Virginia Pine (*Pinus virginiana* Mill.) Provenance and Progeny Performance in Oklahoma

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ABSTRACT: *One hundred and twenty-three open-pollinated families from 38 stands of Virginia pine were tested in Oklahoma. Height and survival data at age 5 for two Christmas tree plantations and at age 5 and 7 for two progeny test plantations were analyzed. In the Christmas tree tests, four stands from North Carolina, three from Tennessee, and one each from Alabama, Kentucky, South Carolina, and Virginia were identified as good seed sources for Christmas tree production. The progeny test analyses identified two stands from each of North Carolina, Tennessee, Virginia, and Georgia, and one each from Kentucky and South Carolina as good seed sources based on age 7 data. One stand from each of North Carolina, South Carolina, and Tennessee were exceptional in both test types. Significant family in stand differences for both height and survival suggests that selection of the best families in the best stands will be an important component of improvement of Virginia pine for Christmas tree production. Based on both height and survival data, and a regression of height on average yearly minimum temperature at the source, the best performing sources and families were from North Carolina, eastern Tennessee, northern Georgia, northern South Carolina, southern Virginia, and southeast Kentucky, all located near or between minimum temperature isotherms of 0° and 5°F. These sources are recommended for use in Oklahoma. South. J. Appl. For. 22(4):209–215.*

Virginia pine (*Pinus virginiana* Mill.) is naturally distributed over much of 16 eastern states of the United States. Its range extends from central Pennsylvania and New Jersey southward to mid-Alabama and along the east coast from New York to Virginia (Figure 1).

Within its natural range, Virginia pine occurs at elevations from 30 to 760 m in areas with annual precipitation ranging from 90 to 140 cm (Williston and Balmer 1980), but its best growth is below 520 m (Kellison and Zobel 1974). It grows best on north and east facing slopes but it is also often found on ridge tops and on south and west facing slopes (Slocum and Miller 1953). Virginia pine usually occurs on soils derived of crystalline rock, sand, and shales (Fowells 1965), and cannot tolerate poor drainage (Fenton and Bond 1964).

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Virginia pine is a small tree usually reaching 9 to 12 m in height (Harlow and Harrar 1958). It is not a good lumber species and is generally used for paper pulp. Over the last few decades, Virginia pine has become accepted among tree farmers as well as buyers in the Southern states as a quality Christmas tree.

Virginia pine has become a preferred species for Christmas tree production in the southeast United States. The Southern Cooperative Technical Committee (1982) reported that among the 13 species grown for Christmas trees in the southern states, Virginia pine is in the top four (others include eastern white pine, *P. strobus* L., Scots pine, *P. sylvestris* L., and Fraser fir, *Abies fraseri* [Pursh] Poir.), with a short rotation of 4–6 yr. Virginia pine has gained popularity as a Christmas tree due to its high survival rate, rapid juvenile growth, positive response to shearing, and relatively good growth on poor soils where other species may not survive (Belanger and Bramlett 1975). Brown (1979) reported that Virginia pine has been accepted as a Christmas tree from Georgia to Texas. McKinley (1989) agrees that Virginia pine

