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Survival, Growth, and Juvenile-Mature Correlations in a West Virginia Sugar Maple Provenance Test 25 Years After Establishment

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Abstract

Survival, total height, diameter at breast height (d.b.h.), and stem quality of sugar maple trees of different provenances were compared 25 years after establishment in north-central West Virginia. Provenances were from Michigan, Minnesota, West Virginia, Massachusetts, New Hampshire, Vermont, Maine, and Quebec, Canada. There were significant differences between provenances for all traits except stem quality. By provenance, total tree height ranged from about 49 to 37 feet; d.b.h. from 6.7 to 3.6 inches; and survival from 100 to 15 percent. The predictability of total tree height 25 years after establishment based on mean provenance height at age 2, 6, 10, and 15 years is discussed. Results suggest that juvenile height growth may be a good predictor of mature height performance, thus decreasing the need for rotation-length trials.

The Author

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Cover photo: Sugar maple provenance outplanting in north-central West Virginia 25 years after establishment

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Introduction

Sugar maple (*Acer saccharum* Marsh.) is an important hardwood species of the eastern, central, and northern hardwood forests of the United States and the southern hardwood forests of Canada. The wood of sugar maple is highly valued for furniture and flooring and the sap is used extensively for the production of maple syrup. Sugar maple represents approximately 6 percent of the total hardwood volume of the United States and in most regions, the growing-stock volume is increasing (Godman and others 1990). Yet, while data are available on the genetic variability of other important hardwood species such as white ash, black walnut, and black cherry, there is relatively little information on the genetic variability of sugar maple as related to survival and growth (Kriebel 1975).

This paper reports on the West Virginia outplanting of a Northeastern Forest Experiment Station rangewide study of sugar maple. As part of this rangewide study, a sugar maple provenance test was established in north-central West Virginia in 1968. Seed sources were from throughout the Northeastern and north-central United States and Southern Canada. In part, the objectives of this study were to determine the nature and extent of genetic variation between provenances and to compare characteristics of juvenile and mature growth. At the inception of this study, characteristics of mature growth were expected to be observed in about 40 years. This paper reports 25-year growth, survival, and characteristics of stem form for sugar maple trees of different provenances, and examines the potential for predicting characteristics of mature trees from juvenile traits. High correlations between juvenile and mature traits imply that shortened breeding cycles and increased gain in genetic improvement per unit of time are possible through the selection of superior genotypes at juvenile ages.

Methods

The West Virginia sugar maple plantation was established on the Fernow Experimental Forest (39.0°N, 79.7°W) in 1968 near Parsons, West Virginia. Mean annual precipitation on the Fernow is about 58 inches and is distributed evenly throughout the year. Mean annual temperature is 48°F and the length of the frost-free season is approximately 145 days.

The study site was previously occupied by second-growth hardwoods consisting of northern red oak (*Quercus rubra* L.), yellow-poplar (*Liriodendron tulipifera* L.), sugar maple, black birch (*Betula lenta* L.), white ash (*Fraxinus americana* L.), and other hardwood species. The site index for the area averaged about 70 for red oaks. Soils in the area are mapped as Dekalb channery loam (coarse-loamy, mixed, mesic Typic Dystrochrept). The area has an easterly aspect and a slope of 5 to 15 percent. The elevation of the study area is about 2,800 feet.

In preparation for planting, the sawtimber and pulpwood were harvested and all remaining stems were felled. Brush and small stems were pushed off to the side to facilitate planting. Surface disturbance was kept at a minimum. Five contiguous blocks, each 130 by 45 feet, were laid out with the long dimension roughly parallel with the contour. Originally, 2-year-old seedlings from 14 provenances each represented by progeny from seven or eight parent trees in two-tree plots were planted at a spacing of 5 by 5 feet, bringing the total number of trees in the initial outplanting to 1,109.

