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To the Graduate Council:

I am submitting herewith a thesis written by George Rink entitled "Provenance Tests of Loblolly Pine (Pinus taeda L.) in Tennessee." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

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PROVENANCE TESTS OF LOBLOLLY PINE (*Pinus taeda* L.) IN TENNESSEE

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

---

by

George Rink

June 1971

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ABSTRACT

Fifteen seed source tests of loblolly pine in Tennessee were measured and analyzed for eight growth characteristics during 1969 and 1970. The provenance tests were evaluated to determine from which locations within the species range superior phenotypes should be selected for establishment of seed orchards of loblolly pine in Tennessee. In addition, five needle characteristics were studied to determine if needle variation follows regional variation patterns.

Results of the growth data indicate that trees from the northeast part of the species range (Maryland, Virginia or North Carolina) are most suitable for maximum wood production in most parts of Tennessee. However, in areas with milder climates, such as in the southwest portion of the state, inland and Piedmont trees seem to have as good or slightly higher wood production than trees of northeast sources. Greatest wood production was by loblolly pines growing in locations with freeze-free periods corresponding in duration to those of their provenance. Trees from northeast sources and from Arkansas had superior stem straightness over trees from all other sources.

Conflicting results were obtained from the wood specific gravity evaluations. However, some weak evidence of a regional variation pattern did seem to be present; there was a tendency for trees of northeast sources to have higher specific gravity wood.

Of the five needle characteristics evaluated, only stomatal frequency appeared to be under strong genetic control. In addition,

a regional variation pattern seemed to be present in three provenance tests for number of serrations per centimeter with the highest frequency of serrations being from trees of inland sources and the lowest from trees of Coastal Plain sources.

Statistically significant differences among sources were obtained only in those provenance tests where widely divergent sources were represented. In order to detect differences among provenances where relatively similar seed sources are represented, either number of replications or number of seed sources must be increased.

CRANES CREST

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CHAPTER I

INTRODUCTION

In the past 20 years the economy of the South has undergone a drastic transformation. Traditionally agrarian, the South experienced a 10 percent decline of cropland and a 12 percent decrease in rural population in the 1950's. Accompanying this transformation was a general increase of 6.7 million acres of commercial forest area in the South. The Central Gulf region (Alabama, Mississippi and Tennessee) had the greatest increase showing a gain of 8 percent commercial forest land during this period (U.S. Forest Service, 1965).

In Tennessee, woodland acreage exceeds areas devoted to all other land uses; forest acreage has increased by approximately 1,000,000 acres since 1950 and presently amounts to approximately 14,000,000 acres. However, the timber growth on this land is estimated to be scarcely a third of the potential for the area. The native hardwood species, predominantly oak-hickory, occupy nearly three-quarters of the commerical forest. The history of these hardwood forests is one of high-grading and mismanagement. For this reason they are largely comprised of low quality trees and culls. In addition, several million acres capable of growing pine are dominated by other species which do not grow well on these sites. One of the most promising remedial measures is to plant pines on such sites.

As a reflection of large scale expansion of pulping processes for

which pine is favored, demand for total softwood timber has increased. This demand raised the question of which species of the southern pines was to be used for maximum timber production in Tennessee. Two species, longleaf (Pinus palustris Mill.) and slash (Pinus elliotti Engelm. var. elliotti) pine are predominantly deep south Coastal Plain species. Loblolly pine (Pinus taeda L.), considered to be the leading commercial timber species in the southern United States, is native to only small portions of southern Tennessee. Two other species, shortleaf (Pinus echinata Mill.) and Virginia (Pinus virginiana Mill.) pine are both native to large portions of the state and merit consideration as timber producers.

The ability of loblolly pine to grow outside its native range is well documented. In parts of Tennessee, southern Illinois and Indiana, western Kentucky and central New Jersey, regions adjoining the northerly and westerly natural boundaries of the species, loblolly pine has been widely planted and continues to exhibit rapid growth characteristics (Parker, 1950). Hocker (1956) used discriminant functions to compare regions inside the species range to regions immediately adjacent to the species range in terms of climatological data. On this basis he found the Tennessee Valley as far north as Knoxville to be sufficiently similar to that within the native species range so that the loblolly species range could be extended into this area. Allen (1961) found that both loblolly and Virginia pines outgrow shortleaf on the poorer sites and that loblolly outgrows both species on the poorly drained sites on the Cumberland Plateau of Tennessee. In a 10-year old species comparison test

replicated in five different physiographic provinces of Tennessee, loblolly pine grew faster than both shortleaf and white (Pinus strobus L.) pine.[1]

Loblolly pine, therefore, seems to be the most desirable species of southern pine for pulpwood production in Tennessee. However, since loblolly pine is an extremely variable species, provenance tests had to be established in order to ascertain which geographic source of the species was most promising for widespread planting in Tennessee. Failure to conduct provenance tests could result in financial losses. Wahlenberg (1960) estimated that $500,000 per year is lost by planting unsuitable sources of loblolly pine within its range with chances of even greater losses outside its range.

When the most suitable sources have been determined the next step is to obtain large quantities of seed of the appropriate source. The trend in seed acquisition in the southeast is toward establishment of seed orchards. Phenotypically superior trees are selected from desirable sources and propagated in seed orchards. The success of such tree improvement programs is dependent upon the identification of both the most suitable populations and the best individual trees. The Tennessee State Division of Forestry is presently establishing loblolly pine seed orchards with a large number of clones from neighboring states. Results from this thesis will be used as a guide for selection of geographic location of ortets.

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[1]Personal communication with Dr. E. Thor.

CHAPTER II

REVIEW OF LITERATURE

I. NATURAL VARIATION PATTERNS

Intelligent selection requires a knowledge of variation patterns of important characteristics within the species range. The general procedure is to sample different parts of the species range and compare the samples to see if any pattern of variation becomes evident. Unfortunately, the nature of most commercially important characteristics is such that their development is intimately related to and, therefore, confounded with the site on which the tree is growing. Most commercially important characteristics, therefore, cannot be evaluated from natural variation surveys. However, surveys to determine variation patterns of characteristics such as wood properties, needle, cone and seed morphology, have been conducted often with the hope that these characteristics may be linked with some other commercially important characteristic. If linkage were found, it would be feasible to use these characteristics as criteria in a selection program. One such example is the high correlation that Schreiner, Littlefield and Eliason (1962) found between needle length in two year old seedlings and volume per acre at age 18 in Pinus sylvestris L. ($r = 0.809$). On the basis of this relationship they suggested that needle length may be a useful criterion for juvenile selection in that species.

Wood Properties

Specific gravity, although usually referred to as a single characteristic, is actually a function of several variables such as percent summerwood, cell wall thickness and cell diameter (Zobel, 1961). Van Buijtenen (1964) found that of these, the percent summerwood has by far the largest influence on the specific gravity of wood in slash pine. Percent summerwood in turn is dependent upon such environmental variables as availability of moisture or amount of summer rainfall (Kramer, 1962). Saucier and Taras (1967, 1969) found that loblolly pines from areas with high summer rainfall tended to have greater volume growth, lower percent summerwood and lower specific gravity.

Zobel et al. (1960) found three phenotypic classes of loblolly pine conforming to three separate parts of the species range. The lowest specific gravity values were found in northern and northwestern parts of the species range, intermediate values in the Piedmont and the highest values in the southeastern Coastal Plain. These results were substantiated by Saucier and Taras (1969) who reported that specific gravity values of loblolly pine increased from north to south along the Coastal Plain but not on the Piedmont of North and South Carolina and Georgia.

Tracheid length seems to have a variation pattern similar to that of specific gravity with tracheids increasing in length from north to south. In slash pine large fiber diameter, thick walls, high summerwood percentage, long fibers and high specific gravity tend to be inherited together (Van Buijtenen, 1964). In loblolly pine, on the other hand,

there seems to be a weak negative correlation between specific gravity and tracheid length (Zobel et al., 1960).

Needle Characteristics

Significant differences among areas for needle length, stomatal frequency and serrations on needles in loblolly pine have been found by Thorbjornsen (1960). Of these three characteristics, only stomatal frequency i.e.; number of stomates per linear unit, showed a distinct regional pattern. Phenotypes with low stomatal frequencies were from sources west of the Mississippi River while phenotypes with high stomatal frequencies were from eastern sources. This variation pattern was found to be correlated ($r = 0.666$) with a ratio of May to August precipitation over the average summer temperature. This relationship seems to be indicative of an adaptive cline in response to a gradual change in moisture supply. A similar clinal pattern for stomatal frequency had previously been reported for slash pine (Mergen, 1958).

Cone and Seed Characteristics

Apparently there are clinal variation patterns for seed coat thickness and seed form in loblolly pine. Thin seed coats were observed in the western part and thick seed coats in the eastern part of the species range. It was postulated that since seed coat thickness is highly correlated with a ratio of precipitation to evaporation, the thinner seed coats may facilitate water absorption and therefore, this characteristic may have some adaptive value. Seed form (seed width as a percent of seed length) had a north-east to south-west pattern with

rounded seeds being from eastern and pointed seeds being from western parts of the species range. No adaptive value for this characteristic was proposed (Thorbjornsen, 1960).

Cone size also seems to have a regional variation pattern. Small cones were from extreme southwest and southeast portions of the range, intermediate size cones were from the northeastern part of the range and large cones were from the central parts of the species range. It was proposed that local environmental conditions largely influence cone size. In the western part of the range introgression of shortleaf into loblolly pine could also account for small cone size (Thorbjornsen, 1960).

II. VARIATION IN PROVENANCE TESTS

A species with a natural range as extensive as that of loblolly pine may be thought of as consisting of a multitude of races or genotypes. Natural selection determines which genotypes will survive and reproduce on a particular site. The population which occurs on any given site should therefore be the one with the optimum available combination of genes for that site. This is the reasoning behind the conservative rule-of-thumb which states that, unless shown otherwise, local sources should be used in regeneration programs. Recently, this rule-of-thumb has been seriously questioned. It has been hypothesized that best growth occurs in areas where environmental conditions are optimum for that species. In areas where these environmental variables are less than optimum (as on the fringes of the species range) there may be a loss in vigor at the expense of adaptation to less productive sites.

This decrease in vigor may also be a reflection of overadaptation to colder climates of the past (Namkoong, 1969). In order to compare growth of different geographic sources provenance tests have to be established. Surveys of natural variation of characteristics within the species range establish variation patterns for these characteristics but they do not resolve how much of this variation is due to environmental effects and how much is genetic variation.

Wood Properties

Variation for specific gravity in a provenance test in Tennessee was not consistent with the variation pattern found in natural populations (Thorbjornsen, 1960; Thor, 1967). It was postulated that specific gravity in loblolly pine is strongly affected by environment and that different populations (or genotypes) react differently to different environments. Similar results were obtained by Saucier and Taras in Alabama (1967). They found that although the genetic component of geographic variation in specific gravity was not large, the natural variation pattern had been reversed; specific gravity and percent summerwood tended to be associated with latitude, increasing from south to north.

Thor and Brown (1962) found no significant differences among seed sources for tracheid length in loblolly pine at age five. Since a considerable amount of individual tree variation for this characteristic was present, they proposed that tracheid lengths in this species are strongly affected by local environmental conditions and that compared to the large amount of variation among trees, regional genetic differences appeared to be small.

