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Clayton E. Posey
Rex B. McCullough

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The Southwide Pine Seed Source Study was undertaken in 1951 to determine the degree to which inherent geographic variation in longleaf pine (*Pinus Palustris* Mill.), slash pine (*Pinus elliottii* Engelm. var. elliottii), loblolly pine (*Pinus taeda* L.), and shortleaf pine (*Pinus echinata* Mill.) is associated with geographic variation in climate and physiography. This is a report of results of ten shortleaf pine seed sources grown in Oklahoma.

Geographic variation has long been recognized in many forest tree species. Geographic variation is caused by environmental differences that exist within the species range and by genetic factors that have arisen as a result of natural selection for those individuals that are best adapted to each locality. Well designed progeny tests are required to determine the relative contribution of genetic and environmental factors to the total variation exhibited by a particular trait. Seed source studies are conducted to determine the presence or relative absence of genetic differences in trees between geographic sources.

The rate of genetic gain obtainable through tree improvement of a given species is largely dependent upon the amount of variation between trees within a local population, variation between geographic areas, and upon the heritability of a particular trait. The presence of genetic differences between seed of the same species from different geographic sources requires the land manager to be concerned that planting stock or seed be well adapted to the area where it will be used.

The U. S. Department of Agriculture in its Forest Seed Policy of 1939 endorsed the statement that local seed is best. Experience has shown the policy to be sound although as data are accumulated it is evident that

*Clayton E. Posey, Associate Professor, Forest Genetics, and Rex B. McCullough, Superintendent, Kiamichi Forest Genetics Research Station, Department of Forestry, Oklahoma State University, Stillwater, Oklahoma.

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exceptions do occur where performance of non-local stock is superior to that of local stock.

In summarizing results of the Southwide Pine Seed Source Study, Wakeley (1961) stated that five and three-year old plantations of shortleaf pine showed a clinal relationship between height growth of seedlings and latitude of seed source. For fifteen seed sources of ten year old loblolly pine Wells and Wakeley (1966) reported that trees of western origin survived best and were least infected by fusiform rust. In all except the coldest locations trees from coastal areas had grown fastest.

Seed source variation in wood properties has not been reported for shortleaf pine. Most seed source studies have been limited to growth, disease resistance, and survival. The presence of natural variation in specific gravity of southern pines has been reported by Zobel *et. al.* (1960), Wheeler and Mitchell (1959) and others. They reported that specific gravity increases from north to south. The role that seed source plays in this geographic pattern is unknown.

In red pine (*Pinus resinosa* Ait.), Rees and Brown (1954) found specific gravity to be significantly different in only one of nineteen seed sources. Studies by Hough (1967) and Buckman and Buckman (1962) indicate that racial variation is less evident in red pine than in most other pines. In Tennessee, Thor (1967) working with loblolly pine found significant differences in specific gravity among six seed sources. The variation did not follow the same geographical patterns as demonstrated for natural populations. Longleaf pine seed sources in Virginia, studied by Saucier and Taras (1966) showed significant differences between sources with the local sources having the highest specific gravity. Five year old jack pine (*Pinus banksiana* Lamb.) exhibited differences in specific gravity and tracheid length among seed sources (King 1968).

The objective of this study was to determine the extent of seed source variation in survival, growth rate, disease resistance, cone production, specific gravity, extractives, tracheid length, and relative volume production among ten shortleaf pine seed sources in Oklahoma.

Procedures

Two shortleaf pine plantations were established in Oklahoma by the late Dr. Michel Afanasiev. Failures caused by drought necessitated several replantings. The Pushmataha County plantation was established in 1957 with 1-0 seedlings representing a north-south transect of the shortleaf pine range.

