SAP SUGAR PARAMETERS OF SILVER MAPLE PROVENANCES AND CLONES GROWN ON UPLAND AND BOTTOMLAND SITES

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ABSTRACT.—Sap sugar concentration (SSC), sap volume, and stem diameter were measured for 49 different silver maple clones representing a range-wide collection of 13 provenances within replicated upland and bottomland plantations in southern Illinois during the winter of 2001. For comparison, 42 sugar maple trees were sampled in a local sugarbush. Silver maple SSC averaged 1.51 percent and did not differ among sites. Differences existed among silver maple provenances and clones in SSC and sap volume but performance was site dependent. Selected silver maple clones compared favorably with local sugar maple trees which averaged 1.87 percent SSC.

Production of syrup and sugar from the sap of maple trees originated with Native Americans and was adopted by early European settlers as a source of food and income (Larsson and Jaciw 1967, Koelling and others 1996). Of the 13 native North American maple species, sugar maple (*Acer saccharum* L.) and black maple (*A. nigrum* Michx. f.) are the most preferred for commercial tapping. Their relatively high sap sugar concentration (SSC) and sap flows, which generally extend later into the spring compared to some other species, account for this bias. High sap sugar content is crucial because the majority of annual production costs are attributed to energy required in the sap to syrup concentration process (Huyler 1982).

Sugar maple tree improvement research has been focused on selecting high sap sugar trees and developing successful clonal propagation methods to rapidly multiply superior genotypes (Kriebel and Gabriel 1969, Yawney and Donnelly 1982). Sap sugar concentration of black and sugar maple averages between 2.0 to 2.5 percent (Heiligmann and Winch 1996) but may range from 1.0 to 5.0 percent or more among a local population (Walters 1982) or from 0.7 to 10.8 percent among a range-wide population of forest-grown trees (Gabriel 1972).

Genetic improvement with sugar and black maple has progressed slowly as clonal propagation methods, such as grafting, rooting cuttings, or tissue culture are generally difficult or unreliable (Atkison 1964, Santamour and Cunningham 1964, Dirr and Heuser 1987, Godman and others 1990, Zaczek and others 1997) and sexual maturity is not attained until at least 22 years of age (Godman and others 1990). Additionally, without sugar maple clones to control genotypic variability, it is difficult to clearly determine the environmental factors that influence sap sugar concentration and production.

Silver maple (*A. saccharinum* L.), with a greater natural range than sugar or black maple, is infrequently tapped for maple syrup production. This is largely attributed to its' lower average SSC (1.5 to 2.0 percent) and a shorter collection season due to earlier spring budbreak, compared to sugar and black maple (Walters 1982, Heiligmann and Winch 1996). However, in a Canadian study, silver maple SSC averaged 2.6 percent and ranged from 1.7 to 5.1 percent (Larsson and Jaciw 1967), suggesting that there may be sufficient variability within the species to make significant genetic gains through selection and propagation in a tree improvement program.

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Silver maple characteristics such as an extremely rapid growth rate, successful clonal propagation protocols, and differences in spring budbreak phenology (Kopp and others 1988, Preece and others 1991) make this species a promising candidate for genetic improvement in maple syrup production. Furthermore, clonal silver maple plantings could be used to more clearly understand and model the influences of genetics, environment, and their interaction on sap parameters in maple.

The objective of this study was to determine if there were differences in sap and size parameters among a variety of clones and provenances of silver maple trees grown on contrasting upland and bottomland sites. Additionally, silver maple SSC performance was compared to that of sugar maple.

STUDY AREAS

This research was conducted on replicated plantations of source-identified silver maple provenances and clones previously established in 1990 for biomass production studies (Preece and others 1991, Ashby and others 1993). The plantations are located in southern Illinois; one in a riparian zone (Chautauqua Bottoms) subjected to periodic flooding and one on a drier upland site (Thunderstorm Road). Each plantation was originally planted with 52 clones arising from 13 provenances, (four clones per provenance) planted in three-tree clonal plots randomly located in each of 10 blocks. Trees were planted on 2 m spacing with two border rows surrounding the plantation.