Resistance to Fusiform Rust

The most extensive provenance test with southern pines is the Southwide Pine Seed Source Study. The loblolly pine portion of the test was replicated in 13 locations in 10 states with 15 different seed sources. Based on 10 year data, Wells and Wakeley (1966) reported that trees of sources from west of the Mississippi River and from Maryland had the lowest rust infection. Trees from the southeastern Louisiana source were moderately infected while those from all other sources were heavily infected. Results were relatively consistent over all planting locations. Similar results have been obtained in Mississippi by Wells (1966) and in Georgia by Collins (1964) and Kraus (1967). However, some data from seed source tests in Louisiana would seem to contradict these results. Apparently some local populations do not follow the general variation pattern (Crow, 1964; Kennedy and Crow, 1969; Crow and Hansbrough, 1970).

Growth Rate

Height. Ten-year results from the Southwide Pine Seed Source Study indicate that loblolly pine from two coastal sources, Livingston Parish, Louisiana, and Onslow county, North Carolina, make outstanding height growth in nine out of 13 plantations. Trees from inland sources exhibit slower growth rates at all locations. Those from the two sources from the northern extremes of the species range, Maryland and southwest Tennessee, had superior height growth only on those sites where these sources represented the local provenance; these relationships were

thought to be a reflection of adaptation of local populations to a cold climate. Regression analysis between height and the combination of average minimum January temperature and average summer rainfall of the seed source showed a strong and significant association between climate and tree height at seven of the 13 plantations:

(1) Trees from regions of high summer rainfall tend to grow faster than trees from regions of low summer rainfall.

(2) Trees from areas with warm winters tend to grow faster than trees from areas with cold winters. In Maryland and Tennessee plantings, which had the coldest climates in the study, the reverse is true.

It was thought that these associations add support to the hypothesis that selection pressure of climatic variables has resulted in development of races with genetic adaptation to a local climate (Wells and Wakeley, 1966).

In reporting 10-year data from a comprehensive seed source test in Georgia, Kraus (1967) substantiated the results of the Southwide Study. Height variation among trees of different sources was statistically significant as was the interaction between seed sources and planting provinces. It was found that the coastal source trees grew fastest when averaged over all planting locations except the mountain province. The variation pattern for height growth was found to be definitely clinal along a northwest-southeast transect with a slight discontinuity or "step" in the vicinity of the fall line. This discontinuity was thought to be the result of a decrease in warm season precipitation that occurs upon crossing the fall line. Increased variability in

topographic and edaphic conditions and the increased possibility of introgression by shortleaf pine were also suggested as adding to this discontinuity. It was hypothesized that this increased variability in topographic and edaphic factors north of the fall line brought about a new "race" of loblolly pine with a greater degree of adaptability to a wider range of site factors encounted in this area at the expense of higher growth rates.

Two provenance tests in North Carolina showed similar results with loblolly pine from coastal sources exhibiting the highest growth rates. Growth patterns in these tests were not as clear as in the Georgia study but the evidence of adaptive genetic differences in height growth seemed to be present (Lantz and Hofmann, 1969).

Several other loblolly pine provenance tests in the extreme northern parts of the species range and outside the species range indicate that trees of northern Coastal Plain sources exhibit superior height growth for these areas. In southern Illinois, Woerheide (1959) found the Maryland trees to rank first out of six sources, trees of a Virginia source were second and those of an Arkansas source third. On the Virginia Piedmont, Kormanik et al. (1961) found that trees from a North Carolina Coastal Plain source showed the best height growth (no Maryland or Virginia sources were represented). In a provenance test in Maryland, Little (1969) found that at age 15 the trees of the local source were the tallest and those of a North Carolina Coastal Plain source ranked second.

Provenance tests of loblolly pine in Tennessee yielded variable

results. The Southwide Study had one planting in west Tennessee; after 10 years trees from the South Carolina Piedmont and the local Tennessee source were tallest. However, mortality due to competition from Lespedeza sp. and other nonrandom environmental influences biased results to such an extent that very little meaningful data could be extracted from this planting (Wells and Wakeley, 1966). Trees from inland sources from Alabama and Georgia were fastest growing and those from Coastal Plain sources (Maryland, Virginia and South Carolina) were slowest five years after outplanting in Anderson and Union counties in Tennessee (Wiesehuegel, 1955). At age 10 the loblolly pines from the north Alabama source in this test were still tallest and those from the Coastal Plain sources were still shortest (Zarger, 1961). In the lower elevations of the Cumberland Mountains, Thor (1967) found trees of a North Carolina Piedmont source to be tallest, closely followed by those of a north Alabama and a North Carolina Coastal Plain source. With the exception of the trees of the North Carolina Piedmont source, frost damage between the ages of five and 10 caused the rankings of height growth among trees of all sources to change.

Volume. Volume growth is a function of many other traits such as height, diameter, survival, rust resistance and resistance to winter damage. On the basis of 15 year data from the Southwide Pine Seed Source Study, Wells (1969) found that three of these characters, survival, rust resistance and height growth, have almost no correlation among them. Although trees with genetic potential for superiority in each of these traits can

be found, nowhere in the species range were trees consistently found that had all three characteristics. Kraus (1967) provides a striking example of the consequences of this; trees of an Arkansas source had only intermediate height, diameter and volume growth. However, due to high survival and rust resistance, the Arkansas trees provided the highest volume growth per acre in three out of five plantings. Apparently the only way to determine which source of loblolly pine will provide maximum volume yield per acre is to conduct provenance tests in the areas in question.

Thor (1967) found that the trees of the North Carolina Piedmont source produced the highest yield (short tons/acre) in the Cumberland Mountains of Tennessee at age 10. In this case, the trees of this source also had the fastest height growth and a minimum of frost damage.

The effect of winter damage (frost, snow and ice) is a variable which should be considered in plantings of loblolly pine in Tennessee. In southcentral Georgia, ice damage was most severe on trees from areas with mild climates (Jones and Wells, 1969). However, despite the greater amount of ice damage, the trees of the coastal sources still had greater yields than those of the inland sources. Winter damage probably has a more pronounced effect on volume yields in plantings north of or in more northerly parts of the species range. In Maryland, the trees of local sources had the highest volume yield and the least winter injury while trees from Georgia and Louisiana sources had the lowest volume yields per acre and the most winter damage (Little, 1969).

III. VARIATION PATTERNS

In southern pines two factors are primarily responsible for variation patterns. First, pollen may be carried by the wind for long distances, resulting in large interbreeding populations. Second, within the species range variation in climatic factors such as temperature, length of growing season and rainfall is gradual and continuous. Variation of any one characteristic which would give a tree an adaptive advantage would therefore also tend to be gradual and continuous (Stebbins, 1950).

Interspecific hybridization is another factor often proposed to explain variation in some characteristics of loblolly pine. In east Texas phenotypes intermediate between loblolly and shortleaf pine seem to be fairly common. One of the greatest barriers to hybridization is the difference in time of flowering. For loblolly pine receptivity of female strobili and pollen dissemination is in March while for shortleaf this optimum period is usually in April. From time to time, however, unusual weather conditions could cause an overlap in the time of pollen dissemination and receptivity of the two species (Zobel, 1953). Thorbjornsen (1960) suggests that this kind of a process may be the cause of small cones in the east Texas area. He also suggests that hybridization with longleaf pine in east Texas may account for rounded seed in that area.

Thorbjornsen (1960) suggests still another alternative explanation for variation in loblolly pine. The majority of the 13 characteristics which he analyzed did not show any regional pattern of variation. These

random patterns may be the result of either local environmental effects on the expression of the characteristic involved or random genetic drift. The latter may be the case if local populations evolved from initially small populations which were genetically "distinct."

Wells and Wakeley (1966) discussed possible causes of the variation pattern for rust resistance. Unlike survival and height growth, rust resistance was not correlated with climatic variables, latitude or longitude. A theory of selection pressure exerted by Cronartium fusiforme Hedgc. & Hunt was explored and was also found unacceptable. In order for selection pressure to be a factor one must assume that the disease caused high mortality and growth loss in natural stands some time in the past and that the disease was more prevalent in Texas, Arkansas and Maryland. There is no evidence that this has ever been the case and at present the disease is less prevalent in these areas than in other parts of the species range. A more likely explanation for resistance to fusiform rust in loblolly pine is introgression by shortleaf pine. The presence of trees with characteristics (needle, bark, cones, general appearance, etc.) intermediate between loblolly and shortleaf pine in east Texas and southwestern Arkansas has long been known.

Hare and Switzer (1969) analyzed and compared proteins of seed from eight eastern sources and four western sources of loblolly and three Mississippi sources of shortleaf pine by electrophoresis. The trees of western sources, on the average, were more similar in seed protein to shortleaf pine than trees of eastern sources. On this basis

they concluded that introgression with shortleaf pine is much more frequent in western than in eastern loblolly pine and that introgression may account for the fusiform rust resistance of trees of the western sources.

Wells and Wakeley (1966) suggest that the rust resistance of the Maryland source may be the result of hybridization with pond pine (Pinus serotina Michx.).

Kraus (1967) discusses another factor which would seem to add credence to the introgression theory. Density and occurence of a species varies a great deal within its range. Density would greatly influence the possibility of a chance interspecific pollination and fertilization. One of the greatest concentrations of shortleaf pine is found in southwest Arkansas, near the source of the most rust resistant loblolly pine in the Georgia study. Furthermore, in Georgia, the density of shortleaf pine increases greatly north of the fall line while on the Georgia coast it is fairly scarce. This observation is consistent with his finding that trees of seed sources from the mountain provinces tend to be more rust resistant than those of the Coastal Plain sources of loblolly pine.

CHAPTER III

PROCEDURE

Ten provenance tests in the state of Tennessee were measured and sampled in the period July, 1969 through July, 1970. Location, agencies responsible for establishment, year of establishment and date of measurement are listed in Table 1. Seed sources represented in each provenance test, number of replications and number of trees per plot are listed in Table 2. Most of the plantations were established on abandoned farm land. Location of the different provenance test plantations in the state is shown in Figure 1, and described in Table 3. Table 4 summarizes all sources represented in the provenance tests.

In addition, five loblolly pine seed source tests, part of a species comparison test established by the University of Tennessee in different physiographic provinces of the state were also measured. These tests were established at Ames, Crossville, Friendship, Highland Rim and Stephen's Switch. They had 25 trees per plot, four replications with four seed sources; central-west Georgia (Manchester), northwest Georgia-southeast Tennessee, north Alabama, and north Mississippi. The tests at Ames, Crossville and Stephen's Switch were established in 1960; the Friendship and Highland Rim tests were established in 1961.