The McCurtain County plantation was established in 1958 using seedlings representing an east-west transect of the shortleaf pine range. Two seed sources, Ashley County, Arkansas and Clarke County, Georgia,

Table 1. Climatic factors at 10 shortleaf pine seed sources[1]

Region	Latitude	Longitude	Annual Temp °F	January Minimum Temp °F	Annual Precip Inches	Jan-Apr Precip Inches	June-Aug Precip Inches	Frost Free Season Days	County of Plantation
Pushmata Co., Oklahoma	34°03′	94°48′	61.8	32.0	54.0	18.5	12.6	227	McCurtain
Ashley Co., Ark.	33°02′	91°56′	64.8	36.2	49.1	20.5	9.4	228	Push. & McCurtain
Tallapoosa Co., Ala.	32°45′	85°40′	65.2	39.1	52.8	21.6	13.8	237	McCurtain
Clarke Co., Ga.	34°00′	83°30′	60.2	33.3	53.7	20.5	14.0	213	Push & McCurtain
Putnam Co., Ga.	33°15′	83°25′	62.7	34.8	49.9	19.7	12.6	217	McCurtain
Union Co., S. Car.	34°50′	81°40′	63.2	34.1	46.7	16.3	13.4	221	McCurtain
Cherokee Co., Tex.	31°45′	95°00′	65.6	38.8	48.3	17.8	9.2	236	Pushmataha
McCurtain Co., Okla.	34°03′	94°48′	61.8	32.0	54.0	18.5	12.6	227	Pushmataha
Anderson Co., Tenn.	36°12′	84°05′	59.3	31.1	45.5	17.7	11.6	217	Pushmataha
Franklin Co., Penn.	39°52′	77°33′	53.0	23.6	36.0	10.7	10.6	201	Pushmataha

[1] Source: Hocker (1955)

were common to both plantings. The climatic factors at the ten shortleaf pine seed sources are presented in Table 1.

The experimental design employed was a randomized complete-block with four replications. Plots were square (11 trees x 11 trees) with trees spaced six by six feet. One plot of the Ashley County, Arkansas, source was not planted in McCurtain County because of a shortage of seedlings.

When the plantations were ten years old the trees were measured for survival, total height and diameter at breast height. Counts were made of incidence of fusiform rust and of those trees bearing cones. Two 12 mm. increment cores were taken from opposite sides of each of ten dominant or co-dominant trees in each plot for a total of 940 cores. Wood samples were taken from the one-foot level rather than at dbh because of the variation in number of annual rings in samples taken at dbh. Bark was trimmed from the samples, then the cores were measured for radial growth rate.

Specific gravity was determined by the maximum moisture content method described by Smith (1954). The cores were resaturated under vacuum then extracted with alcohol-benzene using a modified ASTM (1954) procedure as described by Goggans (1962). Specific gravity of extractive free wood was then determined. Extractives include all resin acids, essential oils, fats, fatty acids, and unsaponifiable water removable through alcohol-benzene and water extraction.

For tracheid length determination a section of summerwood from the last annual ring of each core was macerated by the procedure suggested by Franklin (1945). The length of forty undamaged tracheids was measured for each core utilizing a bioscope.

Statistical analysis of each trait consisted of an analysis of variance. The plot means were the units of analysis. Relative cubic foot volume was computed by the conic formula:

$$\text{Relative volume} = \frac{1}{4}\ \frac{\pi \bar{d}^2 \bar{h}}{144 \times 3}\ n$$

where d is the average diameter in inches, h is average height in feet, and n is the number of surviving trees per plot. The plot data was then converted to cubic foot volume per acre. Specific gravity is an indicator of the amount of wood substance per unit volume. For an estimate of amount of wood substance produced per acre, the weight per cubic foot of wood, for each source, was multiplied by the cubic foot volume to obtain tons of dry wood per acre. Results from the two plantations were analyzed separately and are reported separately because the plantations were established in different years with planting stock of various ages.

Results and Discussion

Survival

In the McCurtain County plantation, where seed sources represent an east-west transect of the species range, survival percent varied from 67 for the Clarke, Georgia, seed source to 84 for the local source. The relationship between longitude of seed origin and survival is shown in Figure 1. These data support the statement of Wells and Wakeley (1966), that loblolly pine from western sources survive best.

