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EARLY RESULTS OF PROVENANCE STUDIES OF
LOBLOLLY AND SLASH PINES IN BRAZIL

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EARLY RESULTS OF PROVENANCE STUDIES OF LOBLOLLY AND SLASH PINES IN BRAZIL

By

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ABSTRACT

EARLY RESULTS OF PROVENANCE STUDIES OF
LOBLOLLY AND SLASH PINES IN BRAZIL

By

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The objectives of this study were to determine if there are: (1) genetic differences in growth traits among provenances, (2) any trends of significance for locating the most suitable provenances, and (3) any genetic-environment interaction. Additional objectives were to determine (4) future uses of the trials, (5) improvements of the experimental procedures, and (6) future direction of the experimentation aiming at the genetic improvement of these two pines.

Thirty-five seedlots of loblolly pine and 20 seedlots of slash pine were tested in two series. Randomized and replicated trials were established in four locations. Mortality was higher in Series 1 for both species due to long-distance transportation of bare root seedlings.

There were very important differences in loblolly pine growth rate due to provenance in both series. One seedlot from Livingston Parish was consistently among the leaders at all test locations. Other seedlots from Florida, Mississippi, South Carolina, and one Brazilian seedlot were also fast growing. Genotype-environment interaction were strong in Series 1 and smaller in Series 2. A general

trend of coastal seedlots to grow faster than interior ones was observed in both series.

The most highly recommended area for seed collection for planting in Brazil is the coastal region stretching 120 kilometers from the coast of the Gulf of Mexico and the Atlantic Ocean in seven southern states. The consistent superiority of Livingston Parish indicates that Brazilian growers can obtain immediate improvement by using seed from that area.

There were significant differences in slash pine growth rates in both series. Differences were smaller than those observed for loblolly pine. In both series there were some best seedlots. Sizable differences occurred among stands close together geographically. No clear geographical trend or pattern was found. Genotype-environment interactions were strong in both series.

No region in southern United States can be generally recommended for seed collection for planting in Brazil. Only individual stands can be suggested as result of their good performance. The close correlation of my results and American results indicates that genetically improved seeds from the United States can be used in Brazil for both loblolly and slash pines.

The studied trials should have three major uses in the future: (1) as producers of information, (2) for demonstration purposes, and (3) as breeding arboreta. A fourth possible use as seed orchards is not recommended. All Nelder-Bleasdale systematic spacing designs should be measured and analyzed in the future. They may or may not give any useful genetic information. Valuable information about spacing can be learned from these systematic grids.

Future trials should follow a different approach, including hundreds of seedlots and sampling several families from each of many stands. Further improvement can be pursued by using already improved American material or superior provenances or stands in the natural range. Seeds from American seed orchards can be used to establish test plantations for future selections. Livingston Parish and surrounding parts of southeastern Louisiana are a natural choice for intensive sampling trials of loblolly pine. In slash pine such a region of superiority has not been detected. The sending of a Brazilian team for seed collection in southeastern Louisiana is necessary for an intensive sampling of stands.

Future genetic research in Brazil should take advantage of some vital improvements in the experimental procedures such as small plots, a greater number of replications, and a greater number of locations. Future intensive sampling trials should be established in such a way that the test plantations can be converted into seed orchards.

Dedicated to my parents, Antonio Daniel and Auracelia; my wife, Michiko; and my sons, Alexandre and Daniel, in recognition of their sacrifices, patience, and love.

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CHAPTER I

INTRODUCTION

The southern states of Brazil were once covered by magnificent warm, temperate forests. They were cleared mainly for agriculture and pastures. Today less than 10% of the land has a forest cover.

An area of about 20 million ha in the highlands between altitudes of 500 and 1500 meters was the habitat of a mixed forest with the native conifer Paraná pine (Araucaria angustifolia) being the dominant species, and the principal commercial tree in southern Brazil. Many valuable hardwoods such as cedro (Cedrela fissilis), imbuia (Ocotea porosa), erva-mate (Ilex sp.), and several species of Lauraceae and Mirtaceae were present. These prize hardwoods have been heavily exploited for industrial uses or simply wasted in clearing the land for agriculture. Few are planted since early attempts often met with little or no success. The silvics of these species are not known; they are slow growing and their natural regeneration has been unsuccessful.

The Araucaria forest was subjected for many years to an annual cut about 10 times the estimated annual increment (Dillewijn et al., 1966). The result was depletion of the easily accessible stands. Based on 1973 remote sensing surveys, only 5.8% of the original 7.4 million ha of Araucaria forest was left in the state of Paraná, and similar situations exist in the other southern states (Siqueira, 1977). In the Araucaria forest, timber extraction is so radical and regeneration so poor that recovery of the stands is uncertain or very far in the future.

According to Golfari (1971, 1978), a leading expert in Brazilian forestry, the small number of seedlings and saplings in wild stands of Araucaria and also in selectively logged stands is due to competition and dominance of associated hardwoods and the presence of several seed predators. Among such enemies are insects, birds, rodents, wild and domestic ungulates. Also people utilize the large starchy seeds as food.

Araucaria, despite producing timber of a quality very high and unmatched by exotic species, has been planted on a limited scale. The reasons for such apparent contradiction are its slow initial growth when compared with other conifers, the need for expensive cultural operations, and its little plasticity and very high edaphic requirements. Due to soil limitation, it is paradoxically restricted to less than 20% of its own natural area of occurrence (Figure 1). Sites potentially suitable for Araucaria are usually high-priced agricultural lands. However, within and beyond that same natural area the introduced pines, loblolly (Pinus taeda) and slash (Pinus elliottii) can be very successfully planted without any limitation (Figure 2).

Loblolly and slash pines have been intensively planted in the past 15 years and have found ideal ecological conditions in the southern states of Brazil. They present an average height growth

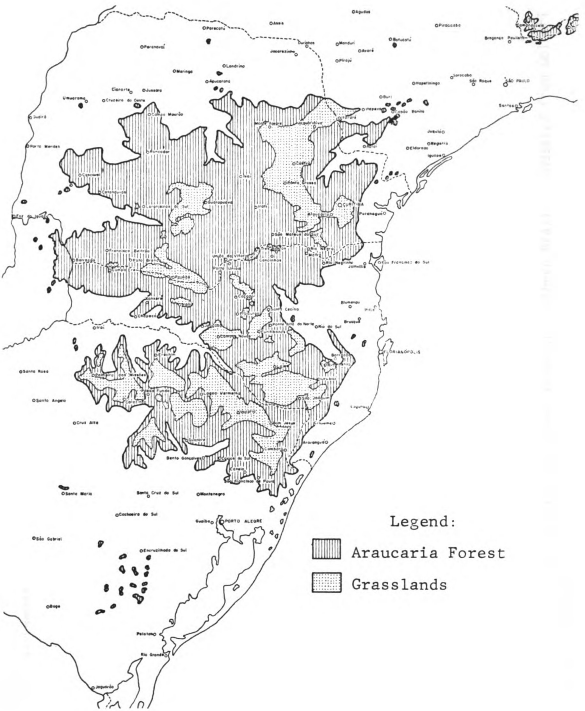


Figure 1.--Natural range for Paranǽ pine (Araucaria angustifolia).
(Adapted from Golfari, 1971.)

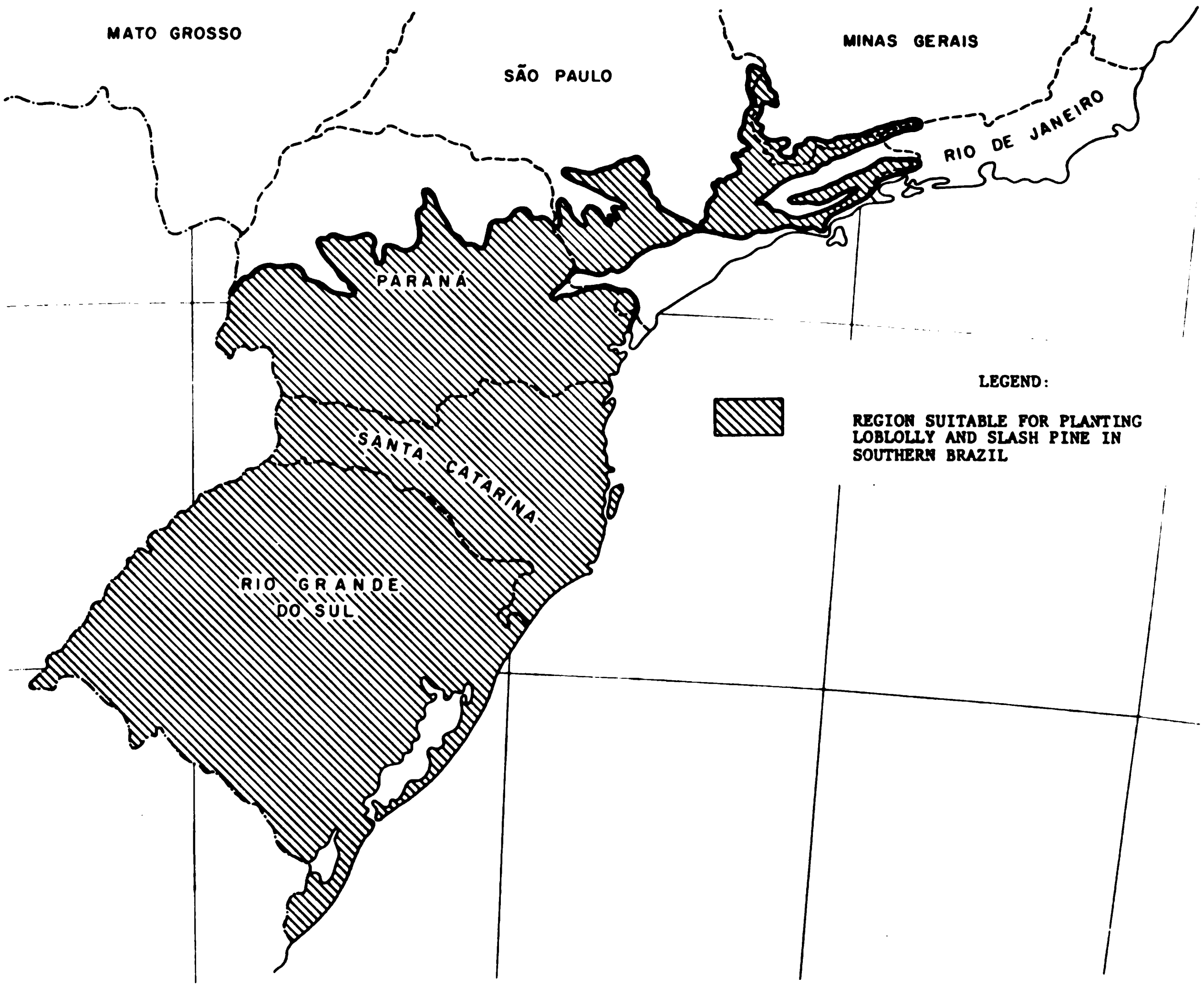


Figure 2.--Suitable area for loblolly and slash pines in southern Brazil. (Adapted from Golfari et al., 1978.)

of 1 to 1.3 m per year and a mean annual increment of about 22 steres/ha/year. (The stere is a pile of wood 1 meter in length, width, and height.) Their planted area has probably reached the 800,000 hectare mark in 1980.

