PERFORMANCE OF SHORTLEAF PINE PROVENANCES IN MISSOURI

David Gwaze, Jennifer Myszewski, and John Kabrick[1]

ABSTRACT.—Two shortleaf pine (*Pinus echinata* Mill.) provenance tests established by the USDA Forest Service North Central Research Station as part of the South-wide Southern Pine Seed Source Study were examined to determine the most suitable seed sources for planting in Missouri. Each test comprised seven different provenances from six to seven states in the natural shortleaf pine distribution. Significant provenance differences in survival and height growth were found in both tests and a strong north-south trend was observed. More northernly sources (New Jersey and Tennessee provenances) had the best survival and greatest height growth while southern sources (Georgia and Louisiana) had the poorest survival and lowest height growth. Regression estimates of slope indicate that New Jersey and Tennessee provenances have the highest relative growth rates. Both survival and height were highly correlated with latitude at the seed source. Results from this study suggest that the best seed sources for planting in central Missouri are not those from Arkansas, as current practice suggests, but instead are in states in the northern portion of the natural shortleaf pine distribution.

INTRODUCTION

Shortleaf pine (*Pinus echinata* Mill.), whose natural range extends from New York and New Jersey south to Florida and west to Oklahoma and Texas, is the most widely distributed of the southern pines (Fig. 1, Lawson 1990). It is the only pine species native to Missouri and its restoration there is important for mitigating chronic oak decline (Law et al. 2004). Shortleaf pine is also an important source of food and habitat for many birds and mammals, and it produces high quality sawtimber on dry, nutrient-poor sites.

Efforts to restore shortleaf pine in Missouri are ongoing, but seed supply is sometimes limited. When seedling shortages occur, Arkansas seed sources are often used in place of locally-adapted stock. It is not known whether Arkansas sources are the most appropriate non-local seed sources for planting in Missouri. However, region-wide seed transfer guidelines for shortleaf pine suggest that Arkansas sources could suffer from cold injury when planted in central Missouri.

Studies such as the South-wide Southern Seed Source Study have shown that local sources are not always the best source of planting stock for afforestation (Wells and Wakeley 1966, Wells 1983). For example, loblolly pine seed originating in Livingston Parish, LA, tends to be fast growing and more resistant to fusiform rust than other sources (Wells 1985). As a result, Livingston Parish stock has been widely planted in Georgia, north Florida, and Alabama in lieu of stock from local sources. Likewise, seeds originating on the coastal plain of North Carolina and South Carolina are frequently planted in Arkansas, where they outgrow local sources (Lambert et al. 1984).

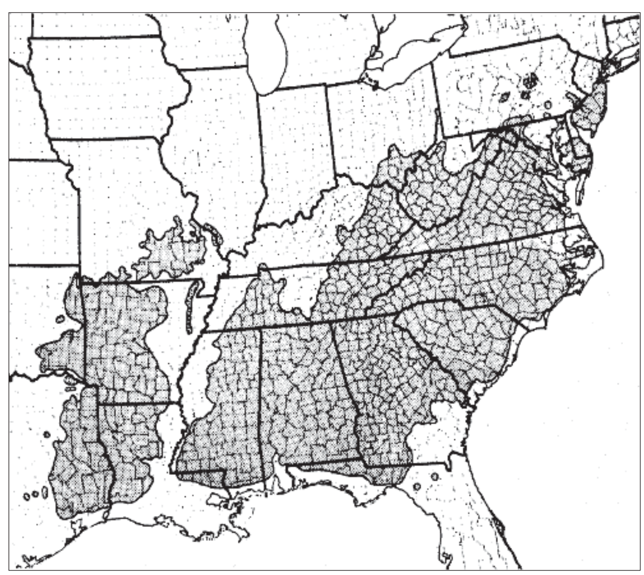

Figure 1.—Natural distribution of shortleaf pine (*Pinus echinata* Mill.) (Lawson 1990).

[1]Resource Scientist (DG), Missouri Department of Conservation, 1110 S. College Avenue, Columbia, MO 65201; Geneticist (JM), Southern Institute of Forest Genetics, 23332 Hwy. 67, Saucier, MS 39574-9344; Research Forester (JK), U.S. Forest Service, North Central Research Station, 202 Natural Resources Building, Columbia, MO 65211. DG is corresponding author: to contact call (573)882-9909 ext. 3320 or email at David.Gwaze@mdc.mo.gov

In this study, the performance of seed sources from across the natural range of shortleaf pine are compared to determine which sources are best adapted to the environmental conditions in Missouri. The stability of provenance performance across ages is also examined.