Trees were measured for height and diameter at breast height (d.b.h.). A 38 foot telescoping aluminum pole was used to determine height of young trees to the nearest foot and a Haga altimeter was used

Table 1. Agencies responsible for establishment of the 10 seed source tests, year of establishment and date of measurement

Plantation	Established by	Year established	Date measured
Ames	Univ. of Tennessee	1961	July 1969
Chickasaw	U.S. Forest Service and Tenn. State Div. of Forestry	1952	July 1969
Counce	Tenn. River Pulp & Paper Co. and Tenn. Valley Auth.	1960	Mar. 1970
Friendship	Univ. of Tennessee and Tenn. Valley Auth.	1954	Aug. 1969
Highland Rim	Univ. of Tennessee	1961	Sept. 1969
Norris	U.S. Forest Service and Tenn. Valley Auth.	1954	Apr. 1970
Norris-Loyston	Tenn. Valley Auth.	1950	Apr. 1970
Sewanee (A)	Univ. of the South and Tenn. Valley Auth.	1955	July 1970
Sewanee (B)	Univ. of the South and Tenn. Valley Auth. and U.S. Forest Service	1956	July 1970
Stephen's Switch	Univ. of Tennessee and Tenn. Valley Auth.	1956	Aug. 1969

Table 2. Sources represented at each provenance test, number of replications and original number of trees in measured plots

Plantation	Sources represented	No. repl.	Trees/ plot
Ames		4	25
	Virginia Coastal Plain Accomac, Va.		
	Virginia Piedmont Chilesburg, Va.		
	South Carolina Coastal Plain Georgetown, S. C.		
	South Carolina Piedmont Johnston, S. C.		
	Georgia Piedmont Griffin, Ga.		
	north central Alabama Cullman, Ala.		
	northeast Mississippi Tishomingo, Miss.		
	south Mississippi Coastal Plain Woodville, Miss.		
	southeast Arkansas Crossett, Ark.		
	Southern (deep south Coastal Plain)[a]		
Chickasaw[b]		4	49
	North Carolina Southeast Coastal Plain Onslow county		
	South Carolina Piedmont Newberry county		
	northwest Georgia Spalding county		
	northeast Georgia Clarke county		
	northeast Alabama Clay county		
	northwest Mississippi Prentis county		
	west Tennessee Hardemann county		
	southwest Arkansas Clarke county		
	southeast Louisiana Livingston Parish		

Table 2 (continued)

Plantation	Sources represented	No. repl.	Trees/ plot
Counce		4	25
	Maryland Coastal Plain		
	North Carolina Coastal Plain		
	South Carolina Coastal Plain		
	Horry county		
	west central Georgia		
	Heard county		
	northwest Alabama		
	southwest Alabama		
	Clarke county		
	northeast Mississippi		
	Monroe county		
	south Mississippi		
	southeast Tennessee		
	Hamilton county		
Friendship		4	49
	Virginia		
	east North Carolina		
	central North Carolina		
	South Carolina		
	Georgia		
	Arkansas		
Highland Rim		4	25
	Virginia Coastal Plain		
	Accomac, Va.		
	South Carolina Piedmont		
	Johnston, S. C.		
	Georgia Piedmont		
	Griffin, Ga.		
	north central Alabama		
	Cullman, Ala.		
	southeast Arkansas		
	Crossett, Ark.		
	Southern (deep south Coastal Plain)[a]		
Norris[c]		4	25
	North Carolina Coastal Plain		
	South Carolina Coastal Plain		
	north Georgia (lot 3)		
	north Georgia (lot 6)		

Table 2 (continued)

Plantation	Sources represented	No. repl.	Trees/ plot
	northwest Georgia (lot 5)		
	southeast Arkansas		
	Crossett, Ark.		
Norris-Loyston		4	25
	Maryland		
	northeast Virginia Coastal Plain		
	northwest Georgia		
	southeast Tennessee		
	north Alabama		
	south Alabama		
	northeast Mississippi		
	east Mississippi		
Sewanee (A)		4	25
	Virginia Coastal Plain		
	North Carolina Coastal Plain		
	North Carolina Piedmont		
	South Carolina Coastal Plain		
	Horry county		
	Georgia Piedmont		
	Upson county		
	southwest Arkansas		
	Howard county		
Sewanee (B)		4	25
	North Carolina Coastal Plain		
	north Georgia Piedmont		
	north Alabama		
	Arkansas		
	Ashley county		
Stephen's Switch		4	49
	North Carolina Coastal Plain		
	North Carolina Piedmont		
	South Carolina Coastal Plain		
	north Georgia Piedmont		
	southeast Tennessee		
	north Alabama		

[a]Southern sources at both Ames and Highland Rim consist of trees from southeast Texas, west central La., southeast La., southwest Ga.,

Table 2 (continued)

and northeast Fla. Due to poor first-year survival trees of these sources were transplanted into the composite Southern sources plot. In the presentation of the Ames needle data, samples from Southern sources are separated into Southwest (southeast Texas and central La.) and Southeast sources (southeast La., southwest Ga., and northeast Fla.).

[b]Fifteen year height and diameter data of the Southern Forest Experiment Station were used for this test since it was measured at the end of the 1967 growing season. This plantation is part of the South-wide Pine Seed Source Study.

[c]This plantation was selectively thinned in 1964; only slowest growing trees, diseased trees or trees with poor form were removed. The plantation is part of the Crossett-in-Reverse loblolly seed source study sponsored by the Southern Forest Experiment Station.

CRANES CREST

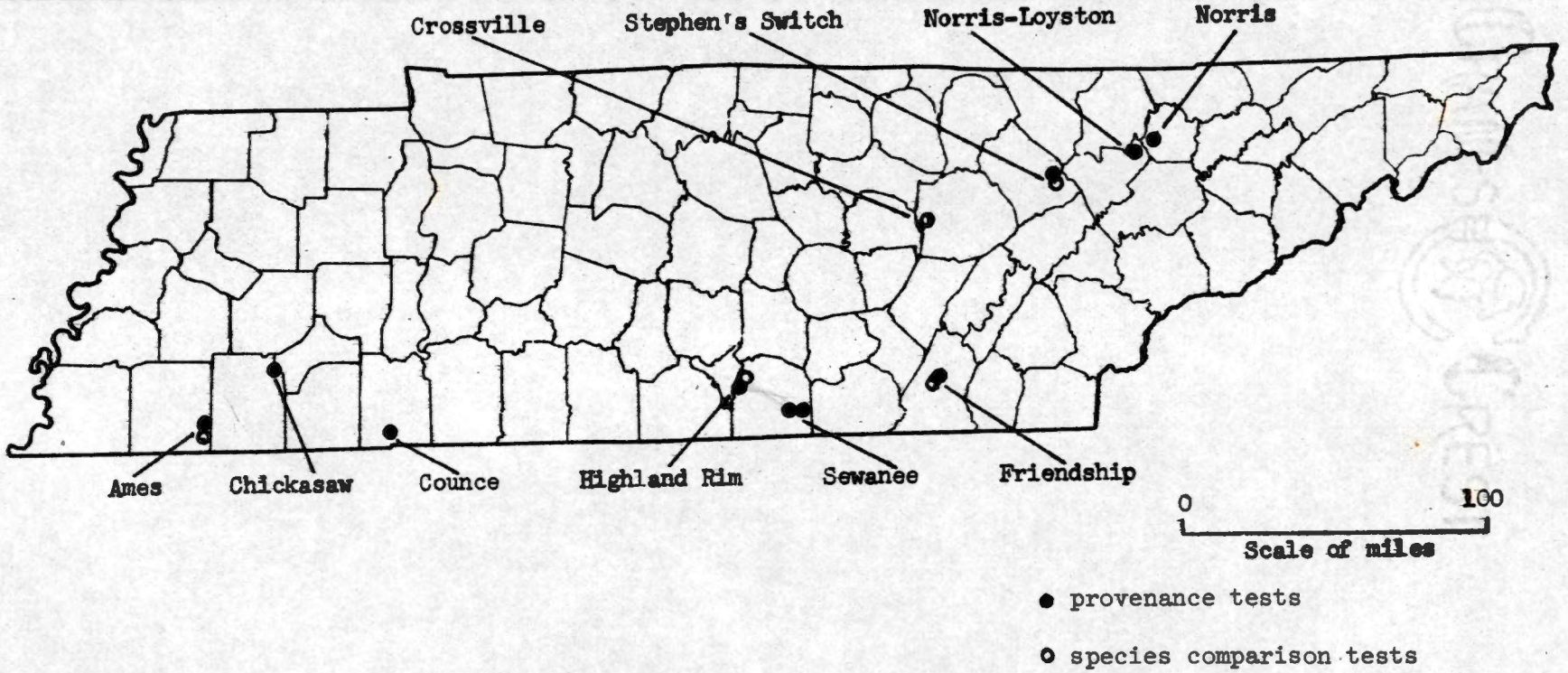


Figure 1. Location of provenance and species comparison tests

Table 3. Location of seed source test plantations

Plantation	County	Longitude	Latitude	Altitude (ft.)	Physiography
Ames	Fayette Hardemann	89°20'	35°05'	500	West Tennessee Slope
Chickasaw	Hardemann Chester	88°50'	35°20'	500	West Tennessee Slope
Counce	Hardin	88°20'	35°05'	400	West Tennessee Slope
Friendship	Hamilton	85°05'	35°15'	800	Ridge and Valley
Highland Rim	Franklin	86°05'	35°20'	1,000	Highland Rim
Norris	Anderson	84°05'	36°10'	1,000	Ridge and Valley
Norris-Loyston	Anderson Union	84°05' 83°55'	36°10' 36°15'	1,000 1,000	Ridge and Valley
Sewanee (A)	Franklin	85°50'	35°15'	2,000	Cumberland Plateau
Sewanee (B)	Franklin	85°50'	35°15'	2,000	Cumberland Plateau
Stephen's Switch	Morgan	84°25'	36°05'	1,500	lower elevations of Cumberland Mountains

Table 4. Summary of sources represented in provenance tests

Seed Source	Plantation	Ames	Chickasaw	Counce	Friendship	Highland Rim	Norris	Norris-Loyston	Sewanee (A)	Sewanee (B)	Stephen's Switch
Virginia Coastal Plain		x			x	x		x	x		
Virginia Piedmont		x									
North Carolina Coastal Plain			x	x	x		x		x	x	x
North Carolina Piedmont					x				x		x
South Carolina Coastal Plain		x		x			x		x		x
South Carolina Piedmont		x	x		x	x					
Georgia Piedmont		x	x		x	x	x	x	x	x	x
Georgia south and central				x							
Alabama north		x	x	x		x		x		x	x
Alabama south				x				x			
north Mississippi		x	x	x				x			
central Mississippi								x			
south Mississippi		x		x							
Louisiana			x								
Arkansas		x	x		x	x	x		x	x	
Tennessee southwest			x								
Tennessee southeast				x				x			x
Deep South Coastal Plain		x				x					
Maryland				x				x			

to measure total height in older plantations. A standard steel diameter tape was used to measure d.b.h. to the nearest 0.1 inch. Individual tree volumes were computed using a volume formula for young loblolly pine (Perry and Roberts, 1964):

$$V = (63.49 + 4.769\ D^2H)/\ (12)^3$$

where V = volume in cubic feet

D = diameter in inches

H = height in feet

Volume per plot was calculated by multiplying mean individual tree volumes per plot by number of surviving trees for that plot. This was converted to a per acre basis by multiplying volume per plot by (43560 sq. ft./acre)/(number of square feet in plot). Tons of wood per acre were computed by the formula:

$$\text{Tons/acre} = \frac{\text{V/acre x 62.4 x sp. gr.}}{2000}$$

Wood and needle samples were obtained from 16 trees per source in each location (i.e.; 4 trees per plot, 4 replications). Dominant or codominant sample trees without symptoms of disease were selected. In addition, it was endeavored to select trees from the inner rows of each plot in order to avoid confounding due to border effects.

