 1953-55 | .01 | .01 | ----- | .05 | ----- | ----- | ----- | ----- |
| Sugar 1953 | .001 | .001 | ----- | .01 | ----- | ----- | .05 | .05 |
| Sugar 1954 | ----- | ----- | ----- | ----- | ----- | ----- | ----- | ----- |
| Sugar 1955 | .001 | .001 | ----- | .001 | ----- | .05 | .01 | .05 |
| Sugar 1953-55 | .001 | .001 | ----- | .05 | ----- | ----- | .05 | .05 |

of different d.b.h. classes. Four d.b.h. classes were distinguished, each consisting of 11 randomly selected trees. Their yields of sap and sugar were analyzed separately for each season, and a separate analysis was devoted to the combined yield of the three-year period. Figure 6 presents the yields of sap and sugar for the three-year period by diameter classes.

The levels of significance between yields of sap and sugar for the three seasons and their combined totals are presented in Table 3.

Table 4 presents the average yields of sap and sugar for each diameter class and year, as well as the least significant difference at 5 percent and 1 percent levels. Among other significant relationships, the data in Table 4 show that the three-year total sap for the 14.6 to 19.8 inch diameter class is significantly higher than that for the smaller diameter classes. In regards to three-year total sugar production, the yield by the largest diameter class is significantly higher at the 1 percent level than the two smallest classes, and significantly higher at the 5 percent level than the 13.1 to 14.5 inch class.

The results of this study demonstrate that significantly higher yields of sap and sugar are obtained from trees having larger diameters than from those with smaller

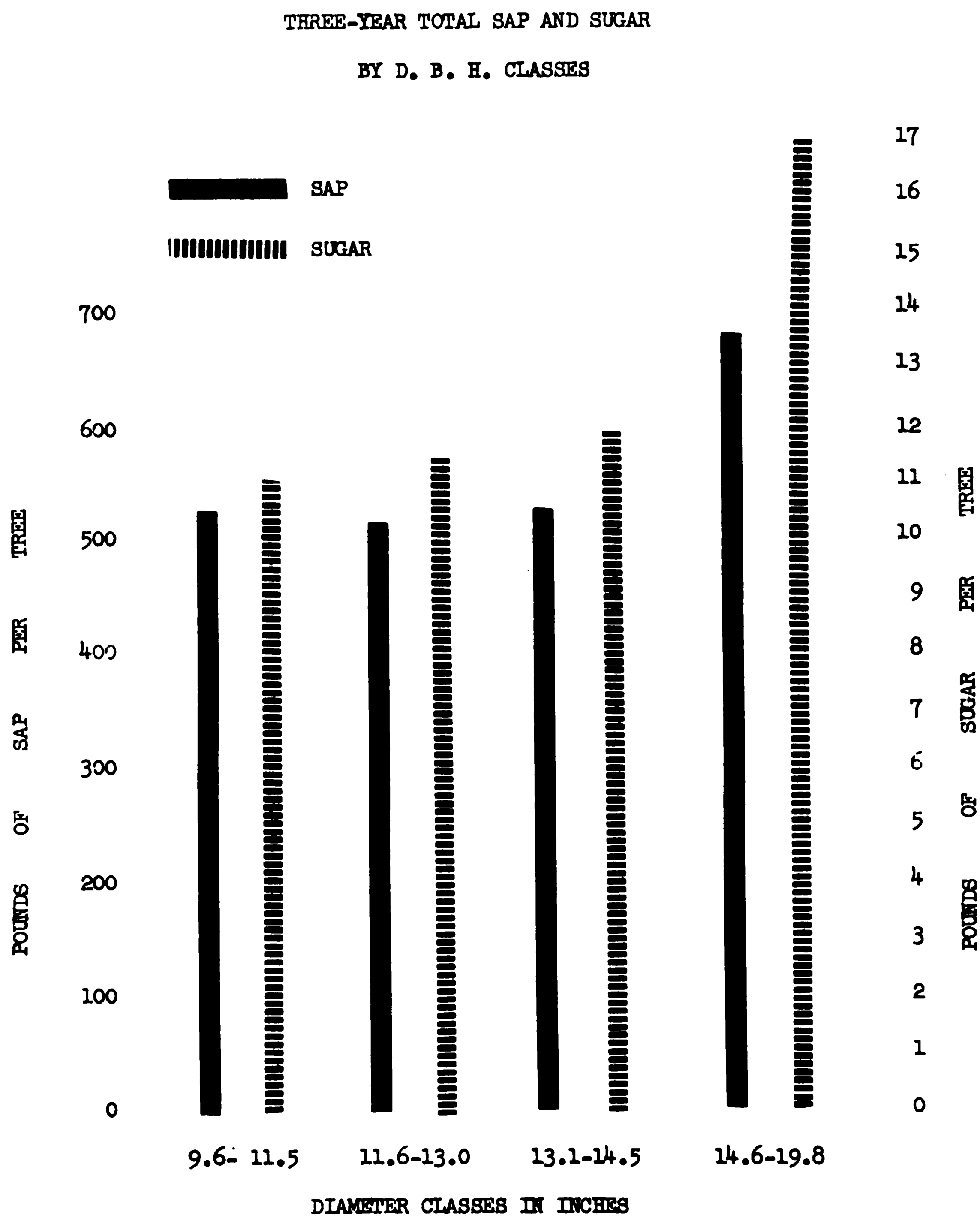

THREE-YEAR TOTAL SAP AND SUGAR
BY D. B. H. CLASSES
SAP
SUGAR
POUNDS OF SAP PER TREE
0
100
200
300
400
500
600
700
POUNDS OF SUGAR PER TREE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
9.6- 11.5
11.6-13.0
13.1-14.5
14.6-19.8
DIAMETER CLASSES IN INCHES

FIGURE 6

TABLE 3. F values for differences in sap and sugar yields between trees of different d.b.h. classes. Each analysis was based on 3 d.f. for diameter classes; 10 for replications; 30 for error; and 42 for total.

| Product | Year of production | F-ratio = $\frac{\text{between size class variance}}{\text{error variance}}$ |
|---|---|---|
| sap | 1953 | 4.86** |
| sap | 1954 | 0.54 |
| sap | 1955 | 5.01** |
| sap | 1953-1955 | 2.97* |
| sugar | 1953 | 7.02** |
| sugar | 1954 | 0.61 |
| sugar | 1955 | 7.10** |
| sugar | 1953-1955 | 4.26* |

