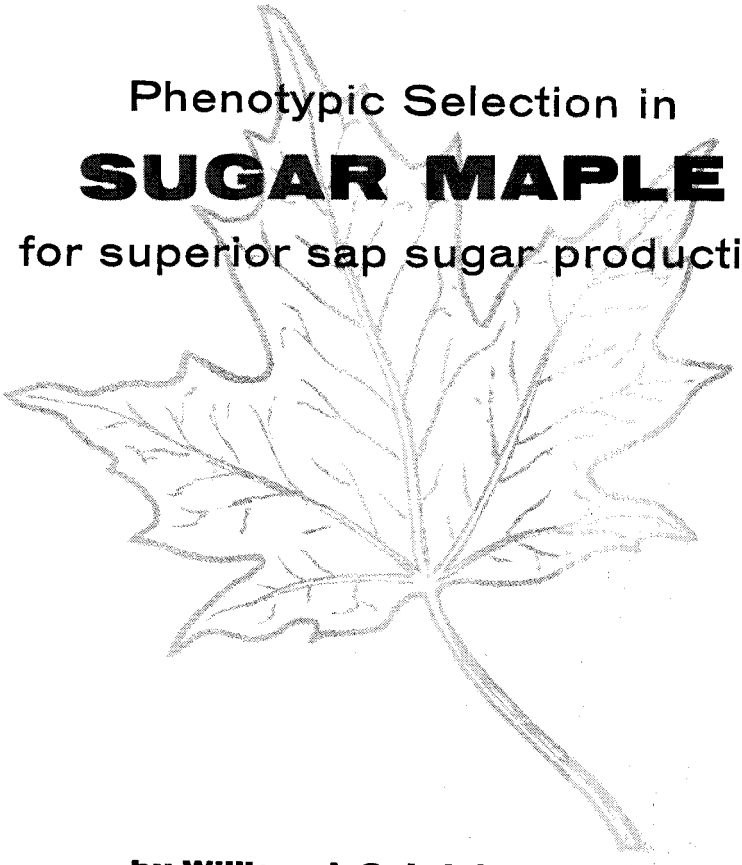
Phenotypic Selection in
SUGAR MAPLE
for superior sap sugar production



by William J. Gabriel

U.S.D.A. FOREST SERVICE RESEARCH PAPER NE-221
1972

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
WARREN T. DOOLITTLE, DIRECTOR

THE AUTHOR

WILLIAM J. GABRIEL holds a B.S. degree from the University of New Hampshire, M.F. degrees from Duke and Harvard Universities, and has completed all requirements for the Ph.D. degree at Harvard except for the thesis. A veteran of 4 years in the 8th Air Force, he worked for a year in forest genetics at the Maria Moors Cabot Foundation. In 1954, he joined the U.S. Forest Service's Northeastern Forest Experiment Station and served 2 years at the Morris Arboretum. He was transferred in 1956 to his present post as geneticist at the Experiment Station's sap production project at Burlington, Vermont.

MANUSCRIPT RECEIVED FOR PUBLICATION 18 JUNE 1971.

Phenotypic Selection in SUGAR MAPLE for superior sap sugar production

ALTHOUGH THE MANUFACTURE of maple syrup is one of our oldest industries, there is little past evidence of organized efforts for improving it. New developments have been due mainly to individual Yankee ingenuity rather than through collective efforts. Now the problems of the industry are receiving the attention of scientists in a number of states where syrup-making is of economic importance.

Our sugar maple sap production project at Burlington, Vermont, is carrying out a research program to reduce the cost of producing maple syrup. One purpose of this program is to develop strains of trees that are superior in sap sugar production.

A problem common to nearly all tree-improvement programs is to find and progeny-test superior phenotypes. It is particularly important that the selection method used will give reasonable assurance that the phenotypes owe their superiority mainly to genetic rather than environmental factors.

This is a report on the results of the sugar maple selection program at Burlington, Vermont. Because of its possible value to other forestry workers, the method used in making the selections has been treated in detail.

BACKGROUND

Previous studies in sap sugar production have dealt mainly with the relations between tree characteristics and sap sweetness.