Each tree measured was subjectively rated for stem straightness. A scale of 1 to 3 was used in which straight trees were rated 1, trees with some crookedness were rated 2 and very crooked trees were rated 3.

I. WOOD SAMPLES

An 11mm. increment borer was used to extract one core at breast

height from each sample tree. In order to minimize the quantity of compression wood, trees were bored parallel to the contour of the slope of the site. Cores included all wood from bark to bark. They were labeled and stored frozen in plastic tubes.

Specific gravity determinations were made on the basis of ovendry weight and green volume. Volumes were calculated using the diameter and length of each core and the formula for volume of a cylinder, $V = \pi r^2 l$ where r is the radius and l is the length of the core. Cores with knots, unusual crooks or high amounts of compression wood were cut in half and specific gravity was only determined for the clear half of the core. The wood samples were then dried at 105° C for two days and extracted in a Soxhlet apparatus. Extraction was accomplished in two parts. First, a 2:1 mixture of benzene and 95 percent ethanol was percolated for 16 hours followed by 95 percent ethanol for four hours.

II. NEEDLE SAMPLES

A cutter pole was used to remove small branches from the upper parts of the crowns. In most cases foliage samples were collected only from younger plantations since reaching the tops of taller trees in the older plantations was too time consuming. Branchlets were labeled, put in plastic bags and stored in a cold room at 36-40° F.

Three separate needle fascicles were evaluated from one branchlet of each sample tree. Five foliage characteristics were measured on each needle fascicle:

1. Number of needles per fascicle.
2. Length of the needles in each fascicle (in centimeters).

3. Number of stomatal lines on the rounded surface of one needle from each fascicle. A dissecting microscope was used at 40 magnifications.
4. Number of serrations per centimeter of one needle from each fascicle. Serrations were counted for a two millimeter length of each needle and multiplied by five to convert to centimeters. Observations were made in the center of each needle.
5. Number of stomates per centimeter of one needle from each fascicle. These were counted on a stomatal line in the center of each needle. The same method as above was used to count stomata.

III. STATISTICAL METHODS

Analysis of variance was used to test for significance among sources within plantations, followed by a Duncan's Multiple Range Test for separation of treatment means. An IBM 360 model 65 computer was used to calculate correlation and regression among different characteristics for plantings where significant differences were found among seed sources.

Stem straightness data was not subjected to statistical analysis because the classification was subjective. Nonnormal distribution of values precluded the use of analysis of variance to test seed source means for significant survival differences.

CHAPTER IV

RESULTS AND ANALYSES

Tables 5 through 14 list mean heights, diameters, extracted specific gravity, percent survival, volume per tree, volume per acre, tons per acre and stem straightness for all sources in their respective provenance tests. Duncan's Multiple Range (D.M.R.) Tests are shown for each characteristic in each test where analysis of variance disclosed significant variation among seed sources at the 95 percent level of probability.

Tables 15 and 16 list growth and yield data from the five species comparison tests. Analysis of variance on each individual plantation failed to disclose any meaningful information. Data from the two nine year old plantations and the three 10 year old plantations were combined and analysis of variance performed with the resultant increased precision (due to added error degrees of freedom). The increased sensitivity of the combined analysis failed, however, to reveal any significant variation among seed sources in the species comparison group.

Means for five foliage characteristics (number of needles per fascicle, needle length, number of stomatal lines, number of serrations per centimeter of needle length, and number of stomates per centimeter) are listed in Tables 17 through 22. Significant differences among sources were found only in three locations (Ames, Counce and Chickasaw).

Table 5. Mean values of eight growth characteristics and Duncan's Multiple Range Test for 10 seed sources at Ames Plantation

Seed source	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	stem str.[a]
Virginia Piedmont	25.04	5.03	.380	62	1.84	678.52	7.99	1.3
Virginia Coastal Plain	25.13	4.64	.362	95	1.39	916.87	10.25	1.5
South Carolina Piedmont	24.01	4.74	.359	97	1.57	1,036.05	11.52	1.7
South Carolina Coastal Plain	20.74	4.12	.370	92	1.01	627.33	7.25	1.8
Georgia Piedmont	23.44	5.00	.353	71	1.66	810.83	8.91	1.6
north central Alabama	22.95	4.83	.360	63	1.51	647.89	7.26	1.6
Mississippi Coastal Plain	19.65	4.00	.357	54	0.95	340.31	3.79	2.0
northeast Mississippi	23.44	4.70	.366	91	1.48	927.15	10.57	1.8
southeast Arkansas	23.39	4.84	.378	66	1.58	720.58	8.49	1.4
Southern	18.18	3.56	.353	76	0.69	358.35	3.94	1.8
	18.18	3.56			0.69	340.31	3.79	
	19.65	4.00			0.95	358.35	3.94	
	20.74	4.12			1.01	627.33	7.25	
	22.95	4.64			1.39	647.89	7.26	
	23.39	4.70			1.48	678.52	7.99	
	23.44	4.74			1.51	720.58	8.49	
	23.44	4.83			1.57	810.83	8.91	
	24.01	4.84			1.58	916.87	10.25	
	25.04	5.00			1.66	927.15	10.57	
	25.13	5.03			1.84	1,036.05	11.52	

[a]Stem straightness rating: 1 for straight stems, 2 for stems with some crooks and 3 for very crooked stems.

Table 6. Mean values of eight growth characteristics and Duncan's Multiple Range Test for six seed sources at Highland Rim Plantation

Seed sources	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	stem str.[a]
Virginia Coastal Plain	25.88	5.19	.346	98	1.96	1,304.83	14.08	1.9
South Carolina Piedmont	23.73	5.15	.351	96	1.77	1,130.66	12.38	1.7
Georgia Piedmont	23.15	4.82	.347	86	1.53	899.58	9.72	1.9
north central Alabama	23.20	4.86	.342	72	1.56	762.98	8.16	1.7
southeast Arkansas	23.58	4.78	.344	99	1.55	1,044.28	11.12	1.6
Southern	20.63	4.11	.350	70	0.99	490.60	5.35	1.8
	20.63	4.11			0.99	490.60	5.35	
	23.15	4.78			1.53	762.98	8.16	
	23.20	4.82			1.55	899.58	9.72	
	23.58	4.86			1.56	1,044.28	11.12	
	23.73	5.15			1.77	1,130.66	12.38	
	25.88	5.19			1.96	1,304.83	14.08	

[a]Stem straightness rating: 1 for straight stems, 2 for stems with some crooks and 3 for very crooked stems.

Table 7. Mean values of eight growth characteristics and Duncan's Multiple Range Test for nine seed sources at Counce Plantation

Seed source	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	stem str.[a]
Maryland Coastal Plain	29.61	4.80	.358	67	1.92	1,556.18	17.33	1.5
North Carolina Coastal Plain	31.72	5.68	.359	63	2.99	2,049.50	22.98	1.6
South Carolina Coastal Plain	28.45	5.60	.355	44	2.52	1,314.42	14.55	1.9
Georgia Piedmont	28.80	4.90	.357	68	2.04	1,521.58	16.90	1.6
northwest Alabama	28.40	4.57	.342	76	1.68	1,521.46	16.23	1.6
southwest Alabama	28.68	5.18	.355	53	2.17	1,322.41	14.65	2.0
southeast Tennessee	26.32	4.76	.375	62	1.70	1,227.55	14.31	1.7
northeast Mississippi	29.15	4.71	.354	79	1.82	1,744.82	19.32	1.5
south Mississippi	26.50	5.11	.356	53	1.95	1,218.11	13.51	2.0
	26.32	4.57			1.68	1,218.11	13.51	
	26.50	4.71			1.70	1,227.55	14.31	
	28.40	4.76			1.82	1,314.42	14.55	
	28.45	4.80			1.92	1,322.41	14.65	
	28.68	4.90			1.95	1,521.46	16.23	
	28.80	5.11			2.04	1,521.58	16.90	
	29.15	5.18			2.17	1,556.18	17.33	
	29.61	5.60			2.52	1,744.82	19.32	
	31.72	5.68			2.99	2,049.50	22.98	

[a]Stem straightness rating: 1 for straight stems, 2 for stems with some crooks and 3 for very crooked stems.

Table 8. Mean values of eight growth characteristics and Duncan's Multiple Range Test for six seed sources at Stephen's Switch Plantation

Seed source	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	stem str.[a]
North Carolina Coastal Plain	43.12	5.25	.396	66	3.36	2,692.62	33.33	2.2
North Carolina Piedmont	44.35	5.48	.375	78	3.72	3,492.83	40.91	2.3
South Carolina Coastal Plain	39.79	5.17	.377	70	2.99	2,498.28	29.26	2.1
north Georgia Piedmont	41.86	5.64	.363	53	3.76	2,295.79	26.11	2.4
north Alabama	42.52	5.50	.392	66	3.58	2,885.60	35.31	2.0
southeast Tennessee	40.10	5.10	.385	83	2.93	2,927.64	35.23	2.0
	39.79					2,295.79	26.11	
	40.10					2,498.28	29.26	
	41.86					2,692.62	33.33	
	42.52					2,885.60	35.23	
	43.12					2,927.64	35.31	
	44.35					3,492.83	40.91	

[a]Stem straightness rating: 1 for straight stems, 2 for stems with some crooks and 3 for very crooked stems.

Table 9. Mean values of eight growth characteristics for nine seed sources at Chickasaw Plantation

Seed source	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	stem str.[a]
North Carolina Coastal Plain	39.97	6.37	.389	17	4.50	1,360.31	16.03	1.7
South Carolina Piedmont	39.40	6.00	.388	59	3.98	2,758.39	33.70	1.3
northeast Georgia	40.00	6.17	.401	46	4.26	2,233.23	28.37	1.5
northwest Georgia	38.13	6.00	.380	49	3.85	2,104.25	25.06	1.4
northeast Alabama	40.80	7.10	.390	27	5.71	2,439.51	30.51	2.0
west Tennessee	36.97	6.47	.379	41	4.59	2,077.08	25.27	1.8
northwest Mississippi	40.10	6.50	.392	16	4.69	1,332.65	16.28	1.0
southeast Louisiana	34.00	6.40	.392	30	3.86	1,847.10	22.81	2.2
southwest Arkansas	36.23	5.87	.393	44	3.52	1,875.50	23.62	1.1

[a]Stem straightness rating: 1 for straight stems, 2 for stems with some crooks and 3 for very crooked stems.