This outplanting included provenances from Michigan, Maine, Massachusetts, Minnesota, New Hampshire, Vermont, New York, and Quebec, Canada (Table 1). Two naturally occurring sugar maple seedlings of about the same size as the planting stock were selected in the area immediately adjacent to each block and included as controls, bringing the total number of provenances to 15. However, their location outside of the plantation grid, unknown age, and fewer trees per provenance make their value as a control group questionable. This problem was exacerbated in 1982 when the rest of the plantation was thinned but the local source was not included in the thinning due to the fewer trees in the provenance relative to the other provenances. The thinning removed the poorest tree in each of the two-tree plots. When only one tree of a pair had survived, the surviving tree was not cut. Survival percentages reported here are not adjusted for the thinning due to the inconsistent application.

The latitude of the 15 provenances ranged from 39°N in West Virginia to 47°N in Minnesota. Longitude ranged from 70°W in Maine to 94°W in Minnesota. The elevation of the source material ranged from 350 feet in Quebec to 2,800 feet in West Virginia. The planting stock was grown in a USDA Forest Service nursery in Burlington, Vermont, for 2 years prior to being shipped to West Virginia before the beginning of the third growing season. After planting, each tree was mulched with a sheet of black plastic, 30 by 30 inches. A screen cylinder of 1/4-inch hardware cloth, 6 inches in diameter and 18 inches long was placed around each tree in the summer of 1968 to protect the stems from rodents. The protective screens were removed in 1973.

Total tree height, d.b.h., survival, and remarks pertaining to the form of the main stem were recorded periodically. Height measurements began after the second growing season; the most recent measurements were recorded at the end of the 25th growing season in November 1992. Stems with desirable form and dominant or codominant relative crown position were designated as potential crop trees at the time of the 1992 measurement. Potential crop trees were defined as dominant or codominant trees with no forks below 17 feet, and no undesirable stem form characteristics such as cankers, excessive crook, butt-log rot, birdpeck, or other characteristics that would reduce the potential grade of the butt log.

Data were analyzed by analysis of variance using linear model procedures incorporating the randomized block design with seed sources nested within provenances. Plot means of the surviving trees were used for tree height, d.b.h., and analyses of stem form (Bresnan and others 1992; Freese 1967; Rink and Kung 1991), and were

Table 1.—Identification and geographic origin of the 15 provenances included in north-central West Virginia sugar maple plantation established in 1968

Provenance	County and state	Latitude °N	Longitude °W	Elevation
				Feet
15	Ingham, MI	42.75	84.50	600-1400
17	Berkshire, MA	42.50	73.25	1500
18	Sullivan, NH	43.45	72.38	400
19	Addison, VT	43.92	72.83	900-1000
20	Lewis, NY	44.00	75.38	900
23	Franklin, ME	44.00	70.13	560
28	Iron, MI	46.25	88.55	1550
29	Quebec, Canada	46.75	71.00	350
31	Cass, MN	47.25	94.50	1300
34	Mille Lacs, MN	46.05	93.67	1300
35	Franklin, VT	44.80	72.95	600
36	Chittenden, VT	44.48	72.88	700-800
37	Rutland, VT	43.45	72.90	1550-1650
38	Bennington, VT	42.95	73.17	900-1100
39	Tucker, WV	39.07	79.67	2800

weighted by the number of trees they represented to account for unequal variances. Differences in survival and stem form were tested for after arcsin transformation of these variables. The West Virginia provenance was not included in the survival analysis since it was not thinned while the other provenances were thinned. Regression analysis was used to estimate relationships between performance factors and provenance latitude, longitude, and elevation. Data were analyzed and tested for significance at the 5 percent level unless otherwise noted. The 6- and 10-year results were reported by Wendel and Gabriel (1974, 1980) and were used for contrast where appropriate.

Results and Discussion

At the end of 25 years, analysis of variance revealed significant differences in provenance survival, total height, and d.b.h. Stem quality also was evaluated but there were no significant differences among provenances. Table 2 reports the provenance means for survival, d.b.h., total height, and stem quality. Latitude, longitude, and elevation of provenances were not correlated with provenance performance.

Seed sources nested within provenances were not significantly different for any of the traits evaluated and reflect a trend in declining variation between families within provenances. After 6 years, average height was significantly different between families within eight provenances. After 10 growing seasons, there were significant differences between families within only four of the provenances (Wendel and Gabriel 1980).