Morrow (*1955*) considered that the open growth of trees favored increased sap volume rather than sugar content in sap. A strong correlation between sap sugar content and sap volume yield was found among trees studied by Marvin et al. (*1967*).

Anderson (*1951*), in a study of environmental effects on sap sugar content, found that crown size of trees was an important factor. Morrow (*1955*) reported that crown length was more closely related with sugar content of sap than was crown diameter, but that large variations in sap sweetness that he observed between trees were due primarily to factors other than those related to tree crowns.

Moore et al. (*1951*) noted no relation of variation in sap sugar content of trees to difference in site or other environmental factors. They suggested that the observed variation might be due to genetic influence.

The application of commercial fertilizers resulted in a significant increase in sap sugar concentration during the sap-flow season immediately after fertilization (*Watterston et al. 1963*). However, a significant decrease in the sugar content of sap was noted during the second sap-flow season.

Consistent season-to-season performances of trees in the production of sap sugar was reported by Taylor (*1956*). When trees were ranked according to sugar content in sap, the same individuals appeared in the same relative positions each year. Taylor observed that phenotypes within the same sugarbush may have sap sugar differences of more than 100 percent. Marvin (*1957*) also noted consistent year-to-year yields of sap sugar in the trees he studied and suggested that this variation was due to inherited traits.

Preliminary reports on the development of procedures used and the problems associated with the selection of sugar ma-

ples for superior sap sugar production have been made by Gabriel (*1964*) and by Gabriel and Howe (*1968*).

METHODS

Organization and Training of Fieldmen

To carry out field work, we enlisted the cooperation of state forestry and extension service organizations, educational institutions, and sugar producers in the major sugar-producing states in the Northeast—Maine, Massachusetts, New Hampshire, New York, Pennsylvania, and Vermont. Committees were set up in each state to act as liaison between the genetics staff at Burlington and the fieldmen, to help disseminate information, and to act as clearing houses for collected data.

Training of 70 participating fieldmen, primarily service foresters and extension agents, was conducted in each state. A short course in genetics was included at each training session, to give the fieldmen a better understanding of the objectives of the program and to explain why it was necessary to adhere closely to the selection method as it was outlined.

Field Selection

Information from preliminary studies provided the basis for developing procedures and criteria for making selections. It seemed best to base selections on direct differences between selected trees and the average performances of adjacent trees, rather than indirectly through comparisons with stand averages, which could be influenced by a wider variety of environmental factors.

(Using the classical approach to selection—computing an average for a population and then selecting phenotypes that exceed the average by a chosen level—would make it difficult to minimize the environmental influences on sugar production because of frequent changes in stand density, site quality, and size and age classes of trees.)

In the method finally adopted, no predetermined absolute level of sap sugar had to be met by a tree before it would qualify as a selection. With a hand refractometer (fig. 1), the trees in a sugarbush were tested along a transect until one was encountered that measured at least 0.5 percent sweeter in sap sugar than the tree previously tested.

Measurements were then made on four or five adjacent and surrounding trees of similar appearance (standards), and their average sap sugar content was computed. Any tree that met the criteria of (1) being at least 30 percent above the average of the standards and (2) exceeding the sweetest of the standards by a minimum of 0.5 percent was selected as a superior phenotype (fig. 2). The number of standards was occasionally reduced to two or three trees because of a lack of individuals similar to the selected phenotypes.

Normally, no more than 100 trees were tested in the initial visit to a sugarbush. This enabled the fieldmen to visit larger numbers of bushes and resulted in a more widespread survey of the general area and more information about variation within and between states. The data that were collected,

Figure 1.—By using a hand refractometer, only one drop of sap is required to determine the sap sugar content of the tree.

Figure 2.—The superiority in sap sugar produced by the selected tree, indicated by the arrow, ranged from 46 to 68 percent above the average of the adjacent standard trees over a 4-year period.

along with information pertinent to each sugarbush, were entered on separate forms (fig. 3).

Selected trees and their standards received several sap sugar tests, and the results were entered on individual tree-record forms (fig. 4). Tests on each selection unit (the selected tree and its surrounding standard trees) were made within the same hour to minimize any variation in sap sugar associated with time of testing. All selected trees and their standards were suitably marked and mapped for later identification.

