PHENOTYPIC VARIATION OF SAP SUGAR CONTENT IN *ACER SACCHARUM* FROM WISCONSIN

by Christy Hauge, University of Wisconsin Extension, Stevens Point, Wisconsin, 54481; Chen H. Lee, University of Wisconsin, Stevens Point, Wisconsin 54481; Raymond P. Guries, University of Wisconsin, Madison, Wisconsin 53706

Abstract.-- Two sugarbushes (natural stands) in Central Wisconsin were selected for sap sugar assessment *in situ* over five sap seasons 1980 through 1984. Crown size, dbh and tree height were also measured to permit simple correlation analyses with sap sugar content. Sap sugar content ranged from 1.1 to 14.0% in Wisconsin trees and this amount of variation appears large enough to warrant genetic improvement efforts. Sap sugar variation followed the normal curve pattern in both sugarbushes in all five sap seasons. Our findings are comparable to those reported from the northeastern United States. Between-stand differences in mean sap sugar content were not significant. However, the year-to-year variation in mean sap sugar content (2.84 to 4.45% for the Marathon County stand and 2.82 to 4.33% for the Langlade County sugarabush) was statistically significant. Year after year, "sweet trees" generally remained "sweet". On the other hand, the sap sugar vs morphological character correlations were statistically significant in some years but non-significant in other years. Silvicultural techniques which modify crown characteristics or increase crown size appear to be useful for increasing sap sugar concentration in some years.

Additional keywords: Sugar maple, genetic improvement, crown size.

INTRODUCTION

Sugar maple (*Acer saccharum* Marsh.) is the state tree of Wisconsin. It is characterized by a moderate growth rate, a relatively long life-cycle and a dense, fine-grained wood. In the northern hardwood forest type, sugar maple is a major species accounting for over 1 million acres in Wisconsin. Of the 26 billion board feet of sugar maple sawtimber growing in the United States (Quigley et al., 1968), Wisconsin ranks fourth in volume (over 1 billion board feet). Sugar maple lumber is also valued by the furniture industry. It is also a common, attractive shade tree throughout the Lake States and Northeast U.S.

Sugar maple is the principal source of maple syrup and maple sugar, one of this country's unique agricultural commodities. Wisconsin is a leader in the production of maple syrup; 125,000 gallons of syrup were produced in 1981 alone. At a retail price of $20 per gallon, this represented $2,500,000 in supplementary income for Wisconsin farmers.

The bulk of sugar maple research has been centered in the Northeast U.S. (especially Vermont), and Ohio. In the Lake States, only Michigan State University has a progeny test plantation established at the Kellogg Forest, Augusta, Michigan containing 46 high sugar-yield families. Unfortunately, Wisconsin has had no active research program for sugar maple improvement. The development of genetically improved sugar maple for syrup production could boost an opportunity for the economic welbeing of farmers and landowners in rural areas.

REVIEW OF PAST WORK

There is limited information on maple syrup production available for Wisconsin growers, most of which is concerned with tapping of trees, syrup collection, processing and grading of syrup and related marketing issues. Biological and genetic aspects of sugar maple research remain unexplored. Previous work on sugar maple improvement in North America can be summarized in the following four areas:

<u>The Study of Genetic Variation</u>: A knowledge of the extent and the pattern of variation is required in any tree improvement program. Earlier studies in New England have demonstrated that sizable variation in sap sugar content exists (Taylor, 1956; Gabriel, 1971; Gabriel et al., 1976), and differences among trees are consistent year after year (Taylor, 1956). In Ohio, at least half of the variation in sap sugar content measured in a limited progeny test appeared to be genetically controlled (Kriebel, 1968). Seasonal variation of sap sugar content from the same tree existed but "sweet trees" were consistently "sweet trees" over years (Marvin et al., 1967).

Other significant maple research findings in the Northeast U.S. include a significant correlation between sap flow and total sap volume production and a strong sap volume and sap sugar content relationship (Blum, 1971; Marvin et al., 1967). This implies that high sugar content and high sap yield can be found in the same tree, and that it is possible to improve the two important sap properties in sugar maple simultaneously.

<u>Selection Criteria</u>: Although the physiological mechanism responsible for high sap sugar and high sap volume is not well understood, large crowns characteristic of open-grown or roadside trees are accepted as a dependable indicator for selecting the sweet trees (Gabriel, 1973; Kriebel, 1960; Lancaster et al. 1974; Marvin, 1968; Moore et al., 1951; Morrow, 1955). In Vermont, sugar content averaged 2.25% and 3.72% for forest-grown and roadside trees, respectively.