The north-south transect of the species range represented by the Pushmataha County plantation did not exhibit large differences in survival. Differences in survival may have been masked by replacement planting with 1-1 stock at the end of the first growing season. Survival by sources for both plantations is presented in Table 2.

Height and Diameter Growth

Height growth in the McCurtain County plantation ranged from 20.2 feet for the Putnam, Georgia, source to 22.2 feet for the Ashley, Arkansas, source. Height differences were not statistically significant and there is a lack of relationship between longitude of seed origin and height growth.

Table 2. Survival, height, cone bearing, and tree with Cronartium for McCurtain and Pushmataha plantations.

McCurtain County Plantation

Seed Source	Survival (percent)	Height (feet)	dbh (inches)	Trees with cones (percent)	Trees with Cronartium (percent)
Pushmataha, Okla.	84	20.7	4.3	11	12
Ashley, Ark.	82	22.2	4.6	8	13
Putnam, Ga.	79	20.2	4.3	16	10
Union, S.C.	74	20.9	4.7	17	8
Tallapoosa, Ala.	72	20.3	4.4	33	10
Clarke, Ga.	67	20.7	4.8	13	10

Pushmataha County Plantation

Seed Source	Survival (percent)	Height (feet)	dbh (inches)	Trees with cones (percent)	Trees with Cronartium (percent)
McCurtain, Okla.	92	24.2	4.2	16	0
Ashley, Ark.	91	25.4	4.4	21	0
Cherokee, Tex.	86	23.2	4.1	23	0
Clarke, Ga.	92	22.4	4.1	22	0
Anderson, Tenn.	90	22.3	3.9	30	0
Franklin, Penn.	90	19.9	4.0	60	0

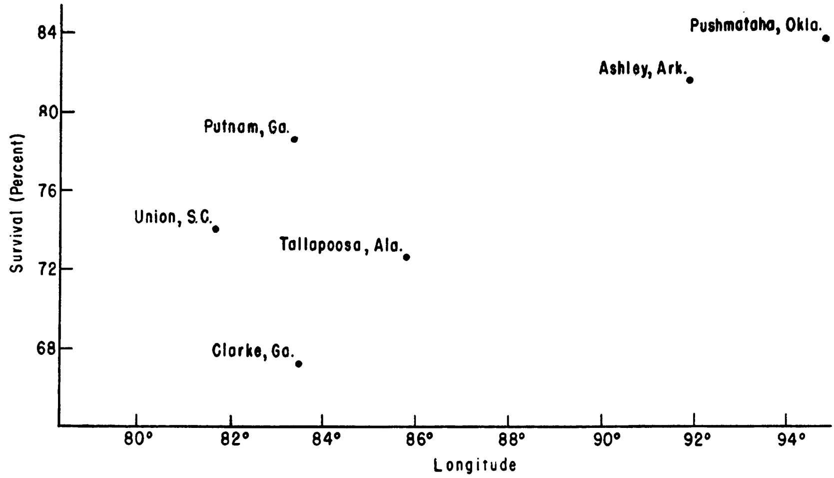

Figure 1. Relationship between longitude of seed origin and survival in the McCurtain County plantation.

In the Pushmataha County plantation height ranged from 19.9 feet for the Franklin, Pennsylvania, source to 25.4 feet for the Ashley, Arkansas, source. The difference between seed sources was significant at the 0.01 level. The relationship between latitude of seed origin and tree height for seed sources in the Pushmataha County plantation is presented in Figure 2. Average tree height by sources for both plantations is shown in Table 2.

Diameter growth in the McCurtain County plantation cannot be interpreted in terms of seed source because of the differences in survival. The seed source with the fewest trees per plot (Clarke, Georgia) had the largest average diameter trees (4.8 inches). The seed source with the greatest number of trees per plot (Pushmataha, Oklahoma) had the smallest average diameter trees (4.3 inches).