Quality

Stem quality, as in previous remeasurements, did not show significant differences related to geographic origin. Overall, stem form was fair and appeared to be improving from earlier observations, though direct comparisons are difficult due to the increased size of the trees. At age 25, approximately 27 percent of the trees qualified as crop trees. The range of values in this category included several provenances above 40 percent and several at 10 percent or less. The most common problem with stem quality was low forking. At the time of the outplanting it was noted that many of the seedlings had multiple stems, and early plantation cleanings may have promoted the persistence of these multiple stems. However, stem form was not recorded and it is impossible to determine if there was a seed-source component to the observed characteristics of stem quality until these observations were initiated in 1978. It should be noted that the seed sources in this study were selected based on sap-sugar characteristics. Observed stem-form or growth characteristics should not be interpreted as potential performance characteristics of a rangewide assessment of superior sugar maple trees with respect to form or growth rate.

Table 2.—Mean total height, d.b.h., survival, and stem quality measured as percent of crop trees for all sugar maple provenances in north-central West Virginia plantation 25 years after establishment

Location (origin)	Height	Percent of mean height	D.b.h.	Percent of mean d.b.h.	Survival	Percent of mean survival	Crop trees	Percent of mean crop trees
	Feet		*Inches*		*Percent*		*Percent*	
Chittenden, VT	48.6	109.5	6.2	119.2	41	110.8	44.2	165.5
Lewis, NY	48.6	109.5	5.8	111.5	34	91.9	40.8	152.8
Sullivan, NH	47.2	106.3	5.8	111.5	42	113.5	36.2	135.6
Berkshire, MA	46.9	105.6	5.6	107.7	34	91.9	30.2	113.1
Bennington, VT	46.8	105.4	4.8	92.3	30	81.1	33.4	125.1
Franklin, VT	46.3	104.3	5.3	101.9	39	105.4	37.8	141.6
Iron, MI	46.1	103.8	6.0	115.4	31	83.8	7.4	27.7
Addison, VT	45.5	102.5	5.1	98.1	39	105.4	22.0	82.4
Franklin, ME	44.8	100.9	5.1	98.1	23	62.2	45.0	168.5
Rutland, VT	44.7	100.7	5.5	105.8	41	110.8	24.4	91.4
Quebec, Canada	44.3	99.8	5.4	103.9	30	81.1	13.4	50.2
Cass, MN	42.4	95.5	5.4	103.9	15	40.5	30.6	114.6
Ingham, MI	42.1	94.8	4.8	92.3	43	116.2	18.8	70.4
Mille Lacs, MN	37.6	84.7	3.6	69.2	17	46.0	6.6	24.7
Tucker, WV	33.6	75.7	4.0	76.9	100	270.3	10.0	37.5
Mean	44.4		5.2		37		26.7	

Survival

Mean provenance survival was 37 percent. Survival ranged from 100 percent for the unthinned West Virginia provenance which was excluded from the analysis of variance of survival to 15 percent for the provenance from Cass County, Minnesota. The highest survival rate of the 14 thinned provenances was from Ingham County, Michigan. This provenance had a survival rate of 43 percent, 16 percent greater than the mean for all provenances. Perhaps the most noteworthy aspect of the differences in provenance survival is that both of the most westerly provenances from Minnesota also had the poorest survival.

Because full site occupancy does not occur until after crown closure, survival is not a good predictor of future performance until competitive interaction occurs between individual trees. Significant differences in provenance survival rates did not occur until 15 years after plantation establishment. At age 25, the provenance effect accounted for 60 percent of the total variation in survival in the analysis of variance. This contrasts with the 2-, 6-, and 10-year results where survival was not significantly different between provenances and overall survival was above 90 percent. A closer initial spacing would decrease the time required until competitive interaction occurs and likely would magnify differences in fitness at a much earlier age than seen here.

The differences in survival have been biased downward by the thinning that occurred after 15 years. Those sources with higher survival were thinned more heavily because they had a greater percentage of two-tree plots.