Vegetative Propagation of Select Trees: Sugar maple has been difficult to propagate vegetatively. The current-year shoot can be rooted successfully by treating cuttings with plant growth hormones. Extensive among-tree variations in rooting response (from 1.4 to 46.1%) was observed (Donnelly, 1971; Gabriel et al., 1961; Yawney et al., 1982) and large shoots (longer cuttings) were found to root better than smaller ones (Donnelly, 1977). In Vermont, early June is recommended for collecting the cuttings (Donnelly, 1977) at a time when the current-year shoot has attained its maximum development. Difficulties with overwinter survival of rooted cuttings presents another problem, however. Atkinson (1963) and Yawney al. (1982) found that more than 3 weeks of chilling treatment would be necessary to improve the survival.

Clonal differences in sap sugar content are well recognized and the within-clone (or between-ramet) variation was also found to be extensive (Demeritt, 1985; Santamour, et al. 1964). Furthermore, they suggested the existence of a strong influence of rootstock on the performance (sap sugar content) of the grafted scions.

The Production of Improved Material: The final goal of any tree improvement program is to secure adequate quantities of improved planting material to meet the market demand. In Ohio, a bumper crop of improved sugar maple seeds was experienced in 1984 and they were favored and in a strong demand among farmers in Ohio (personal communication with Dr. Daniel Houston, Ohio Agricultural Research Development Center, Wooster, Ohio). Research findings from Northeast U.S. and Ohio provide a valuable source of information for maple syrup researchers and farmers in Wisconsin. The initiation of Wisconsin improvement programs will be made easier becasue of these findings. However, they will not be totally applicable due to differences between the two regions.

MATERIAL AND METHODS

The purpose of this study was to assess the pattern and magnitude of variation in sap sugar content in two Wisconsin sugarbushes. The information is important to provide a basis for future sugar maple improvement work for high sugar yield.

One hundred twenty-three maple trees were selected from a wild sugarbush in Marathon County (Section 3, T24N, R10E) and another set of 209 trees was selected from a separate sugarbush in Langlade County (Section 22, T30N, R11E), Wisconsin in 1980. The two sugarbushes are less than 10 kilometers apart. Each tree in both sugarbushes has been assessed for its sap sugar content using a single measurement per sap season made with a refractometer since 1980. The most recent measurement was made in spring 1984. Dbh was measured in 1980 when the study was started. In November 1984, additional morphological characteristics including total height, crown ratio (obtained by dividing crown depth by total tree height), mean crown width (average of two measurements, i. e. east-west and north-south directions)and crown surface area in square feet (assumed to be a pyramidal shape and obtained as one half of the product between mean crown width and crown depth) were evaluated on 37 select trees (with sap sugar content of 3.5% or higher) from the Marathon County sugarbush.

There were 10 mean sap sugar contents (1 mean sap sugar content/sap season/sugarbush x 5 sap seasons x 2 sugarbushes) available for an analysis of variance. They were analyzed following a randomized complete block design with 1, 4 and 4 degrees of freedom for sugarbush, blocks (sap seasons) and error term, respectively. Simple as well as multiple regressions were examined between sap sugar content and those morphological characteristics. The year vs year correlations in sap sugar content were also investigated to determine whether "sweet trees" were consistently "sweet trees".

RESULTS AND DISCUSSION

The distribution curves of sap sugar content were prepared individually by sap seasons and separately for each sugarbush. Each approximated a bell-shaped normal curve (on file in the Department of Forestry, University of Wisconsin-Madison, available on request). The range of sap sugar content in individual trees was from 1.1 to 14.0%. Ninety-five percent of the trees in each stand had sap sugar contents ranging between 2.3 and 8.1% most years. We believe this range of variation is large enough to warrant a genetic improvement effort in Wisconsin.

The between-stand (sugarbush) differences in mean sap sugar content were not statistically significant (Table 1). The two sugarbushes are separated by only 10 kilometers in distance and are on similar site. On the other hand, the variations in sap sugar content among different sap seasons were significant at the 5 percent level (F = 15.108) supportive of the earlier Vermont studies (Taylor, 1956). The powerful influence of environmental factors (especially microsite factors) on the phenotypic expression of maple trees is very real and can not be ignored.