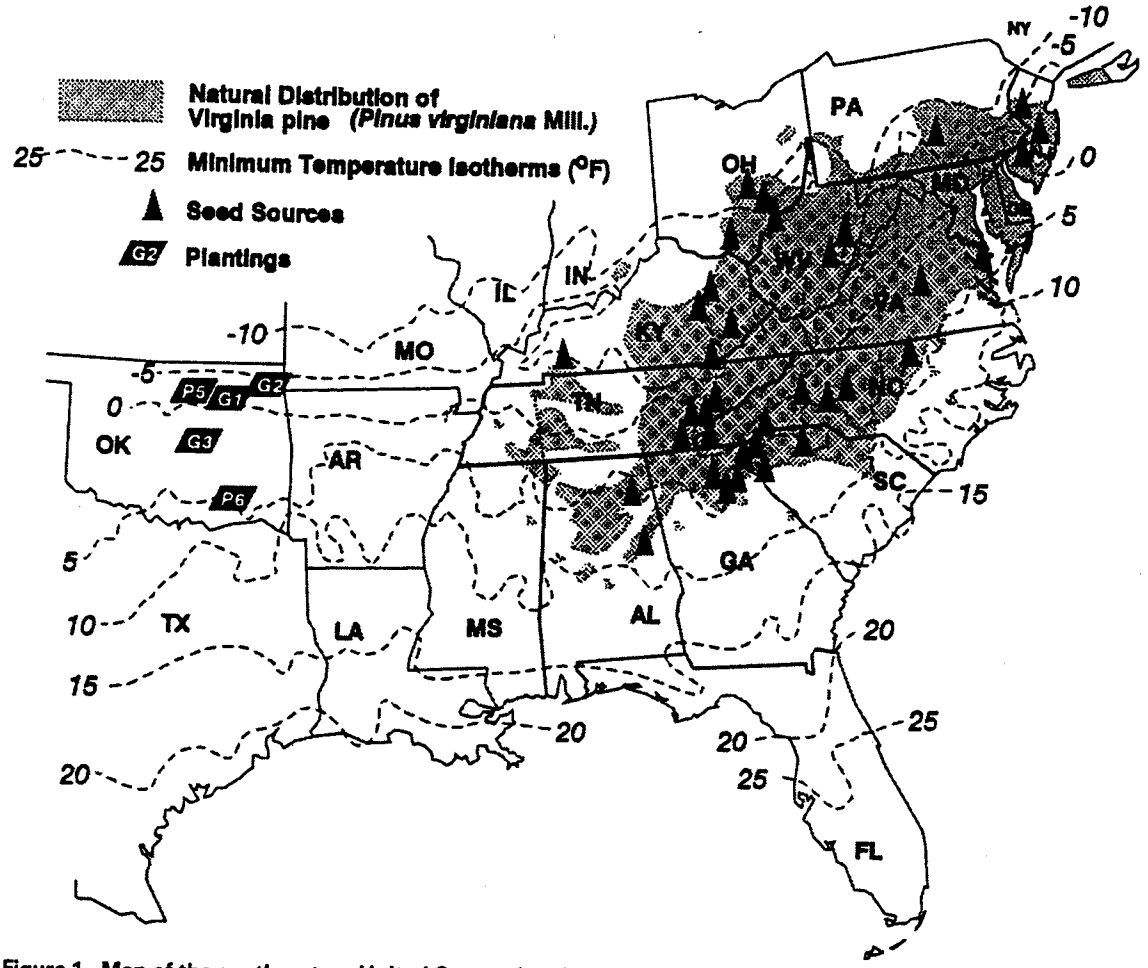

Figure 1. Map of the southeastern United States showing the natural distribution of Virginia pine (adapted from Critchfield and Little 1966) and the location of seed sources and the provenance/progeny (P) and growers' (G) plantings for the study. Stands TN1 and NC2 were not mapped because their in-state location is unknown. Minimum temperature isotherms, which define plant hardiness zones, are adapted from USDA (1990).

is widely accepted as a Christmas tree across the South due to its natural appearance and its ability to grow on a wide variety of soils.

Virginia pine is a prolific seed producer. It generally starts cone production around 5 yr of age and produces large seed crops at 1 to 4 yr intervals. The prolific seed production habit of Virginia pine makes its breeding faster and easier than most other pines. Most importantly, Virginia pine shows considerable tree to tree and source to source variation in growth and survival (Thor 1979). This variation is useful in selection of sources and families for a tree improvement program.

Identifying and utilizing variation among provenances of a species can be a significant first step in the improvement of that species. Variation in growth, form, survival, and other characteristics from provenance to provenance, stand to stand, and tree to tree is the basis for genetic improvement through selection of the desired trees. There are considerable data reported on variation within many forest tree species, but there are limited data on Virginia pine source and family variation.