Table 10. Mean values of eight growth characteristics for six seed sources at Norris Plantation

Seed source	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	stem str.[a]
North Carolina Coastal Plain	45.21	5.95	.383	54	4.46	2,910.78	34.73	2.2
South Carolina Coastal Plain	44.20	6.15	.394	40	4.67	2,268.63	27.92	2.4
north Georgia (lot 3)	45.25	5.85	.379	53	4.32	2,772.71	32.90	1.7
north Georgia (lot 6)	45.19	5.85	.390	51	4.49	2,750.21	33.51	2.0
northwest Georgia (lot 5)	42.48	5.95	.377	51	4.20	2,580.45	30.37	1.6
southeast Arkansas	44.29	6.04	.393	51	4.55	2,798.49	34.25	1.4

[a]Stem straightness rating: 1 for straight stems, 2 for stems with some crooks and 3 for very crooked stems.

Table 11. Mean values of eight growth characteristics for eight seed sources at Norris-Loyston Plantation

Seed source	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	stem str.[a]
Maryland	53.16	7.21	.428	51	7.68	4,019.80	53.53	1.7
Virginia Coastal Plain	53.63	7.40	.398	33	8.14	2,517.55	31.48	1.4
northwest Georgia	56.05	7.54	.401	53	8.83	5,050.52	62.99	1.6
north Alabama	57.61	7.76	.407	60	9.65	6,167.88	78.49	1.7
south Alabama	53.01	7.49	.401	52	8.34	4,444.34	73.29	2.2
southeast Tennessee	52.03	7.39	.424	43	7.92	3,553.43	47.02	1.4
northeast Mississippi	53.88	7.84	.394	37	9.28	3,669.42	45.58	1.6
east Mississippi	53.49	7.74	.394	45	9.04	4,305.09	53.16	1.7

[a]Stem straightness rating: 1 for straight stems, 2 for stems with some crooks and 3 for very crooked stems.

Table 12. Mean values of eight growth characteristics for six seed sources at Sewanee (A) Plantation

Seed source	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	stem str.[a]
Virginia Coastal Plain	40.12	5.53	.398	68	3.48	2,673.01	32.29	1.6
North Carolina Coastal Plain	42.40	5.66	.404	65	3.79	2,958.94	37.44	2.1
North Carolina Piedmont	41.16	5.41	.395	61	3.38	2,427.38	29.94	2.1
South Carolina Coastal Plain	40.50	5.45	.371	66	3.37	2,669.26	30.92	2.3
Georgia Piedmont	41.38	5.55	.390	64	3.58	2,756.50	33.48	2.0
southwest Arkansas	40.95	5.50	.395	71	3.45	2,963.53	36.35	1.8

[a]Stem straightness rating: 1 for straight stems, 2 for stems with some crooks and 3 for very crooked stems.

Table 13. Mean values of eight growth characteristics for four seed sources at Sewanee (B) Plantation

Seed source	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	Stem str.[a]
North Carolina Coastal Plain	38.77	5.48	.374	55	3.24	2,005.82	23.48	2.1
north Georgia Piedmont	38.33	5.75	.373	34	3.52	1,240.37	14.38	2.2
north Alabama	39.27	5.17	.391	72	2.96	2,585.89	31.64	2.0
Arkansas	39.55	5.49	.405	57	3.36	2,289.56	28.96	1.6

[a]Stem straightness rating: 1 for straight stem, 2 for stem with some crooks and 3 for very crooked stems.

Table 14. Mean values of eight growth characteristics for six seed sources at Friendship Plantation

Seed source	Height (ft.)	d.b.h. (in.)	Sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre	tons/ acre	stem str.[a]
Virginia	43.72	5.37	.401	80	3.52	3,369.48	42.18	1.9
east North Carolina	43.84	5.31	.403	88	3.46	3,675.19	46.28	2.0
central North Carolina	43.28	5.09	.399	91	3.10	3,348.51	41.69	2.0
South Carolina	42.55	5.31	.385	83	3.36	3,360.16	40.44	2.3
Georgia	40.96	5.27	.384	80	3.21	2,990.71	35.84	2.2
Arkansas	42.02	5.28	.401	88	3.27	3,407.20	42.61	1.8

[a]Stem straightness rating: 1 for straight stems, 2 for stems with some crooks and 3 for very crooked stems.

Table 15. Mean values of six growth characteristics for four seed sources in the 10 year old plantations at Ames, Stephen's Switch and Crossville

Seed source	Height (ft.)	d.b.h. (in.)	extracted sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre
central west Georgia - Manchester	27.23	5.65	.359	84	2.54	1,526.64
northwest Georgia - southeast Tennessee	27.48	5.78	.363	85	2.65	1,575.87
north Alabama	27.08	5.48	.369	88	2.33	1,432.49
north Mississippi	27.84	5.59	.361	90	2.53	1,555.91

Table 16. Mean values of six growth characteristics for four seed sources in the nine year old plantations at Highland Rim and Friendship

Seed source	Height (ft.)	d.b.h. (in.)	extracted sp. gr.	Surv. %	cu. ft./ tree	cu. ft./ acre
central west Georgia - Manchester	28.30	5.86	.344	91	2.73	1,677.88
northwest Georgia - southeast Tennessee	26.98	5.54	.363	95	2.33	1,510.82
north Alabama	26.81	5.54	.361	95	2.31	1,483.22
north Mississippi	27.74	5.68	.351	99	2.51	1,684.99

Table 17. Mean values for five needle characteristics and Duncan's Multiple Range Test for 10 seed sources at Ames Plantation

Seed source	No. needles per fascicle	Needle length, cm.	No. stomatal lines	No. serr. per cm.	No. stomates per cm.
Virginia Piedmont	3.2	17.5	16.3	54.1	137
Virginia Coastal Plain	3.2	18.4	16.0	47.8	134
South Carolina Piedmont	3.2	17.7	16.1	54.8	140
South Carolina Coastal Plain	3.3	18.4	14.6	48.3	134
Georgia Piedmont	3.3	17.3	16.3	48.8	137
north central Alabama	3.2	17.5	15.8	49.2	135
Mississippi Coastal Plain	3.1	18.7	15.8	52.7	135
northeast Mississippi	3.2	18.4	13.8	48.5	137
southeast Arkansas	3.3	17.7	15.4	49.4	128
Southeast	3.5	16.9	15.1	46.7	130
Southwest	3.4	18.1	15.6	51.2	133
			13.8	46.7	
			14.6	47.8	
			15.1	48.3	
			15.4	48.5	
			15.6	48.8	
			15.8	49.2	
			15.8	49.4	
			16.0	51.2	
			16.1	52.7	
			16.3	54.1	
			16.3	54.8	

Table 18. Mean values for five needle characteristics for six seed sources at Highland Rim Plantation.

Seed source	No. needles per fascicle	Needle length, cm.	No. stomatal lines	No. serr. per cm.	No. stomates per cm.
Virginia Coastal Plain	3.2	17.7	15.5	50.1	137
South Carolina Piedmont	3.2	18.3	16.2	48.9	138
Georgia Piedmont	3.3	17.8	16.2	47.5	129
north central Alabama	3.2	18.8	16.3	44.0	133
southeast Arkansas	3.3	18.0	15.9	47.6	132
Southern	3.5	18.4	15.9	48.3	127

Table 19. Mean values for five needle characteristics and Duncan's Multiple Range Test for nine seed sources at Counce Plantation

Seed source	No. needles per fascicle	Needle length, cm.	No. stomatal lines	No. serr. per cm.	No. stomates per cm.
Maryland Coastal Plain	3.0	16.8	14.1	53.8	133
North Carolina Coastal Plain	3.2	16.9	14.6	47.6	132
South Carolina Coastal Plain	3.0	18.2	13.3	45.6	139
Georgia Piedmont	3.0	17.1	14.2	53.9	137
northwest Alabama	3.0	16.7	13.9	53.2	138
southwest Alabama	3.1	16.7	13.5	52.0	140
southeast Tennessee	3.0	16.9	13.0	51.8	140
northeast Mississippi	3.0	17.3	14.3	51.9	138
south Mississippi	3.0	18.1	14.2	51.7	139
		16.7		45.6	
		16.7		47.6	
		16.8		51.7	
		16.9		51.8	
		16.9		51.9	
		17.1		52.0	
		17.3		53.2	
		18.1		53.8	
		18.2		53.9	

Table 20. Mean values for five needle characteristics and Duncan's Multiple Range Test for nine seed sources at Chickasaw Plantation

Seed source	No. needles per fascicle	Needle length, cm.	No. stomatal lines	No. serr. per cm.	No. stomates per cm.
North Carolina Coastal Plain	3.2	18.3	13.2	50.0	139
South Carolina Piedmont	3.0	19.6	14.4	55.7	137
northeast Georgia	3.0	19.5	14.5	51.6	132
northwest Georgia	3.2	17.8	13.6	55.8	140
northeast Alabama	3.0	18.8	14.4	50.7	134
west Tennessee	3.1	19.2	13.8	53.0	138
northwest Mississippi	3.0	18.7	14.2	48.0	143
southeast Louisiana	3.0	18.7	13.9	50.3	136
southwest Arkansas	3.0	18.0	13.8	50.9	136
		17.8		48.0	132
		18.0		50.0	134
		18.3		50.3	136
		18.7		50.7	136
		18.7		50.9	137
		18.8		51.6	138
		19.2		53.0	139
		19.5		55.7	140
		19.6		55.8	143

Table 21. Mean values of five needle characteristics for four seed sources in the 10 year old plantations at Ames, Stephen's Switch and Crossville

Seed source	No. needles per fascicle	Needle length, cm.	No. stomatal lines	No. serr. per cm.	No. stomates per cm.
central west Georgia - Manchester	3.1	17.8	14.9	51.8	137
northwest Georgia - southeast Tennessee	3.1	17.6	15.1	51.8	136
north Alabama	3.2	17.9	14.8	52.1	137
north Mississippi	3.1	17.2	15.1	50.8	139

Table 22. Mean values of five needle characteristics for four seed sources in the nine year old plantations at Highland Rim and Friendship

Seed source	No. needles per fascicle	Needle length, cm.	No. stomatal lines	No. serr. per cm.	No. stomates per cm.
central west Georgia - Manchester	3.3	17.6	15.4	47.6	135
northwest Georgia - southeast Tennessee	3.1	17.7	15.7	51.9	139
north Alabama	3.3	17.8	15.8	48.2	133
north Mississippi	3.3	17.9	15.9	52.1	138

I. GROWTH

Height

Of the 10 provenance tests measured and analyzed, four showed significant height growth differences among seed sources. In tests at Ames, the Highland Rim, Counce and Stephen's Switch (Tables 5 through 8, pages 30 through 33) a source from the northeast part of the species range (North Carolina, Virginia or Maryland) had trees with the fastest height growth. The D.M.R. Test showed that in each case these trees were significantly taller than all others. In most cases loblolly pines of deep south Coastal Plain sources were the shortest; trees of other sources had intermediate height growth. It is perhaps significant that each of these plantations is in a different physiographic region.

Diameter

Analyses of variance indicate significant differences among sources in the Ames, Counce and Highland Rim provenance tests. In all three cases trees from the northeast part of the species range (Virginia or North Carolina) had the greatest diameter growth. The D.M.R. Test for the Ames plantation (Table 5, page 30) showed the Virginia Piedmont, Georgia Piedmont and southeast Arkansas trees to have the greatest diameter growth while trees of Southern and Mississippi Coastal Plain sources had the slowest diameter growth. Similarly, at Highland Rim loblolly pines of the Virginia Coastal Plain source had the fastest diameter growth and those of Southern sources the slowest growth (Table 6, page 31). In the Counce plantation trees of the North Carolina Coastal Plain source had best diameter growth (Table 7, page 32).