Do "sweet trees" remain persistently sweet year after year? We examined the year vs year correlations using individual sap sugar measurements as items in the analyses with 121 degrees of freedom for the Marathon County sugarbush and 207 degrees of freedom for the Langlade County maple stand. The correlation coefficients were all statistically significant at the 1 percent level (Table 2). In general, trees with high sap sugar content continued to behave as sweet trees from one sap season to another. This trend is regarded as encouraging because future genetic work will be easier if the select trees are consistent in their performance. A similar trend was found with the Vermont maple trees (Marvin et al, 1967).

Reliable criteria leading to the identification, screening and testing of high sugar yield maple trees need to be defined. Results of the Vermont studies (Gabriel, 1972; Gabriel et al. 1976) stressed the importance of the quality of tree crown. Large and vigorous crowns were considered to be a reliable predictor for high sugar yield. We selected 37 trees from the Marathon County sugarbush with 3.5% or higher in mean sugar content. Their ranges in dbh, total height, crown depth, % crown ratio, crown width and crown surface area were 3.1 to 24.3 inches, 33 to 91 feet, 22 to 74 feet, 57 to 88%, 13.7 to 44.5 feet and 151 to 1,402 square feet, respectively. Each of these characteristics was used to run a simple regression analysis with sap sugar content (Table 3) as the dependent variable. All but one trait (i. e. % crown ratio) were useful predictors for high sap sugar in some sap seasons but were unreliable in other seasons. When two or more of those morphological traits were combined in multiple regression analyses, no improvement over the simple regression in the efficiency of predicting the performance of maple trees was obtained. Five-year average sap measurements were no more consistently predictable than single sap season measurements.

The inconsistent relationships between the growth traits and sap sugar content present a problem hindering an efficient identification and screening of sweet trees from mediocre ones. A single measurement per sap season adopted in our study did not seem sufficient. Wilkinson (1985) was in favor of more concentrated measurement efforts per sap season. This refinement in sap sugar measurement tactics needs to be evaluated in Wisconsin.

The age of individual trees was not determined in either sugarbush. Results of the present study contributed to the understanding of the magnitude of variation in sap sugar content in Wisconsin. However, the genetically controlled portion of the total variation in % sap sugar remains to be determined in the future. The effectiveness of silvicultural treatments such as spacing manipulation (planting fewer trees per acre and thinning, etc.) and fertilizer application over genetic effort or vice versa seems warranted for further investigation.

ACKNOWLEDGEMENT

This project was funded through the University of Wisconsin System Agricultural Consortium Grant. We would like to express our gratitude for its most generous support.

LITERATURE CITED

Atkinson, O. R. 1963. Vegetative propagation problems with sugar maple. Proc. 11th Northeast For. Tree Improve. Conf. pp 12-15.

Demeritt, M. R. Jr. 1985. Sap-sugar content of grafted maple trees. USFS Res. Note NE-328, 4p.

Donnelly, J. R. 1971. Individual tree differences confound effects of growth regulators in rooting sugar maple softwood cuttings. USFS Res. Note NE-129, 6p.

Donnelly, J. R. 1974. Shoot size significantly affects rooting response of sugar maple softwood cuttings. USFS Res. Note NE-184, 4p.

Donnelly, J. R. 1977. Morphological and physiological factors affecting formation of adventitious roots on sugar maple stem cuttings. USFS Res. Note NE-365, 5p.

Gabriel, W. J. 1971. One-parent progeny test of sugar maples selected for superior sap sugar production -- early results. Proc. 19th Northeast For. Tree Improve. Conf. pp 12-16.

Gabriel, W. J. 1973. Phenotypic selection of sugar maples for superior sap volume production. Proc. 21st Northeast For. Tree Improve. Conf. pp 19-26.

Gabriel, W. J., J. W. Marvin and F. H. Taylor. 1961. Rooting greenwood cuttings of sugar maple -- effect of clone and medium. USFS Sta. Paper 144, 14p.

Gabriel, W. J. and D. W. Seegrist. 1976. Phenotypic variation in sap sugar among sugar maple stands in Northeast United States. Proc. 24th Northeast For. Tree Improve. Conf. pp 41-49.

Gabriel, W. J., R. S. Walters and D. W. Seegrist. 1972. The relationship between sap flow rate and sap volume in dormant sugar maples. USFS Res. Note NE-153, 4p.

Gunter, J. E. and M. R. Koelling. 1975. Maple sap production economics in Michigan. Mich. Agri. Exp. Sta., Mich. Sta. Univ. Res. Rep. 274, 18p.

