SEEDLING-SAPLING GROWTH VARIATION IN A SOUTHERN ILLINOIS BLACK WALNUT PROVENANCE/PROGENY TEST

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Abstract.--Nursery root and shoot measurements and annual height, basal diameter and survival data for the 5 years after outplanting were used to describe black walnut growth variation in southern Illinois. At age 5 sapling height narrow-sense heritability was found to be 0.49 for 131 open-pollinated families from across the black walnut commercial range. Greatest height and diameter growth was from previously identified provenances within 200 miles south of the planting site; local sources also provided good results. Although the largest seedlings in the nursery tended to remain the largest throughout the 5-year period, there was a negative correlation between nursery height and net height growth in the first year after outplanting. The best predictor of fifth-year height and basal diameter was the amount of lateral shoot growth; however, none of the correlations between fifth-year performance and first-year seedling growth traits suggested reliable prediction of future performance.

Additional keywords: *Juglans nigra*, narrow-sense heritability, variance, seed source, expected gains.

INTRODUCTION

A trend of declining availability of high quality black walnut trees (*Juglans nigra* L.) became apparent in the early 1960's and has continued to the present time. For example, between 1963 and 1980, total walnut sawtimber volume on commercial forestland declined by approximately 19 percent (Rink 1985). This increasing dearth of high quality walnut trees stimulated interest in genetic improvement of black walnut as a means of providing high quality trees in shorter rotations. Thus, a series of range-wide Midwestern provenance tests was established in 1967, an effort typical of early tree improvement programs (Bey 1979, 1980). Early results from these provenance tests were used to delimit preliminary black walnut seed collection zones throughout the species natural range (Deneke et al. 1980). We conducted a study to provide an independent test of those preliminary seed source recommendations for the southern Illinois area. An additional objective was to determine which seedling growth characteristics could be most closely associated with future growth potential.

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METHODS

The provenance/progeny test was established on the Shawnee National Forest in Hardin County in southeastern Illinois. The plantation is located on a wide floodplain of Big Creek, a tributary of the Ohio River that is subject to flash and backwater flooding. The site is on gently rolling terrain, which had been farmed for corn and annual lespedeza. Soils in the area are classified as Belknap silt loams (Parks 1975); however, this soil did not have the dark brown surface layer overlying a light brown friable silt loam typical of a Belknap soil. The soil is low in fertility (NO_3 = 40 ppm, P = 8 ppm) and in organic matter, it has a pH of 5.4, and a high available water content, and it tends to be somewhat poorly drained. Only the better drained area was used for this planting and soil probes to a depth of 1 meter did not show any subsurface mottling which would indicate poor drainage.

Seedlings of 131 open-pollinated families from 14 provenances (seed collection zones) were grown at the Indiana Department of Natural Resources Tree Nursery at Vallonia, Indiana. The seedlings were lifted as bare-root 1-0 stock in November 1980. Upon lifting from nursery beds, a random sample of 32 seedlings per family was measured for basal diameter (3 cm above the root collar), root and shoot length, and an index of root fibrosity (3 = six or more lateral roots/cm of taproot; 1 = less than three lateral roots/cm of taproot). The seedlings were stored in Kraft paper at 4° C and outplanted on March 21, 1981, with the Michigan State University Cultiplanter. Seedlings with excessive lateral roots or taproots over 25 cm long were root pruned before planting. Seedlings were planted in four-tree family row plots in a randomized complete block design with four blocks at a spacing of 2 m between trees within rows and 3 m between rows. Weed control consisted of strip-spraying the plantation early each spring with a simazine-glyphosate mix for 3 years. Height and basal diameter of each seedling were measured at outplanting and after each growing season. In addition, the lengths of first-year terminal and lateral new growth were measured and the former were used to calculate the amount of stem dieback.

Data were analyzed by univariate analyses of variance and Pearson's and Spearman's correlation analyses; data included measurements from nursery and annual measurements through age 5. Spearman's rank correlation analysis was used when non-normality was indicated (net height growth and shoot growth variables were not normally distributed). The linear model for the individual tree analyses of variance included the random effects of blocks (b), provenance or collection zones (z), and half-sib families nested within zones (f/z) as well as interactions among those terms; expected mean squares are presented in Table 1. Mean squares and variance components were obtained from Type IV sums of squares generated by the General Linear Models (GLM) Procedure of the Statistical Analysis System (SAS Institute 1979). Narrow-sense heritabilities (h^2) were calculated using the equation:

$$h^2 = \frac{4\sigma^2_{f/z}}{\sigma^2_{f/z} + \sigma^2_{(bf/z)} + \sigma^2_e}$$