In 1995 all trees were cut to determine above ground biomass and the coppice was allowed to regrow. After coppicing, the trees developed multiple stems. In 1996, at Thunderstorm Road, in each three tree clonal plot within five blocks, coppiced trees were randomly thinned to either a single stem, to two stems, or left unthinned. Trees from five thinned blocks at Thunderstorm Road as well those within five unthinned blocks at Chautauqua Bottoms were utilized in this study of maple sap characteristics.

METHODS

In January 2001, the largest diameter tree in each three-tree clonal plot was chosen for tapping. For multi-stemmed trees the largest stem was tapped. Consequently, most of the study trees at Chautauqua Bottoms tended to be multi-stemmed whereas trees at Thunderstorm Road tended to be single-stemmed. Tapping involved drilling a 9.5 mm diameter hole on the north-facing side of trees 1.0 m above the ground in the largest stem of each chosen tree. A 1.5 ml conical centrifuge tube (Fisher Scientific, Pittsburg, PA) with the bottom cut out was used as a spile and driven into the hole with a rubber mallet. At Thunderstorm Road, total sap volume (ml) was collected by routing tubing from the spile to a sample container at the base of each tree. At Chautauqua Bottoms a 5 cm long piece of tubing was placed in the spile to allow for placement of an SSC sample tube.

At both sites, when climatic conditions were favorable for sap flow (below freezing at night and above freezing during daylight) and the majority of tapped trees exhibited flow, fresh SSC samples were collected by placing a pre-labeled 1.5 ml centrifuge sample tube on the end of the tubing. Sap samples were kept cold and returned to the lab for determination of SSC using a temperature compensated refractometer within 24 hours. A refractometer measures the total amount of solids in a solution, which has been shown to be highly correlated ($r = 0.99$) to SSC (Gregory and Hawley 1983).

Collections were made on four separate dates between 2001 January 22 and 2001 February 11. Sap volume (ml) was totaled for each tree over this same time period. Additionally, samples were collected over the same dates from sugar maple trees in a cooperators' sugaring operation located within 35 km from the silver maple plantings. In early spring of 2001, diameter (to the nearest 0.1 cm) at breast height (1.4 m above ground) of each stem of the silver maple study trees (except for those in a single block at the upland site) in the plantations was measured for use in correlation analyses against sap parameters. Sap sugar concentration was averaged for each tree over the four sample dates. Basal area (cm^2) was determined for each tapped stem. Total basal area for multi-stemmed trees was computed by summing the basal area of each stem.

Basal area and SSC of the trees were tested for significant sources of variation between sites, among provenances, among clones, and the interaction between site and provenance, and site and clone using the General Linear Model procedure of SAS (Statistical Analysis System Institute Inc., Cary, NC) at the alpha = 0.05 level. Total sap volume was tested among provenances and clones for trees at Thunderstorm Road. Type III error was used to calculate mean squares because it more conservatively partitions variance especially for design imbalances related to missing data. Because of mortality and the lack of sap production of trees in some clones, only 49 clones were used in the analysis. Means are reported using LSMEANS that adjusts for missing plot data. Sap sugar concentration and volume were tested for significant correlations to diameter, basal area, and latitude and longitude of geographic origin. Sugar maples were tested for differences in SSC among individual trees by using each of the four sap collection dates as replicates and performing an analysis of variance.

RESULTS

Out of 520 plots originally planted at both sites, 447 plots had living trees. Some clones exhibited poor survival at both sites. Those clones tended to be members of provenance 13 arising from central Ontario. At the upland site all remaining clones were represented. However, at Chautauqua Bottoms two clones from central Kansas failed to survive.