It is estimated that in 1980 alone loblolly and slash pines will save the country more than US$300,000,000 in foreign exchange by replacing the otherwise imported cellulose and lumber (Beattie & Ferreira, 1978). They are now the solution to one of the major national problems of the past two decades--how to maintain or expand the timber industries in face of dwindling forest resources.

In 1974 the Brazilian Council for Economic Development (CDE) established production goals for pulp and paper aiming at self-sufficiency and increased exports by the year 2000. To attain such objectives, an annual planting rate of softwoods of over 100,000 ha is necessary during the next 20 years. The domestic consumption of other products such as lumber, plywood, and particle board is also rapidly growing.

The total industrial demand for wood in Brazil requires not only more plantings but increasing productivity. One way to increase productivity is genetic improvement, and one major approach to genetic improvement is the testing of trees from different geographic origins in provenance trials. This study is an assessment of such trials of loblolly and slash pines planted in southern Brazil.

CHAPTER II

OBJECTIVES

The Project for Forestry Development and Research (PRODEPEF) was a joint undertaking of FAO (Food and Agriculture Organization of the United Nations) and IBDF (Instituto Brasileiro de Desenvolvimento Florestal). In 1971 PRODEPEF initiated its operation in southern Brazil by establishing the Southern Forest Research Center (CPFRS) in Curitiba. One of its assignments was to carry out genetics and tree improvement research.

The few provenance trials of southern pines existing in Brazil at that time were 5 years old or younger. The originating agencies were the Forest Service of São Paulo, the Forestry School of Curitiba, and the Institute of Forest Research and Studies (IPEF) of Piracicaba. The existing trials were considered to be an important factor adding to the knowledge of the performance of various species. They were not adequate, however, to present a complete picture, due to some inherent limitations:

1. the number of origins under test,
2. the representativeness of the natural range,
3. the number of locations of test plantations, and
4. experimental design

These limitations suggested that a need existed for establishing new trials. They were subsequently carried out by PRODEPEF as Project No. 5-032-3. This project tested the four major southern United States pines, loblolly pine (*Pinus taeda*), slash pine (*P. elliottii*), longleaf pine (*P. palustris*), and shortleaf pine (*P. echinata*), in a number of locations in southern Brazil. Three minor southern pines were later included: spruce pine (*P. glabra*), pond pine (*P. serotina*), and sand pine (*P. clausa*).

Objectives of the PRODEPEF Provenance Trials

The original objectives of the PRODEPEF trials are mentioned in the informative handout "IBDF/FAO Provenance Trials" (PRODEPEF, 1973) and the information brochure "Centro de Pesquisas Florestais da Região Sul-Programação Técnica" (PRODEPEF, 1976). They were as follows:

1. To determine if there are genetic differences in growth traits among provenances.

2. To determine if there are any trends of significance for locating the most suitable provenances.

3. To determine if there are any genetic-environment interactions.

4. To determine the best or better provenances for further trials of a much higher intensity. This second level of testing would have the objective of locating the optimum subpopulation for further exploitation through selective breeding.

5. To compare two different experimental designs: the accepted standard randomized complete block design and the more recently introduced Nelder-Bleasdale design.

6. To determine the wood quality under several different site and spacing conditions.

Objectives of the Present Study

The specific objectives of my study were the same as objectives number 1 through number 5 of the original objectives. In addition, the following objectives were established:

6. To determine the advisability of converting the trials into seed orchards.

7. To determine future uses of the trials, e.g., for breeding arboreta.

8. To examine and determine possible improvements of the experimental procedures.

CHAPTER III

MATERIALS AND METHODS

The methodology of the PRODEPEF trials is described in detail in "IBDF/FAO Provenance Trials" (PRODEPEF, 1973) and "Centro de Pesquisas Florestais da Região Sul-Programação Técnica" (PRODEPEF, 1976).

Personnel

The provenance project was implemented by PRODEPEF's Southern Forest Research Center (CPFRS) as a team effort. The Regional Coordinator of CPFRS was Eng. Agr. Ernesto da Silva Araujo, who fully supported the study. The FAO experts, Mr. Robert W. Fishwick, Dr. John A. Pitcher, and Mr. Tapani Korhonen, were respectively the principal silviculturist, principal geneticist, and associate geneticist of CPFRS. They were in charge of planning and implementing the project and they supervised, coordinated, and worked in all phases of it.

The Brazilian counterparts to the FAO experts were Antonio J. de Araujo, Jarbas Y. Shimizu, and Mario F. Terajima. More than a dozen other people have participated in the project, and they were foresters of the CPFRS, resident foresters of the test sites, forest technicians and workers in the test sites, and "estagiários" (summer-winter jobbers) from the Forestry Schools of Curitiba and

Santa Maria and the Forestry Technician School of Irati. As a member of the research team during the period of 3.5 years, I participated in the planning, establishment, and early measurements of the provenance experiments.

Seed Procurement

In 1971 five seedlots of slash pine and four of loblolly pine were kindly supplied by Dr. Carl Ostrom, Division of Timber Management Research, U.S. Forest Service, Washington, D.C. In 1972 Mr. Fishwick ordered 38 seedlots of loblolly, slash, longleaf, and shortleaf pines from the United States Forest Service Tree Seed Center at Macon, Georgia. Two Brazilian seedlots (one of slash and one of loblolly pine) from Irati, Paraná, were collected in the plantations of the Irati FLONA (National Forest). A total of 49 seedlots were obtained by 1972. They were tested in several plantations as Series 1.

In 1974 Mr. Fishwick ordered 49 seedlots of loblolly, slash, longleaf, shortleaf, spruce, pond, and sand pines from the Macon Tree Seed Center. One Brazilian seedlot of loblolly pine from Telemaco Borba, Paraná, collected in the plantations of Fazenda Monte Alegre was kindly supplied by Klabin do Paraná (IKPC). A Brazilian seedlot of slash pine from Capão Bonito, São Paulo, was collected in the plantations of the Capão Bonito FLONA. The total of 52 seedlots obtained in 1974 and their test in several experiments is referred to as Series 2. Two provenances of slash pine, two of loblolly pine, and one of shortleaf pine which had been tested in Series 1 were among the 52 seedlots of Series 2.

A summary of species and seedlots tested by the CPFRS in southern Brazil is presented in Table 1.

Germination Tests and Stratification

Series 1 seedlots were subjected to germination tests prior to sowing. I conducted the tests using the facilities of the Forestry School at Curitiba. Each of the 49 seedlots was represented by two random samples (replications). Each sample consisted of 50 seeds in a petri dish. The position of the petri dish in each replication was randomly assigned in the trays of the germination chamber. Germination was monitored during 45 days. Germination results were used to calculate the number of viable seeds.

In the winter of 1972, Pitcher, Shimizu, and I stratified all seedlots following recommendations in a report by Miller (1970). Stratification was accomplished by immersing each lot of seed in a separate container of cold water for a period of 30 minutes to 1 hour. The seed was then drained and put into double plastic sacks which were twisted and tied shut. The sacks were then spread on shelves in the refrigerated seed storage room at the Irati FLONA, at a temperature of 3 to 5°C. The sacks were turned over at weekly intervals to prevent accumulation of free water in the bottoms. Loblolly pine seedlots were stratified for 45 days and other pines were stratified for 30 days.

Table 1.--Number of seedlots of *Pinus* tested in PRODEPEF provenance trials.

Species	Number of seedlots tested		
	Series 1	Series 2	Total[a]
P. taeda	17	20	35
P. elliottii	13	9	20
P. palustris[b]	9	9	18
P. echinata[b]	10	3	12
P. glabra[b]	-	5	5
P. serotina[b]	-	3	3
P. clausa[b]	-	3	3
Total	49	52	96

[a]Excluding seedlots of Series 1 retested in Series 2.

[b]Not included in my study.

Series 2 seedlots were stored in a refrigerator at the CPFRS headquarters in Curitiba. Each seedlot was split into four portions and each portion sent to local nurseries at the test plantations. I sent stratification instructions along with the seeds and the resident foresters performed the treatment.

Handling in the Nursery

The production of outplanting stock for planting in Series 1 was carried out at Irati FLONA's nursery, Paraná. The nursery soil had been treated with methyl bromide 1 month earlier. All 12 seedbeds were 1 meter wide and prepared for seedling production by the bare-root system. The seeds were sown by Fishwick, Shimizu, Albino B. Dietrich, and me in early spring 1972. It took several days to complete the sowing due to intermittent rainy weather.

Sowing was performed in the following manner. Each seedlot was randomly split into two sublots. The smaller sublot contained 200 viable seeds for the nursery trial; the larger sublot contained the balance for the bulk production of outplanting stock. Each sublot was divided into five equal parts by volume and sown as replicates. The smaller sublots, containing 40 viable seeds, were sown in single-row plots in the central bed (bed #6). Some thinning or transplanting was done within the row plots to achieve optimum spacing (5 cm between seedlings within the rows and 10 cm between rows). The experimental design for the nursery trial (bed #6) was single-row plots of 20 seedlings per provenance, randomly assigned to species blocks. Species blocks were replicated five times within that central bed. The larger sublots, also divided into five equal parts by volume, were broadcast sown in a randomized complete block design. Density was about 500 seedlings per square meter.

In Series 2 nursery handling was quite different. Seedlings were raised in four nurseries at the test plantation locales. Black polyethylene bags 7.5 cm in diameter and 15 cm tall were used as containers. Seedbeds were 20 plastic bags wide to allow easier sowing, weeding, counting, and other nursery practices. Sowing was done during January 1975.

Nursery Measurements and Analysis

In Series 1 measurements were made by Korhonen and me in the replicated nursery trial in bed #6. During the spring, summer, and winter after sowing, five traits were measured in each row plot:

1. Germination: counted at 2-day intervals.

2. Height: total height, measured to the nearest centimeter, from the ground surface to the uppermost part of the growing tip. Seedlings numbered 6, 8, 10, 12, and 14 in the row plot were always measured and their average recorded as the plot mean. Measurements started at age 70 days after sowing and were repeated four times at 5-week intervals.

3. Stem diameter: measured in millimeters at the point just above the root collar, on the same trees used for height measurements. One assessment was made at age 213 days and only plot means were recorded.

4. Bud set: the number of seedlings in each plot presenting a definite terminal bud were counted at ages 168 and 213 days.

5. Lammas growth: the number of seedlings presenting a second flush of growth after the terminal bud had been set were recorded at ages 168 and 213 days.

An analysis of variance was calculated for each set of measurements to determine significant differences between provenances. In Series 2 no nursery trial was carried out.

Outplanting Procedure

After 8 months of nursery growth, the seedlings in Series 1 were lifted in early June 1973 by CPFRS personnel and local FLONA workers. Immediately after lifting, the roots were immersed in a bucket containing Agricol, a moistening and protective agent. The purpose of the treatment was to avoid water loss and drying out of the root system. Following a root pruning, bundles were made and packed (intermixed with moist sphagnum moss) in wooden boxes. These boxes were put in the Irati FLONA cold storage room and there kept at a temperature of 3 to 5°C for a few days or up to 2 weeks, depending on outplanting schedules.

Series 1 experimental plantations were established in four locations (Figure 3). Some geographic and climatic characteristics for each location are presented in Table 2.