Genys (1966) reported that Virginia pine sources from Alabama, Tennessee, South Carolina, and Virginia performed poorly on poor sites in northeastern Pennsylvania. He also reported that sources from high elevations grew best near their natural range; and that an Alabama source was below average in growth and survival compared to local sources in Maryland and Tennessee plantings. In a study of 21 seed sources planted in Michigan, Maryland, and Tennessee, Genys et al. (1974) reported high mortality, 42 to 45%, in the sources from Alabama and Mississippi. Greater variation among families than among sources was found in sources from Kentucky and Tennessee when grown in Tennessee (Thor 1979). Warlick et al. (1985) reported significant differences in height growth among seed sources of Virginia pine in an Alabama study.

A few studies have examined the performance of Virginia pine sources outside their natural range. Zobel et al. (1956) reported good survival and growth of Virginia pine sources when planted on droughty sites in west Louisiana and east Texas. In a study by Chandler (1985), good growth on acidic soils in East Texas proved Virginia pine a major species for Christmas tree production on acidic soils. Osterhaus and Lantz (1978) have recommended Virginia pine for Oklahoma due to its good survival and growth on shallow soils. It has also been successfully adapted in Korea (Han et al. 1988).

Virginia pine sources have shown significant variation in growth and survival, and good performance outside their natural range in previous studies. It was thus logical to examine survival and growth of Virginia pine sources for

Oklahoma for Christmas tree production and perhaps other uses. In this study, 123 open pollinated families from 38 stands of Virginia pine representing much of its natural range were planted at different locations in central and eastern Oklahoma for Christmas tree production testing and provenance/progeny testing to identify the best surviving and fastest growing sources of Virginia pine for use in Oklahoma.

Materials and Methods

Seed collection was initiated in 1983. Cones from randomly selected trees were requested from foresters and resource managers across the natural range of Virginia pine. The cones shipped represented 38 stands with 1 to 9 trees per stand, constituting a total of 123 open pollinated families of Virginia pine. This collection sampled much of the natural range of Virginia pine (Figure 1). After extraction, cleaning, and stratification, seed were sown in replicated nursery beds in the Oklahoma State University Forestry nursery at Idabel in spring 1984.

One-year-old seedlings of Virginia pine were outplanted near Collinsville, Tulsa County; Foyil, Mayes County; and Oklahoma City, Oklahoma County; on Christmas tree growers' land for testing for Christmas tree potential in Oklahoma (Figure 1). The planting at each location was a randomized complete block design with four-tree family-row plots at 1.5 × 1.8 m spacing and two blocks per location. Plantings were limited to two blocks to accommodate the growers, who plant a limited number of seedlings each year.

Plantings were also established on an Atoka and a Payne county site for provenance/progeny testing (Figure 1). These plantings were randomized complete block designs with four-tree family-row plots and six blocks at each location. Spacing for the progeny test was 2.4 × 2.4 m, larger than that of the Christmas tree plantings because these trees will be grown for a longer time period to identify the best sources for Oklahoma for possible uses other than Christmas trees. These tests will also allow quick access to scions or seed of the selected sources for breeding. One block was lost to fire at the Atoka county plantation, and five blocks were included in this study.

Test plantations on growers' locations were given cultural treatments such as mowing, irrigation, herbicide, and insecticide application and shearing for shaping into Christmas trees. No treatment beyond mowing was given to the plantations established for provenance/progeny testing.

Height of surviving trees was measured at age 1 through age 5 after each growing season for both the Christmas tree plantations and the progeny test plantations. In addition, height data were collected at age 7 for the progeny test plantations. A record of shearing and of the trees sold as Christmas trees to age 5 was maintained.

Height and survival data of Virginia pine at plantation age 5 for Christmas tree tests and at plantation age 5 and 7 for progeny tests were analyzed separately and are reported here. All statistical analyses were performed using the General Linear Model Procedure (SAS Institute 1985). The analyses of variance were performed on a family plot mean basis. The calculation of F values was based on a random model (Table 1).

Results and Discussion

Growers' Plantings

Survival.—Survival of Virginia pine in the growers' test plantations at age 5 was 75% in Oklahoma county and 67% in Mayes county, with an across location average of 69%. Flooding in the Tulsa county plantation after the second growing season resulted in 13.7% survival in that planting. The Tulsa county data were not included in the analysis. Harvested trees were counted as survivors in the analysis.