* Significant at 5% level

** Significant at 1% level

TABLE 4. Sap and sugar yields in pounds, per tree, for different diameter classes (d.b.h.) in different years

| Product | Year of production | Sap and sugar yields from trees with diameters (breast height) of: | | | | | Least significant difference between classes means at | |
|---|---|---|---|---|---|---|---|---|
| | | 9.6–11.5 inches | 11.6–13.0 inches | 13.1–14.5 inches | 14.6–19.8 inches | All classes | 5% level | 1% level |
| | | Pounds per tree | | | | | | |
| sap | 1953 | 105 | 127 | 127 | 164 | 131 | 32 | 43 |
| sap | 1954 | 237 | 200 | 199 | 240 | 219 | --- | --- |
| sap | 1955 | 185 | 190 | 203 | 277 | 214 | 55 | 74 |
| sap | 1953-55 | 527 | 517 | 528 | 680 | 563 | 131 | --- |
| sugar | 1953 | 2.65 | 3.39 | 3.51 | 4.82 | 3.59 | 0.98 | 1.22 |
| sugar | 1954 | 4.82 | 4.39 | 4.23 | 5.54 | 4.75 | ---- | ---- |
| sugar | 1955 | 3.54 | 3.69 | 4.21 | 6.39 | 4.46 | 1.43 | 1.93 |
| sugar | 1953-55 | 11.02 | 11.47 | 11.95 | 16.90 | 12.84 | 3.82 | 5.15 |

diameters. There is also indication (see Table 4) that the increase in sugar production is not attributed only to the increase in volume, but also to the higher percentage of sugar in the sap of trees with larger diameter.

# EFFECT OF BASAL AREA ON THE YIELDS OF MAPLE SAP AND SUGAR

The squares of d.b.h. of each of the 52 trees were calculated in order to represent the approximate value for the basal area. These values were included in a simple correlation analysis to show how their correlation coefficients compare with those of d.b.h. in regards to the yields of sap and sugar. Tables 1 and 2 show the extent and the significance level of correlation between the basal area and the sap and sugar yields for three seasons and their combined total. It appears that the correlation coefficients of the basal area are almost identical with those of d.b.h. and that the levels of significance of the two factors are exactly the same.

Significant correlation exists between the basal area and the sap and sugar yields only so long as the d.b.h. itself is significantly correlated. In other words, the effect of the basal area of a tree on the yields of sap and sugar is none other than that already expressed by its diameter.

To determine whether the correlation coefficients of d.b.h. and basal area with the sap yield are significantly different from each other, a t-test is required. The procedure is as follows:

$r_1$ = .419 = correlation coefficient between d.b.h. and sap yield for 3-year period (see Table 1).

$r_2$ = .428 = correlation coefficient between basal area and sap yield for 3-year period (see Table 1).

$$s_{r_1} = \frac{1 - r_1^2}{\sqrt{n-2}} \qquad s_{r_2} = \frac{1 - r_2^2}{\sqrt{n-2}}$$

$$= \frac{1 - (.419)^2}{\sqrt{50}} \qquad = \frac{1 - (.428)^2}{\sqrt{50}}$$

$$= \frac{.824}{7.070} \qquad = \frac{.817}{7.070}$$

$$= .118 \qquad = .117$$

$$s_{(r_1-r_2)} = \sqrt{s_{r_1}^2 + s_{r_2}^2}$$

$$= \sqrt{(.118)^2 + (.117)^2}$$

$$= \sqrt{.0276}$$

$$= .166$$

$$t = \frac{r_1 - r_2}{s_{(r_1 - r_2)}}$$

$$= \frac{.419 - .428}{.116}$$

$$= \frac{.009}{.116}$$

$$= .054$$

The difference between the correlation coefficients of d.b.h. and basal area with the sap yield was not significant. To be significant, the computed t at the 5 percent level and 50 d.f. must have the value of 2.0.

In order to determine whether the inclusion of basal area in a simple correlation analysis brought forth better results in predicting sugar yield than if d.b.h. data alone were employed in such analysis, the same procedure, as before, is followed:

$r_1$ = .499 = correlation coefficient between d.b.h. and sugar yield

$r_2$ = .512 = correlation coefficient between basal area and sugar yield

$$s_{r_1} = \frac{1 - r_1^2}{\sqrt{n-2}} \qquad s_{r_2} = \frac{1 - r_2^2}{\sqrt{n - 2}}$$

$$= \frac{1 - (.499)^2}{\sqrt{50}} \qquad = \frac{1 - (.512)^2}{\sqrt{50}}$$

$$= \frac{.751}{7.070} \qquad = \frac{.738}{7.070}$$

$$= .106 \qquad = .104$$

$$s_{(r_1 - r_2)} = \sqrt{s_{r_1^2} + s_{r_2^2}}$$

$$= \sqrt{(.106)^2 + (.104)^2}$$

$$= \sqrt{.0221}$$

$$= .148$$

$$t = \frac{r_1 - r_2}{s_{(r_1 - r_2)}} = \frac{.499 - .512}{.148} = .088$$

The difference between the correlation coefficients of d.b.h. and basal area with sugar yield is, therefore, not significant.

## EFFECT OF THE TREE HEIGHT ON THE MAPLE SAP AND SUGAR YIELDS

In an effort to show what correlation exists between tree height and the production of sap and sugar, a simple correlation analysis was conducted in which the yields of 52 trees for three seasons and their combined total were included.

From Table 1 it appears that a consistent negative correlation exists between tree height and the sap and sugar yields, although it was not significant for any one season or for the three-year total. The magnitude (negative) is higher with sugar than with sap.

There are indications that the increased total height of a maple tree has a depressing effect on both sap and sugar production, but with greater extent on the latter. However, the decrease in the sap and sugar yields due to increased tree height was not significant in any of the three study years.

While this observation substantiates the results obtained in previous work (29), further experiments specifically designed along this line are needed in order to show the exact effect of tree height on the yields of sap and sugar.