Survival

Results from the Ames, Counce and Highland Rim provenance tests indicate that trees from deep south Coastal Plain sources have the poorest survival rates while trees of inland sources have higher survivals. At Counce trees of a northeast Mississippi source, at Ames those of the South Carolina Piedmont source and at the Highland Rim the southeast Arkansas loblolly pines had the highest survivals.

Stem Straightness

Trees from an Arkansas source or from a source in the northeast part of the species range had the straightest stems in nine out of 10 provenance tests. Loblolly pines from Arkansas sources had straight stems in each plantation in which they were represented (Ames, Chickasaw, Friendship, Sewanee (A), Sewanee (B), Norris, and Norris-Loyston). Trees from deep south Coastal Plain sources on an average had more crooked stems in seven out of 10 plantations (Ames, Counce, Chickasaw, Friendship, Sewanee (A), Norris-Loyston and Norris).

Volume Per Tree

Analysis of variance disclosed significant differences among sources for provenance tests at Ames, Counce and the Highland Rim. In each case trees from the northeastern part of the species range had the highest volume growth per tree. Virginia Piedmont trees had the greatest volume growth in the Ames plantation. At the Highland Rim plantation the D.M.R. Test indicated that trees of the Virginia Coastal Plain source had the greatest volume growth. In both cases

loblolly pines from southern sources had the slowest volume growth. At Counce, the North Carolina Coastal Plain trees had the greatest volume growth per tree.

Volume Per Acre

Significant differences among sources were found at the Ames, Counce, Highland Rim and Stephen's Switch provenance tests. The D.M.R. Test showed trees from northeast sources to produce the greatest volume per acre at Counce, Highland Rim and Stephen's Switch. In each case trees of a deep south source had the slowest per acre volume growth. At Ames the South Carolina Piedmont trees had the greatest per acre volume and trees from the deep south sources the lowest volumes.

II. EXTRACTED SPECIFIC GRAVITY

Analysis of variance disclosed no significant differences among sources at any of the provenance test locations. Evidence of trends seemed to be present in the Ames, Stephen's Switch, Norris-Loyston, Sewanee (A) and Friendship plantations where trees from northeast sources had the highest specific gravity wood. However, results from Norris, Chickasaw and Highland Rim conflicted with this trend; trees of southern sources had high specific gravity wood at these locations.

III. WOOD PRODUCTION (TONS/ACRE)

Significant differences among sources were obtained in the Ames, Highland Rim, Counce and Stephen's Switch provenance tests. At Counce trees of the North Carolina Coastal Plain source had the highest wood

production per acre while those of a southern Mississippi source had the lowest. In the Highland Rim plantation the D.M.R. Test indicates that Virginia Coastal Plain trees had the highest while those of southern sources had the lowest wood production. At Ames the trees of a South Carolina Piedmont source produced the greatest number of tons of wood per acre and again, trees of the southern sources were the poorest. Loblolly pines from the North Carolina Piedmont had the highest wood production and the north Georgia trees the lowest production per acre at Stephen's Switch.

IV. FOLIAGE CHARACTERISTICS

Number of Needles Per Fascicle

Analysis of variance did not disclose any significant variation among sources for this characteristic. No regional distribution pattern for this characteristic was evident.

Needle Length

Significant differences among sources for needle length were found at the Counce and the Chickasaw plantations. At Counce needles from South Carolina Coastal Plain trees were the longest and at Chickasaw trees from a South Carolina Piedmont source had the longest needles. This may be a coincidence, however, because no regional trends for this characteristic seemed to be present.

Number of Stomatal Lines

A regional trend for number of stomatal lines seemed to be

present at the Ames plantation with the greater numbers of stomatal lines being on needles from trees of eastern sources and lower numbers for those of western sources. This trend was not apparent in the other plantations. Significant differences among sources were found only at the Ames plantation. The D.M.R. Test indicates that at Ames the greatest number of stomatal lines were found on needles of Georgia and Virginia Piedmont sources; trees of the northeast Mississippi source had the lowest number.

Number of Serrations Per Centimeter

Significant differences among sources for frequency of needle serrations were obtained at Ames, Counce and Chickasaw. The D.M.R. Test for the Ames plantation showed the South Carolina and Virginia Piedmont trees to have the greatest number of serrations per centimeter. At Chicasaw the northwest Georgia and western South Carolina trees had the highest frequencies of serrations. At Counce the D.M.R. Test indicates that the Georgia Piedmont, Maryland Coastal Plain and northwest Alabama trees have the highest frequency. With the exception of the Maryland Coastal Plain source, trees with the highest frequency of needle serrations are of inland sources. The D.M.R. Tests also indicate that with one exception (Chickasaw) loblolly pines with the lowest serration frequency are from the Coastal Plain.

Stomatal Frequency

Significant differences among sources for stomatal frequency were found only in the Chickasaw plantation. However, no trend was evident

at this plantation. In addition, no evidence of a regional variation pattern was found in any of the remaining plantations.

CHAPTER V

DISCUSSION AND CONCLUSIONS

I. GROWTH AND WOOD PRODUCTION

Current knowledge of which seed sources of loblolly pine are best adapted for planting in Tennessee is based primarily on results from a few local individual provenance tests and from large scale comprehensive provenance tests, such as the Southwide Pine Seed Source Study, which have little representation in this state. The overall result is conflicting and often confusing information.

Growth data from the 10 provenance tests evaluated in this report indicate that trees from the northeast part of the species range are best suited for planting in Tennessee. Loblolly pines from deep south Coastal Plain sources consistently showed the poorest growth. Trees from northeast sources had the fastest growth in height, diameter, volume of wood per tree and volume of wood per acre. The only exception was the South Carolina Piedmont source; trees of this provenance had the greatest volume growth per acre at the Ames plantation. This result was in part a reflection of unusually high survival, but South Carolina Piedmont trees also had good growth at Chickasaw, Friendship and the Highland Rim plantations.

In addition, results of the stem straightness data indicate that loblolly pines of northeast sources have superiority in stem straightness over those from inland and southern Coastal Plain sources. In

this case trees from Arkansas sources were the exception; they rivaled and in some cases were superior to trees from northeast sources. Good stem straightness for trees of Arkansas seed sources was also reported by Little (1969). In most cases trees from the southern Coastal Plain sources were most crooked.

The adaptability of loblolly pine for planting in Tennessee appears to be related to mean length of the freeze-free period. Table 23 lists mean freeze-free periods of the northeast, inland and deep south Coastal Plain provenances based on three representative locations in each state (Dickson, 1960; Hocker, 1955). Mean freeze-free period for Tennessee, based on six locations, is also included. Trees of provenances with between 190 and 210 freeze-free days (northeast sources) produced the most wood; this period corresponds to the mean freeze-free period of most of the provenance test locations. Provenances with freeze-free periods between 210 and 240 days (inland sources) produced trees with intermediate growth and trees adapted to longer freeze-free periods (deep south Coastal Plain sources) generally yielded the poorest results.

These results are in agreement with other studies conducted north of the natural range or in the northern part of the natural range by Woerheide (1959), Kormanik et al. (1961), Thor (1967) and Little (1969). However, the apparent superiority of trees from inland sources when planted in Tennessee was not confirmed in this study; significant differences among sources in height in the Norris-Loyston plantation which were present at ages 5 and 10 (Wiesehuegel, 1955; Zarger, 1961) had disappeared at age 20.

Table 23. Mean freeze-free period of the three primary geographic provenances and Tennessee

Provenance	No. freeze-free days	Mean
Northeast		
Snow Hill, Md.	190	208
Solomons, Md.	213	
Crisfield, Md.	224	
Lynchburg, Va.	204	
Fredericksburg, Va.	193	
Danville, Va.	209	
Goldsboro, N. C.	217	
Durham, N. C.	200	
Fayetteville, N. C.	222	
Inland and Piedmont		
Greenville, S. C.	228	226
Columbia, S. C.	246	
Newberry, S. C.	221	
Rome, Ga.	217	
Athens, Ga.	217	
Atlanta, Ga.	233	
Birmingham, Ala.	239	
Anniston, Ala.	226	
Tuscaloosa, Ala.	231	
Boonville, Miss.	218	
Clarksdale, Miss.	217	
Water Valley, Miss.	215	
Camden, Ark.	229	
Hope, Ark.	231	
Hot Springs, Ark.	221	
Deep South Coastal Plain		
Charleston, S. C.	273	252
Orangeburg, S. C.	241	
Florence, S. C.	236	
Waycross, Ga.	254	
Brunswick, Ga.	282	
Albany, Ga.	249	
Montgomery, Ala.	261	
Troy, Ala.	247	
Thomasville, Ala.	237	
Hattiesburg, Miss.	233	

Table 23 (continued)

Provenance	No. freeze-free days	Mean
Natchez, Miss.	245	
Vicksburg, Miss.	252	
Ruston, La.	243	
Hammond, La.	255	
Baton Rouge, La.	269	
Tennessee		
Crossville	176	206
Savannah	207	
Knoxville	217	
Tullahoma	196	
Bolivar	203	
Chattanooga	235	

Source: R. R. Dickson, 1960. Climates of the states-Tennessee. U. S. Dept. of Commerce Weather Bureau No. 60-40, 15 pp; H. W. Hocker, Jr., 1955. Climatological summaries for selected stations in and near the southern pine region, 1921-1950. U. S. Forest Service, Southeastern Forest Experiment Station Paper No. 56, 12 pp.

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Wood production expressed as tons per acre followed a pattern very similar to volume growth per acre. At Counce and Ames there was a very strong correlation between these characteristics with r^2>98%. Figures 2 through 5 graphically depict mean wood production of trees from northeastern, inland and deep south sources in the Ames, Highland Rim, Counce and Stephen's Switch plantations. All sources north of and including North Carolina were combined into the northeast group, all Piedmont and inland sources south of North Carolina were in the inland group and all Coastal Plain provenances south of North Carolina were included in the deep south Coastal Plain sources. Histograms for the Highland Rim, Counce and Stephen's Switch plantations indicate that the trees of northeast sources have the highest wood production. At Ames however, trees from inland sources produced slightly more wood per acre than trees of the northeast sources. Ames is the most southwestern planting location and has the mildest climate of the four plantations. Higher wood production of trees from inland sources at Ames would, therefore, seem to support the hypothesis that adaptability of loblolly pines for planting in Tennessee is related to the mean freeze-free period.