Stem Diameter

Mean provenance d.b.h. 25 years after establishment was 5.2 inches, with the largest trees originating from Chittenden County, Vermont (Table 2). This source averaged 6.2 inches and was 19 percent greater than the mean for all provenances. Provenance differences for stem diameter were significant and accounted for 44 percent of the total variation in this tract. The source from Mille Lacs County, Minnesota, had the smallest mean d.b.h. of 3.6 inches and seems poorly suited for the growing conditions of the central Appalachian region as reflected by both poor survival and growth. As expected, the results for mean provenance d.b.h. and the results for mean provenance total height were highly correlated (r = 0.78).

Total Height

Overall provenance average height was 44.4 feet at age 25. Average tree height varied significantly between provenances and the provenance effect accounted for 56 percent of the total variation in tree height. The tallest trees in the plantation originated from seed collected in Chittenden County, Vermont, and from Lewis County, New York. These trees averaged nearly 49 feet in height at age 25 and were nearly 10 percent taller than the mean for all provenances (Table 2). Average height for the local seed source was about 34 feet and was only about 75 percent of the mean total height for all provenances. These results suggest that significant improvements in height growth of sugar maple might be possible using superior trees from the correctly identified provenances. However, it is difficult to determine whether the relatively poor performance of the local provenance is due to meaningful genetic differences or to differences in experimental design previously addressed.

Phenotypic Age-Age Correlations

In this study, there were significant differences in provenance tree height at each measurement period (2, 6, 10, 15, and 25 years after establishment; Table 3). The measurements at age 2 are significantly and positively correlated with the results from age 25 ($p < 0.01$). A correlation matrix of provenance tree height reveals a highly significant but declining correlation as time lengthens from the first measurement period (Table 3). A matrix of Spearman correlation coefficients, which evaluates relative rank rather than absolute value, provides similar results. It appears that genetic differences in sugar maple are exhibited in seedling and sapling stages and persist for at least 25 years, an age that is characterized by pole-size trees. Although remaining significant, the correlations have declined consistently with age and it cannot be determined if this relationship will remain significant for an additional 50 to 75 years or until such time as end-of-rotation characteristics are realized. However, the objective is to identify only the superior provenances; the correlation of juvenile and mature characteristics of all of the provenances is not necessary.

To further evaluate the potential for seedling and sapling demonstration of genetic superiority, the provenances were stratified into rankings based on the first height measurements taken 2 years after establishment. At that time, significant provenance differences accounted for 51 percent of the total height variation, similar to the provenance effect 25 years after establishment. The provenances were stratified into three groups based on the top 20 percent (n = 3), the bottom 20 percent, and the middle 60 percent (n = 9). Although subjective, these groups were used to characterize the best and worst performers after graphical analysis of the 2-year results. The relationship between these three groups has not changed over time (Fig. 1). The provenances from Chittenden County, Vermont, and Lewis County, New York, were ranked second and third tallest after 2 years and have remained in the top category at every remeasurement period. The provenance from Berkshire County, Massachusetts, was ranked first in total height after 2 years and is currently ranked fourth in total height. Further, after 10 growing seasons, the top three provenances have remained the same without exception. Thus, while the correlation of all the provenances continues to decline with respect to total height, the tallest provenances just 2 years after establishment generally remain the tallest 25 years after establishment.

Table 3.—Correlation matrix of sugar maple mean provenance total height for 15 provenances included in a north-central West Virginia plantation established in 1968 (all relationships significant at 0.01 level)

Age (years)	Age 2	Age 6	Age 10	Age 15
6	0.812			
10	0.642	0.866		
15	0.545	0.517	0.523	
25	0.420	0.461	0.435	0.713

Conclusions

Sugar maple, an important species of the eastern hardwood forest, exhibits genetic variation in total height, d.b.h., and survival. Much of this variation appears to be related to geographic origin. Such variation could be used to enhance desirable traits through breeding programs. For such programs to be most effective, the time between subsequent generations and selection should be minimized. The minimal duration of a breeding cycle must be at least as long as the time required for establishment of consistent genetic differences among seed sources and the onset of flowering for sexual reproduction. Sugar maple usually does not flower before 22 years of age (Olson and Gabriel 1974). This factor appears to be the most limiting for minimizing the breeding cycle interval as sustained genetic differentiation in height seems to occur at a much earlier age. While early selection of breeding traits is bound to be less than perfect, the gain per unit of time may greatly accelerate the breeding process.