Silver maple SSC did not differ among sites ($p = 0.134$) and averaged 1.51 percent (1.53 percent at Thunderstorm Road and 1.49 percent at Chautauqua Bottoms). There were highly significant differences ($p < 0.0001$) in SSC among provenances (ranging from 1.36 percent to 1.63 percent) and among clones (ranging from 1.23 to 1.87 percent). Significant interactions between site*provenance ($p = 0.041$) and site*clone ($p = 0.010$) existed in SSC indicating variable performance and rankings of clones and provenances depending on site (table 1).

Considering individual silver maple trees, SSC ranged from 0.87 to 3.18 percent at Thunderstorm Road and from 1.00 to 2.08 percent at Chautauqua Bottoms. In comparison, there were significant differences among individual sugar maple trees ($p < 0.001$) in SSC with an average of 1.87 percent and a range from 1.13 to 3.18 percent.

Basal area (cm^2) per tree did not differ among sites ($p = 0.093$) and averaged 65.7 cm^2 per tree. There were highly significant differences ($p < 0.001$) in basal area among provenances (ranging from 34.1 cm^2 to 90.6 cm^2) and clones (from 20.3 cm^2 to 114.8 cm^2). Significant site x provenance ($p = 0.195$) and site x clone ($p = 0.343$) interactions did not exist for basal area.

Sap volume differed ($p < 0.001$) among provenances and among clones (table 1). Sap volume ranged from 0.0 to 9048 ml among clones.

When considering both sites, significant positive correlations existed between sap parameters and tapped stem diameter, tapped stem basal area, and tree basal area (table 2). SSC tended to increase with increasing longitude of the trees origin but the correlation was relatively weak (0.122). SSC was not significantly correlated with latitude. Sap volume tended to increase with decreasing latitude and increasing longitude or origin.

DISCUSSION

There was considerable variation among provenances, clones, and individual silver maple

Table 1.—*Provenance means and rankings of sap sugar concentration (SSC) and sap volume (ml) by site*

	CHAUTAUQUA BOTTOMS		THUNDERSTORM ROAD			
	SSC		SSC		Volume	
Provenance	Percent	Rank	Percent	Rank	(ml)	Rank
08 (s. central WI)	1.61	1	1.63	3	1,433	4
01 (s. central MS)	1.58	2	1.67	2	3,755	1
11 (northeast PA)	1.55	3	1.52	5	1,988	2
05 (s. central IN)	1.53	4	1.49	6	1,616	3
12 (s. central Ont.)	1.52	5	1.73	1	1,130	6
07 (s. central WV)	1.48	6	1.39	12	156	12
17 (s. central NY)	1.47	7	1.31	13	1,067	7
06 (central IA)	1.47	8	1.63	4	568	9
15 (central NH)	1.45	9	1.48	7	307	11
16 (northwest VT)	1.41	10	1.42	10	386	10
18 (southwest VA)	1.37	11	1.45	9	629	8
20 (central KS)	1.35	12	1.45	8	1,161	5
13 (central Ont.)	1.29	13	1.42	11	0.4	13
std. error	0.04		0.06		262	

trees in SSC. High sap sugar concentration is an important factor in the production of maple syrup because the majority of annual production costs are attributed to energy required to process the sap to syrup (Huyler 1982). The sugar maple sampled in this study had an average SSC (1.87) and range (1.13 to 3.18 percent) that was comparable to previous studies (Gabriel 1972, Walters 1982, Heiligmann and Winch 1996). In comparison, average SSC for silver maple was somewhat reduced at 1.51 percent which was similar to the 1.43 percent SSC that was found within a different more diverse planting of silver maple (Keeley and others 2001).

For the current study, SSC ranged from 0.87 to 3.18 percent for individual trees suggesting that gains could be made by selection. Considering that these trees had been grown at relatively high density in these plantings that restricted full crown development, the full potential of sap performance may have been limited. Additionally, the interactions between site and provenance and site and clone suggest that care must be taken when making selections for high SSC because relative performance is dependent upon site conditions.

Sap volume also varied significantly with large differences among provenances and among clones. Average sap volume per tree was relatively small but trees of this small size would not normally be tapped in a commercial maple sugaring operation. Sap volume tends to increase with increasing tree size so it should be expected that increasing sap volume should be realized as a tree grows larger at least while a tree remains vigorous and does not become decadent.