In the Pushmataha County plantation, where survival between sources was not significantly different, there is a relationship between latitude of seed origin and diameter growth. The pattern is almost identical to the relationship between height and latitude. Trees from latitudes north of the plantation sites grow less in diameter and height. The average diameter by sources for both plantations is presented in Table 2.

Cone Production

Production of cones in the McCurtain County plantation was greatest for the Tallapoosa, Alabama, source (33 percent of trees bearing

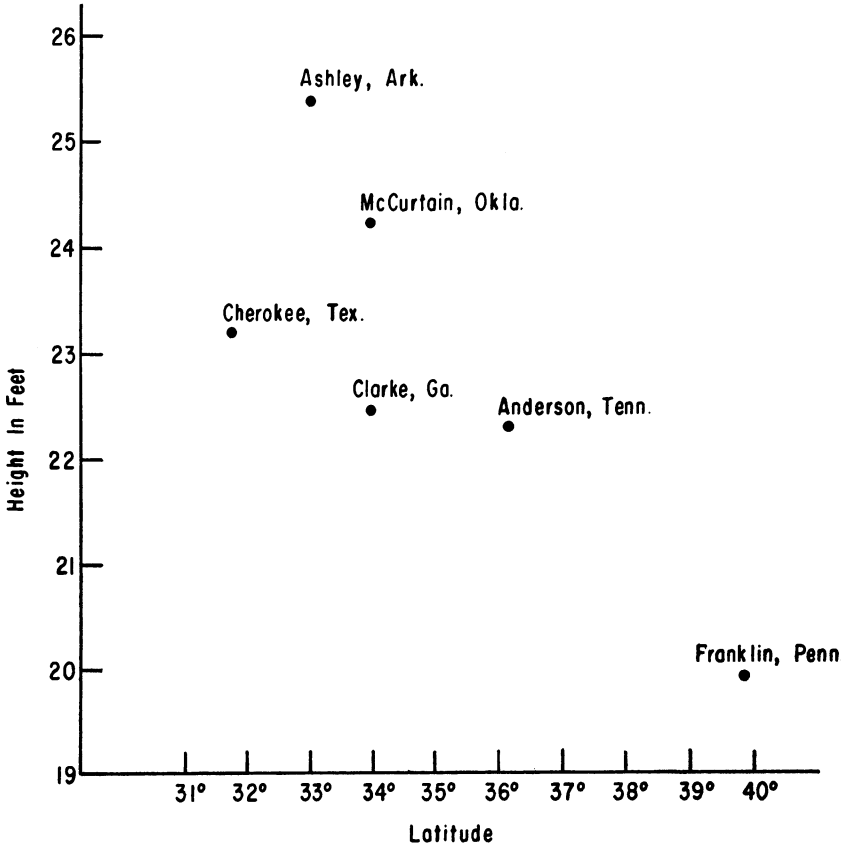

Figure 2. Relationship between latitude of seed origin and tree height in the Pushmataha County plantation.

cones) and least for the Ashley, Arkansas, source (8 percent). In the Pushmataha County plantation the difference in cone production between sources ranged from 16 percent for the local source to 60 percent for the Franklin, Pennsylvania, source. In both plantations there was a tendency for cone production to be greatest for those sources farthest from the plantation sites. The average number of trees bearing cones by sources for both plantations is presented in Table 2.

Disease

The only disease noted on any of the trees was the eastern gall rust (*Cronartium cerebrum* Hedgc. and Long.). All of the galls observed were on branches. There appeared to be no source difference in infection in the McCurtain County plantation. The disease was not observed on trees in the Pushmataha County plantation. Since the Ashley, Arkansas, and Clarke, Georgia, seed sources were in both plantations and since trees from these sources were infected in McCurtain County and not infected in Pushmataha County the differences in infection between plantations are probably environmental. The number of trees exhibiting infection by source and plantation is presented in Table 2.

Specific Gravity and Extractives

Data for the relationship between increment core samples taken from below dbh and whole tree values are not available. For this reason, data presented here are for comparative purposes and do not necessarily represent actual tree values.