# EFFECTS OF TREE VOLUME ON THE YIELDS OF SAP AND SUGAR

The approximate tree volume was computed by multiplying the square of d.b.h. by the total height. In this experiment, no conversion factor was used to correct for the taper of the bole, because the degree of taper was assumed to be constant for all the trees studied. Values thus obtained for each of the 52 trees were included in a simple correlation analysis to determine the effect that tree volume has on the yields of sap and sugar. Correlation coefficients and the level of significance appear in Tables 1 and 2, respectively. This correlation, while positive, is much less significant than either of those pertaining to d.b.h. or basal area. Undoubtedly, this reduction in the level of significance is due to the depressing effect of the tree height which is a vital component of the volume.

Significant increases in yields of sap and sugar are expected as tree volume increases. It is evident that this favorable effect is attributed to the part d.b.h. contributes to the increase in volume of a particular tree rather than its total height.

# EFFECT OF CROWN LENGTH ON THE MAPLE SAP AND SUGAR YIELDS

Crown lengths of 52 trees, along with their yields of sap and sugar for three seasons and their total were included in a simple correlation analysis. From Table 2 it appears that no significant correlations exist between the crown length of maple trees and their sap and sugar production.

No significant increases in the yields of sap and sugar are, therefore, expected from increased crown length of the trees in this experimental area.

It appears that an increase in tree foliage due to increased crown length does not result in a significant increase in photosynthetic activity. This is attributed to the fact that the dense crown canopy in this woodlot limits the amount of solar radiation reaching the lower strata of the tree foliage and is not sufficient to bring about significantly greater production of carbohydrates.

## EFFECT OF LIVE CROWN RATIO ON THE MAPLE SAP AND SUGAR YIELDS

Live crown ratio is the proportion of the crown length to the total height of a tree, and it is, therefore, obtained by dividing the former by the latter and then multiplying the product by 100.

The correlations in the three study years were positive but non-significant. The correlations involving sugar yield and live-crown ratio were also positive. These latter correlations were not significant except in 1955, when the relation was significant at the 5 percent level.

To restate this in words rather than statistical terms, live crown ratio had no discernible effect on sap yield but may have had a slight effect on sugar yield.

# EFFECT OF CROWN DIAMETER ON THE MAPLE SAP AND SUGAR YIELDS

Yields of sap and sugar for three seasons and their total were included in a simple correlation analysis to determine how they are correlated with the crown diameter. Data in Table 1 show that positive correlation exists between crown diameter and the sap and sugar yields. Although in only one season (1955) was the crown diameter significantly correlated with sap yield (see Table 2), it was very close to being significant in the 1953 season as well as for the combined three-year sap yield. With sugar yields, on the other hand, crown diameter was found to be significantly correlated in 1953, 1955, as well as for the three-year total.

In order to determine the degree of variation between sap and sugar yields in trees of different crown diameter classes, analysis of variance was carried out. From the 52 trees originally used in this study, 42 were selected at random to represent three crown diameter classes, each with 14 trees. Table 5 presents the F-ratios between yields of sap and sugar, with the level of significance indicated for each season. This, along with Table 6 reveals that the larger crown diameter is associated with significantly higher yields than the smaller classes in all the three years studied.

It is also shown that, for both sap and sugar, the yields from trees with larger crown diameters are very significantly higher than yields from trees with smaller crown diameters in the 1953 season and in the three-year period. The yields of sap and sugar for the three-year period are presented graphically by crown classes in figure 7.

Significant increases in the yields of sap and sugar are obtained from trees with larger crown diameters than from those with smaller crown diameter. This study also shows that the influence of larger crown diameter is equally effective in increasing sugar production and sap yields.

TABLE 5. F-values for differences in sap and sugar yields between trees of different crown diameter classes. Each analysis was based on 2 d.f. for crown classes; 13 for replications; 26 for error; and 41 for total.

| Product | Year of production | F-ratio = $\frac{\text{between size class variance}}{\text{error variance}}$ |
|---|---|---|
| sap | 1953 | 5.88** |
| sap | 1954 | 3.42* |
| sap | 1955 | 4.61* |
| sap | 1953-1955 | 6.53** |
| sugar | 1953 | 6.40** |
| sugar | 1954 | 3.50* |
| sugar | 1955 | 5.22* |
| sugar | 1953-1955 | 5.97** |

* Significant at 5% level

** Significant at 1% level

TABLE 6. Sap and sugar yields in pounds, per tree, for different crown diameter classes in different years

| Product | Year of production | Sap and sugar yields from trees with crown diameters of: 16-24 feet | 25-30 feet | 31-48 feet | All classes | Least significant difference between classes means at: 5% level | 1% level |
|---|---|---|---|---|---|---|---|
| | | -------- Pounds per tree | | | --------- | | |
| sap | 1953 | 112 | 115 | 155 | 128 | 29 | 39 |
| sap | 1954 | 193 | 168 | 267 | 209 | 81 | -- |
| sap | 1955 | 167 | 180 | 252 | 203 | 60 | 85 |
| sap | 1953-55 | 472 | 473 | 675 | 540 | 133 | 180 |
| sugar | 1953 | 2.88 | 3.25 | 4.47 | 3.53 | 0.96 | 1.35 |
| sugar | 1954 | 4.23 | 3.66 | 5.98 | 4.62 | 1.98 | ---- |
| sugar | 1955 | 3.33 | 3.96 | 5.70 | 4.33 | 1.64 | 2.11 |
| sugar | 1953-55 | 10.49 | 10.90 | 16.23 | 12.54 | 3.81 | 5.15 |