With large sugar maple trees the amount of sap volume a tree produces tends to be relatively consistent from year to year (Morrow 1952, Marvin and others 1967). Sap volume was also positively correlated with SSC (r = 0.278). Marvin and others (1967), working with sugar maple, found a stronger relationship (r = 0.708) between sap volume and SSC over 18 years. Conse-quently, selecting for trees with either superior SSC, sap volume, or basal area characteristics should indirectly select for gains in the other characteristics.

Correlations between tree size and sap parameters were significant and positive suggesting that larger trees tended to produce greater volumes of sweeter sap. Blum (1971) reported similar findings when testing three sugarbushes where sap volume was correlated with basal area (r = 0.55 ranging to r = 0.62). However, SSC and dbh was found to be weakly correlated r = 0.13 to r = 0.19 (Larochelle and others 1998) or uncorrelated (Blum 1971).

In the current study, there was a stronger relationship between the basal area of the individually tapped stem and SSC (r = 0.419) or sap volume (r = 0.583) than basal area of the entire tree and SSC or sap volume (r = 0.185 and r = 0.468, respectively). This suggests that multi-stemmed trees impart more unaccounted variability in sap parameters. Although the individual stems within a multi-stemmed tree

Table 2.—*Pearson product moment correlations coefficients (r), significance level (p), and the number of observations (n) for sap sugar concentration (SSC), sap volume, diameter at breast height of tapped stem only (dbh tapped, cm), basal area tapped stem only (BA tapped cm^2), basal area per tree (BA tree cm^2), latitude (decimal degrees) and longitude (decimal degrees)*

	Sap volume	dbh tapped	BA tapped	BA tree	Latitude	Longitude
SSC						
r=	0.278	0.396	0.419	0.185	-0.023	0.122
p=	0.001	0.001	0.001	0.001	0.622	0.010
n=	230	401	401	401	447	447
Sap volume						
r=		0.541	0.583	0.468	-0.272	0.136
p=		0.001	0.001	0.001	0.001	0.036
n=		401	401	401	447	447
Basal area per tree						
r=					-0.191	0.088
p=					0.001	0.074
n=					413	413

are indeed attached, they appear to perform somewhat independently in sap parameters.

Examining provenance rankings at the two contrasting sites (table 1) shows some provenances are relatively consistent while others vary considerably. The same is true among clones. Some clones of provenance 13 from central Ontario failed to survive at both sites perhaps suggesting that they may not be fit to the relatively warm southern Illinois climate. The five provenances listed at the bottom of table 1 were among the poorest performers when considering SSC and volume together. These sources tended to originate from the furthest reaches from the planting site and on the fringes of the range of silver maple.

In some cases, there were relationships, albeit relatively weak ones, between the latitude and longitude of origin and sap parameters and basal area further suggesting that regional climate may not be suitable for all provenances or clones. Contrastingly, some clones appear to perform well at one site and not the other suggesting that while those clones may be fit to the regional climate, site-to-site variation within the region or even microsite variation must also be carefully considered when choosing stock.

CONCLUSION

Although silver maple has not traditionally been used for maple syrup production because of lower average sap sugar concentration, this study has demonstrated that the species possesses considerable genetic variability in sap parameters with individuals that are comparable to sugar maple. Silver maple grows rapidly on a variety of sites and can be readily propagated through vegetative means. Consequently, silver maple offers great promise as a species that could be integrated into sustainable forest product systems on marginal agricultural or in riparian filters to provide tangible ecological and economic benefits to landowners.

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LITERATURE CITED

Ashby, W.C.; Bresnan, D.F.; Kjelgren, R.K.; Roth, P.L.; Preece J.E.; Huetteman, C.A. 1993. Coppice growth and water relations of silver maple. Biomass and Bioenergy. 5: 317-323.

Atkison, O.R., Jr. 1964. Vegetative propagation problems with sugar maple. In: Proceedings, 11th Northeastern Forest Tree Improvement Conference: 12-15.