Specific gravity of unextracted and extractive free wood of six seed sources grown in Pushmataha County, Oklahoma, is presented in Table 3. Analyses of variance showed differences in both unextracted specific gravity and specific gravity of extractive free wood between seed sources to be significant at the 0.05 level. The variance associated with seed sources was greater for specific gravity of extractive free wood than for unextracted wood, indicating that extractives tend to mask the actual specific gravity differences between seed sources.

The rank of seed sources for specific gravity changed after extraction for all sources except the Cherokee County, Texas, seed source which had the lowest specific gravity before and after extraction. The Ashley County, Arkansas, seed source, which was ranked fourth for specific gravity of unextracted wood (0.429), was ranked first for specific gravity of extractive free wood (0.411). The local seed source was not the best for high specific gravity, being surpassed by the Ashley County, Arkansas, and the Franklin County, Pennsylvania, seed sources. These results show that comparisons of specific gravity between seed sources may not be valid unless comparisons are based on the specific gravity of extractive free wood.

Table 3. Pushmataha County, Oklahoma. Specific gravity of unextracted and extractive free wood of six seed sources.

Source	Unextracted sp. gr.	Rank	Extractive content	Extracted sp. gr.	Rank
Franklin, Pa.	0.443	1	0.034	0.409	2
McCurtain, Okla.	0.433	2	0.036	0.397	3
Clarke, Ga.	0.432	3	0.040	0.392	5
Ashley, Ark.	0.429	4	0.018	0.411	1
Anderson, Tenn.	0.424	5	0.031	0.393	4
Cherokee, Tex.	0.418	6	0.033	0.385	6

The influence of extractive content on interpretation of specific gravity data in the McCurtain County, Oklahoma, plantation was not a significant factor. Extractive content averaged 0.028 and was approximately the same for all seed sources. This is in agreement with the work of Thor (1967). Comparison of specific gravity of seed sources utilizing unextracted wood can be accurate but, in view of the results from the Pushmataha County plantation, it would be advisable to base comparisons on specific gravity of extractive free wood only. Reports by Stonecypher and Zobel (1966), Posey and Robinson (1968), and Posey and Goggans[1] have indicated the strong environmental influence on variation in extractive content. In field experiments with considerable plot-to-plot variation in site, one could expect extractive content to influence interpretation of seed source data based on the specific gravity of unextracted wood.

The specific gravity of unextracted and extractive free wood for the six seed sources grown in McCurtain County, Oklahoma, is presented in Table 4. The rank of seed sources is the same for specific gravity of unextracted and extractive free wood.

The difference between seed sources is significant at the 0.05 level of confidence. The Ashley County, Arkansas, seed source again had the highest specific gravity of extractive free wood (0.383) followed by the local seed source (0.369). The Putnam County, Georgia, seed source had the lowest specific gravity of extractive free wood (0.352).

Tracheid Length

Mean tracheid length by plantations and seed sources is presented in Table 5. Tracheid length is of interest mainly from the standpoint of tear resistance in paper. Long tracheids yield paper more resistant to tear than do short tracheids.

In the Pushmataha County plantation the Ashley County, Arkansas, seed source had the longest tracheids (3.02 mm.) followed by the local

[1]Posey, C. E. and J. F. Goggans. Unpublished Report. Alabama Agricultural Experiment Station, Auburn, Alabama.

Table 4. McCurtain County, Oklahoma. Specific gravity of unextracted and extractive free wood of six seed sources.

Source	Unextracted sp. gr.	Rank	Extractive content	Extracted sp. gr.	Rank
Ashley, Arkansas	0.411	1	0.028	0.383	1
Pushmataha, Okla.	0.398	2	0.029	0.369	2
Union, S.C.	0.398	3	0.029	0.369	3
Tallapoosa, Ala.	0.393	4	0.025	0.368	4
Clarke, Ga.	0.389	5	0.027	0.362	5
Putnam, Ga.	0.381	6	0.029	0.352	6

Table 5. Mean tracheid length by plantations and seed sources.