THREE-YEAR TOTAL SAP AND SUGAR

BY CROWN DIAMETER CLASSES

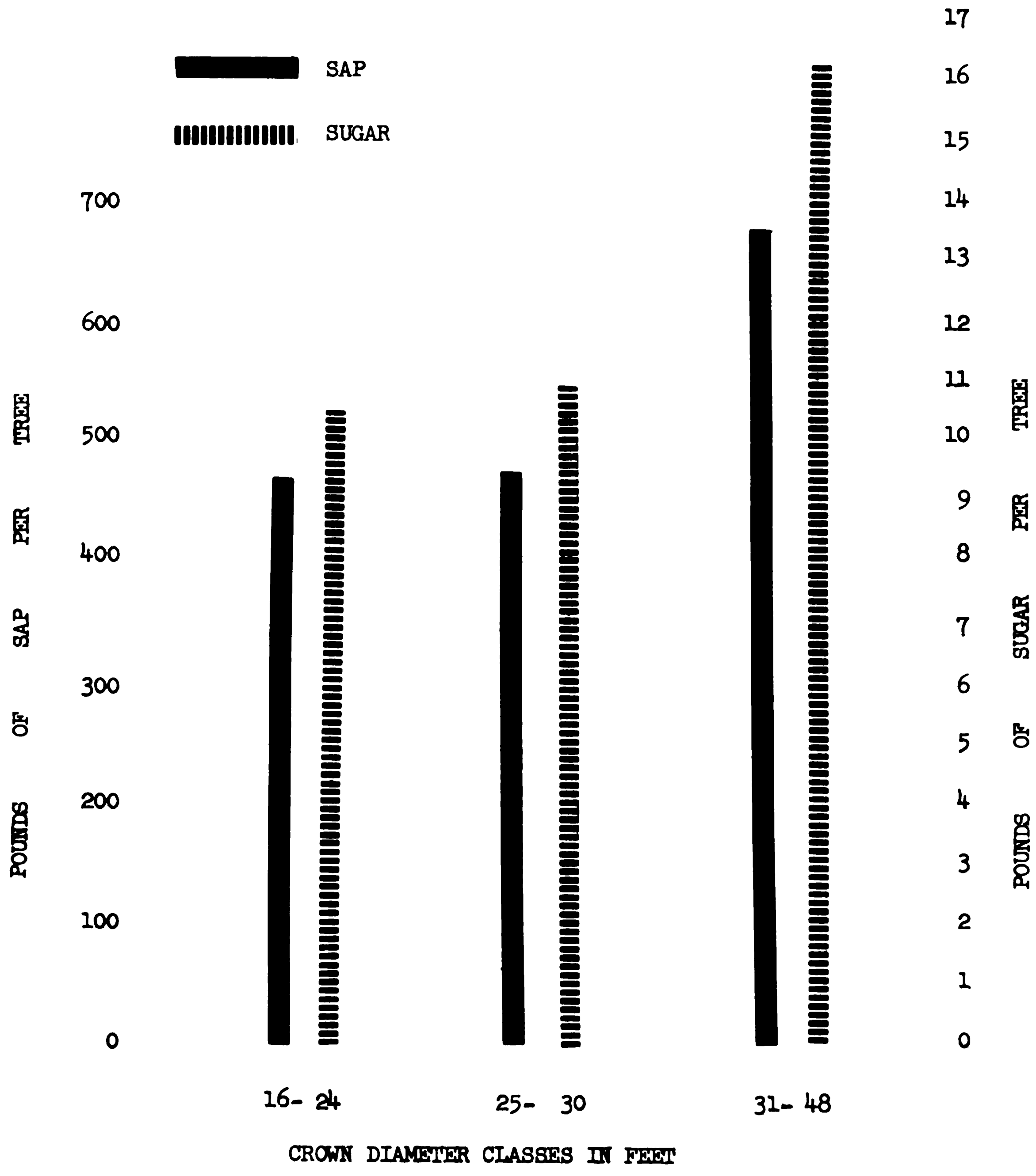



FIGURE 7

# EFFECT OF CROWN AREA ON THE YIELDS OF MAPLE SAP AND SUGAR

The squares of the crown diameter, as an approximate value of the crown area, of 52 trees were included in a simple correlation analysis to determine the degree of correlation between crown area and the yields of sap and sugar. Table 1 shows that positive correlation exists between crown area and the yields of sap and sugar. There was no significant correlation between crown area and sap yields. The same table shows that the correlation between the crown area and sugar yield is as significant as that between crown diameter and sugar production.

Crown area of a sugar maple tree has approximately the same significant effect on the yield of sugar as that of crown diameter. Although positive, the correlation between crown area and the sap yields was not significant.

# COMBINED EFFECT OF D.B.H., HEIGHT, CROWN DIAMETER, AND LIVE CROWN RATIO ON THE YIELDS OF MAPLE SAP AND SUGAR

In an effort to determine the combined effect of d.b.h., height, crown diameter, and live crown ratio on the yields of sap and sugar for 52 trees for the three-year period (1953-1955), a multiple correlation analysis was conducted. From Table 7 the following relationships are noted:

A. The expected yield of sap or sugar can now be predicted, using a multiple regression equation (sometimes called the prediction equation) as follows:

$$\hat{Y} = A + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 \pm S_{\bar{y}}$$

where

$\hat{Y}$ = expected yield

$A$ = Y intercept on x

$b_i$ = partial regression coefficients

$x_i$ = tree characteristics (d.b.h., height, etc.)

$S_{\bar{y}}$ = standard error of estimate.

To illustrate, let us assume that a particular tree in Baker Woodlot has the following characteristics:

TABLE 7. Summary of the multiple correlation analysis, based on 3-year total sap and sugar yields of 52 trees

| Product (pounds) | Y intercept on $x_i$ | Partial regression coefficients of y on $x_i$ — Regression of the yield on: d.b.h./10 | height | crown diameter | live crown ratio | Standard error of estimate | Multiple correlation coefficient | Coefficient of determination |
|---|---|---|---|---|---|---|---|---|
| | A | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $S_{\bar{Y}}$ | R | $R^2$ |
| sap | 216 | 3.54 | -2.47 | 1.01 | 4.97 | 177 | .439 | .193 |
| | | ∓1.59 | ∓2.43 | ∓5.24 | ∓2.07 | | | |
| sugar | 2.59 | .11 | -.10 | .05 | .04 | 4.33 | .565 | .319 |
| | | ∓.03 | ∓.05 | ∓.11 | ∓.05 | | | |

d.b.h. = 15.0 inches

height = 80.0 feet

crown diameter = 30.0 feet

live crown ratio = 60.0 percent

Insertion of these data and factors from Table 7 results in a prediction equation for the sap yield of this tree as follows:

$$\hat{Y} = 216 + 3.54(150) - 2.47(80) + 1.01(30) + 4.97(60) \mp 177$$
$$= 216 + 531 - 198 + 30 + 298 \mp 177$$
$= 700$ to $1054$ pounds of sap for a three-year period, or 233 to 351 pounds annually.

Likewise, sugar production of the same tree is predicted as follows:

$$\hat{Y} = 2.59 + .11(150) - .10(30) + .05(30) + .04(60) \mp 4.33$$
$$= 2.59 + 16.50 - 8.00 + 1.50 + 2.40 \mp 4.33$$
$= 10.66$ to $19.32$ pounds of sugar for a three-year period, or 3.55 to 6.44 pounds annually.