Difference in survival among stands was not significant (Table 1). This probably reflects the small error degrees of freedom in the test, since there was a wide range in percent survival among stands. In the larger progeny tests, survival among stands was significant.

A significant difference in survival among families in stands was found. There was no significant family or stand × location interaction suggesting that survival of families of Virginia pine is essentially similar across locations in central and eastern Oklahoma.

Table 1. Analysis of variance results for Virginia pine in Oklahoma by growers and provenance test presented by *P*> *F* values.

	Growers			Provenance tests				
Source	df[1]	Survival age 5	Ht age 5	df[2]	Survival age 5	Survival age 7	Ht age 5	Ht age 7
Locations	1	0.2444	0.1209	1	0.6847	0.6451	0.1056	0.0775
Blocks (locations)	2	0.0204	0.0509	9	0.0001	0.0001	0.0001	0.0001
Stands	37	0.3232	0.0140	37	0.0329	0.0609	0.0001	0.0001
Families (stands)	80	0.0098	0.1824	85	0.0018	0.0004	0.0249	0.0016
Location × stands	37	0.3565	0.7070	36	0.7697	0.6181	0.3924	0.1060
Location × families (std)	77	0.8563	0.2596	82	0.4518	0.6599	0.2258	0.7460
Error	226			1,075				
Total	460			1,324				

[1] df adjusted for missing values; location × stands df = 36, error df = 176 and total df = 408 for height analysis.
[2] df adjusted for missing values, error df = 1027, 1024 and total df = 1277, 1274 for age 5 and 7 height analysis, respectively.

Percent survival of Virginia pine by stand at age 5 (Table 2) across locations varied from 91.5 for a Tennessee stand (TN7) to 25.0 for a New Jersey stand (NJ3). Of the ten stands with highest survival, four were from North Carolina and three from Tennessee. With the exception of one stand from New Jersey (NJ5), all stands from New Jersey and Ohio had poor survival.

The significant family within stand variance component suggests selection of the best families from the best stands to improve survival of Virginia pine in Oklahoma. The best surviving families were from stands from Tennessee, North Carolina, South Carolina, Kentucky and Virginia. Ten of the best 20 families were from Tennessee and North Carolina.

Height.—Age five across location mean height was 186.0 cm, 194.1 cm in Oklahoma county and 176.9 cm in Mayes county. There were significant positive correlations between heights at age 1 and 5 based on both stand and family means (for both $r_p = 0.67$ at $\alpha = 0.0001$), suggesting that the tallest stands and families at age 1 were also generally the tallest at age 5.

There were significant differences in height among stands but not among families in stands in the variance analyses

Table 2. Virginia pine survival and height by stand across growers' plantings at age 5 and provenance test plantings at age 5 and 7, ranked by age 5 height.