MATERIALS AND METHODS

Materials

Two Dent County, Missouri provenance tests (441 and 444) were included in this study. Both were originally established by the USDA Forest Service's North Central Research Station in collaboration with the Committee on Southern Forest Tree Improvement as part of the Southwide Southern Pine Seed Source Study. In 1951 and 1955, seed was collected from multiple sources within the eastern part of the natural range of shortleaf pine (table 1). Source locations from as far north as New Jersey, south to Georgia and west to Louisiana were selected based primarily on their average annual temperatures (which ranged from 11.7 to 19.4 °C). At each source, seed were collected from 20 or more average-appearing trees to produce a representative sample of genotypes from each location. Each source collection was then mixed together and assigned a provenance number.

Seed for the two tests were sown and bedded at the George O. White Forest State Nursery near Licking, MO. After 1 year in the nursery, bare-root seedlings were lifted and graded. Then, seedlings were root pruned to about 20 cm and the best trees were outplanted on the Sinkin Experimental Forest located 5 miles northwest of Bunker in Dent County, Missouri (Lat. 91° 15'; Long. 37° 30', Alt. 380 m above sea level). In Spring 1953, Test 441 was planted using the seed collected in 1951 and in Spring 1957, Test 444 was planted using seed collected in 1955.

Test Design and Measurement

Test 441 and Test 444 were both established using a randomized complete block design (Snedecor and Cochran 1980). For each test, there were four blocks comprising seven provenances. Each provenance was planted in square plots of 11 x 11 tree planted at 1.8 x 1.8 m spacing. To minimize edge effects, only the center 49 trees in each square plot were measured. Tests 441 and 444 were assessed at ages 1, 3, 5, 10, 15, 20, 25, and 30. Because of large differences in survival and the sensitivity of diameter to competition, only survival and height were analyzed in this study.

Table 1.—Description of the shortleaf pine provenances planted in two tests in Dent County, Missouri.

Test	Year of collection	Provenance Number	State	County/Parish	Lat. (North)	Temp.* (°C)
441	1951	429	Arkansas	Ashley	33° 02'	-11.6
		427	Arkansas	Clark	34°	-11.8
		421	Louisiana	St. Helena	31°	-8.1
		419	Mississippi	Lafayette	34° 18'	-13.8
		433	Missouri	Dent	37° 31'	-20.2
		403	New Jersey	Burlington	39° 41'	-18.9
		435	Tennessee	Morgan	36°	-16.2
444	1955	465	Georgia	Webster	32°	-9.3
		473	Louisiana	St. Helena	31°	-8.1
		485	Missouri	Dent	37° 31'	-20.2
		453	New Jersey	Burlington	39° 41'	-18.9
		457	South Carolina	Union	35°	-12.0
		487	Tennessee	Anderson	36°	-16.2
		455	Virginia	Southampton	36°	-14.1

*Average annual minimum temperature

Statistical Analyses

Using the SAS PROC GLM procedure (SAS Institute 1985), analyses of variance (ANOVAs) were used to test for significant differences in height among provenances and blocks. To increase statistical power, we used P = 0.10 for all tests. Because the two provenance tests were established in different years, the data were analyzed separately by provenance test. Where significant differences were detected among provenances, Duncan's Multiple Range Test was used to compare means.

The stability of provenance growth rates was determined by regressing the provenance mean height against the overall test mean height at each age. The slope of the regression evaluates the provenance height growth trend in relation to the average trend and can be considered as a temporal stability parameter for the given provenance (Finlay and Wilkinson 1963). A value close to 1 indicates an average trend, values over 1 indicate a higher growth rate, and values below 1 indicate a lower growth trend.

Survival was analyzed using a chi-squared test. Only survival data for ages 1 through 15 were analyzed because the tests were thinned after collection of the 15-year data. We used the Kaplan-Meier method (Kaplan and Meier 1958) to compare the survival functions of the different provenances.

To determine the importance of climatic variables, simple linear regression analyses were performed with survival and height as dependent variables and latitude as the independent variable.

RESULTS AND DISCUSSION

Provenances had significantly different mean heights at age 30 (P < 0.1, Tables 2 and 3). Height ranged from 14.4 m for the Louisiana provenance to 16.2 m for the New Jersey provenance in Test 441 and from 13.0 m for the Louisiana provenance to 15.6 m for the New Jersey provenance in Test 444. In both tests, the New Jersey provenance was significantly taller than the local Missouri provenance and the Missouri provenance was significantly taller than the Arkansas provenances.