Other descriptive features of the sites are as follows:

1. Capão Bonito FLONA, 200 km northeast of Curitiba, southeastern São Paulo; compartment 23. Nearly level site. Previous

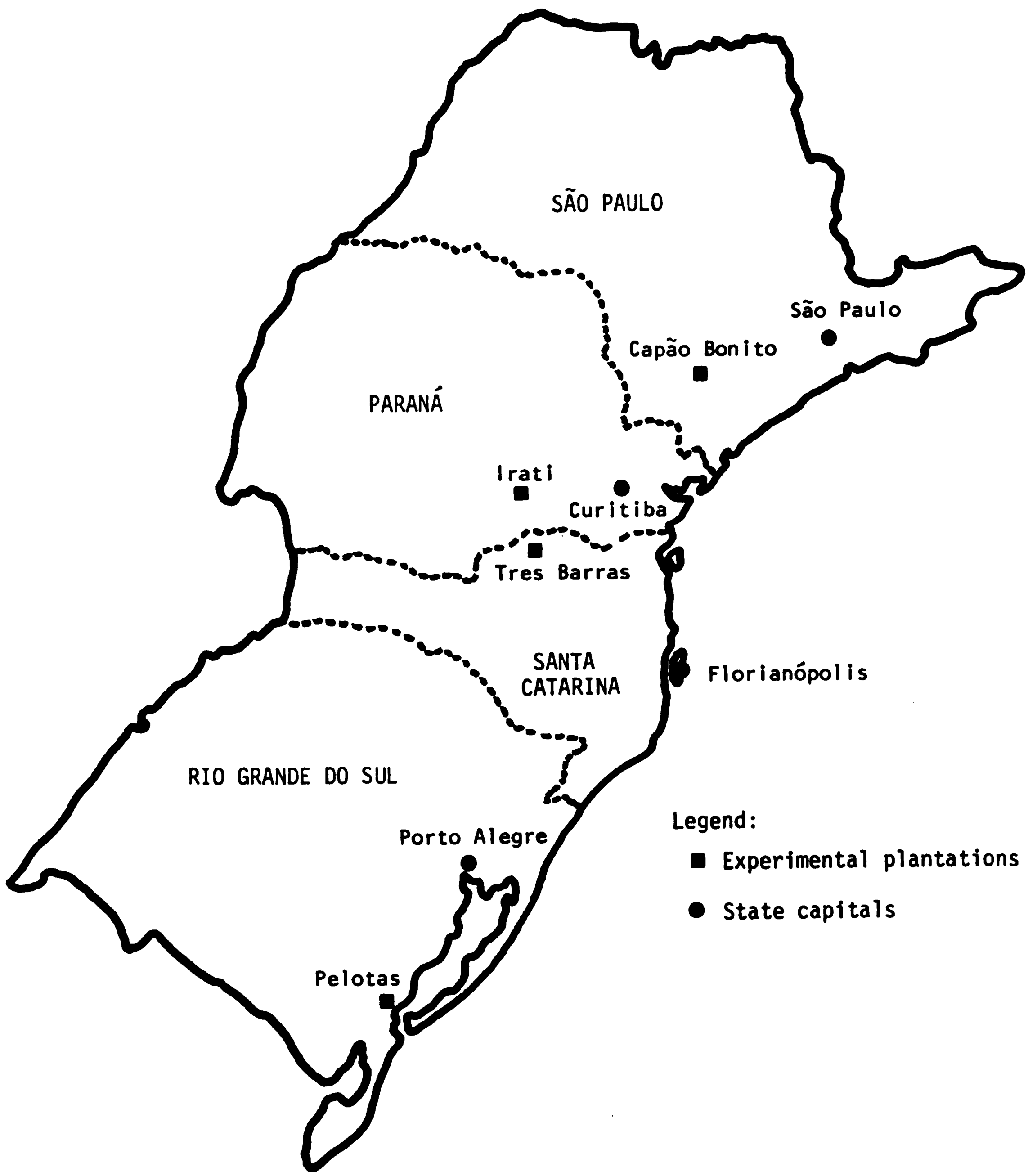


Figure 3.--Location of the provenance trials in southern Brazil.

Table 2.--Geographic and climatic site parameters by location.

Parameters and unit of measure	Capão Bonito	Irati	Tres Barras	Pelotas
Latitude (°S)	23.9	25.5	26.2	31.8
Longitude (°W)	48.5	50.6	50.3	52.4
Altitude (m)	675	850	800	10
Rainfall (mm)	1405	1442	1341	1394
Mean annual temperature (°C)	18.9	17.2	16.3	17.5
Mean of max. temp. for January (°C)	29.0	27.1	28.8	29.0
Mean of min. temp. for July (°C)	9.3	7.5	5.5	7.0

vegetation was a 26-year-old Paraná pine plantation clearcut due to poor growth. After cutting, the slash was burned. No other soil preparation was performed. Planting was done under rainy and cloudy weather from June 11 to 14, 1973. Cultural operations after planting consisted of ant control and manual weeding for two to three times during the first and second years.

2. Irati FLONA, 160 km west of Curitiba, southern Paraná, compartment 19. Nearly level and gently sloping site. Previous vegetation was a 22-year-old Paraná pine plantation, clearcut due to poor growth. After cutting, the slash was burned and the soil disked. Planting was done June 18, 1973, under mostly cloudy weather after heavy rain. Fishwick and I, with the help of 14 workers, planted manually 3,600 trees in 4 hours. Cultural operations were as at Capão Bonito FLONA.

3. Tres Barras FLONA, 160 km southwest of Curitiba, northern Santa Catarina. Nearly level, low-lying site subject to short-term flooding due to somewhat poor drainage after heavy rain. Previous vegetation was a sod cover burned before planting. No other soil preparation was performed. Planting was done in mid-June 1973, after a nightly rain. Cultural operations were as at Capão Bonito FLONA.

4. Pelotas EFLEX (Experimental Forest Station), 900 km south of Curitiba, coastal plain in southeastern Rio Grande do Sul. Nearly level and gently sloping site with a moderately good drainage. The previous vegetation was grassland. Soil preparation consisted of plowing and disking. Planting was done in mid-June 1973. Cultural operations were as at Capão Bonito FLONA.

Series 1 test plantations in all locations followed a randomized complete block design with 36-tree plots and 4 replicates. Spacing between trees was 2 by 2 meters. Two Nelder-Bleasdale systematic designs were also planted at all locations.

Series 2 seedlings raised in local nurseries were outplanted manually in all locations. The polyethylene bags were removed just before setting the seedlings in the planting hole. Series 2 experimental plantations were also established in the same four locations as Series 1. The geographic and climatic characteristics were presented in Table 2. The descriptive features of the sites are basically the same as previously discussed for Series 1 with the following differences:

1. Capão Bonito FLONA, compartment 27. Previous vegetation was a poor-quality Paraná pine plantation, clearcut and the slash burned in 1975. Outplanting stock was 10 months old when planting was done on December 2-3, 1975. The soil was moist from previous rain; the weather was sunny and hot. Test plantations followed a randomized complete block design, with 49-tree plots and 4 or 5 replicates. Spacing was 2.5 by 2.5 meters. Surplus trees were planted in unreplicated plots in the same compartment using a 3 by 3 meters spacing. One Nelder-Bleasdale systematic design was also established.

2. Irati FLONA. Previous vegetation was a wild Paraná pine stand destroyed by a forest fire in 1974. Outplanting stock was 10-11 months old when planting was done on November 19, 1975 (slash pine), and December 30, 1975 (loblolly pine). Test plantations followed a randomized complete block design with 36-tree plots and 4

replicates. Spacing was 2.5 by 2.5 meters. One Nelder-Bleasdale systematic design was also established.

3. Tres Barras FLONA. Outplanting stock was 11-12 months old when planting was done in November 1975 (slash pine) and January 1976 (loblolly pine). Test plantations followed a randomized complete block design with 49-tree plots and 4-5 replicates. Spacing was 2.5 by 2.5 meters. Two Nelder-Bleasdale systematic designs were also established.

4. Pelotas EFLEX. Outplanting stock was 10 months old when planting was done in October 1975. Test plantations followed a randomized complete block design with 16-49-tree plots and 5 replicates. Spacing was 2 by 2 meters. One Nelder-Bleasdale systematic design was also established.

Plantation Measurements

The following traits were measured, some of them several times: mortality, height, diameter, form (forking, crooks, foxtail), damage (ants, fungi), and flowering. A within-plot border was considered and only the central trees were measured. For example, in the 36-tree plots only the 16 central trees were measured and values recorded. I later calculated plot means for height and diameter and also the standard deviation, range, and mean of the tallest 25% of the trees. Metrical traits were measured to an accuracy of approximately 1/20th of the range between extremes. Fishwick and I went to the several sites in the winter of 1974 to perform the first measurement with the local personnel. Subsequently the resident forester and technicians performed most of the assessments.

Analysis

The standard procedure for most characteristics was an analysis of variance. Plot means were used as items. A typical analysis of variance table follows:

Source of variation	Degrees of freedom	Expected mean squares
Provenance	P-1	$\sigma_e^2 \quad R\sigma_p^2$
Replication	R-1	$\sigma_e^2 \quad P\sigma_r^2$
Replication x Provenance	(P-1)(R-1)	σ_e^2
Total	(P x R) - 1	

R and P are the number of replicates and provenances, respectively. Differences between provenances were tested with replication x provenance mean square.

The "least significant difference" was used as a post-ANOVA test. This technique was used to determine which provenances differ from each other. Correlation analysis was performed, and either Pearson's correlation coefficients or rank-correlation coefficients were calculated to determine the degree of association of selected variables. Chi-square analysis was used in some cases. All differences quoted as being important are statistically significant at least at the 5% level.

CHAPTER IV

LOBLOLLY PINE PROVENANCE TRIALS

The Species

Loblolly pine is the most important introduced conifer in the Brazilian southern plateau. It grows faster than slash pine and its wood has a lesser resin content. These two reasons make loblolly pine the choice of many pulp and paper companies. It is expected to attain greater longevity and reach bigger diameters than slash pine and is counted on for the future production of lumber and veneer in southern Brazil.

In its native country, loblolly pine grows in the entire south and southeastern United States, with the exception of the lower part of Florida. Its natural range extends from southern New Jersey to eastern Texas, throughout 15 states (Figure 4). There is one major range gap represented by the Mississippi River Valley. That discontinuity is 25 to 120 miles wide, essentially pineless, and offers a barrier to east-west migration.

Climatic conditions are not uniform. As discussed by Dorman (1976), the loblolly pine region presents wide variation in temperature and rainfall. In Florida, average monthly temperatures have a range of only about 10°C throughout the year. In Dover, Delaware, that range is two and one-half times greater. In Florida, range in rainfall per month is the widest, with a minimum of slightly over

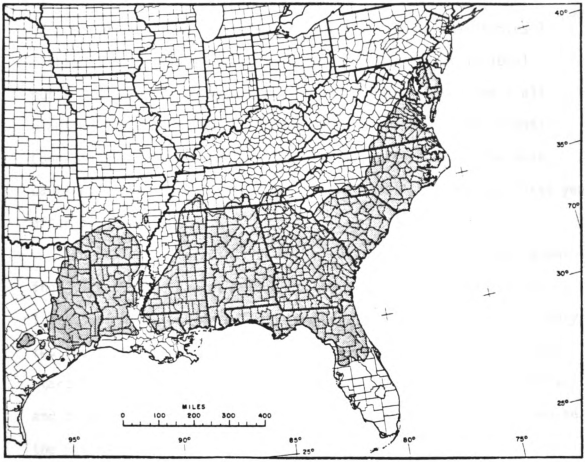


Figure 4.--Natural range for loblolly pine, Pinus taeda. (From Dorman, 1976.)