Growers				Provenance tests				
	%	Mean ht	% surviving		% survival		Mean ht (cm)	
Stand no.[1]	survival[2]	(cm)	trees sold	Stand no.[1]	Age 5	Age 7	Age 5	Age 7
TN3	82.1	222.7(2)[3]	10.3	TN1	81.8	81.8	194.9(1)[3]	271.8(1)[3]
TN7	91.5	211.4(1)	16.0	TN5	48.5	48.5	192.1	270.2
TN2	65.6	211.3	23.4	NC1	79.5	78.4	191.8(3)	267.5(4)
VA2	68.8	206.1	12.4	NC4	72.3	71.8	189.4	264.9
VA3[4]	72.2	202.9(8)	10.0	AL1	71.6	71.6	188.6	260.7
NC7	77.3	198.9(6)	19.0	VA2	84.1	84.1	187.9(1)	260.0(2)
NC4	82.5	198.7(3)	25.3	TN7	77.3	77.3	186.8(10)	262.1(7)
AL1	75.0	198.3(7)	4.0	NC7	83.3	82.6	186.5(3)	260.5(3)
TN5	72.7	198.3(9)	12.5	GA3	75.0	75.0	186.1	257.1
NC2	86.2	197.9(4)	13.1	TN3	65.3	65.3	186.0	257.4
KY3	70.3	195.9	9.3	KY5	79.5	79.5	183.1(8)	256.5(8)
NC5	90.6	194.3(4)	10.0	GA1	82.4	82.4	182.1(7)	249.9(9)
KY1	75.0	190.5(9)	13.0	VA1	77.9	77.1	182.1	264.9(9)
NC1	50.0	189.4.	12.5	NC2	66.7	65.4	181.4	256.4
GA1	70.3	188.5	6.5	SC2	84.1	83.3	180.9(5)	254.3(4)
SC2	79.2	186.1(9)	10.5	NC6	72.7	72.7	180.3	253.7
KY2	67.5	185.4	6.8	GA2	86.4	86.4	180.0(5)	248.6(6)
SC1	65.1	184.3	9.4	SC3	78.4	77.3	179.3	248.3
KY4	63.8	183.5	13.2	VA3[4]	77.5	77.3	178.4	247.9
GA2	73.3	182.8	9.0	SC1	76.4	76.4	177.9	250.2
SC4	85.7	182.6	7.2	OH3	86.2	84.9	177.2(9)	235.2
GA3	75.0	182.4	20.8	KY2	71.4	71.4	175.6	240.7
NC6	60.7	182.1	13.3	NJ5	79.5	79.5	175.0	243.1
KY5	71.9	181.4	6.7	SC4	79.5	79.5	174.4	245.7
NC8	62.5	180.8	7.1	NC5	84.1	83.0	174.0	244.9
SC3	65.6	180.7	4.0	TN2	68.2	65.9	172.8	248.6
VA1	68.2	179.0	20.6	KY1	67.9	67.9	171.9	237.2
AL2	62.5	177.1	12.8	KY4	69.0	67.1	171.6	242.5
NJ5	76.8	174.9	3.0	NC8	81.8	81.8	171.3	243.3
TN1	81.3	172.4	30.1	AL2	67.3	66.8	170.5	243.3
OH1	52.1	172.0	34.6	OH4	80.9	80.4	166.8	231.8
OH2	67.2	169.9	6.5	KY3	70.5	70.5	166.7	238.1
OH4	72.7	167.3	0.0	OH2	87.1	87.1	162.7	221.0
WV2	87.5	166.7	28.0	OH1	73.6	73.6	162.4	225.4
OH3	66.7	166.2	9.8	WV2	79.2	79.2	146.0	194.6
WV1	68.8	163.6	2.5	NJ3	52.3	47.7	137.2	190.2
NJ3	25.0	139.0	0.0	NJ2	71.6	70.5	135.4	178.2
NJ2	37.5	137.6	9.5	WV1	59.1	59.1	130.6	178.7

[1] First two letters denote state and the digit stand in state.
[2] Harvested trees counted as alive.
[3] Number in parentheses following height is the rank of the best ten stands based on the rank sum for both height and survival at that age.
[4] Nine open-pollinated families from a seed orchard.

(Table 1). There were no significant genotype × location interactions, suggesting Virginia pine performance across sites in Oklahoma will be consistent.

The ten stands with the fastest growing trees were from Tennessee (4), North Carolina (3), and Virginia (2), and one stand from Alabama (Table 2). Trees from all stands from Ohio, West Virginia, and New Jersey showed below average growth at age 5. A significant negative correlation (r_p = -0.76 at α = 0.0001) between latitude and average stand height suggests that in general poor growth of northern sources of Virginia pine might be expected in Oklahoma.

The families with the tallest trees were generally from stands with the greatest mean heights. Eleven of the best 20 families were from Tennessee and North Carolina. The majority of the families with poor average growth rate were from northern stands, including Ohio, New Jersey and West Virginia.

Mean height at age 5 by families varied from 119 to 236 cm. Except for the poorest growing 33 families, all families were 165 cm or greater in height at age 5, which is the most suitable size for Christmas trees for household use. On the basis of average height by family at age 5, 73% of the families tested appear suitable for Christmas tree production in eastern Oklahoma. This summary cannot, of course, account for trees already sold.