B. The multiple correlation coefficients, R, for sap and sugar were found to be significant at 1% and .1% levels, respectively.

C. The coefficients of determination, $R^2$, for maple sap and sugar in this woodlot are 19.3% and 31.9%, respectively.

This means that only about 19% of the sap and about 32% of the sugar yields are determined by the four tree characteristics studied. The remaining variability in sap and sugar yields is subject to genetic, soil, climatic and unknown factors (29).

The coefficients of determination for a definite set of factors vary from one place to another depending upon the conditions of sugar bushes in different locations. Morrow (29) reports that live crown ratio and crown diameter combined accounted for 21 percent, 8 percent, and 38 percent of the variation in sugar percentage in three different sugar bushes with various degrees of crown closure.

D. This multiple correlation analysis was employed in the hope of obtaining better results for the prediction of sap and sugar yields than by employing a simple correlation involving data pertaining to d.b.h. only. In order to show whether this objective was achieved, a t-test is necessary. Computations for this test are as follows:

$r_1$ = .419 = correlation coefficient between d.b.h. and sap yield (see Table 1)

$r_2$ = .439 = multiple correlation coefficient of four factors with sap yield (see Table 7).

$$s_{r_1} = \frac{1 - r_1^2}{\sqrt{n-2}} \qquad s_{r_2} = \frac{1 - r_2^2}{\sqrt{n-2}}$$

$$= \frac{1 - (.419)^2}{\sqrt{50}} \qquad = \frac{1 - (.439)^2}{\sqrt{50}}$$

$$= .118 \qquad = .114$$

$$s_{(r_1 - r_2)} = \sqrt{s_{r_1^2} + s_{r_1^2}}$$

$$= \sqrt{(.118)^2 + (.114)^2}$$

$$= \sqrt{.0265}$$

$$= .163$$

$$t = \frac{r_1 - r_2}{s_{(r_1 - r_2)}} = \frac{.419 - .439}{.163} = .122$$

The difference between the multiple correlation coefficient (with four factors) and the correlation coefficient of d.b.h. with sap yield was not significant. To be significant, the computed t at 5 percent level and 50 d.f. must have the value of 2.0.

The same procedure is followed to determine whether a significant improvement in predicting sugar yield was obtained by the multiple correlation analysis than by employing a simple correlation involving d.b.h. data only.

$r_1$ = .499 = correlation coefficient of d.b.h. with sugar yield.

$r_2$ = .565 = multiple correlation coefficient of four factors with sugar yield.

$$s_{r_1} = \frac{1 - r_1^2}{\sqrt{n-2}} \qquad\qquad s_{r_2} = \frac{1 - r_2^2}{\sqrt{n-2}}$$

$$= \frac{1 - (.499)^2}{\sqrt{50}} \qquad\qquad = \frac{1 - (.565)^2}{\sqrt{50}}$$

$$= .106 \qquad\qquad = .096$$

$$s_{(r_1 - r_2)} = \sqrt{s_{r_1^2} + s_{r_1^2}}$$

$$= \sqrt{(.106)^2 + (.096)^2}$$

$$= \sqrt{.0204}$$

$$= .143$$

$$t = \frac{r_1 - r_2}{s_{(r_1 - r_2)}} = \frac{.499 - .565}{.143} = .461$$

The difference between multiple correlation analysis involving four factors and a simple correlation involving d.b.h. in predicting sugar yields is not significant.

The yields of sap and sugar can be predicted from data pertaining to d.b.h., height, crown diameter and live crown ratio of the sugar maple trees. However, the prediction formula, due to a large margin of error expressed by the standard error of estimate, is of little use.

The d.b.h., height, crown diameter, and live crown ratio are significant factors in determining the yields of sap and sugar, even though they account only for 19% of sap and for about 32% of the sugar yields.

# SUMMARY AND CONCLUSIONS

This study was designed to determine the relationship which exists between tree characteristics namely, d.b.h., basal area, height, volume, live crown ratio, crown length, crown diameter, and crown area, on the one hand, and the yields of sap and sugar on the other.

Tree measurements for 52 trees relative to the eight tree characteristics were made in 1952. Maple sap and sugar yields of these trees were gathered for three consecutive seasons (1953 through 1955). The experimental area is located in Baker Woodlot on the campus of Michigan State University.

In order to obtain maximum information about the effect of tree characteristics on the yields of sap and sugar, the following three statistical procedures were conducted: (1) Analysis of variance, in which the difference in sap and sugar means of d.b.h. and crown diameter classes were tested. (2) Simple correlation analysis, to determine the correlation that exists between each of the eight tree characteristics and the yields of sap and sugar. (3) Multiple correlation analysis, which included measurements of d.b.h., height, live crown ratio, and crown diameter, as well as sap and sugar yields for the 3-year period. The objectives from the last analysis were: (A) To determine how much (in percent) of sap and sugar was influenced by the four tree characteristics involved. (B) To determine whether the multiple correlation analysis including four tree characteristics will bring about superior results in predicting the yields of sap and sugar than a simple correlation analysis with d.b.h. data only.

Upon the completion of the different analyses discussed above, the following conclusions were derived:

1. Significant increases in the yields of sap and sugar are obtained from trees with larger diameters (d.b.h.) compared to those with smaller diameters. There are indications that the increase in sugar production is not attributed only to the increase in the volume of sap produced, but also to the higher sugar percentage in the sap of trees with larger diameters.

2. Significant increases in sap and sugar yields are obtained from the increased basal area of a tree. However, this increase is none other than that already expressed by d.b.h.

3. Consistent negative correlation existed between tree height and the yields of sap and sugar in the three study years, but this correlation was not significant. It will be

worth-while to further investigate the effect of tree height in an experiment specifically designed for this purpose.

4. Significant increase in the yields of sap and sugar are expected by the increased tree volume. This increase is attributed to the part which d.b.h. contributes to the increase in volume rather than to the effect of height.

5. No significant increase in the yields of sap and sugar are expected from increased crown length of a tree in this experimental area.

6. Live crown ratio was positively correlated with the yields of sap and sugar in all the three study years, but this relation was not significant except with sugar yield in 1955. Therefore, no significant increase in the yield of sap is expected by a higher live crown ratio of maple tree. However, significant increase in sugar yield may be obtained with a larger live crown ratio.