25 mm to a maximum of nearly 203 mm. In the northern part of the region, rainfall is well distributed throughout the year. In Florida, periods of high rainfall coincide with the seasons of high temperature, while in northern Mississippi, southern Arkansas, and Texas, high rainfall occurs when temperatures are low.

Condition of the Plantations

Series 2 plantations had much lower mortality than Series 1 (Table 3). The planting stock in Series 2 was raised in local nurseries using polyethylene bags. In contrast, in Series 1 all planting stock was produced in one central nursery (Irati FLONA). Long-distance transportation of bare-root seedlings was the main cause of higher mortality, which occurred mostly during the first year after planting.

In Series 1, the Capão Bonito plantation was the fastest growing. The average annual height increment for this plantation was 1.4 m, which is considered very good for Brazilian conditions. Very few trees are forked or crooked. At age four, flowering had just started: 11% of the trees had male flowers, 3% had female flowers, and 2% had both. In 1980 at age seven, crown closure has started in the fastest and higher-survival parts of the plantations.

All four Series 2 plantations present a good average growth for their ages. Overall the plantations of both series are in good condition with few trees forked or crooked. The most important lesson of these results is that not only are careful site selection and adequate care after planting essential for high survival and good

Table 3.--Location, mortality, and average height of eight loblolly pine test plantations in southern Brazil.

Location of plantation	Measurement age (months)	Mortality (%)	Average height (cm)
Series 1			
Capão Bonito--São Paulo	49	69	554
Irati--Paraná	25	12	129
Tres Barras--Santa Catarina	52	10[a]	358
Pelotas--Rio Grande do Sul	26	65	171
Series 2			
Capão Bonito--São Paulo	20	6	106
Irati--Paraná	18	5	94
Tres Barras--Santa Catarina	25	2	229
Pelotas--Rio Grande do Sul	24	2	212

[a]Based on survival after replanting. Original mortality was higher (26%).

growth, but also the method of raising the planting stock and the time and transportation distances involved are important.

Growth Rates

A summary of the origin and nursery growth data for Series 1 is presented in Table 4. In that table the seedlots were arranged in decreasing order according to the overall growth rate to date. There were significant differences in nursery traits due to seed source. Northern seedlots had a greater number of trees with bud set and Lammas growth was higher for southern seedlots. The correlation coefficient for latitude and bud set was $r = .69$, and for latitude and Lammas growth was $r = -.67$, both coefficients being significant at the 1% level.

The seedlots which were tallest in the nursery also tended to be tallest in the plantations, although the correlations were not strong. For the plantations at Capão Bonito, Irati, Tres Barras, and Pelotas they were $r = .74$, .32, .26, and .19, respectively, only the first being significant. The rank correlation between nursery height and average height in all plantations was $r_s = .67$, significant at the 1% level. Almost half of the deviation from a perfect correlation was caused by seedlot 2-FL Marion. Without that seedlot the rank correlation would have been $r_s = .81$.

There were very important differences in growth rate due to provenance in both series (Tables 5-10). In Series 1, seedlot 6-LA Livingston was consistently among the leaders at all test locations. Seedlot B-FL Jackson and A-FL Marion were also fast growing. While

Table 4.--Origin and nursery data for loblolly pine, Series 1, grown in the Irati Flona's nursery for 213 days (May 7, 1973).

Seedlot number[a] and state[b] and county (or parish) of origin	Lat. (°)	Long. (°)	Altitude (m)	Height (cm)	Diameter (mm)	Trees with Bud set (%)	Trees with Lammas growth (%)
6 LA Livingston	30.4	90.7	--	19.8	3.5	41	18
A FL Marion	29.3	82.0	--	19.8	3.2	30	9
B FL Jackson	30.8	85.3	--	19.8	3.6	53	8
11 NC Jones	35.8	77.2	9	20.2	3.9	68	7
C LA Washington	30.8	90.0	--	19.7	3.6	55	17
10 MS Stone	30.6	89.0	107	18.3	3.7	42	5
1 SC Berkeley	33.3	79.7	8	20.0	3.4	29	9
13 GA Jones	33.0	83.7	122	18.0	3.8	58	4
5 LA Calcasieu	30.0	93.0	15	17.2	3.3	59	18
D MS Forrest	31.0	89.3	--	19.2	3.7	57	23
99 PR Irati, BRAZIL	--	--	850	16.6	3.0	46	11
2 FL Marion	29.2	82.5	24	22.3	3.6	9	20
12 GA Oglethorpe	33.9	83.2	152	16.7	3.6	65	4
4 MD	38.0	75.0	30	13.0	3.0	71	0
14 GA Oglethorpe	33.8	83.1	--	16.6	3.8	56	0
3 MD Worcester	38.2	75.5	9	16.2	3.7	86	4
7 TX Nacogdoches	31.3	95.0	91	17.8	3.1	68	11

[a]Numbers are those originally given by the U.S. Forest Tree Seed Center, and letters are used for the unnumbered seedlots from Dr. C. Ostrom.

[b]LA = Louisiana; FL = Florida; NC = North Carolina; MS = Mississippi; SC = South Carolina; GA = Georgia; PR = Paraná; MD = Maryland; TX = Texas.

Table 5.--Location and relative growth rate of loblolly pine seedlots (Series 1) collected from various parts of the species range and tested in southern Brazil.
Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Relative height when grown at			
	Capão Bonito	Irati	Tres Barras	Pelotas
	(% of plantation mean)			
6 LA Livingston	116	115	105	135
A FL Marion	114	--	138	--
B FL Jackson	--	--	128	--
11 NC Jones	94	111	111	113
C LA Washington	113	--	114	--
10 MS Stone	106	119	89	129
1 SC Berkeley	111	129	59	125
13 GA Jones	82	104	114	99
5 LA Calcasieu	106	92	90	107
D MS Forrest	106	88	118	92
99 PR Irati, BRAZIL	108	99	103	78
2 FL Marion	127	85	94	81
12 GA Oglethorpe	83	102	91	94
4 MD	--	--	99	--
14 GA Oglethorpe	79	71	87	102
3 MD Worcester	64	85	75	100
7 TX Nacogdoches	104	--	87	81
Year of measurement	1977	1975	1977	1975
Age when measured (mo.)	49	25	52	26
Mean height (cm)	554	129	358	171

Table 6.--Location and height rank of loblolly pine seedlots (Series 1) tested in southern Brazil.
Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Height rank when grown at			
	Capão Bonito	Irati	Tres Barras	Pelotas
6 LA Livingston	2	3	7	1
A FL Marion	3	-	1	-
B FL Jackson	-	-	2	-
11 NC Jones	11	4	6	4
C LA Washington	4	-	5	-
10 MS Stone	8	2	13	2
1 SC Berkeley	5	1	17	3
13 GA Jones	13	5	4	8
5 LA Calcasieu	7	8	12	5
D MS Forrest	9	9	3	10
99 PR Irati, BRAZIL	6	7	8	13
2 FL Marion	1	11	10	11
12 GA Oglethorpe	12	6	11	9
4 MD	-	-	9	-
14 GA Oglethorpe	14	12	15	6
3 MD Worcester	15	10	16	7
7 TX Nacogdoches	10	-	14	12

Table 7.--Rank correlations (r_s) of height growth of 12 loblolly pine seedlots (Series 1) tested at four locations in southern Brazil.

Location	Rank correlation with results at		
	Irati	Tres Barras	Pelotas
Capão Bonito	.31	.09	.09
Irati		.02	.63*
Tres Barras			-.31

*Correlation significant at 5% level.

Table 8.--Location and relative growth rate of loblolly pine seedlots (Series 2) collected from various parts of the species range and tested in southern Brazil.
Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state[a] and county (or parish) of origin	Lat.	Long.	Alti-tude	Relative height when grown at			
				Capão Bonito	Irati	Tres Barras	Pelotas
	(°)	(°)	(m)	(% of plantation mean)			
9 MS Harrison	30.5	89.1	46	127	118	115	113
8 MS Scott & Smith	32.5	89.5	30	110	129	120	--
98 PR Klabin, BRAZIL	--	--	780	142	123	102	113
17 SC Charleston	33.1	79.5	8	128	112	108	113
18 SC Berkeley	33.0	79.8	6	145	96	117	111
11 NC Jones	35.8	77.2	9	106	123	111	105
16 MS Scott	32.5	89.0	30	118	93	119	110
29 TX Angelina	31.0	94.1	30	109	104	111	94
20 NC Robeson	35.9	79.0	--	114	109	98	97
30 NC Perquimans	35.0	77.8	7	96	111	102	92
27 SC Kershaw	34.3	80.5	75	101	97	100	104
13 GA Jones	33.0	83.7	122	108	97	100	94
22 MS Chickasaw	33.9	89.0	--	95	98	100	95
28 AL Talladega	33.3	86.0	250	83	103	87	95
24 NC Pasquotank	36.3	76.2	5	92	99	93	91
19 GA Greene	--	--	152	81	71	95	86
25 MD Worcester	38.2	75.5	3	53	82	83	89
21 NC Durham	36.0	79.0	--	72	85	85	--
23 VA Nottoway	37.1	78.0	121	63	85	76	--
26 MD Kent	39.1	76.2	0	60	76	76	--
Year of measurement				1977	1977	1978	1977
Age when measured (mo.)				20	18	25	24
Mean height (cm)				106	94	229	212

[a]AL = Alabama; VA = Virginia; other abbreviations are the same.

Table 9.--Location and height rank of loblolly pine seedlots (Series 2) tested in southern Brazil.
Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Height rank when grown at			
	Capão Bonito	Irati	Tres Barras	Pelotas
9 MS Harrison	4	4	4	1
8 MS Scott & Smith	7	1	1	-
98 PR Klabin, BRAZIL	2	2	8	2
17 SC Charleston	3	5	7	3
18 SC Berkeley	1	14	3	4
11 NC Jones	10	3	5	6
16 MS Scott	5	15	2	5
29 TX Angelina	8	8	6	11
20 NC Robeson	6	7	13	8
30 NC Perquimans	12	6	9	13
27 SC Kershaw	11	13	12	7
13 GA Jones	9	12	10	12
22 MS Chickasaw	13	11	11	9
28 AL Talladega	15	9	16	10
24 NC Pasquotank	14	10	15	14
19 GA Greene	16	20	14	16
25 MD Worcester	20	18	18	15
21 NC Durham	17	16	17	-
23 VA Nottoway	18	17	19	-
26 MD Kent	19	19	20	-

Table 10.--Rank correlations (r_S) of height growth of 16 loblolly pine seedlots (Series 2) tested at four locations in southern Brazil.

Location	Rank correlation with results at		
	Irati	Tres Barras	Pelotas
Capão Bonito	.44*	.80***	.85***
Irati		.31	.52*
Tres Barras			.71**

*, **, ***: correlation significant at 5, 1, and 0.1% levels, respectively.

seedlot A-FL Marion was overall the second best, another seedlot from the same county, seedlot 2-FL Marion, had a very erratic performance, being the best at Capão Bonito but consistently poor at all other locations. This suggests that differences occur among stands close together geographically.

Genotype-environment interaction was very evident in Series 1 as Table 7 shows by means of rank correlations among plantations. The poor correlations found are an indication of the performance of a few seedlots that were among the best in some plantations and among the poorest in others. The most interactions were presented by seedlot 2-FL Marion and 1-SC Berkeley. No plausible interpretation can be given for those interactions.

The Brazilian seedlot from Irati performed from average to below average. In general, seedlots from the southern coastal plain from Louisiana to North Carolina were faster growing than other provenances. Trees from the Piedmont and northern portion of the range grew slower.