Pushmataha County Plantation		McCurtain County Plantation	
Source	Tracheid length (mm)	Source	Tracheid length (mm)
Ashley, Ark.	3.02	Ashley, Ark.	2.96
McCurtain, Okla.	2.88	Union, S.C.	2.84
Clarke, Ga.	2.73	Tallapoosa, Ala.	2.83
Cherokee, Tex.	2.71	Clarke, Ga.	2.81
Anderson, Tenn.	2.67	Putnam, Ga.	2.80
Franklin, Penn.	2.63	Pushmataha, Okla.	2.80

seed source (2.88 mm.). The difference in tracheid length between sources was significant at the 0.01 level of confidence. Tracheids of the Ashley County, Arkansas, seed source were 15 percent longer than the tracheids of the Franklin County, Pennsylvania, seed source and five percent longer than the local seed source.

In the McCurtain County plantation the Ashley County, Arkansas, seed source again had the longest tracheids. The difference between seed sources was not significant. The difference between extreme means of tracheid length between sources in the McCurtain County plantation is approximately one-half the difference between extreme means for the Pushmataha County plantation. This is also true for other traits reported in this study. The Pushmataha County plantation is made up of seed sources representing a north-south transect of the species range, whereas the McCurtain County plantation is composed of sources representing an east-west transect of the species range. In studying survival and height of seed sources in the southwide seed source study, Wakeley (1961), reported that variation is consistently more frequent among the plantations containing sources along the north-south transect than among those containing sources along the east-west transect.

Relative Volume and Tons of Dry Wood Per Acre

Relative volume is used because volume tables for young trees are not available for shortleaf pine. Relative volume is computed considering the height, diameter and survival for each source. Tons of dry wood per acre is computed so that variations in specific gravity can be considered with volume. Data for relative volume and tons of extractive free wood per acre are presented in Table 6.

In the Pushmataha County plantation the Ashley County, Arkansas, seed source produced 18 percent more wood by weight than the local source, and 58 percent more wood than did the Franklin County, Pennsylvania, seed source. In the McCurtain County plantation the local source was surpassed in wood production by the Ashley County, Arkan-

Table 6. Relative volume and tons of extractive free wood per acre by plantations and seed sources.

Pushmataha County Plantation			McCurtain County Plantation		
Source	Relative vol. cu. ft.	Extracted wood in tons/acre dry wt.	Source	Relative vol. cu. ft.	Extracted wood in tons/acre dry wt.
Ashley, Ark.	975	12.49	Ashley, Ark.	842	10.07
McCurtain, Okla.	852	10.55	Union, S.C.	744	8.53
Clarke, Ga.	802	9.82	Pushmataha, Okla.	704	8.10
Cherokee, Tex.	765	9.21	Clarke, Ga.	705	7.96
Anderson, Tenn.	670	8.21	Putnam, Ga.	639	7.02
Franklin, Penn.	619	7.90	Tallapoosa, Ala.	623	7.17

sas, seed source by 24 percent and by the Union, South Carolina, seed source by five percent. The seed source producing the most wood (Ashley County, Arkansas) was 43 percent better than the poorest seed source (Putnam County, Georgia).

Conclusions

Based on overall performance — height growth, dbh, survival, tracheid length, and specific gravity of extractive free wood the Ashley, County, Arkansas, seed source is superior to other seed sources tested including local seed sources. Results based on ten year old trees should not be considered conclusive because of changes that can occur with time. Ashley County, Arkansas, stock may not be better for Oklahoma because of the number one regeneration problem in Oklahoma which is drought. Because of the possibility of improving Oklahoma wood production through utilization of Ashley County, Arkansas, stock, two procedures for improvement and further testing are suggested:

1. Include progeny from Ashley County, Arkansas, shortleaf pine select tree controlled crosses in progeny tests of local clonal seed orchards.
2. Include progeny of Ashley County, Arkansas, select shortleaf x local select shortleaf in progency tests of local clonal seed orchards.

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