7. Significant increases in the yields of sap and sugar are obtained from trees with larger crown diameters than from trees with smaller ones. This experiment also shows that large crown diameter is equally effective in increasing sap and sugar yields.

8. Large crown area of sugar maple trees significantly increases the yields of sugar. Although crown area and sap

yields are positively correlated, the correlation is not significant.

9. The d.b.h., crown diameter, and live crown ratio are significant factors in the production of sap and sugar. These three factors, along with the total height which has a depressing effect on both sap and sugar yields, determine 19 percent of the sap yield and 32 percent of the sugar yield in this experimental woodlot.

10. From yield data relative to the four tree characteristics, it is possible to predict the yields of sap and sugar for any given tree. However, due to the large standard error of estimate for both predicted sap and sugar, the importance of the prediction formula is much minimized.

11. No significant improvement was achieved in predicting sap and sugar yields by a multiple correlation analysis involving four tree characteristics than by a simple correlation using d.b.h. data only.

12. Since the four visual tree characteristics, namely d.b.h., height, crown diameter, and live crown ratio, determine only about one-fifth of the sap yield and about one-third of the sugar yield for trees in this particular woodlot, it is of great importance to know what other factors determine the remainder of the sap and sugar yields of maple trees. Intensive

research in the effects of soil characteristics and genetic variation is suggested for future study. It may provide the answer as to how important these two factors are in determining sap and sugar yields.

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# A P P E N D I X

# APPENDIX

ANALYSIS 1. Maple sap yields for the 1953 season and diameter (d.b.h.) classes

Table of Means:

| | d.b.h. classes - inches/10 | | | |
|---|---|---|---|---|
| | < 115 | 116-130 | 131-145 | > 145 |
| Means (pounds) | 104.73 | 127.27 | 126.64 | 163.55 |

Standard deviation of the mean = 11.05
General mean = 130.55

Analysis of Variance Table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 43 | 79020.905 | | |
| Repl. | 10 | 19113.412 | | |
| Classes | 3 | 19597.275 | 6532.426 | 4.862 |
| Error | 30 | 40310.217 | 1343.677 | |

Computations for the comparison between yields for d.b.h. classes, using Studentized Range Test and standard deviation of the mean:

At 1% level:

| DF | (2) | (3) | (4) |
|---|---|---|---|
| Table value | 3.89 | 4.06 | 4.16 |
| Standard dev. mean | 11.05 | 11.05 | 11.05 |
| Least sig. diff. | 42.98 | 44.86 | 45.97 |

At 5% level:

| | (2) | (3) | (4) |
|---|---|---|---|
| | 2.89 | 3.04 | 3.12 |
| | 11.05 | 11.05 | 11.05 |
| | 31.93 | 33.59 | 34.49 |

ANALYSIS 2. Maple sap yields for the 1954 season and d.b.h. classes

Table of means:

| | d.b.h. classes - inches/10 | | | |
|---|---|---|---|---|
| | $<$ 115 | 116-130 | 131-145 | $>$ 145 |
| Means (pounds) | 237.09 | 199.64 | 198.73 | 240.18 |

Standard deviation of the mean = 31.10
General mean = 218.91

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 43 | 606829.625 | | |
| Repl. | 10 | 270508.131 | | |
| Classes | 3 | 17180.363 | 5726.791 | 0.538 |
| Error | 30 | 319141.131 | 10638.041 | |

ANALYSIS 3. Maple sap yields for the 1955 season and d.b.h. classes

Table of means:

| | d.b.h. classes - inches/10 | | | |
|---|---|---|---|---|
| | < 115 | 116-130 | 131-145 | > 145 |
| Means (pounds) | 185.45 | 190.18 | 202.82 | 276.64 |

Standard deviation of the mean = 19.01
General mean = 213.77

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 43 | 218431.719 | | |
| Repl. | 10 | 39446.230 | | |
| Classes | 3 | 59733.182 | 19911.064 | 5.009** |
| Error | 30 | 119252.307 | 3975.074 | |

Computations for the comparison between yields for d.b.h. classes, using Studentized Range Test and standard deviation of the mean:

At 1% level:

| D.F. | (2) | (3) | (4) |
|---|---|---|---|
| Table value | 3.89 | 4.06 | 4.16 |
| Standard dev. mean | 19.01 | 19.01 | 19.01 |
| Least sig. difference | 73.91 | 77.14 | 79.04 |

At 5% level:

| | (2) | (3) | (4) |
|---|---|---|---|
| | 2.89 | 3.04 | 3.12 |
| | 19.01 | 19.01 | 19.01 |
| | 54.94 | 57.79 | 59.31 |

ANALYSIS 4. Maple sap yields for three-year period (1953-55) and d.b.h. classes

Table of means:

| | d.b.h. classes - inches/10 | | | |
|---|---|---|---|---|
| | < 115 | 116-130 | 131-145 | > 145 |
| Means (pounds) | 527.27 | 517.09 | 528.18 | 680.36 |

Standard deviation of the mean = 45.44
General mean = 563.23

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 43 | 1457677.710 | | |
| Repl. | 10 | 574202.724 | | |
| Classes | 3 | 202074.455 | 67538.153 | 2.966* |
| Error | 30 | 681400.542 | 22713.348 | |

Computations for the comparison between yields for d.b.h. classes, using Studentized Range Test and the standard deviation of the mean:

At the 5% level:

| | | | |
|---|---|---|---|
| D.F. | (2) | (3) | (4) |
| Table value | 2.89 | 3.04 | 3.12 |
| Standard dev. mean | 45.44 | 45.44 | 45.44 |
| Least sig. difference | 131.32 | 137.14 | 140.77 |

ANALYSIS 5. Maple sugar yields for the 1953 season and d.b.h. classes

Table of means:

| | d.b.h. classes - inches/10 | | | |
|---|---|---|---|---|
| | < 115 | 116-130 | 131-145 | > 145 |
| Means (lbs./100) | 265.45 | 339.27 | 351.09 | 481.55 |

Standard deviation of the mean = 33.91
General mean = 359.34

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 43 | 828229.895 | | |
| Repl. | 10 | 182364.637 | | |
| Classes | 3 | 266413.342 | 88804.446 | 7.021** |
| Error | 30 | 379451.906 | 12648.396 | |