Among the leaders at all locations in Series 2 were two seedlots from Mississippi (9-MS and 8-MS), the Brazilian seedlot from Klabin (98-PR), and a South Carolina seedlot (17-SC), as shown on Tables 8 and 9. Their performance at all locations was fairly consistent and more dependable than that of the Florida seedlots in Series 1. Two of these four top seedlots, 9-MS Harrison and 17-SC Charleston, presented the least amount of interaction for the whole experiment.

The most interaction was displayed by seedlots 16-MS Scott and 18-SC Berkeley, both above average in growth rate. It should be noted that another seedlot from Berkeley County South Carolina also showed most interaction in Series 1. In general, genotype-environment interaction was smaller in Series 2 than in Series 1. Table 10 shows that much stronger rank correlations were found in Series 2.

The same tendency of coastal seedlots to grow faster than interior ones was confirmed and expanded in Series 2. Seedlots from Maryland, Virginia, and the Piedmont from North Carolina to Alabama grew poorly, from average to 50% below average. The fastest-growing seedlots were up to 2 to 2.5 times taller than these noncoastal seedlots. The good performance of the Brazilian seedlot from Klabin was a promising evidence that for some of the plantations established with commercial seed of unknown origin the right provenances may have been used.

Seedlots 11-NC Jones and 13-GA Jones included in both series for comparison purposes were consistent. The seedlot from North Carolina was above average in seven of eight plantations, and the seedlot from Georgia was just about or slightly below average.

There were also significant differences in diameter growth due to seed sources. The correlation between height and diameter was $r = .90$ or higher and significant at the .01% level.

Combining data and observations from both series, it was possible to delimit three regions within the natural range of loblolly pine (Figure 5). Region 3 produces slow-growing trees in Brazilian conditions. It includes northern Mississippi, Alabama and Georgia, the Piedmont of the Carolinas and Virginia, Maryland, Delaware, and New Jersey. Region 2 wasn't adequately sampled to give a complete picture of its potentiality. Seedlots from this region may grow

Legend:

●A Location and seedlot identification in Series 1.

●6 Location and seedlot identification in Series 1.

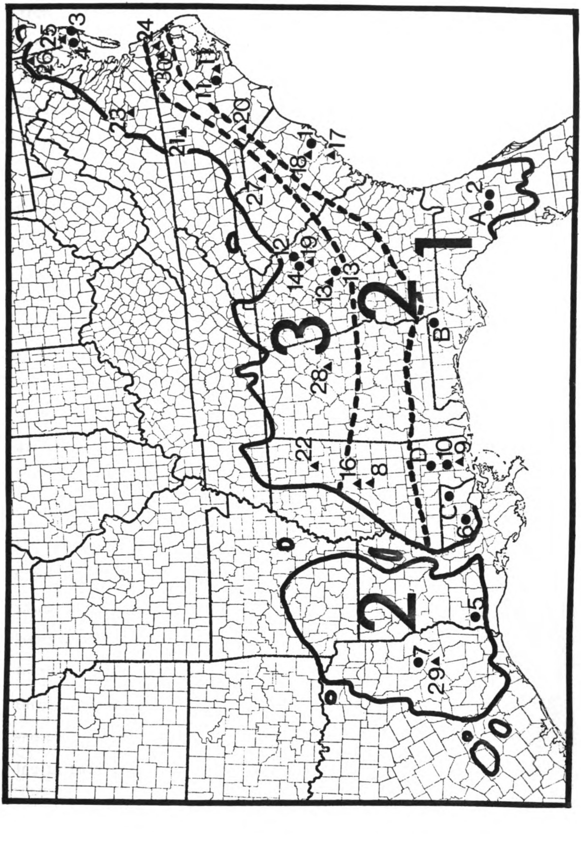
▲9 Location and seedlot identification in Series 2.

1 Region 1 produces fast-growing trees. Most suitable region for seed collection for southern Brazilian plantations.

2 Region 2 was not adequately sampled. Some seedlots from this region may be suitable for Brazil.

3 Region 3 produces slow-growing trees in Brazilian conditions. Seedlots from this region are not recommended.

Figure 5.--Geographic location of loblolly pine seedlots tested in southern Brazil and delimitation of regions for seed collection.



from average to above average. It includes the central parts of Mississippi, Alabama, Georgia, South and North Carolina, as well as the entire part of the range west of the Mississippi River. Region 1 produces fast-growing trees, and seed from it is most suitable for southern Brazilian plantations. The region lies in seven states from coastal North and South Carolina to southern Georgia, northern and western Florida, and southern Alabama, Mississippi, and Louisiana.

Comparison With Results of Previous Studies

Previous provenance research on loblolly pine was summarized by Wells and Wakeley (1966), Wells and Switzer (1971), and Dorman (1976).

The first provenance trial of loblolly pine was planted in 1926 in southeastern Louisiana. It included four seedlots, sampling different areas within the natural range of the species. In 1944 P. C. Wakeley published the first report about the Louisiana trial. He demonstrated the existence of geographic differences and showed the importance of using the correct seed. In all traits the Louisiana stock performed better than that from any other area. The rule of thumb "local is best" was then adopted for a long period of time. Remeasurements at age 35 strongly confirmed the inherent variation in the species (Wakeley & Bercaw, 1965). The PRODEPEF trials tested three of those four provenances included in the 1926 Louisiana trial, and provenances from Louisiana, Georgia, and Texas had the same ranking in both trials.

In 1937 trees from 11 widely distributed provenances were supplied by the U.S. Southern Forest Experiment Station to South Africa. The trials were established in eight locations in latitudes and climatic conditions similar to those of southern Brazil. The same 11 seedlots were tested in the United States, but the plantations were destroyed by fire. This South African experiment is probably the oldest replicated loblolly pine provenance test outside the United States (Dorman, 1976). Thirty-five-year results showed significant differences between provenances at most trials. Provenances from coastal southern Texas, southern Louisiana, and Florida were most suitable for South African conditions (Falkenhagen, 1978). Examining the location of the seedlots tested in South Africa on a base map with names of counties, similar to my Figure 5, one observes that three of the top four seedlots in South Africa came from the same area considered most suitable as seed source for Brazilian plantations. The South African trial also showed that it was possible to select the best provenances at age 2-3 years, or at most at age 9 years.

In 1951, P. C. Wakeley organized the "Southwide Pine Seed Source Study," a series of provenance tests of the four major southern pines. For each species there was a separate experiment involving several seedlots and plantations in various parts of the species' range. This large cooperative approach was undertaken to determine the degree to which inherent geographic variation in loblolly pine is associated with geographic variation and physiography. Many correlation and regression analyses were performed to test the role of winter temperature, length of growing season, annual precipitation, etc., on the geographic variation pattern (Wells & Wakeley, 1966).

The loblolly pine portion of the Southwide Study contained 15 seedlots and plantations in 13 localities. This experiment provides information on the performance of the same seedlots over a wide range of conditions, information not available from earlier studies. A general conclusion was that in all but the coldest locations trees from coastal areas grew fastest. Trees from two coastal sources, Livingston Parish, Louisiana, and Onslow County, North Carolina, made outstanding height growth in a majority of the plantations. In 9 of the 13 plantings, neither ranked lower than third among all trees tested, and in 7 of these 9 they outranked all others. Results of the PRODEPEF trials are very similar to those of the Southwide Study and agree not only in the general conclusion but also in some specific performances, e.g., the Livingston Parish seedlot. Results of the whole study were used by Wells (1969) to delimit practical seed-collecting zones for loblolly pine. He recommends seed from southeastern Louisiana (Livingston Parish) to a substantial portion of the southern states, from the Mississippi River to the South Carolina border.

Crow (1964) reported on his loblolly pine study started in 1953, which tested two southeastern Louisiana seedlots (Livingston and Washington Parishes), one from central Louisiana and a fourth one from near the Louisiana-Arkansas state line. He concluded that on the basis of good growth and better disease resistance, Livingston Parish loblolly merits serious consideration for planting in southeastern Louisiana and Washington Parish stock should probably not be planted. These two seedlots were also included in the PRODEPEF trials with similar results.

A very intensive sampling study of loblolly pine was carried out by Wells and Switzer (1971), who tested stands from southeastern Louisiana, Mississippi, and parts of Alabama and Tennessee immediately adjacent to Mississippi. This experiment included open-pollinated offspring of five trees in each of 115 different stands. This combined provenance-progeny test yielded the important conclusion that there is an area in southeastern Louisiana (which includes Livingston Parish) which can be considered as a center of superiority. Trees from this area grow more rapidly and are resistant to fusiform rust. A gradual decrease in growth rate and rust resistance exists the farther one progresses from the center.

Additional provenance research in southern United States was carried out in Alabama (Goggans et al., 1972), Georgia (Kraus, 1967), North Carolina (Lantz & Hoffmann, 1969), and on a rangewide basis by Grigsby (1973). From all these studies we learn that there is a poor performance of trees from the Piedmont and mountain areas when they are planted in the flatwoods and Coastal Plain provinces and a relatively good performance of trees from the flatwoods and Coastal Plain sources everywhere except in the mountains. The PRODEPEF results are parallel to these general conclusions.

Provenance studies with loblolly pine have been carried out in Australia (Nikles, 1962; Burgess, 1973), New Zealand (Burley, 1966), Japan (Iwakawa et al., 1964), Zimbabwe (Prevôst et al., 1973b), Colombia (Perez, 1967), and Uruguay (Králl, 1969, 1973). Results obtained in those countries are also comparable to the PRODEPEF experiments.

Results from neighboring countries such as Argentina and Uruguay as well as from Brazil (Canavera, 1971; Barrichelo et al., 1978; Fonseca et al., 1978) are very important for comparison purposes.

The good performance of the Brazilian seedlot from Klabin in the Series 2 trials was not consistent with results obtained by Barrichelo et al. (1978). In that 1968 provenance trial, one Klabin seedlot was among 20 seed sources tested in Fazenda Monte Alegre (Klabin's Forestry Farm). Klabin's seedlot ranked seventh in volume production, which meant about 15% less than the three top provenances from South Carolina, Mississippi, and Florida.

Another good comparison is possible with a 4-year-old provenance trial established by IPEF in Lages, Santa Catarina (Fonseca et al., 1978). That trial utilizes 11 of the 17 seedlots of PRODEPEF's Series 1 experiment. The rank correlation between the two tests is $r_s = .64$, significant at the 2.5% level.

Barrett (1974) established well-designed and replicated trials over 20 locations in Northeast Argentina. Among 29 seed origins tested, the leading ones were from Livingston Parish, Louisiana; Decatur County, Georgia; and Columbia County, Florida. Argentinian and Brazilian results relate very closely.

Application of the Results

For pulpwood and timber production, growth rate is the single most important trait. Because of the north-south and interior-coastal clinal variation in growth rate also found by Kraus (1967) and Barrett (1974), the recommended area for seed collection for planting in southern Brazil is the coastal region stretching 120 kilometers from the coast of the Gulf of Mexico and the Atlantic Ocean in the states of Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, and North Carolina (Region 1 in Figure 5).

Within that region, however, the consistent superiority of seed-lots from Livingston Parish has been observed in tests in the United States, Brazil, and other countries. Brazilian growers can obtain immediate improvement by using seed from that area.

There were enough correlations between my results and American results to indicate that genetically improved seeds from seed orchards in the United States (Region 1) can be used in Brazil.