In terms of monetary values these differences among seed sources can be considerable. Using cubic feet of wood per acre and 90 cubic feet of wood per cord, production at Ames plantation varied from a minimum of 3.8 cords for the Mississippi Coastal Plain trees to a maximum of 11.5 cords per acre for trees of the South Carolina Piedmont source eight years after outplanting. Assuming stumpage values of $5 per cord, this would translate into the difference between a return of $2.80 and $7.20

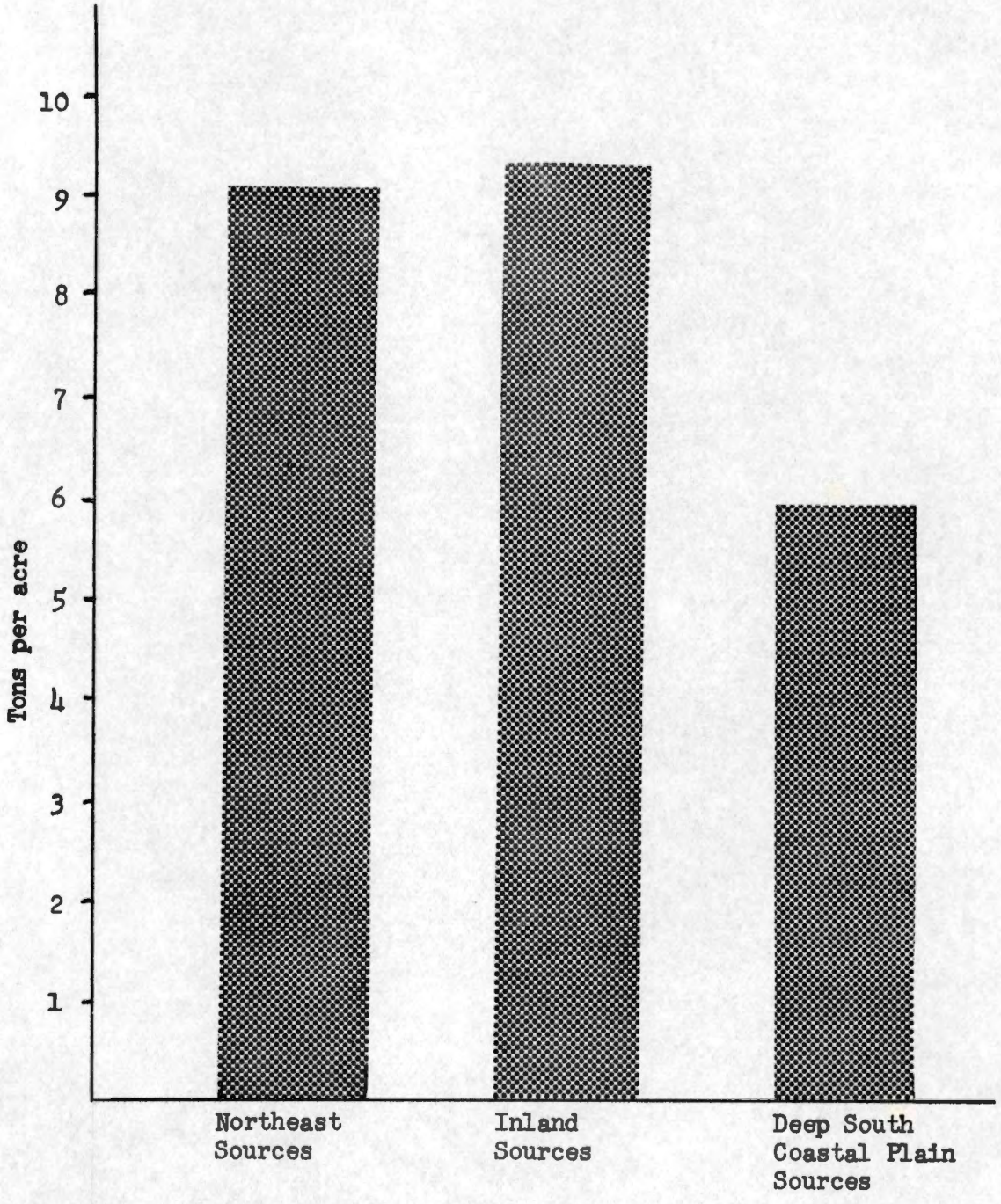


Figure 2. Mean wood production of loblolly pine from the three primary geographic provenance areas in the Ames Plantation.

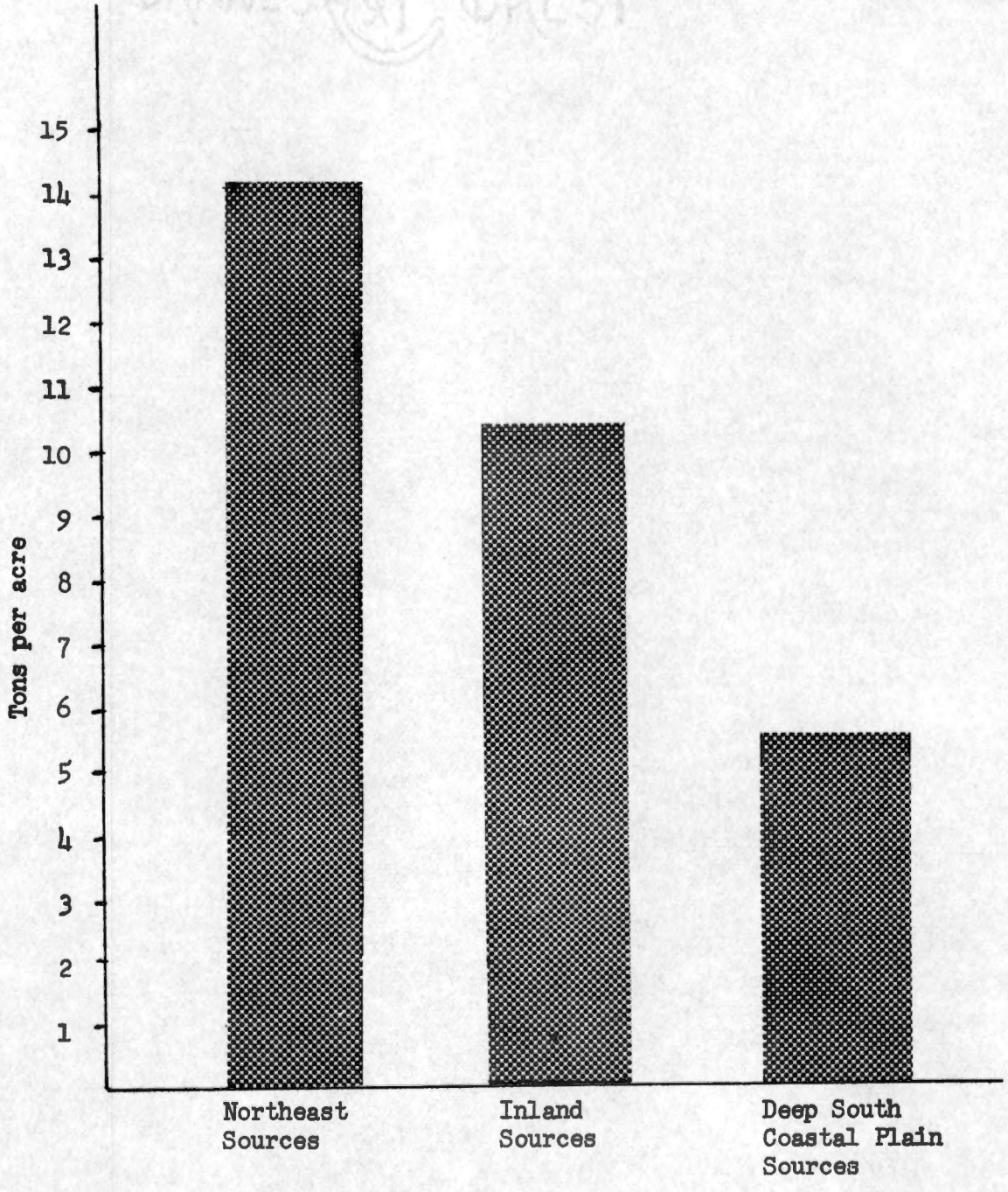


Figure 3. Mean wood production of loblolly pine from the three primary geographic provenance areas in the Highland Rim Plantation.

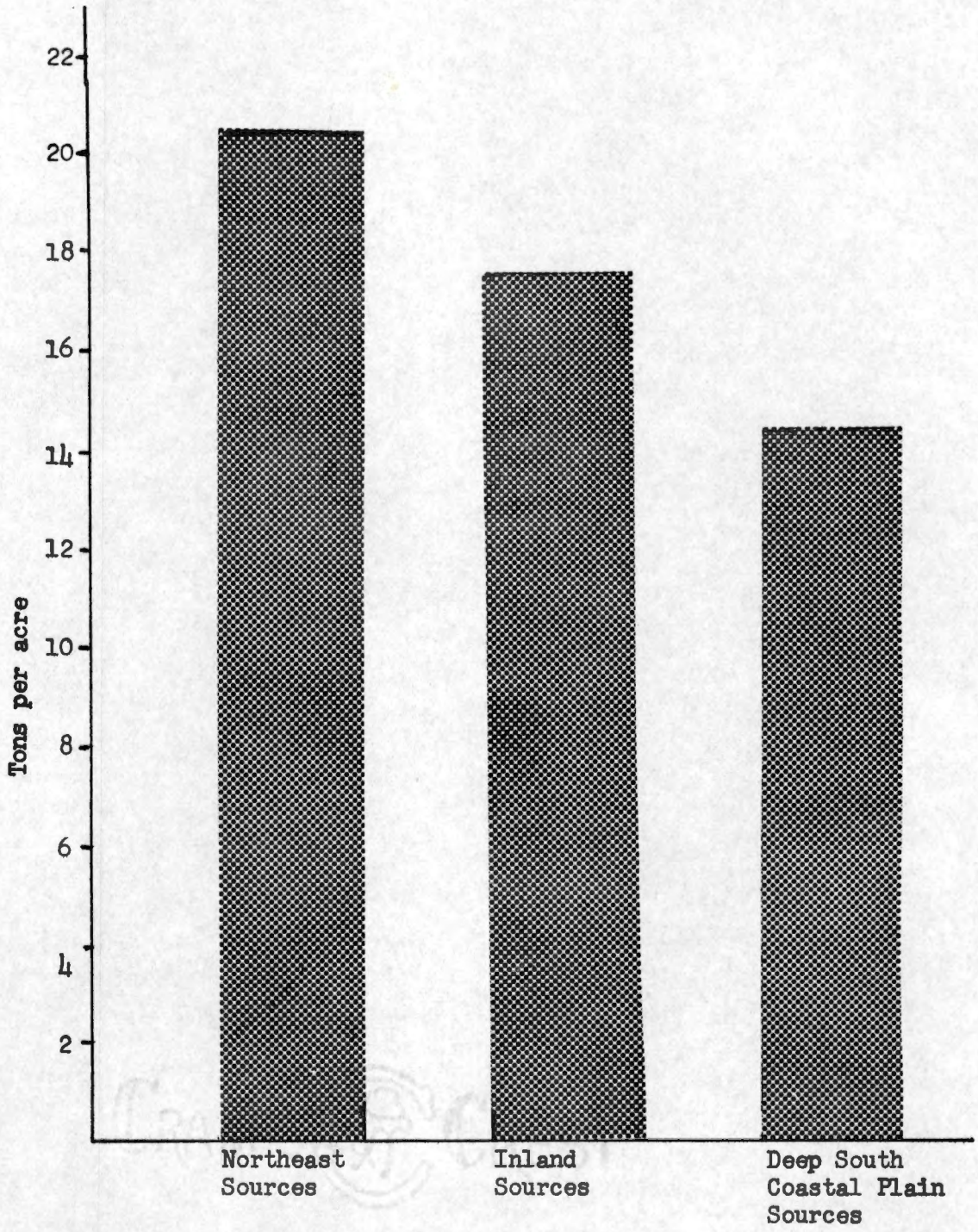


Figure 4. Mean wood production of loblolly pine from the three primary geographic provenance areas in the Counce Plantation.