Final Screening

Since the success of the tree-improvement program hinged on the genetic worth of the phenotypic selections, the selected trees were subjected to a critical final screening by a geneticist from the Burlington office. The primary purpose

12-63 #2

Sugarbush Number

Do not write in this space

SURVEY RECORD FORM

8c .

☐ SUGARBUSH ☐ ROADSIDE OR FENCELINE TREES

Name of Owner: Leach (Last Name) Initial Carrol (First Name)

Address: West Enosburg, Vermont

Location of Bush if different from owner's address:

100-Tree Sample

Tree No.		Tree No.		Tree No.		Tree No.		Tree No.	
1.	2.6 %	21.	3.0 %	41.	3.0 %	61.	4.0 %	81.	3.6 %
2.	2.2	22.	3.0	42.	4.0	62.	3.0	82.	3.8
3.	3.0	23.	3.0	43.	2.6.	63.	4.0	83.	3.0
4.	3.0	24.	2.0	44.	3.0	64.	4.0	84.	3.6
5.	2.8	25.	2.0	45.	2.2	65.	3.8	85.	3.8
6.	3.0	26.	3.0	46.	2.2	66.	4.6	86.	2.6
7.	5.0	27.	2.8	48.	2.0	68.	4.0	88.	3.6
8.	3.4	28.	2.8	48.	2.0	68.	4.0	88.	3.6
9.	3.0	29.	3.8	49.	3.8	69.	4.2	89.	3.0
10.	3.0	30.	3.2	50.	2.8	70.	4.0	90.	3.4
11.	2.6	31.	2.2	51.	3.2	71.	3.8	91.	3.0
12.	2.4	32.	2.4	52.	3.4	72.	4.0	92.	5.0
13.	4.0	33.	2.4	53.	4.0	73.	3.0	93.	4.0
14.	4.0	34.	3.0	54.	3.0	74.	3.0	94.	3.0
15.	3.0	35.	3.8	55.	3.0	75.	5.0	95.	3.0
16.	4.0	36.	2.8	56.	4.2	76.	4.0	96.	3.2
17.	3.4	37.	2.8	57.	3.0	77.	3.0	97.	4.4
18.	3.2	38.	4.2	58.	3.6	78.	4.0	98.	3.4
19.	3.0	39.	3.6	59.	4.0	79.	4.0	99.	3.8
20.	2.4	40.	2.0	60.	3.2	80.	2.2	100.	3.0

Date: 4-20-63 Time Started: 2:00 P.M. Time Completed: 4:00 P.M.

By J. P. Harrington Title Forestry Technician

Remarks: Sugarbush made up mainly of old, open-grown trees.

Figure 3.—Completed record showing sap sugar test data and other information pertinent to the sugarbush.

of the screening was to evaluate the selected trees and their standards in terms of their similarities and differences and to derive an index figure that would be indicative of how well they compared with each other (fig. 4). The greater their similarities, the smaller would be the index number and the more valid would be the comparison between them for sap sugar production. Thus the screening procedure was a graduated series of penalties against a field-selected tree as it departed from its standards in appearance.

Vt. (12-63); 1(14-63) — Survey Number

4 — Catalogue Number

FINAL FIELD SCREENING FORM

9a.

SUGAR MAPLES SELECTED FOR HIGH SAP SUGAR CONCENTRATION

Name of Tree Owner: Leach (Last Name) Carrol (First Name)

Address: West Enosburg, Vermont

COMPARATIVE PERFORMANCE: SELECTED TREES VS. STANDARDS

1. Sap Sugar Concentration

	Percent Sugar							
	Selected	Standards					Standard	Difference
Date of Test	Tree	1	2	3	4	5	Average	Percent
3/11/63	6.2	4.0	3.2	4.0	3.7		3.7	67
4/15/63	5.4	3.5	3.0	3.0	3.3		3.2	68
4/16/63	5.2	3.4	3.0	2.9	3.2		3.1	67
4/6/64	5.4	4.7	3.0	3.3	3.0		3.5	54
4/8/64	5.1	4.2	2.6	3.4	2.9		3.2	59
4/10/64	5.2	4.7	2.8	2.7	2.8		3.3	57
3/9/65	5.3	4.2	4.0	3.4	2.8		3.4	56
3/19/65	6.0	4.9	4.3	4.0	3.1		4.1	46
4/12/66	6.3	4.4	4.1	3.5	3.7		3.8	65