Computations for the comparison between yields for d.b.h. classes, using Studentized Range Test and the standard deviation of the mean:

At 1% level:

| D.F. | (2) | (3) | (4) |
|---|---|---|---|
| Table value | 3.89 | 4.06 | 4.16 |
| Standard dev. mean | 33.91 | 33.91 | 33.91 |
| Least sig. difference | 121.91 | 137.67 | 140.07 |

At 5% level:

| | (2) | (3) | (4) |
|---|---|---|---|
| | 2.89 | 3.04 | 3.12 |
| | 33.91 | 33.91 | 33.91 |
| | 98.00 | 103.09 | 105.80 |

ANALYSIS 6. Maple sugar yields for the 1954 season and d.b.h. classes

Table of means:

| | d.b.h. classes - inches/10 | | | |
|---|---|---|---|---|
| | < 115 | 116-130 | 131-145 | < 145 |
| Means (lbs./100) | 482.10 | 439.45 | 423.27 | 554.10 |

Standard deviation of the mean = 75.00
General mean = 474.73

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 43 | 3228552.746 | | |
| Repl. | 10 | 1259834.724 | | |
| Classes | 3 | 112690.003 | 37563.338 | 0.607 |
| Error | 30 | 1856026.956 | 61867.599 | |

ANALYSIS 7. Maple sugar yields for the 1955 season and d.b.h. classes

Table of means:

| | d.b.h. classes - inches/10 | | | |
|---|---|---|---|---|
| | < 115 | 116-130 | 131-145 | > 145 |
| Means (lbs./100) | 354.36 | 368.55 | 420.82 | 639.09 |

Standard deviation of the mean = 49.57
General mean = 445.70

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 43 | 1496987.169 | | |
| Repl. | 10 | 210642.904 | | |
| Classes | 3 | 575457.337 | 191819.116 | 7.097** |
| Error | 30 | 810886.907 | 27029.567 | |

Computations for the comparison between the yields for d.b.h. classes, using Studentized Range Test and the standard deviation of the mean:

At 1% level:

| D.F. | (2) | (3) | (4) |
|---|---|---|---|
| Table value | 3.89 | 4.06 | 4.16 |
| Standard dev. mean | 49.57 | 49.57 | 49.57 |
| Least sig. difference | 192.83 | 201.25 | 206.21 |

At 5% level:

| | (2) | (3) | (4) |
|---|---|---|---|
| | 2.89 | 3.04 | 3.12 |
| | 49.57 | 49.57 | 49.57 |
| | 143.26 | 150.51 | 154.66 |

ANALYSIS 8. Maple sugar yields for three-year period (1953-1955) and d.b.h. classes

Table of means:

| | d.b.h. classes - inches/10 | | | |
|---|---|---|---|---|
| | < 115 | 116-130 | 131-145 | > 145 |
| Means (lbs./100) | 1101.91 | 1147.27 | 1195.18 | 1690.18 |

Standard deviation of the mean = 132.50
General mean = 1283.64

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 43 | 11602151.863 | | |
| Repl. | 10 | 3337920.288 | | |
| Classes | 3 | 2471955.854 | 823985.637 | 4.268* |
| Error | 30 | 5792275.720 | 193075.705 | |

Computations for the comparison between yields for d.b.h. classes, using Studentized Range Test and the standard deviation of the mean:

At 5% level:

| | | | |
|---|---|---|---|
| D.F. | (2) | (3) | (4) |
| Table value | 2.89 | 3.04 | 3.12 |
| Standard dev. mean | 132.50 | 132.50 | 132.50 |
| Least sig. difference | 382.92 | 402.80 | 413.40 |

At 1% level:

| | | |
|---|---|---|
| (2) | (3) | (4) |
| 3.89 | 4.06 | 4.16 |
| 132.50 | 132.50 | 132.50 |
| 515.42 | 537.95 | 551.20 |

ANALYSIS 9. Maple sap yields for the 1953 season and crown diameter classes

Table of means:

| | Crown classes - in feet | | |
|---|---|---|---|
| | < 25 | 25-30 | > 30 |
| Mean (pounds) | 112.29 | 115.64 | 155.29 |

Standard deviation of the mean = 9.87
General mean = 127.74

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 41 | 75710.115 | | |
| Repl. | 13 | 24255.448 | | |
| Classes | 2 | 16015.186 | 8007.596 | 5.875** |
| Error | 26 | 35439.481 | 1363.058 | |

Computation for the comparison between yields for crown diameter classes, using Studentized Range Test and the standard deviation of the mean:

At the 1% level:

| | | |
|---|---|---|
| D.F. | (2) | (3) |
| Table value | 3.93 | 4.11 |
| Standard dev. mean | 9.87 | 9.87 |
| Least sig. difference | 38.79 | 40.57 |

At 5% level:

| | |
|---|---|
| (2) | (3) |
| 2.91 | 3.06 |
| 9.87 | 9.87 |
| 28.72 | 30.20 |

ANALYSIS 10. Maple sap yields for the 1954 season and crown diameter classes

Table of means:

| | Crown classes - in feet | | |
|---|---|---|---|
| | < 25 | 25-30 | > 30 |
| Mean (pounds) | 192.64 | 167.93 | 267.00 |

Standard deviation of the mean = 27.90
General mean = 209.19

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 41 | 551598.468 | | |
| Repl. | 13 | 193890.476 | | |
| Classes | 2 | 74456.332 | 37228.169 | 3.417* |
| Error | 26 | 283251.660 | 10894.294 | |

Computations for the comparison between yields for crown diameter classes, using Studentized Range Test and the standard deviation of the mean:

At the 5% level:

| | | |
|---|---|---|
| D.F. | (2) | (3) |
| Table value | 2.91 | 3.06 |
| Standard dev. mean | 27.90 | 27.90 |
| Least sig. difference | 81.19 | 85.36 |

ANALYSIS 11. Maple sap yields for the 1955 season and crown diameter classes

Table of means:

| | Crown classes - in feet | | |
|---|---|---|---|
| | < 25 | 25-30 | > 30 |
| Mean (pounds) | 166.79 | 189.71 | 252.43 |