CHAPTER V

SLASH PINE PROVENANCE TRIALS

The Species

Slash pine has the smallest natural range of the four major southern pines. It grows in six states from southeastern Louisiana to southeastern South Carolina (Figure 6). It does not occur naturally west of the Mississippi River, but is often planted there. Slash pine has a large population center in southeast Georgia and adjacent Florida and a small one in south Mississippi and Alabama based on wood volume (Dorman, 1976).

Climatic conditions vary less in the slash pine range than in loblolly pines range. Mean annual temperature is about 19°C in the North and 22°C in the South, or a difference of only 3°C. Mean January temperatures increase gradually from a low of about 10°C at the northern extreme in South Carolina to a high of about 21°C in the Florida Keys. Mean July temperatures average about 27-28°C throughout the region. Mean annual precipitation varies from as high as 1625 mm in southeastern Florida and southern Louisiana and Mississippi to as low as 1120 mm at the northern limits in eastern Georgia. Precipitation is uniformly distributed in the northern portion of the species range. In the south, most of the rainfall occurs in the mid-summer months, and wintertime droughts are rather common (Squillace, 1966b).

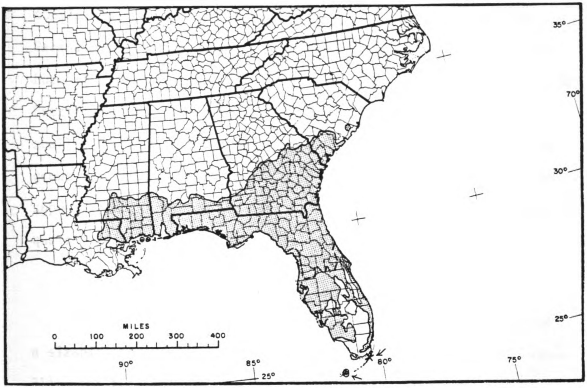


Figure 6.--Natural range for slash pine, Pinus elliottii. (From Dorman, 1976.)

South Florida slash pine (Pinus elliottii var. densa) is found from Central Florida southward to the Florida Keys. Typical slash pine (Pinus elliottii var. elliottii) and its variety have different ranges, but there is a gradient in traits where they meet, and no clear distinction in the boundary between the two can be made (Squillace, 1966a).

Slash pine is a very important and successfully introduced conifer in the southern states of Brazil. It grows faster than Paraná pine and its edaphic requirements are minimal. This attribute of high soil adaptability is very important because many of the Brazilian plantations are on poor and eroded sites, sand dunes, shallow and rocky soils, and on poorly drained soils. Slash pine grows well in all these types of sites. Its wood, however, is not superior to the native Araucaria. Slash pine, however, will adequately replace it for many uses.

Condition of the Plantations

The average mortality for Series 2 was 9%, which represented a sizable improvement over Series 1 average mortality of 50% (Table 11). The reason for such progress was the change in methods of raising and distributing the planting stock. In Series 2 planting stock was containerized (polyethylene bags) and raised in local nurseries. In Series 1 bare-root seedlings were transported for long distances from one central nursery to the plantation sites. Most of the mortality occurred during the first year after planting.

Table 11.--Location, mortality, and average height of seven slash pine test plantations in southern Brazil.

Location of plantation	Measurement age (months)	Mortality (%)	Average height (cm)
Series 1			
Capão Bonito--São Paulo	49	70	496
Irati--Paraná	14	49	49
Tres Barras--Santa Catarina	52	33	384
Series 2			
Capão Bonito--São Paulo	20	5	105
Irati--Paraná	20	8	109
Tres Barras--Santa Catarina	27	20	208
Pelotas--Rio Grande do Sul	25	2	200

The fastest-growing plantation in Series 1 was at Capão Bonito. The mean annual increment in height for this plantation was 1.25 m, which is classified as excellent (Class 1) for Brazilian conditions (Golfari, 1971). Very few trees are forked, and foxtail was observed in less than 2% of the trees at Tres Barras. At age 4, flowering had just started: 6% of the trees at Capão Bonito had male flowers. At age 7, crown closure had suppressed the weeds in the higher-survival parts of the plantations.

Growth is about average for all Series 2 plantations. Overall, plantations of both series are in good condition. The very important lesson to be learned and applied in future experiments is that the method of raising and distributing the planting stock determines high survival and good growth as much as careful site selection and adequate care after planting.

Growth Rates

Origin and nursery growth data for Series 1 are presented in Table 12. In that and subsequent tables, seedlots are arranged in decreasing order according to their overall growth rate. Significant differences due to seed source were found in nursery traits. The variation in nursery traits was explained by latitude only in the case of Lammas growth. The correlation between latitude and Lammas growth was $r = -.78$, significant at the 1% level. Height growth, diameter, and bud set had correlations with latitude, respectively, of $r = .003$, $.24$, and $-.06$, none significant.

Table 12.--Origin and nursery data for slash pine, Series 1, grown in the Irati Flona's nursery for 213 days (May 7, 1973).

Seedlot number[a] and state[b] and county (or parish) of origin	Lat. (°)	Long. (°)	Altitude (m)	Height (cm)	Diameter (mm)	Trees with Bud set (%)	Trees with Lammas growth (%)
A FL Levy	29.3	83.0	--	19.9	3.7	9	39
D LA Allen	30.8	92.8	--	19.4	3.8	8	27
6 FL Calhoun	30.6	85.1	65	23.2	4.6	24	12
E MS Covington	31.8	89.8	--	19.6	3.9	23	7
2 FL Columbia	29.8	82.5	61	22.5	3.3	18	34
1 FL Marion	28.5	82.0	24	19.6	4.2	24	44
B FL Flagler	29.5	81.3	--	18.5	3.2	6	27
4 LA St. Tammany	30.5	90.0	46	19.3	3.7	12	18
7 GA Dooly	32.1	83.7	98	19.8	4.1	8	9
99 PR Irati, BRAZIL	--	--	850	17.8	4.1	13	10
5 MS Harrison	30.5	89.1	46	16.7	3.6	7	7
C FL Bay	30.3	87.8	--	21.1	3.8	7	4
3 FL Calhoun	30.6	85.1	46	21.5	4.4	30	18

[a]Numbers are those originally given by the U.S. Forest Tree Seed Center, and letters are used for the unnumbered seedlots from Dr. C. Ostrom.

[b]FL = Florida; LA = Louisiana; MS = Mississippi; GA = Georgia; PR = Paraná.

No significant correlations were found between height in the nursery and height at the plantation sites. However, correlations between first-year height and fourth-year height in the field were strong. For the plantations at Capão Bonito and Irati, they were $r = .71$ and $r = .68$, respectively, both significant at the 1% level.

There were important differences in growth rate due to seedlot in both series (Tables 13 to 18). Differences, however, were smaller than those observed for loblolly pine. In Series 1 seedlot A-FL Levy was consistently the best (Tables 13 and 14). Seedlots D-LA Allen and 6-FL Calhoun were also fast-growing. Seedlot D-LA Allen came from a plantation outside the natural range. While seedlot 6-FL Calhoun was overall the third best, another seedlot from the same county, 3-FL Calhoun, was consistently poor at all locations. This suggests that sizable differences occur among stands close together geographically.

In Series 2 seedlot 14-FL Columbia was the best as shown on Tables 16 and 17. Seedlot 6-FL Calhoun was second best overall. Seedlot 10-FL Calhoun was second poorest overall. This reinforces the previous observation that important differences occur among stands despite their geographic proximity. The Brazilian seedlot from Irati performed from average to below average in Series 1 and a little better than average in Series 2.

Genotype-environment interactions were very evident in both series as Table 15 and 18 show by means of rank correlations among plantations. The poor correlations found are an indication of the erratic performance of a few seedlots that were among the best in

Table 13.--Location and relative growth rate of slash pine seedlots (Series 1) collected from various parts of the species range and tested in southern Brazil.
Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Relative height when grown at		
	Capão Bonito	Irati	Tres Barras
	(% of plantation mean)		
A FL Levy	--	122	109
D LA Allen	103	106	109
6 FL Calhoun	101	108	104
E MS Covington	--	--	109
2 FL Columbia	98	98	105
1 FL Marion	111	96	98
B FL Flagler	110	--	104
4 LA St. Tammany	105	94	96
7 GA Dooly	93	96	98
99 PR Irati, BRAZIL	95	100	88
5 MS Harrison	96	94	88
C FL Bay	94	--	98
3 FL Calhoun	94	78	95
Year of measurement	1977	1974	1977
Age when measured (mo.)	49	14	52
Mean height (cm)	496	49	384

Table 14.--Location and height rank of slash pine seedlots (Series 1) tested in southern Brazil.
Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Height rank when grown at		
	Capão Bonito	Irati	Tres Barras
A FL Levy	-	1	1
D LA Allen	4	3	2
6 FL Calhoun	5	2	5
E MS Covington	-	-	3
2 FL Columbia	6	5	4
1 FL Marion	1	7	7
B FL Flagler	2	-	6
4 LA St. Tammany	3	8	10
7 GA Dooly	11	6	9
99 PR Irati, BRAZIL	8	4	13
5 MS Harrison	7	9	12
C FL Bay	9	-	8
3 FL Calhoun	10	10	11

Table 15.--Rank correlations (r_s) of height growth of nine slash pine seedlots (Series 1) tested at three locations in southern Brazil.

Location	Rank correlation with results at	
	Irati	Tres Barras
Capão Bonito	.18	.47
Irati		.55

Table 16.--Location and relative growth rate of slash pine seedlots (Series 2) collected from various parts of the species range and tested in southern Brazil.
Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state[a] and county (or parish) of origin	Lat. (°)	Long. (°)	Alti-tude (m)	Relative height when grown at (% of plantation mean): Capão Bonito	Irati	Tres Barras	Pelotas
14 FL Columbia	30.3	82.6	75	110	113	110	104
6 FL Calhoun	30.6	85.1	65	101	96	102	106
11 MS Harrison	30.9	89.2	45	100	103	97	105
99 PR Irati, BRAZIL	--	--	850	97	107	92	105
12 MS Harrison	30.9	89.2	--	101	101	92	98
13 SC Hampton	32.5	81.0	--	94	94	109	96
10 FL Calhoun	30.4	85.4	46	93	101	105	96
8 SC Berkeley	33.2	79.7	8	101	84	93	91
Year of measurement				1977	1977	1978	1977
Age when measured (mo.)				20	20	27	25
Mean height (cm)				105	109	208	200

Table 17.--Location and height rank of slash pine seedlots (Series 2) tested in southern Brazil.
Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Height rank when grown at			
	Capão Bonito	Irati	Tres Barras	Pelotas
14 FL Columbia	1	1	1	4
6 FL Calhoun	2	6	4	1
11 MS Harrison	5	3	5	3
99 PR Irati, BRAZIL	6	2	7	2
12 MS Harrison	3	4	8	5
13 SC Hampton	7	7	2	6
10 FL Calhoun	8	5	3	7
8 SC Berkeley	4	8	6	8

Table 18.--Rank correlations (r_s) of height growth of eight slash pine seedlots (Series 2) tested at four locations in southern Brazil.

Location	Rank correlation with results at		
	Irati	Tres Barras	Pelotas
Capão Bonito	.26	.00	.38
Irati		.02	.52
Tres Barras			-.10

some plantations and among the poorest in others. The most interactions were presented by seedlot 99-PR Irati (in both series) and by seedlot 1-FL Marion (in Series 1) and seedlot 6-FL Calhoun (in Series 2). In Series 1 a very important interaction was displayed by seedlot 1-FL Marion, which is the best at Capão Bonito and poor at other locations. No reasonable interpretation can be given for the interactions.