Christmas Tree Production.—On a choose and cut basis, 12.2% of the surviving trees on the growers' plantations were sold as Christmas trees by age 5 (Table 2). The trees sold as Christmas trees were mainly from the Mayes County plantation (which was the best managed), with a negligible number sold (1.6% of the surviving trees) from the Oklahoma County plantation. A total of 27.4% of the surviving trees from the Mayes County plantation had been sold as Christmas trees by age 5. Obviously, with proper management, Virginia pine are marketable as Christmas trees by age 5 or younger in Oklahoma.

Stands contributing salable Christmas trees exceeding 20% of surviving trees were from West Virginia, Virginia, Ohio, North Carolina, Tennessee (two stands), and Georgia. All these stands exceeded the 165 cm height requirement for optimum tree size. Interestingly, roughly 10% or more trees were sold from most stands. Since Virginia pine are sheared and colored for sale, this suggests that as long as the trees are large enough, they will be sold. Thus, perhaps height and survival are the most important criteria for evaluation of Virginia pine for Christmas tree production. Response to shearing may also be important.

The Best Stands on Growers' Sites.—Some stands were among the best in survival, but among the poorest or below average in growth rate, or vice versa. Therefore, ranking of the best stands was carried out by summing the rank of survival and height. Those stands having the best survival as well as growth were ranked as the best performing. Three stands from Tennessee, TN3, TN5, and TN7; four from North Carolina, NC2, NC4, NC5 and NC7; and one each from Alabama, AL1, South Carolina, SC2, Kentucky, KY1, and Virginia VA3 were among the top 10 stands (11 are listed as 3 tied for ninth) considering both survival and growth (Table 2). The best performing stands (except for VA3, a seed orchard source) are all from the same general geographic region, that is, eastern Tennessee and western North Carolina to northwestern South Carolina and southeastern Kentucky. Sources of Virginia pine from Tennessee and North Carolina have previously been reported to perform well outside their natural range (Zobel et al. 1956, Han et al. 1988).

Provenance Plantings

Survival

At the end of the fifth growing season, mean survival across locations was 74.5%, with 77.9% survival in Atoka county and 72.3% survival in Payne county. There was no significant difference in Virginia pine survival between the two locations or in survival at age 5 and 7.

Virginia pine stands and families in stand were significantly different in survival at both age 5 and 7 in the across locations analyses (Table 1). There were no significant genotype × location interactions, thus no significant change in ranking by survival across locations. Virginia pine survival by stand varied from 87.1% (OH2) to 48.5% (TN5) at age 5 and 87.1% (OH2) to 47.7% (NJ3) at age 7 (Table 2).

At age 5, all stands of Virginia pine exceeded 65% survival except for three, one each from West Virginia, New Jersey, and Tennessee (WV1, NJ3 and TN5, respectively). One additional stand from North Carolina (NC2) was below 65% survival at age 7. All stands from Ohio showed high survival, exceeding 70%, and two (OH2 and OH3) were among the top three stands with 87.1 and 84.9% survival at age 7. Except for stands from West Virginia, at least one stand each from the rest of the states exceeded 75% survival at age 7. There was no distinction between northern and southern sources in survival. A nonsignificant correlation, approximating zero, (r_p = 0.04 at α = 0.8292) between Virginia pine survival and latitude also suggests that survival was not related to latitude. The significance of the family in stand component of variance suggest selection of good families from the best stands is warranted.

Height

Plantation mean height at age 5 was 181.9 cm in Atoka county, and 169.4 cm in Payne county, with an across plantation average of 175.3 cm. At age 7, plantation mean height increased to 252.3 cm in Atoka county and 236.8 cm in Payne county with an across plantation average of 244.2 cm.

Significant differences in height were found among Virginia pine stands and families in stands at age 5 as well as at age 7 in the across location analyses (Table 1). No significant genotype × location interactions in height growth were found in either the age 5 or age 7 analysis. Stand and family growth of Virginia pine appears relatively stable across environments in central and eastern Oklahoma.