The north-south trend is supported by a high positive correlation between height and latitude in both tests (Table 4). The superior performance of northern sources observed in this study is not consistent with the results of provenance studies in other states. In Oklahoma, Tauer (1980) found that southern sources of shortleaf pine were more productive at age 20 than northern sources of shortleaf pine. Similarly, Schmidtling (1995) and Wells and Wakeley (1966) found that seeds moved a modest distance northward out-performed seeds from local sources. According to Schimdtling (2001) seedlings will survive and grow well if they come from any area having a minimum temperature within 2.8 °C of the planting site's minimum temperature. Seedlings from an area with cooler winters will grow slower than seedlings from local sources. In our study, the provenance from New Jersey was collected on sites with annual minimum temperatures within 2.8 °C of those in Dent County, Missouri. Provenances collected in Mississippi, Tennessee, South Carolina, and Virginia came from sites within 2.8 to 8.4 °C higher than those of Dent County in Missouri. However, provenances collected in Arkansas, Georgia, and Louisiana came from sites with annual minimum temperatures 8.4 to 14 °F higher than those of Dent County, Missouri. It appears that the north-south

Table 2.—Summary of the analyses of variance for age 30 height in two shortleaf pine provenance tests in Missouri+.

Test	Source	DF	Mean Square
441	Block	3	2.5*
	Provenance	6	1.9*
	Residual	18	0.7
444	Block	3	2.4^{ns}
	Provenance	6	3.3*
	Residual	18	1.2

+Significance level: *P < 0.1; ns = not significant

Table 3.—Provenance means for age 30 height growth in two shortleaf pine provenance tests in Missouri+.

Test	Provenance Number	Provenance (Country/Parish)	HT (m)
441	429	Ashley, AR	14.9^{cd}
	427	Clark, AR	14.9^{abc}
	421	St. Helena, LA	14.4^{d}
	419	Lafayette, MS	15.9^{abc}
	433	Dent, MO	15.2^{abc}
	403	Burlington, NJ	16.2^{a}
	435	Morgan, TN	16.1^{ab}
444	465	Webster, GA	13.6^{b}
	473	St. Helena, LA	12.2^{c}
	485	Dent, MO	13.5^{bc}
	453	Burlington, NJ	15.2^{a}
	457	Union, SC	13.7^{ab}
	487	Anderson, TN	14.3^{ab}
	455	Southampton, VA	14.8^{b}

+Means with the same letter are not significantly different at the 10% level on a Duncan's Multiple Range Test.

Table 4.—Estimated regression coefficients based on linear models for survival and latitude, and height and latitude of shortleaf pine in two provenance tests in Missouri.

Test	Dependent variable	Independent variable	Regression coefficient (slope)	Residual mean square	DF	R^2
441	Height	Latitude	0.18	0.10	5	0.62
	Survival	Latitude	4.19	63.88	5	0.76
444	Height	Latitude	0.26	0.44	5	0.56
	Survival	Latitude	3.63	47.40	5	0.77

trend observed in this study is the result of moving seed to a site with much colder annual minimum temperatures.

A similar north-south trend was found in percent survival (Figs. 2 and 3). The survival functions were significantly different in Test 441 (χ^2 = 388.3, P = <0.001) and in Test 444 (χ^2 = 297.9, P = <0.001). Similarly, the chi-square test at age 15 showed significant survival differences among provenances in Test 441 (χ^2 = 27.8, P = <0.001) and in Test 444 (χ^2 = 13.9, P = 0.031). In Test 441, survival at age 15 ranged from 23.5 percent for the Louisiana provenance to 62.2 percent for the New Jersey provenance and in Test 444, from 31.1 percent for the Georgia provenance to 69.4 percent for the Missouri provenance. Survival was positively correlated with latitude (r = 0.76 and 0.77 for Tests 441 and 444, respectively) (Table 4). In the past, Missouri has obtained seed from Arkansas for its restoration programs. Results from this study suggest that while northern Arkansas sources may survive well, the more southern sources break the seed transfer guidelines and could have poor survival.

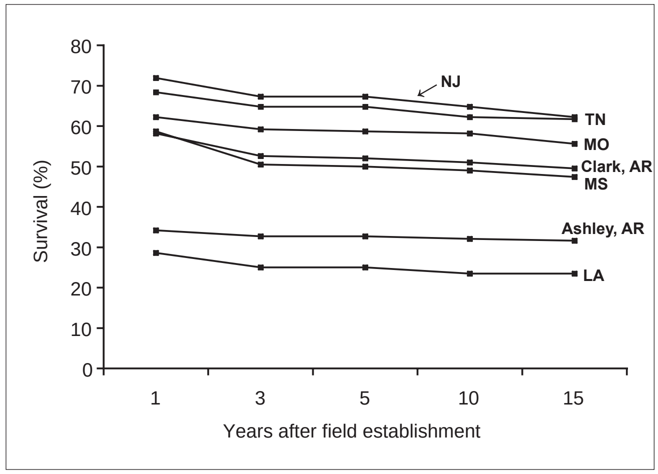

Figure 2.—Survival of shortleaf pine provenances established in Missouri in Test 441.