Kriebel, H. B. 1960. Selection and testing for sugar yield in _Acer saccharum_. Proc. 5th World For. Congr., Seattle, Wash. Vol. 2: 750-753.

Kriebel, H. B. 1968. Tree improvement -- present status and recommendation for future research. IN: Proc. Sugar Maple Conf., Mich. Tech. Univ. pp 19-22.

Kriebel, H. B. and W. J. Gabriel. 1969. Genetics of sugar maple. USDA WO-7, 17p.

Lancaster, K. R., R. S. Walters, F. M. Laing, and R. T. Foulds. 1974. A silvicultural guide for developing a sugar bush. USFS Res. Pap. NE-286, lip.

Marvin, J. W. 1968. Physiology of sap production. IN: Proc. Sugar Maple Conf., Mich. Tech. Univ. pp 12-15.

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: 346-351.

Moore, H. R., W. R. Anderson and R. H. Baker. 1951. Ohio maple syrup -- some factors influencing production. Ohio Agri. Exp. Sta. Res. Bull. 718, 53p.

Morrow, R. T. 1955. Influence of tree crowns on maple sap productin. Cornell Agri. Exp. Sta. Bull. 916, 30p.

Quigley, K. R. and J. T. Morgan. 1968. Sugar maple timber resources. IN: Proc. Sugar Maple Conf. Mich. Tech. Univ., pp 3-8.

Smith, H. C. and G. M. Keiser. 1971. Testing sugar maple sap for sweetness with a refractometer. USFS Res. Note NE-138, 4p.

Santamour, F. S. and F. E. Cunningham. 1964. Variation in sugar content in a budded sugar maple. USFS Res. Note NE-17, 4p.

Taylor, F. H. 1956. Variation in sugar content of maple sap. Vermont Agri. Exp. Sta. Bull. 587, 39p.

Wilkinson, R. C. 1985. Year-to-year variation in sap-sugar concentration of sugar maple progenies and its potential effects on genetic selection for high sap sugar. Proc. 29th Northeast For. Tree Improve. Conf. pp 120-133.

Yawney, H. W. 1980. Clonal propagation of sugar maple by rooting cuttings. Proc. 27th Northeast For. Tree Improve. Conf. pp 72-81.

Yawney, H. W. and J. R. Donnelly. 1982. Rooting and overwintering sugar maple cuttings. USFS Gen. Tech. Rep. NE-72: 61-70.

Table 1. Year-to-year variation of % sap sugar content in Wisconsin sugar maple trees.

	Year				
	1980	1981	1982	1983	1984
Marathon County (123 trees)					
Mean (%)	4.45	3.51	3.34	2.84	2.92
Range (%)	2.2 - 8.0	2.6 - 5.2	2.1 - 6.0	1.8 - 5.2	1.6 - 5.0
S. D. (%)	1.057	0.578	0.704	0.542	0.636
Langlade County (209 trees)					
Mean (%)	4.33	3.14	3.82	2.97	2.82
Range (%)	2.0 - 14.0	2.0 - 5.5	2.0 - 10.0	1.9 - 6.0	1.1 - 10.0
S. D. (%)	1.353	0.625	0.929	0.641	0.748

Table 2. The significant year-to-year correlation coefficients in sap sugar content

	1980	1981	1982	1983	1984	5-year average
1980		0.497 0.667	0.373 0.642	0.367 0.670	0.383 0.694	0.778 0.908
1981			0.549 0.561	0.474 0.592	0.430 0.635	0.767 0.796
1982				0.559 0.620	0.424 0.684	0.754 0.837
1983					0.475 0.574	0.722 0.801
1984						0.701 0.846

Upper correlation coefficients = Marathon County sugarbush (121 d.f.)

Lower correlation coefficients = Langlade County sugarbush (207 d.f.)

Table 3. The sap sugar content-morphological characteristic correlations for 37 Marathon County sugar maple trees

Sap Seasons	Growth traits				
	dbh	Total tree ht	% Crown ratio	Mean crown width	Crown surface area
1980	0.637**	0.530**	0.063	0.559**	0.568**
1981	0.241	0.155	0.032	0.205	0.155
1982	0.310	0.138	0.277	0.348*	0.176
1983	0.241	0.161	0.237	0.221	0.126
1984	0.521**	0.455**	0.045	0.533**	0.536**
5-year average	0.524**	0.395*	0.126	0.498**	0.431**

$r_{.95}$ (35 df) = 0.325

$r_{.99}$ (35 df) = 0.418