2. Environment and Morphology Comparison of Standards and Selected Tree

							Total
(1) DBH	Inches	22	22	27	23	18	
	Index		0	2	0	1	3
(2) Height	Feet	72	82	80	74	81	
	Index		1	1	0	1	3
(3) Crown			0	0	0	1	1
(4) Insect Damage			0	0	0	0	0
(5) Disease Damage			0	1	0	0	1
(6) Topography			0	0	0	0	0
(7) Distribution		0	0	0	0	0	0
						Total Index	8

(3)-(7) Only the index number is entered.

Remarks: Crown size of Standard #4 smaller than selected tree. Standard #2 has small conk on trunk. Negatives in file.

Figure 4.—Completed record showing individual performances of the selected tree and its standards, together with the final screening data.

Standard trees were scored on how near they approached the selected tree in height, diameter, crown shape, crown size, and insect and disease damage. Standards were also scored on how well they were distributed about the selected tree and on their topographic relation to the selected tree (table 1).

I realize that certain unknown factors affecting sap sugar content may not have been considered in the screening proc-

Table 1.—Criteria assigned for determining index number for characters used in screening sugar maples selected for superior sap sugar production.

Character of factor	Index No.	Limits
Diameter	0	± 0-10% of selected tree diameter.
	1	± 11-20% of selected tree diameter
	2	± 21-30% of selected tree diameter.
	3	± 31% and over selected tree diameter.
Height	0	± 0-10% of selected tree height.
	1	± 11-15% of selected tree height.
	2	± 16-20% of selected tree height.
	3	± 21% and over selected tree height.
Distribution	0	Within 0-25 feet of selected tree.
	1	Within 26-40 feet of selected tree.
	2	Within 41-60 feet of selected tree.
	3	Beyond 60 feet of selected tree.
Crown	[1]0	Completely comparable to selected tree.
Insect damage		Some variation but still considered comparable.
Disease damage	2	Considerable variation, comparability questionable.
Topography	3	Not comparable to selected tree.

[1] Criteria limits 0 through 3 assigned to each character from crown through topography.

Under Remarks on Final Field Screening Form (fig. 4), it was indicated how the standard differed from the selected tree in the last 4 characters.

ess. However, in conjunction with the data on sap-sweetness tests, the screening provided a base for eliminating those field selections that appeared to have little potential genetic value.

The characters of height and diameter and the distribution of standards about the selected trees were measured by instruments. Scoring of the remaining characters was based on the judgment of the screening geneticist. Since both the standards and the selected trees were in the same view, any

pronounced variability in these characteristics became quite apparent and was judged by eye.

RESULT AND DISCUSSION

The success of the selection method was reflected in the widespread response from personnel in each of the six participating states. Seventy fieldmen visited 279 different sugarbushes over a 4-year period. Tests for sap sugar content were made on 21,080 trees, from which 319 field selections were made (table 2), representing 1.5 percent of the trees tested.

A number of the selected trees were dropped before screening because of (1) failure to meet the selection criteria, (2) extreme morphological differences between corresponding standards, (3) an excessive amount of disease, and (4) lost field identification. In a few instances trees were lost when they were cut by the owners. Eighty-two trees were dropped from the selection roster, leaving 237 to be screened.

In the screening process, each selected tree was visited by

Table 2.—Summary of survey-selection and screening results according to state

State	Sugar-bushes surveyed	Trees tested	Field selections		Final selections[1]	
	No.	*No.*	*No.*	*Pct.*	*No.*	*Pct.*
Vermont	102	7,426	126	1.7	18	0.24
New York	72	4,896	74	1.5	15	.31
Pennsylvania	44	3,671	29	.8	7	.19
Massachusetts	35	2,537	34	1.3	6	.24
New Hampshire	18	1,952	46	2.4	5	.26
Maine	8	598	10	1.7	2	.33
Totals	279	21,080	319	—	53	—

[1] Final selections made after screening field selections.

a geneticist, and the surrounding standards were scored according to the criteria outlined in table 1. Based on the score obtained, together with the degree of superiority in sap sugar production that was shown, 53 final selections were made that will serve as sources of parent and clonal stock in our improvement program. These selections are being propagated vegetatively and held in a clonal bank at Burlington.