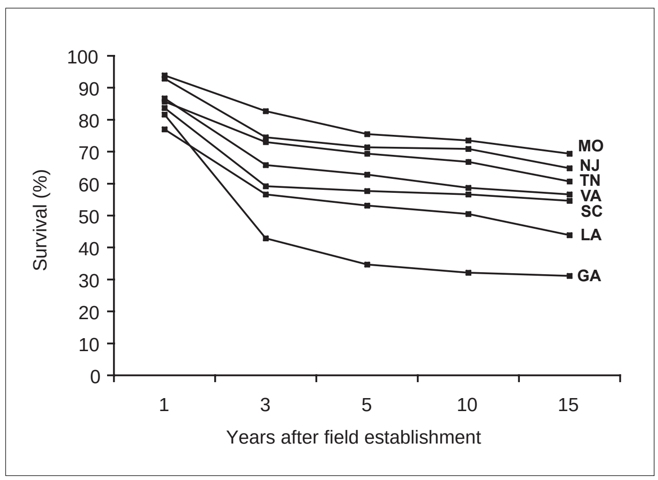

Figure 3.—Survival of shortleaf pine provenances established in Missouri in Test 444.

Stability of Provenances Across Ages

When the mean heights of each provenance were regressed on the overall test means, the linear equations were highly significant (R^2 = 1.00). Differences in the relative growth rate of the provenances were evidenced by differences in the slopes of the regression lines for each provenance (Table 5). Growth rate is important as it can be a more efficient selection parameter than early total height because some provenances can be slow starters and outperform the early starters with time. In this study, provenances with high early height growth also had the highest relative growth rates.

Correlations

Correlations between height at the oldest assessed age in each test and height at earlier measurement ages are presented in Table 6. As expected, the correlations increased as the time between ages decreased. Correlations involving heights at a young age were very low, with a negative correlation between heights at age 1 and 30 in Test 444. In general, heights assessed prior to age 10 years were not reliable predictors of height at the oldest assessed age. These findings are in close agreement with those of Lambeth (1980), who reported poor age-age correlations in several *Pinaceae* species when heights at ages less than 4 years were used. Possible explanations for the low correlations in this study include post-planting stress and browsing.

Table 5.—Estimated regression coefficients based on linear models for mean height of each provenance and test mean height for two shortleaf pine provenance tests in Missouri.

Test	Provenance number	Provenance	Regression coefficient (slope)	Residual mean square	DF	R^2
441	429	Ashley, AR	0.972	0.0045	6	1.00
	427	Clark, AR	0.968	0.0286	6	1.00
	421	St. Helena, LA	0.958	0.0003	6	1.00
	419	Lafayette, MS	1.019	0.0149	6	1.00
	433	Dent, MO	0.998	0.0088	6	1.00
	403	Burlington, NJ	1.050	0.0106	6	1.00
	435	Morgan, TN	1.037	0.0026	6	1.00
444	465	Webster, GA	0.929	0.0706	6	1.00
	473	St. Helena, LA	0.909	0.0201	6	1.00
	485	Dent, MO	0.985	0.0019	6	1.00
	453	Burlington, NJ	1.102	0.0045	6	1.00
	457	Union, SC	0.998	0.0381	6	1.00
	487	Anderson, TN	1.035	0.0136	6	1.00
	455	Southampton, VA	1.039	0.0076	6	1.00

Table 6.—Pearson product-moment correlation coefficients between heights at age 30 and heights at earlier measurement ages in two provenance tests in Missouri.

Test 441		Test 444	
Age	Correlation	Age	Correlation
1	0.16*	1	-0.13*
3	0.40*	3	0.10
5	0.54*	5	0.23*
10	0.69*	10	0.57*
15	0.83*	15	0.70*
20	0.88*	20	0.83*
25	0.94*	25	0.90*

*Significant at 0.05 or lower

CONCLUSION

Significant differences in the survival and height growth of trees with different seed origins were identified in two shortleaf pine provenance tests established in Dent County, Missouri. There was a north-south trend in survival and height growth with the northern sources tending to have better survival and height growth than the southern sources. In both tests, trees from New Jersey and Tennessee had the highest rate of survival and the greatest height growth while trees from Louisiana and Georgia performed the poorest. Results from this study suggest northern seed sources should be favored for planting in Missouri.

ACKNOWLEDGMENTS

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