Blum, B.M. 1971. Some correlations between sugar maple tree characteristics and sap sugar yields. Res. Note NE-143. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Dirr, M.A.; Heuser, C.W., Jr. 1987. The reference manual of woody plant propagation. Atlanta, GA: Varsity Press. 239 p.

Gabriel, W.J. 1972. Phenotypic selection in sugar maple to superior sap-sugar production. Res. Pap. NE-221. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Godman R.M.; Yawney, H.W.; Tubbs, C.H. 1990. In: Burns, R.M.; Honkala, B.H., tech. coords. Silvics of North America, Volume 2, Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service: 78-91.

Gregory R.A.; Hawley, G.J. 1983. Sap extraction and measurement of soluable sap sugars in sugar maple. Canadian Journal of Forest Research. 13: 400-404.

Heiligmann, R.B.; Winch, F.E., Jr. 1996. The maple resource. In: Koelling, M.R.; Heiligmann, R.B., eds. North American maple syrup production manual. Bull. 856. Columbus, OH: Ohio State University Extension: 9-17.

Huyler, N.K. 1982. Economics of open-pan evaporators. In: Sugar maple research: sap production, processing, and marketing of maple syrup. Gen. Tech. Rep. NE-72. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 79-82.

Keeley, M.T.; Zaczek, J.J; Preece, J.E. 2001. Variability of sap volume and sugar concentration among silver maple (*Acer saccharinum* L.) within upland plantings and riparian zone forests. Southeastern Biology. 48: 185.

Koelling, M.R.; Laing, F.; Taylor, F. 1996. History of maple syrup and sugar production. In: Koelling, M.R.; Heiligmann, R.B., eds. North American maple syrup production manual. Bull. 856. Columbus, OH: Ohio State University Extension: 3-8.

Kopp, R.K.; Geyer, W.A.; Lovett W.R. 1988. Silver maple seed sources for increased biomass production. Northern Journal of Applied Forestry. 5: 180-184.

Kriebel, H.B.; Gabriel, W.J. 1969. Genetics of sugar maple. Res. Pap. WO-7. Washington, DC: U.S. Department of Agriculture, Forest Service. 17 p.

Larochelle, F.; Forget, E.; Rainville, A.; Bousquet J. 1998. Sources of temporal variation in sap sugar content in a mature sugar maple (*Acer saccharum*) plantation. Forest Ecology and Management. 106: 307-313.

Larsson, H.C.; Jaciw, P. 1967. Sap and syrup of five maple species. Res. Rep. #69. Ontario Department of Lands and Forests. 62 p.

Marvin, J.W.; Morselli, M.; Laing, F.M. 1967. A correlation between sugar concentration and volume yields in sugar maple - an 18-year study. Forest Science. 13(4): 346-351.

Morrow, R.R. 1952. Consistency in sweetness and flow of maple sap. Journal of Forestry. 50: 130-131.

Preece, J.A.; Huetteman, C.A.; Ashby, W.C.; Roth, P.L. 1991. Micro- and cutting-propagation of silver maple. II. Genotype and provenance affect performance. Journal of the American Society for Horticultural Science. 116: 142-148.

Santamour, F.S., Jr.; Cunningham, F.E. 1964. Variation in sugar content in a budded sugar maple clone. Res. Note NE-174. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Walters, R.S. 1982. Sugarbush management. In: Sugar maple research: sap production, processing, and marketing of maple syrup. Gen. Tech. Rep. NE-72. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 25-37.

Yawney, H.W.; Donnelly, J.R. 1982. Rooting and overwintering sugar maple cuttings. In: Sugar maple research: sap production, processing, and marketing of maple syrup. Gen. Tech. Rep. NE-72. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 61-70.

Zaczek, J.J.; Heuser, C.W., Jr.; Steiner, K.C. 1997. Effect of shade levels and IBA during the rooting of eight tree taxa. Journal of Environmental Horticulture. 15(1): 56-60.