Table 1.--Sources of variation, degrees of freedom, and expected mean squares in analyses of variance used for height and diameter analyses

Source of variation	d.f.	Expected mean square
Blocks	(b-1)	$\sigma^2_e + 3.09\sigma^2_{(bf)/z} + 51.90\sigma^2_{bz} + 405.42\sigma^2_b$
Seed collection zones	(z-1)	$\sigma^2_e + 3.18\sigma^2_{(bf)/z} + 27.31\sigma^2_{bz} + 9.50\sigma^2_{f/z} + 81.94\sigma^2_z$
Block x zone	(b-1)(z-1)	$\sigma^2_e + 3.21\sigma^2_{(bf)/z} + 27.51\sigma^2_{bz}$
Family/zone	(f-1)(z-1)	$\sigma^2_e + 3.23\sigma^2_{(bf)/z} + 8.79\sigma^2_{f/z}$
(Block x family)/zone	(b-1)(f-1)z	$\sigma^2_e + 3.32\sigma^2_{(bf)/z}$
Within plot	(w-1)bfz	σ^2_e

RESULTS AND DISCUSSION

Although the plantation has undergone almost annual flash flooding as well as prolonged flooding by backwaters of the Ohio River for 3 weeks in late April 1983, survival after the fifth growing season averaged 85 percent in three of the four blocks. Low survival and growth in block II due to poorer drainage precluded its use in this analysis. Similarly, height growth has also been acceptable, averaging 2.5 m at age 5 in three of the four blocks.

All effects in analyses of variance for fifth-year height and basal diameter were statistically significant ($P < 0.01$), reflecting the sensitive nature of this random effects model (Table 2). Results for height and basal diameter were very similar. In both cases more than half of total variance, expressed as a percent, was found in the within-plot error term; the only other effect with more than 10 percent of total variance was the interaction of blocks and families within collection zones. Within-plot variance of this magnitude seems to be relatively common in black walnut plantations of this age (Rink 1984; Rink and Clausen, in press) and usually indicates high potential gain from individual tree selection. High potential gain from selection is also reflected in the large narrow-sense heritabilities (0.49 and 0.38 for 5-year height and basal diameter, respectively). These narrow-sense heritabilities are higher than heritabilities for tree height of most other commercially valuable species. However, because these heritabilities are based on data from only one outplanting location, an estimate of genotype x environment interaction could not be extracted. As a result, the heritabilities may be inflated due to a presence of the genotype x environment interaction.

Variance components for collection zones and for families within zones account for between 7 and 10 percent of total variance (Table 2). These two components, directly exploited in selecting for genetic improvement, were approximately equivalent for both height and basal diameter. The implication of this result is that similar genetic gains could be achieved by selecting both the proper geographic seed source and the best open-pollinated families within the appropriate geographic area, assuming equivalent selection intensities.

Table 2.--Mean squares, variance components, variance components as a percent of total variance, and narrow-sense heritabilities (h^2) for 5-year total height and basal diameter from analysis of variance on an individual tree basis

Source of variation	d.f.	Total height Mean square	 Variance component	 Variance percent	Basal diameter Mean square	 Variance component	 Variance percent
Blocks	2	244713.2	571.4	9.0	7698.5	17.6	5.2
Seed collection zones	13	54776.8	471.9	7.5	3408.7	32.6	9.7
Block x zone	26	12333.8	123.8	2.0	592.7	4.5	1.3
Family/zone	119	10146.4	633.2	10.0	477.5	27.0	8.0
(Block x family)/ zone	235	6854.5	1007.2	15.9	359.6	44.6	13.2
Within plot	952	3509.4	3509.4	55.6	211.6	211.6	62.6
h^2				0.49			0.38

Mean 5-year heights and basal diameters for each geographic seed source are listed in Table 3. Scheffe's Method of Contrasts, used for mean separation, indicated that trees from east Tennessee provided the greatest height and diameter growth, followed by trees from west Tennessee and southern Illinois, among others. Although these are three of four collection zones recommended by Deneke et al. (1980) for planting in southern Illinois, only the east Tennessee provenance provided trees with statistically superior growth. East Tennessee trees averaged 10.5 percent taller and 13.2 percent larger in diameter than local southern Illinois trees and 20 percent taller than overall mean height. According to the Scheffe test, trees from west Tennessee were not statistically superior to local southern Illinois trees. Trees of the fourth seed source recommended by Deneke et al. (1980), southern Missouri, were statistically in the same category as the local southern Illinois trees for height but not for diameter and, therefore, are probably marginally inferior to the local source and definitely inferior to the east Tennessee provenance. As expected, the worst performance was generally by trees from origins north of the planting site (Iowa, northern Illinois, Pennsylvania, etc.). Therefore, our results support Bey (1979, 1980) in the sense that four of the seed sources with the fastest growing trees are from latitudes within 200 miles south of the planting site. We also agree with Deneke et al. (1980) in recommending that three of these sources be used as collection zones for southern Illinois.