A chi-square test applied to the data showed a significant difference between states in the number of field selections that were made. An examination of the data indicated that most of the variability could be assigned to New Hampshire and Pennsylvania, where the percentages of tested trees selected were respectively the highest and lowest of the six participating states.

A low correlation found between rankings of states for percentage of field selections and for final selections made would indicate that variation between states in trees qualifying as field selections was probably due mainly to variations in the application of the selection method by the fieldmen.

During the sap season, a change was observed in the pattern of variation among trees. In a number of instances the differences between selected and standard trees in sap sugar levels gradually dropped below the level of the selection criteria. In some cases, the average sweetness of the standards exceeded those of the selected trees. Although many of the selected trees maintained their high degree of superiority throughout the season, in nearly all selection units there was a gradual reduction in selection differentials. It is conceivable that this reduction is associated with the increasing amount of sucrose, a compound sugar, that becomes hydrolized as the sap season progresses.

SUMMARY

A program for the selection of superior sugar-producing phenotypes of sugar maple was carried out in the six-state area of Maine, New Hampshire, Vermont, Massachusetts, New York and Pennsylvania.

Selection procedures were designed to minimize the effects of environmental factors and were easily understood and applied by fieldmen. The screening method provided for graduated penalties against selections. As the corresponding standard trees that were used for comparison departed from the selected tree, the latter became a less desirable candidate.

Seventy fieldmen visited 279 sugarbushes over a 4-year period, during which 21,080 trees were tested and 319 selections were made. A rigid screening applied to the selections reduced this number to 53 final trees. These trees are being propagated vegetatively by grafting at Burlington, Vermont.

The differences observed between states in the percentage of tested trees that qualified as field selections were related more to the differential application of the selection method by fieldmen in the various states than to genetic influences.

■

LITERATURE CITED

Anderson, W. R.
1951. OPEN CROWN MAPLES ARE BASIS FOR PROFITABLE SUGAR OPERATION. Ohio Farm and Home Res. 36: 51, 62-63.

Gabriel, W. J.
1964. SELECTION OF SUGAR MAPLES FOR HIGH SUGAR CONTENT IN SAP — DEVELOPMENT OF PROCEDURES. NE. Forest Tree Improve. Conf. Proc. 11: 8-11.

Gabriel, W. J., and G. E. Howe.
1968. PRACTICAL PROBLEMS OF A SUGAR MAPLE SELECTION PROGRAM. NE. Forest Tree Improve. Conf. Proc. 15: 72-74.

Marvin, J. W.
1957. INVESTIGATIONS OF THE SUGAR CONTENT AND FLOW MECHANISM OF MAPLE SAP. Tappi 40(4): 209-216.

Marvin, J. W., M. Morselli, and F. M. Laing.
1967. A CORRELATION BETWEEN SUGAR CONCENTRATION AND VOLUME YIELDS IN SUGAR MAPLE—AN 18-YEAR STUDY. Forest Sci. 13(4): 346-351.

Moore, H. R., W. R. Anderson, and R. H. Baker.
1951. OHIO MAPLE SYRUP — SOME FACTORS INFLUENCING PRODUCTION. Ohio Agr. Exp. Sta. Res. Bull. 718, 53 pp.

Morrow, R. R.
1955. INFLUENCE OF TREE CROWNS ON MAPLE SAP PRODUCTION. N.Y. Agr. Exp. Sta. Bull. 916, 30 pp.

Taylor, F. H.
1956. VARIATION IN SUGAR CONTENT OF MAPLE SAP. Vt. Agr. Exp. Sta. Bull. 587, 39 pp.

Watterston, K. G., A. L. Leaf, and J. H. Engelken.
1963. EFFECT OF N, P, AND K FERTILIZATION ON YIELD AND SUGAR CONTENT OF SAP OF SUGAR MAPLE TREES. Soil Sci. Soc. Amer. Proc. 27(2): 236-238.

■

☆U.S. GOVERNMENT PRINTING OFFICE: 1972-706-727/263

THE FOREST SERVICE of the U. S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.