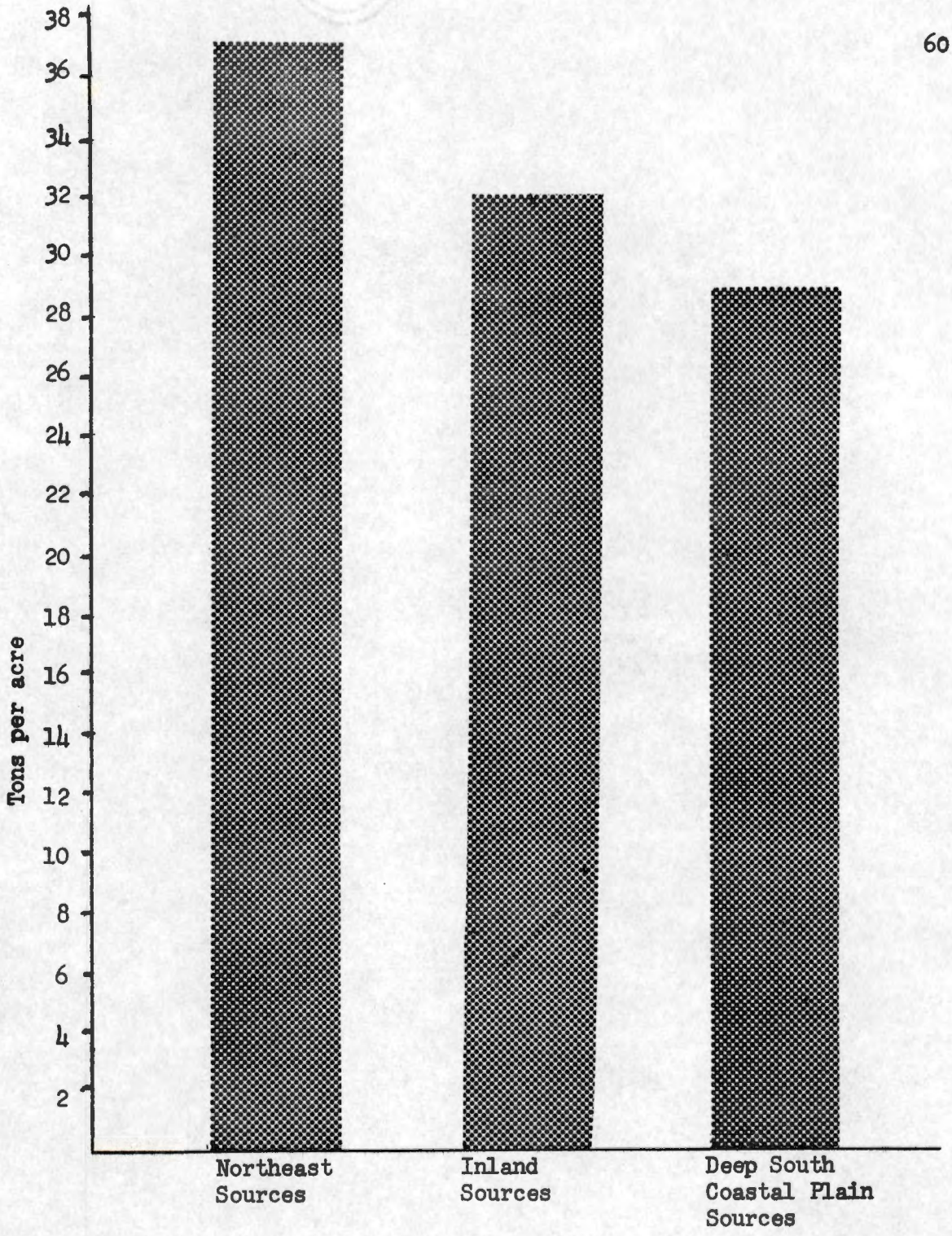


Figure 5. Mean wood production of loblolly pine from the three primary geographic provenance areas in the Stephen's Switch Plantation.

per acre per year. Wood production at the 15-year old Stephen's Switch plantation probably provides a more accurate picture of economic return since it is closer to rotation age. Production varied from 25.5 cords per acre for the north Georgia trees to 38.8 cords per acre for trees from the North Carolina Piedmont. This difference results in returns of $8.50 and $12.90 per acre per year.

II. EXTRACTED SPECIFIC GRAVITY

No significant differences among sources seemed to be present for this characteristic. Some weak evidence of trends seemed to be present with trees of northeast sources having the highest specific gravity wood at five locations. Evidence for this trend appeared to be strongest at Ames where a Virginia Piedmont source was ranked highest and the Southern sources lowest. This trend was even more apparent when the Southern source was separated into its component Southwest and Southeast sources (as with foliage data). Analysis of variance at this location now revealed significant differences among seed sources and the Duncan test indicated that wood from the Virginia Piedmont trees had significantly higher specific gravity than from trees of all other sources. Trees of the Southeast sources had significantly lower specific gravity wood than trees of all other sources. These results seem to confirm the work of Saucier and Taras (1967) where a regional pattern of specific gravity was observed with highest specific gravity wood from trees of northern sources and lowest from southern sources. However, there is conflicting evidence from some of the other provenance test plantations; a southern

source was ranked high with regard to extracted specific gravity in four locations. Apparently, the regional variation for wood specific gravity is weak and not consistent with the pattern observed in studies of natural variation of this characteristic. The large among-tree variation and apparent genotype-environment interaction tend to confuse any regional pattern.

Significant differences among sources which were present in the Stephen's Switch provenance test at age 5 and 10 (Thor and Brown, 1962; Thor, 1967) were no longer evident at age 15. However, trees of the north Georgia Piedmont source still retained the lowest specific gravity wood.

Correlation analysis for the 10-year old Ames plantation (183 wood samples) and the 15-year old Stephen's Switch plantation (95 wood samples) disclosed no correlation between specific gravity and d.b.h. This confirms results of previous research where no relationship between growth rate and specific gravity was found (Zobel et al., 1960; Saucier and Taras, 1967). The well known relationship between age and specific gravity was also confirmed with older plantations having higher values than younger plantations. At Ames the average specific gravity was 0.364, at Stephen's Switch 0.381 and the 20-year old Norris-Loyston plantation averaged 0.406.

III. FOLIAGE CHARACTERISTICS

The Ames provenance test was established from seed collected in a 1958 study of natural variation in which needle characteristics were

included (Thorbjornsen, 1960). The Ames needle data reported here are from progeny of the trees examined in the 1958 study. To determine if variation of needle characteristics is genetically controlled, the Ames data were subjected to correlation analysis with parental data from the 1958 study.

The variation in two of the five needle characteristics studied is primarily environmental. There were no significant differences among sources for number of needles per fascicle and no evidence of regional trends. Significant differences among sources for needle length were observed in two plantations but no regional variation pattern was apparent. Parent trees and progeny were not correlated for either characteristic.

Significant variation among seed sources for number of stomatal lines was present only at the Ames plantation. Needles from trees of eastern sources seemed to have a higher number of stomatal lines than those of more western sources. The data also supports a pattern found in the Stephen's Switch provenance test by Thorbjornsen (1960) where number of stomatal lines were more numerous on trees from the Piedmont than those of Coastal Plain sources.

Significant differences among sources for number of serrations per centimeter were obtained in three provenance tests. In each case there was a tendency for trees of Piedmont and inland sources to have a higher number of serrations than those of coastal sources. Correlation analysis between parental trees and progeny at Ames disclosed no significant correlation, indicating that this characteristic is probably

under considerable environmental influence. However, in natural populations of loblolly pine a tendency for trees of inland and Piedmont sources to have a higher frequency of serrations than trees of coastal sources was reported by Thorbjornsen (1960). No pattern of variation in serration frequency seems to be present in slash pine (Mergen, 1958).

Significant variation among seed sources in stomatal frequency was obtained only at the Chickasaw provenance test although no regional variation pattern seemed evident. Correlation analysis between parental trees and progeny for stomatal frequency in the Ames plantation indicates that a correlation exists ($r = 0.535$) which is significant. The correlation implies the existence of some genetic control over this characteristic. These results support the 1958 natural variation study where trees from the sources west of the Mississippi River had lower stomatal frequencies than trees from eastern sources. It was hypothesized that the variation pattern of stomatal frequency was the result of adaptation in response to selection pressure of precipitation and transpiration (Thorbjornsen, 1960).

IV. STATISTICAL RESULTS

Statistically significant differences among sources for growth characteristics were obtained in only four of the 10 provenance tests evaluated. In each case northeast and deep south Coastal Plain sources were represented. Apparently detection of growth differences without increasing replication may be insured by the use of widely divergent sources. This observation is supported by lack of statistical significance

for the species comparison and the Friendship and Sewanee (B) provenance tests where seed sources from the extremes of the species range were not represented. Evidently, in order to detect significant differences among sources where no widely divergent provenances are used the precision of the test must be increased either by increasing number of seed sources in the test or by increasing replication.

Although a considerable amount of variation is present at the Chickasaw plantation, much of it appears to be the result of nonrandom environmental influences. The 1964 selective thinning at the Norris plantation probably removed whatever growth differences were present in that provenance test.

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CHAPTER VI

SUMMARY

Fifteen seed source tests of loblolly pine in Tennessee were measured and analyzed for eight growth characteristics during 1969 and 1970. The provenance tests were evaluated to determine from which locations within the species range superior phenotypes should be selected for establishment of seed orchards of loblolly pine in Tennessee. In addition, five needle characteristics were studied to determine if needle variation follows regional variation patterns.

Results of the growth data indicate that trees from the northeast part of the species range (Maryland, Virginia or North Carolina) are most suitable for maximum wood production in most parts of Tennessee. However, in areas with milder climates, such as in the southwest portion of the state, inland and Piedmont trees seem to have as good or slightly higher wood production than trees of northeast sources. Greatest wood production was by loblolly pines growing in locations with freeze-free periods corresponding in duration to those of their provenance. Trees from northeast sources and from Arkansas had superior stem straightness over trees from all other sources.

Conflicting results were obtained from the wood specific gravity evaluations. However, some weak evidence of a regional variation pattern did seem to be present; there was a tendency for trees of northeast sources to have higher specific gravity wood.

Of the five needle characteristics evaluated, only stomatal frequency appeared to be under strong genetic control. In addition, a regional variation pattern seemed to be present in three provenance tests for number of serrations per centimeter with the highest frequency of serrations being from trees of inland sources and the lowest from trees of Coastal Plain sources.

Statistically significant differences among sources were obtained only in those provenance tests where widely divergent sources were represented. In order to detect differences among provenances where relatively similar seed sources are represented, either number of replications or number of seed sources must be increased.

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VITA

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