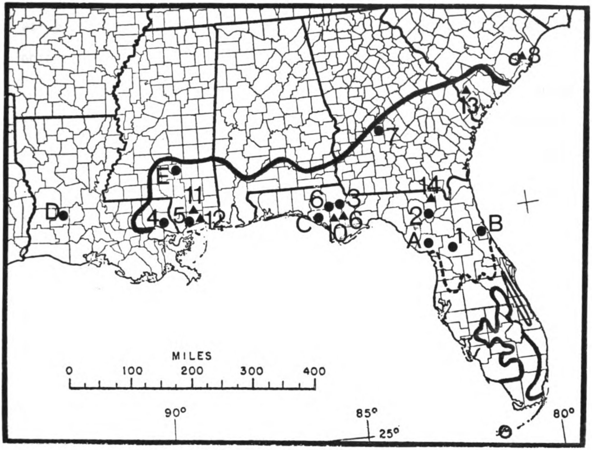
Differences in diameter growth due to seedlot were also significant. The correlation between height and diameter was r = .90 or higher and significant at the .01% level.

Combining the data and observations from both series, it was not possible to delimit a region of fastest-growing seedlots. Growth-rate differences among stands sampled within the species range of slash pine were real and significant but exhibited no distinctive geographical trends such as clines or ecotypes (Figure 7).

Comparison With Results of Previous Studies

Previous provenance studies in slash pine were summarized by Burley (1966), Squillace (1966a), Wells (1969), and Dorman (1976).

From 1937 to 1949, the U.S. Southern Forest Experiment Station established 10 provenance plantations of slash pine in the United States and contributed to seven plantings in South Africa. None sampled the whole range of the species. Those in the United States were less well designed and maintained than the South African tests (Snyder et al., 1967). Thirty-five-year results from the seven plantations in South Africa showed no significant differences between the



●B Location and seedlot identification in Series 1.

● 3 Location and seedlot identification in Series 1.

▲ 6 Location and seedlot identification in Series 2.

Figure 7.--Geographic location of slash pine seedlots tested in southern Brazil.

provenances at any of the trials and for any growth traits studied. In most trials highly significant correlations were found between early and late growth (Falkenhagen, 1978). Similar results were obtained in the United States (Snyder et al., 1967).

In 1951, P. C. Wakeley organized the "Southwide Pine Seed Source Study," which was summarized in Chapter IV. The slash pine portion of the Southwide Study sampled six areas and plantations in 12 localities. Height and survival showed significant differences but no pattern of variation (Wakeley, 1961; Wells, 1969).

In 1957, a combined provenance-progeny test was established in southern Mississippi testing 61 seedlots. Of these, 37 were randomly selected in five native south Mississippi stands, 16 were randomly selected in a south Mississippi plantation grown from northeast Florida seed, and 8 were phenotypically superior trees selected in a Georgia planting. Morphological and juvenile characters of the progenies were assessed. Six characters, including height, were highly significant among progenies within stands. Of the six traits, four (including height) varied among stands within geographic source. Of a total of nine characters studied, only height varied between geographic sources, and this was because of the superior growth of the progenies from Georgia which had been selected for vigor (Snyder et al., 1967).

Squillace (1966b) reported on his large provenance-progeny test, which included seedlings from 54 natural stands scattered throughout the range. Most of the traits studied showed significant differences due to geographic source. In the parental data, stand-to-stand variation was relatively strong in cone, seed, and needle traits. In the progeny data, stand variation was strong for germination rate, height, and diameter.

There was a major general trend in Florida. Seedlings of the South Florida variety grew faster in diameter but slower in height than trees of the typical or North Florida variety. This clinal pattern through Florida has little practical significance for southern Brazil planting conditions, where the typical variety is utilized almost exclusively. In the northern part of the range, the pattern was largely random and Squillace could not recommend any one portion of the range as likely to produce the fastest-growing trees.

Squillace's nursery work has had a follow-up (Gansel et al., 1971), in which 270 seedlots (54 sources x 5 mother trees) were planted at four locations. The results are parallel to a 1954 Georgia-Florida study, in which slash pines from 15 seed sources were planted at seven locations in the Georgia-Florida area. Differences in growth rate due to seed source and genetic-environment interactions were present and highly significant in both studies.

In the 1954 study, considering the average height over the plantations, the best sources occurred in a narrow band extending from Calhoun County northeastward to Effingham County, Georgia. In Squillace's field follow-up trial, one plantation closely agrees with these results, but another indicates that the presumed optimum zone is farther south in central Florida.

A slightly different optimum growth zone is defined by Wells (1975). It includes southeastern South Carolina, southern Georgia, part of western Florida, southern Alabama, and southern Mississippi. He recommends that seed be collected from the optimum growth zone for local plantings and up to 150 miles south of this zone.

The PRODEPEF trials include five seedlots from within that "optimum zone." Seedlot 6-FL Calhoun was third best in Series 1 and second best in Series 2. The four other seedlots (13-SC, 8-SC, 10-FL, and 3-FL) were among the poorest. Obviously the data do not indicate that the "optimum zone" produces the best seed for Brazil.

The overall good performance of seedlot 6-FL Calhoun when compared with the poor performance of two other seedlots from the same county raises questions about the extent of stand-to-stand variation. Unfortunately, neither the American nor PRODEPEF trials provide an adequate measure of stand-to-stand variation over the entire range.

Additional provenance research in southern United States was carried out in Florida (Goddard et al., 1962; Goddard, 1964; Goddard & Cole, 1966; Goddard & Smith, 1969) and in Texas (van Buijtenen, 1969). From all these studies we learn that geographic variation should also be recognized in clonal selection for tree seed orchards.

Slash pine provenance trials have been carried out in many Southern Hemisphere countries such as Malawi (Andersen, 1967), Kenya (Burley, 1966), Zimbabwe (Prevost et al., 1973a), Australia (Slee & Reilly, 1966; Burgess, 1973), New Zealand (Streets, 1962), Colombia (Perez, 1967), Uruguay (Burley, 1966), and Argentina (Barrett, 1974). Results are quite variable due to deficiencies in experimental design, quality of care after planting, and number of seedlots tested. In general, differences due to seedlot have been found in most trials, and results are comparable to the PRODEPEF experiments.

Results from neighboring countries such as Argentina and Uruguay as well as from Brazil (Canavera, 1971; Fonseca et al., 1978; Shimizu, 1978) are very important for comparison purposes. A good comparison is possible with a 4-year-old provenance trial established by IPEF in Lages, Santa Catarina (Fonseca et al., 1978). That trial utilizes 7 of the 13 seedlots of PRODEPEF's Series 1 experiment. The rank correlation between the two tests is $r_s = .14$. This result reinforces what was said in the previous section about the large amount of genotype-environment interaction.

Barrett (1974) established a good network of well-designed trials over 20 locations in Northeast Argentina, testing 38 seedlots. Significant differences due to seed source existed. Such variation was smaller considering only the typical variety. Seedlots from Florida were faster growing than more northern ones, but no clear pattern of variation existed. Among the best provenances for each site were seedlots from Florida, Louisiana, and Georgia. A discontinuous variation in growth rate was found between neighbor stands. Brazilian and Argentinian results were very closely related.

Shimizu (1978) reported some early results of a comparison between a Brazilian seedlot and some American progenies of slash pine. The local seedlot was collected at Capão Bonito. The American progenies of high and low vigor were families selected respectively for their high and low resin yield. Height growth of the best family was 2.7 times higher than the Brazilian seedlot. In the comparison with the low-vigor families the Brazilian seedlot was significantly smaller than two of the low-vigor families. Capão Bonito's plantations were established by using seeds from the United States of unknown origin. A great quantity of seeds collected at Capão Bonito have been used in reforestation programs.

Application of the Results

There were growth rate differences due to seed source in slash pine, but the variation was random. Differences among stands were real, but no definite geographical pattern existed. Because of this, no region in southern United States can be generally recommended for seed collection for planting in Brazil.

Individual stands, however, can be recommended. The specific stands which originated seedlots A-FL Levy, D-LA Allen, 6-FL Calhoun, and 14-FL Columbia should be considered as seed sources as a result of being the four best seedlots overall in Series 1 and/or 2. The stand where seedlot 1-FL Marion was collected can be considered as a seed source for Capão Bonito but not Irati or Tres Barras.

There was enough correspondence between my results and results in the United States and other countries to indicate that genetically improved seeds from seed orchards in the United States can be used in Brazil.

CHAPTER VI

FUTURE USES OF THE PRODEPEF TRIALS

All genetic plantations established by PRODEPEF are presently under responsibility of EMBRAPA (Empresa Brasileira de Pesquisa Agropecuária). The creation by EMBRAPA of a well-staffed Regional Unit of Forestry Research at Colombo, Paraná, when PRODEPEF ended assures that all genetic research previously established will have continuity.

Provenance Trials

The three major uses of the provenance trials in the future are (1) as producers of information, (2) for demonstration purposes, and (3) as breeding arboreta. A fourth possible use is as seed orchards.

Production of information is the most important function of the trials. Additional measurements should be taken at intervals of approximately 3 to 5 years. Some of the questions to be addressed by them are:

1. Are early trends consistent with later performance?
2. How strong are the age-age correlations?
3. Is there any genetic variation in the height-diameter ratio among seedlots?

4. Which measurements will be most appropriate for future correlations when the plots have been thinned or height measurements have become difficult?

Future assessments may include a thorough evaluation of form, quantification, and timing of flowering habits, and other traits regarded as important at the time. A comprehensive wood-quality study and a biomass study will be most appropriate if coincident with first thinning. Such studies may be advantageously undertaken as research topics of graduate theses in joint collaboration of EMBRAPA and Graduate Programs in Forestry.

Use of the trials as demonstration areas is also important. Tree improvement results ought to be transmitted to the general public. Communication and acceptance of results are more likely to be effective through publications and demonstration tours of the test plantations rather than through publications alone. Test plantations are located in easily accessible areas. All four areas are portions of "forestry districts" in the southern states. A state forestry district is an area designated by the federal government as most suitable for tree planting due to superior economical and ecological conditions. The demonstrational value of the test plantations can be enhanced by good maintenance. Thinning is an essential part of future care. All plantations were established in good alignment, and their growth is comparable to commercial plantings.

A breeding arboretum is a plantation or groups of trees used chiefly as parental stock in forest genetic experimentation. Utilization of the test plantations as breeding arboreta is a potential and recommended use for the trials. A favorable aspect for such use is the relatively large plot size. Selection within as well as between seedlots will be possible. Maintenance of the maximum number of trees of the best seedlots until maturity will also be feasible. Enhancement of the breeding value of the plantations can be accomplished by thinning to increase spacing and allow better crown development, and consequently heavier flowering. Good maintenance should also be given to the areas, including weed control.

Conversion of the test plantations into seed orchards is not advisable. PRODEPEF test plantations are not amenable for an effective conversion into seed orchards because they have large plot sizes. Conversion into seed orchards is performed by a series of thinnings. Maximum improvement results if thinning removes all trees of the poorest seedlots and the poorest trees of the best seedlots. Removal of all trees of the poorest seedlots is feasible only in small plot experiments. In large-plot experiments as the PRODEPEF trials, thinning would leave large and undesirable gaps in the plantations.