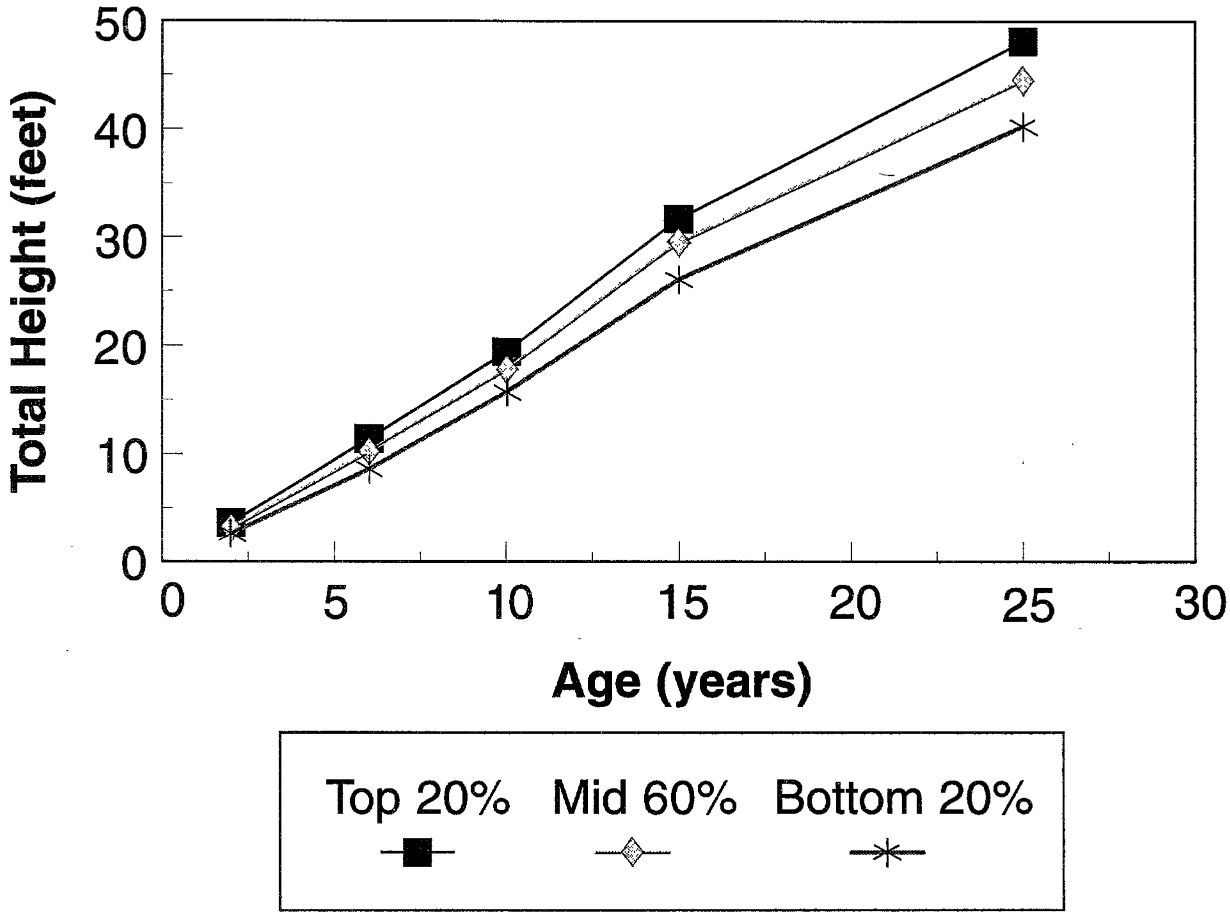

Figure 1.—Relationship between mean provenance total height and year of remeasurement. The classifications used are based solely on height measurements taken 2 years after establishment.

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Keywords: *Acer saccharum*, genetic variation, seed sources, phenotypic age-age correlations.

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