Standard deviation of the mean = 20.65
General mean = 202.98

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 41 | 244982.973 | | |
| Repl. | 13 | 45718.976 | | |
| Classes | 2 | 55036.333 | 27518.170 | 4.609* |
| Error | 26 | 155227.663 | 5970.298 | |

Computations for the comparison between yields for crown diameter classes, using Studentized Range Test and the standard deviation of the mean:

At the 5% level:

| | | |
|---|---|---|
| D.F. | (2) | (3) |
| Table value | 2.91 | 3.06 |
| Standard dev. mean | 20.65 | 20.65 |
| Least sig. difference | 60.09 | 63.19 |

At the 1% level:

| | | |
|---|---|---|
| | (2) | (3) |
| | 3.93 | 4.11 |
| | 20.65 | 20.65 |
| | 81.15 | 84.87 |

ANALYSIS 12. Maple sap yields for three-year period (1953-1955) and crown diameter classes

Table of means:

| | Crown classes - in feet | | |
|---|---|---|---|
| | $< 25$ | 25-30 | $> 30$ |
| Mean (pounds) | 471.71 | 472.57 | 674.71 |

Standard deviation of the mean = 45.76
General mean = 539.67

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 41 | 1623715.356 | | |
| Repl. | 13 | 478507.331 | | |
| Classes | 2 | 383000.192 | 191500.096 | 6.532** |
| Error | 26 | 762207.807 | 29315.682 | |

Computations for the comparison between yields of sap for three crown diameter classes, using Studentized Range Test and the standard deviation of the mean:

At the 1% level:

| | | |
|---|---|---|
| D.F. | (2) | (3) |
| Table value | 3.93 | 4.11 |
| Standard dev. mean | 45.76 | 45.76 |
| Least sig. difference | 179.84 | 188.07 |

At the 5% level:

| | |
|---|---|
| (2) | (3) |
| 2.91 | 3.06 |
| 45.76 | 45.76 |
| 133.16 | 140.03 |

ANALYSIS 13. Maple sugar yields for the 1953 season and crown diameter classes

Table of means:

| | Crown classes - in feet | | |
|---|---|---|---|
| | < 25 | 25-30 | > 30 |
| Mean (pounds/100) | 287.71 | 324.64 | 447.36 |

Standard deviation of the mean = 33.04
General mean = 353.24

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 41 | 797029.614 | | |
| Repl. | 13 | 204091.618 | | |
| Classes | 2 | 195572.334 | 97786.170 | 6.398** |
| Error | 26 | 397365.662 | 15283.292 | |

Computations for the comparison between yields of sugar for three crown diameter classes, using Studentized Range Test and the standard deviation of the mean:

At 1% level:

| | | |
|---|---|---|
| D.F. | (2) | (3) |
| Table value | 3.93 | 4.11 |
| Standard dev. mean | 33.04 | 33.04 |
| Least sig. difference | 129.85 | 135.79 |

At 5% level:

| | | |
|---|---|---|
| | (2) | (3) |
| | 2.91 | 3.06 |
| | 33.04 | 33.04 |
| | 96.15 | 101.10 |

ANALYSIS 14. Maple sugar yields for the 1954 season and crown diameter classes

Table of means:

| | Crown classes - in feet | | |
|---|---|---|---|
| | $<$ 25 | 25-30 | $>$ 30 |
| Mean (pounds/100) | 523.29 | 365.93 | 597.43 |

Standard deviation of the mean = 64.44
General mean = 462.21

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 41 | 3045491.059 | | |
| Repl. | 13 | 1127125.745 | | |
| Classes | 2 | 406969.854 | 203484.927 | 3.500* |
| Error | 26 | 1511395.485 | 58130.593 | |

Computations for the comparison between sugar yields for three crown diameter classes, using Studentized Range Test and the standard deviation of the mean:

At the 5% level:

| | | |
|---|---|---|
| D.F. | (2) | (3) |
| Table value | 2.91 | 3.06 |
| Standard dev. mean | 64.44 | 64.44 |
| Least sig. difference | 187.52 | 197.19 |

ANALYSIS 15. Maple sugar yields for the 1955 season and crown diameter classes

Table of means:

| | Crown classes - in feet | | |
|---|---|---|---|
| | < 25 | 25-30 | > 30 |
| Mean (pounds/100) | 333.36 | 395.57 | 570.00 |

Standard deviation of the mean = 53.70
General mean = 432.98

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 41 | 1720802.964 | | |
| Repl. | 13 | 249714.975 | | |
| Classes | 2 | 421380.332 | 210690.166 | 5.219* |
| Error | 26 | 1049707.644 | 40373.373 | |

Computations for the comparison between sugar yields for three crown diameter classes, using Studentized Range Test and the standard deviation of the mean:

At the 5% level:

| | | |
|---|---|---|
| D.F. | (2) | (3) |
| Table value | 2.91 | 3.06 |
| Standard dev. mean | 53.70 | 53.70 |
| Least sig. difference | 156.26 | 164.32 |

At 1% level:

| | | |
|---|---|---|
| | (2) | (3) |
| | 3.93 | 4.11 |
| | 53.70 | 53.70 |
| | 211.04 | 220.91 |

ANALYSIS 16. Maple sugar yields for three-year period (1953-1955) and crown diameter classes

Table of means:

| | Crown classes - in feet | | |
|---|---|---|---|
| | $< 25$ | 25-30 | $> 30$ |
| Mean (pounds/100) | 1048.64 | 1090.14 | 1622.93 |

Standard deviation of the mean = 131.04
General mean = 1253.91

Analysis of variance table:

| Source | DF | Sum of squares | Variance | F |
|---|---|---|---|---|
| Total | 41 | 12354871.434 | | |
| Repl. | 13 | 3232209.358 | | |
| Classes | 2 | 2871805.910 | 1435908.276 | 5.973** |
| Error | 26 | 6250846.166 | 240417.742 | |

Computations for the comparison between sugar yields for three crown diameter classes, using Studentized Range Test and the standard deviation of the mean:

At 1% level:

| | | |
|---|---|---|
| D.F. | (2) | (3) |
| Table value | 3.93 | 4.11 |
| Standard dev. mean | 131.04 | 131.04 |
| Least sig. difference | 514.99 | 538.57 |

At 5% level:

| | |
|---|---|
| (2) | (3) |
| 2.91 | 3.06 |
| 131.04 | 131.04 |
| 381.33 | 400.98 |