Trees from four stands from Tennessee, six from North Carolina, four from South Carolina, three from Georgia and Virginia, two from Kentucky, and one from Ohio, Alabama, and New Jersey showed good growth in Oklahoma at age 5. Mean height of trees from these stands exceeded the across

location mean height of 175.3 cm. The tallest trees were in stands from Tennessee (TN1 and TN5) with mean heights of 194.9 cm and 192.1 cm, respectively, both approximately 11% taller than the plantation mean. At age 7, all stands from Georgia, Tennessee, North Carolina (except NC8), Virginia, and South Carolina exceeded the across locations mean height of 244.2 cm. With the exception of one stand from Kentucky (KY5), trees from all stands from Kentucky, New Jersey, Ohio, and West Virginia showed poor growth and were below the across location average height at age 7. A significant negative correlation (r_p = -0.65 at α = 0.0006) between Virginia pine mean height by stand and latitude suggests that poor growth of Virginia pine from northern sources can be expected in Oklahoma. No significant difference in the order of ranking of stands by height was found between ages 5 and 7, although some minor changes occurred.

Generally, families with the best average height were from the stands with the best average height. Families from the northern sources of Ohio, West Virginia, and New Jersey were consistently the poorest in height growth, and families from North Carolina and Tennessee were consistently the best in growth at ages 5 and 7.

The Best Stands and Families on Provenance Test Sites

All stands from Ohio, a northern source, were among the best surviving, with 73 to 87% survival at age 7. However, all Ohio stands were among the bottom ten stands in height. So, in spite of high survival, trees from Ohio stands should generally not be selected for use in Oklahoma because faster growing sources with similar survivability are available.

The stands and families from North Carolina, Virginia, and Tennessee were almost all among the best stands and families in survival, exceeding 60% (with a few exceptions) and were excellent in height growth, having mean heights above the plantation average. Considering both height and survival at age 7, ten stands (Table 2), all exceeding 77% in survival with mean heights greater than the across location plantation mean, were identified as the best in overall performance in Oklahoma.

Based on both height and survival, two out of three Georgia stands were among the best ten stands at age 7. These stands contained three outstanding families. Three North Carolina stands, out of seven in the test, ranked in the top ten. But perhaps more interestingly, 15 of the 17 North Carolina families tested were excellent in height growth, with mean heights exceeding the plantation average, and 10 of these families exceeded 75% survival as well. The Virginia seed orchard families, compared as a stand collection (VA3) did not rank among the top 10 stands, although 3 families performed well. All 13 Tennessee families tested exceeded the plantation average height, and 5 had survival exceeding 75%. Four of the 7 Georgia families tested exceeded 75% survival and the plantation mean in height.

Only 1 of the 4 stands from South Carolina (SC2) was among the top 10 stands at age 5 or 7, but 6 of the 15 families did perform well in growth and survival. None of the stands or families from Alabama (except one family), Ohio, New Jersey, or West Virginia ranked among the top 10 stands or the top families in overall performance at age 7. One stand from Kentucky (KY5) was among the top 10 stands at age 5 as well as 7, but only 1 of 21 families from Kentucky were among top performing families at age 5 or 7.

The best performing sources are mostly from North Carolina, eastern Tennessee, and neighboring areas lying between 35° to 36° 15′ latitude, essentially the same latitude as central Oklahoma.

Growers versus Provenance Test

Many stands and families of Virginia pine from Georgia, North Carolina, Virginia, South Carolina, and Tennessee performed well in both Christmas tree test plantations and provenance/progeny test plantations at age 5. Most stands and families from Ohio, New Jersey, West Virginia, Kentucky, and Alabama performed poorly in survival and height on test sites. Three stands, one each from North Carolina (NC7), Tennessee (TN7), and South Carolina (SC2) were among the best ten stands based on both height and survival, in both tests at age 5. Stands TN3, TN5, TN7, NC4, NC7, SC2, and VA3 all contributed outstanding families to both test types.