Table 3.--Separation among geographic seed source means for 5-year height and basal diameter according to Scheffe's Method of Contrasts[1]

Seed collection zone	No. of families in zone	Mean height[1] (cm)	Mean basal diameter[1] (mm)
East Tennessee	15	286.4 a	53.0 a
West Tennessee	5	263.9 b	47.3 b
Southern Illinois	10	259.1 b	46.8 b
NE Kentucky	31	258.1 b	46.4 bc
Central Indiana	5	251.2 bc	46.6 bc
Southern Missouri	3	247.6 bc	43.2 cd
SE Kentucky	17	238.7 c	43.6 cd
Southern Michigan	21	226.5 d	37.7 e
Eastern Virginia	2	224.0 de	43.7 bcd
W. Pennsylvania	1	221.9 de	38.7 de
W. Missouri	2	220.2 de	35.9 e
Northeast Missouri	5	218.0 de	35.6 e
Northern Illinois	5	216.7 de	36.5 e
Southern Iowa	9	210.5 e	34.3 e

[1] Means followed by the same letter are not significantly different from each other at the 95 percent probability level.

Family mean correlation coefficients disclosed that seedlings from the tallest families at age 5 were also among the tallest when outplanted ($r = 0.31$), with the largest outplanting basal diameters ($r = 0.54$) and the greatest root fibrosity ($r = 0.20$). Similarly, seedlings from families with the largest basal diameters at age 5 had the largest basal diameters ($r = 0.58$), were the tallest ($r = 0.35$), and had the greatest root fibrosity (0.23) when outplanted. However, in northern red oak (Quercus rubra L.) the number of first-order lateral roots, another measure of root fibrosity, was much more highly correlated with freshly lifted nursery seedling height and diameter (Ruehle and Kormanik 1986). Fifth-year survival of black walnut was also positively correlated with outplanting height ($r = 0.28$) and basal diameter ($r = 0.23$) but not with root fibrosity. Although second- and third-year survival were correlated with increased root fibrosity ($r = 0.19$ and 0.18, respectively), this correlation is apparently dissipated by the fifth year. Our results confirm earlier observations of Williams (1972) that initial increased root fibrosity was not significantly related to fifth-year survival.

Correlation coefficients between mean fifth-year family height and height at earlier ages ranged from $r = 0.31$ at outplanting to $r = 0.96$ after the fourth year. The low early correlations for height appear to result from first-year dieback. Similarly, outplanting height was poorly correlated with outplanting basal diameter ($r = 0.31$); however, by age 3, height was closely correlated with basal diameter ($r = 0.95$). Similar correlations were obtained between the fifth-year basal diameter and earlier diameters ranging from $r =$

0.57 at outplanting to r = 0.94 at age 3. Dieback was highly correlated with outplanting height (r = 0.75) but not with basal diameter. Conversely, the first-year new shoot growth was highly correlated with outplanting basal diameter (r = 0.66) but not with height. We hypothesize that larger seedlings suffered more damage during lifting and frequently required additional root pruning at planting, which reduced the number of sites to regenerate new roots. Perhaps for the same reason large seedlings were unable to obtain adequate moisture, which contributed to the stem dieback. In contrast, the amount of new shoot growth is determined by the carbohydrates (primarily starches) stored in the taproot (Rietveld et al. 1982). Because basal diameter is closely correlated with taproot volume and taproot volume is generally not substantially reduced by root pruning (Rietveld, personal communication), large seedlings have more stored reserves available for growth of new shoots and new roots.

Although significant, none of the correlation coefficients between fifth-year performance and first-year seedling growth characteristics suggested we could reliably predict future performance. The best indicator of fifth-year height and basal diameter was the amount of new lateral shoot growth (r = 0.34 and 0.38, respectively) followed closely by the total (i.e., terminal + lateral) amount of new shoot growth (r = 0.32 and 0.35, respectively). However, first-year net height growth, dieback, and survival were not significantly correlated with either fifth-year height or diameter. Apparently first-year total shoot growth is responsive to planting site conditions whereas net height growth and dieback reflect conditions related to initial seedling size. Previously, Williams et al. (1985) found that planting site had the greatest influence on fifth-year height, followed by geographic seed origin. Effects of seedling size resulting from nursery cultural manipulations gradually disappeared. A similar pattern exists in this provenance/progeny test.

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