There were some differences in stand performance between the growers' test and the provenance test. For example, stand TN1 ranked first in the provenance test at both age 5 and 7, but did not make the top ten in the growers' test. The difference was due to poor height growth on the growers' sites. Perhaps because of poor form, it was sheared heavily. Certainly shearing influenced the height ranking of any number of families, since 48% of the trees were sheared for 3 yr by age 5, 80% for 2 yr, and all trees by age 5. All the Ohio sources, which showed excellent survival in the provenance tests, showed poor survival in the growers' plantings, possibly a negative response to irrigation. The reasons for such differences were not examined, but response to cultural treatment deserves further investigation. Fortunately, most stands performed consistently across tests, and since Virginia pine are sheared and colored for sale, growth, and survival are probably the most important criteria to use on selecting sources and families for Christmas tree production.

Sources and families from North Carolina, eastern Tennessee, southern Virginia, southeast Kentucky, northern Georgia, and northern South Carolina were the best in overall performance both in survival and height in both test plantation types. Seed collection of Virginia pine for planting in Oklahoma should be from these areas, and these sources and families should be utilized in local seed orchards and breeding programs. The following analysis serves to more clearly define the suggested collection area.

Provenance Effects.—Although the study was not designed solely as a provenance test, nearly the entire range of Virginia pine was sampled (Figure 1), and it is useful to look at the results with a genecological interpretation.

It has often been observed that seed sources can be moved northward a modest distance to colder climates, where they will outperform local sources. If moved too far, however, they suffer cold damage and will not perform as well as the

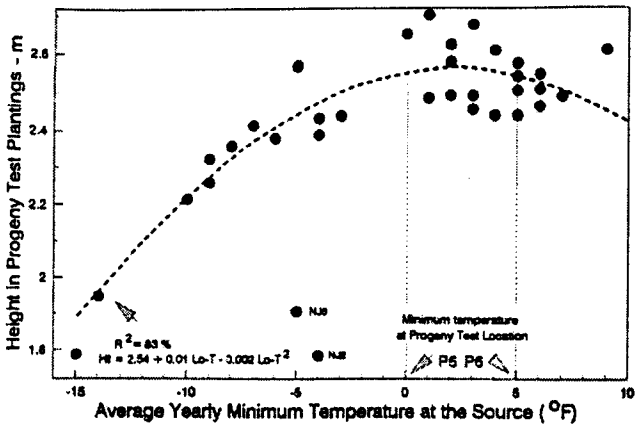

Figure 2. A plot of 7 yr height of Virginia pine sources grown in Oklahoma versus average yearly minimum temperature at the seed source, which defines plant hardiness zones (USDA 1990). The quadratic regression does not include two of the New Jersey sources, NJ2 and NJ3. If these are included, the R^2 is 54%. Four stands were excluded from the analysis because their in-state locations were unknown.

local source. Seed sources from climates colder than the local climate generally grow slower. Schmidtling (1994, 1995) as well as Schmidtling and Sluder (1995) found that the most important climatic variable associated with north-south variation in growth in provenance tests of southern pines was average yearly minimum temperature at the source. This has been used by horticulturists for many years to determine "plant hardiness zones" (USDA 1990).

In this study, a very close relationship was found between minimum temperature at the source and growth (Figure 2). Two of the New Jersey sources, NJ2 and NJ3, did not conform to the relationship, but these two sources represented a total of only three parent trees. A quadratic regression using minimum temperature and its square as the independent variables explained 84% of the variation in height growth in the progeny test plantings after 7 yr. If the two New Jersey outliers are included, $R^2 = 54\%$.

A very similar relationship between minimum temperature at the source and growth was found for the 5 yr data from the growers' plantings, but the regression yielded an R^2 of only 40% (again excluding NJ2 and NJ3). The intensive culture apparently modified the response of some of the provenances to climate.

Both regressions indicate that the most favorable sources for future selections of Virginia pine for use in Oklahoma would come from areas with minimum temperatures between 0 and 5°F, or zone 7a on the USDA (1990) Plant Hardiness Zone Map.

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