Nelder-Bleasdale Spacing Trials

Several test plantations using Nelder-Bleasdale systematic spacing designs have been established by CPFRS in southern Brazil from 1973 to 1976. PRODEPEF trials were the first in the country to utilize the full layout of a systematic spacing design in a forestry experiment. A detailed discussion of the designs including suggestions for their analysis is presented in Appendix C.

Provenances were not replicated in Series 1, and a few replications (up to four) were used in Series 2 trials. The lack of replication and randomization in Series 1 and the moderate mortality with replacements by different provenances has discouraged measurements and analyses of the established trials.

PRODEPEF systematic grids may or may not give any useful genetic information. Their main value will be the spacing data. Nelder-Bleasdale systematic grids used in PRODEPEF trials should be measured and analyzed in the future. Measurements and analyses should be done every year from age 4 to 10 when competition is expected to start for most of the spacings under test, and at intervals of 2 to 3 years afterward.

There are very few spacing experiments with loblolly and slash pine in Brazil. The valuable information about spacing that can be learned from these systematic grids is by itself a very strong reason to maintain, measure, and analyze all existing plantations.

CHAPTER VII

WHERE DO WE GO FROM HERE?

The PRODEPEF provenance trials of loblolly pine were successful in identifying a region producing seed of superior quality for Brazilian conditions (Figure 5). The same wasn't true for slash pine, for which no definite geographic pattern existed. In loblolly pine this provenance study made a real contribution to practical tree improvement in Brazil. In slash pine, however, it has not.

PRODEPEF trials followed the conventional approach of provenance testing. In slash pine, they succeeded in selecting a few better stands among a dozen or so tested. They did not succeed, however, in delimiting any region for seed collection nor in selecting the very best stands in the natural range. If additional provenance trials are to be carried out in Brazil, they should follow a different approach. They should include hundreds of seedlots, sampling several families from each of many stands.

Wright (1980) advised that in species containing a limited amount of geographic variation there should be less of the conventional type of provenance test and more of an intensive sampling type of experimentation. Wells and Switzer (1971), following this approach, were very successful with loblolly pine and reached important conclusions from the practical standpoint.

Future Improvement

Further improvement is, of course, desirable and needed in Brazil. This can be pursued by (a) using already improved American material or (b) superior provenances or stands in the natural range. American seed orchards do not produce enough seeds for American needs. Seeds from American seed orchards, however, can be procured in enough quantities to establish test plantations for future selections. The choice of a superior provenance for more intensive sampling trials is simple in the case of loblolly pine. Livingston Parish and surrounding parts of southeastern Louisiana are the natural choice. In slash pine such a region of superiority has not been detected, and northern Florida may be as appropriate as western Florida for further trials.

Seed procurement for an intensive sampling of southeastern Louisiana or any other region will probably require not only mail contacts with industries and government agencies in the region but also the sending of a Brazilian team for seed collection. The extent of work to be carried out by such a team will depend upon the amount of material which could be obtained from the forestry industry and government in the area. A Brazilian team selecting in Louisiana should be able to cause at least a 1% improvement in growth rate of loblolly pine. Such improvement would be worth many thousands of dollars--much more than the cost of sending the team.

Improvements of the Experimental Procedures

Genetic research in Brazil has followed a very traditional approach. Usually a small number of seedlots (2 to 20) have been tested using a small number of replications (2 to 5) and large plots (25 to 121 trees). Such procedures have limited the scope of the trials in terms of the material tested, and they have also decreased the precision and efficiency of the trials.

Statistical precision is the ability of an experiment to differentiate among treatments. Statistical precision is greater in a plantation containing small plots and many blocks than in one containing large plots and fewer blocks. Small plots make up smaller blocks with less intrablock site variability, and therefore more reliable are the comparisons among seedlots planted in the same block.

Statistical efficiency is the ability of an experiment to produce the greatest amount of useful information per unit of cost, as measured by number of trees planted, measurement time, etc. It has been demonstrated that efficiency decreases with increasing plot size (Wright & Freeland, 1959; Conkle, 1963; Wright, 1963). Calculations made by these same investigators showed that 1- to 10-tree plots were statistically most efficient, giving the most information per unit of time spent on measurement and analysis.

Another serious limitations of past Brazilian research has been the limited number of locations tested in a given experiment. PRODEPEF trials including four locations were the first step toward a more desirable situation. Such a number, however, is minimal and should be increased for a more reliable sampling of environmental conditions. Genetic-environment interaction exists for both pines, and the only way of studying it is through multiplantation experiments.

Future genetic research in Brazil with loblolly and slash pines should make use of small plots (1 to 10 trees), a greater number of replications (8 to 10), and a greater number of locations (15 to 30). This recommendation is especially important for the intensive sampling approach suggested for future experimentation in Brazil.

Progeny and Combined Provenance-Progeny Tests

The intensive sampling approach for the testing of already improved American material or superior provenances or stands in a chosen region should be performed as progeny tests or combined provenance-progeny tests. Such trials should be established in such a way that the test plantations can be converted into seed orchards, as discussed by Nanson (1972). The three most important features which will allow efficient conversion are a very large number of seedlots (100 to 300), small plot sizes (1 to 4), and a large number of replications (8 to 10).

A few advantages of using this approach in Brazil are the following:

1. Low costs: It will not involve much more cost than ordinary provenance experiments.

2. Rapidity and ease of establishment: Seedling plantations are easy to establish because no special skills are required beyond those necessary for a commercial planting.

3. Broad genetic basis: A very broad genetic basis will be assured by the diversity of provenances, stands, and individuals making up the seed orchard. The trees produced by such a seed orchard will be a genetic synthesis of individuals which are the best adapted to the planting site.

4. Reduction of inbreeding: The use of hundreds of seedlots reduces the chances of inbreeding.

Modifications in design will be required to handle large progeny tests or combined provenance-progeny tests. A simplified design that can be conducted almost as simply as an ordinary provenance test was proposed by Wright (1978). Such experiments can yield considerable genetic improvement and be converted into seed orchards.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Paraná pine (Araucaria angustifolia) was a very important conifer in southern Brazil. The Araucaria forest has been depleted due to intensive logging, and regeneration is very poor. Araucaria has been planted but in a limited scale due to silvicultural and economic limitations.

Loblolly pine (Pinus taeda) and slash pine (P. elliottii), introduced from the southern United States, can be very successfully planted. About 800,000 ha of these two species have been established. The total industrial demand for wood in Brazil requires not only more planting but better productivity. Genetic improvement based on provenance trials is one major approach to increase productivity.

This study is an assessment of loblolly and slash pine provenance trials planted in southern Brazil by the Project for Forestry Development and Research (PRODEPEF). The major objectives of this study were to determine if there are:

1. Genetic differences in growth traits among provenances,
2. Any trends of significance for locating the most suitable provenances,
3. Any genetic-environment interaction.

In addition, the following objectives were pursued:

4. To determine the advisability of future uses of the trials,
5. To determine possible improvements of the experimental procedures,
6. To determine the future direction of the experimentation aiming at the genetic improvement of loblolly and slash pines.

Seeds were obtained from the U.S. Forest Service (Macon, Georgia, and Washington, D.C.). Thirty-five seedlots of loblolly pine and 20 seedlots of slash pine were tested in two series. In Series 1 (1973 plantations), bare root seedlings were raised in one nursery at Irati, Paraná. In Series 2 (1975 plantations), containerized seedlings were raised at the plantation sites. A nursery trial was conducted in Series 1. Plantations were established in four locations: Capão Bonito (São Paulo); Irati (Paraná); Tres Barras (Santa Catarina), and Pelotas (Rio Grande do Sul). Plantations followed a randomized complete block design with 16- to 49-tree plots and 3 to 5 replicates. Spacing was 2 by 2 m or 2.5 by 2.5 m. Mortality was assessed, and several growth traits (height, diameter, forking, foxtail, etc.) were measured. Each set of measurement data was subjected to statistical analysis. All differences quoted as being important are statistically significant at least at the 5% level.

Mortality was much lower in Series 2 for both species. The main cause of mortality in Series 1 was the long-distance transportation of bare root seedlings. Loblolly pine and slash pine at Capão Bonito presented an average annual height increment of 1.4 m and

1.25 m, respectively--very good for Brazilian conditions. Form was generally good for both species, with few trees forked or crooked. Flowering was observed at age 4 in Capão Bonito in 15% of the loblolly pine trees. In slash pine, 6% of trees had flowers.

Nursery traits were significant for both pines. Some latitudinal trends were observed in loblolly pine seedlings related to height growth ($r = -.66$), bud set ($r = .69$), and Lammas growth ($r = -.67$). In slash pine only Lammas growth had a significant correlation with latitude ($r = -.78$). Loblolly pine seedlots which were tallest in the nursery also tended to be tallest in the plantations. The rank correlation between nursery height and average height in all plantations was $r_s = .67$. For slash pine no significant correlations were found between height in the nursery and height at the plantation sites. Correlations between first-year height and fourth-year height in the field, however, were generally strong for both species ($r = .70$ in the average).

Loblolly Pine Growth Rate Results and Conclusions

There were very important differences in growth rate due to provenance in both series. In Series 1, seedlot 6-LA Livingston was consistently among the leaders at all test locations. Seedlots B-FL Jackson and A-FL Marion were also fast growing. In Series 2, among the leaders at all locations were two seedlots from Mississippi (9-MS and 8-MS), a Brazilian seedlot from Klabin (98-PR), and a South Carolina seedlot (17-SC). Genotype-environment interactions were strong in Series 1 and smaller in Series 2.

A general trend of coastal seedlots to grow faster than interior ones was observed in both series. Seedlots from Maryland, Virginia, and the Piedmont from North Carolina to Alabama grew poorly from average to 50% below average. The fastest-growing seedlots were up to 2 to 2.5 times taller than northern or interior seedlots.

PRODEPEF results were compared with previous studies in the United States. American and Brazilian results were very similar. Results obtained in many other countries were also comparable to those of the PRODEPEF experiments.

The most highly recommended area for seed collection for planting in Brazil is the coastal region stretching 120 kilometers from the coast of the Gulf of Mexico and the Atlantic Ocean in the states of Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, and North Carolina.

The consistent superiority of seedlots from Livingston Parish indicates that Brazilian growers can obtain immediate improvement by using seed from that area. The close correlation of my results and American results indicates that genetically improved seeds from the United States (recommended region) can be used in Brazil.

Slash Pine Growth Rate Results and Conclusions

Important differences in growth rate existed in both series. Differences were smaller than those observed for loblolly pine. In Series 1, seedlot A-FL Levy was consistently the best. Seedlots D-LA Allen and 6-FL Calhoun were also fast growing. In Series 2, seedlot 14-FL Columbia was the best. In both series it was observed that sizable differences occurred among stands close together geographically. Genotype-environment interactions were strong in both series.

Growth rate differences among stands sampled within the species range of slash pine were real and significant, but no clear geographical trend or pattern was found. Many other experiments in the United States and other countries (especially Argentina) had similar results.

No region in the southern United States can be generally recommended for seed collection for planting in Brazil. Individual stands which originated seedlots A-FL Levy, D-LA Allen, 6-FL Calhoun, and 14-FL Columbia can be suggested as a result of their good performance.

The close correspondence of results in Brazil and in the United States indicates that genetically improved seeds from seed orchards in the United States can be used in Brazil.

Future Uses of the Trials

Provenance trials established by PRODEPEF should have three major uses in the future, which are (1) as producers of information, (2) for demonstration purposes, and (3) as breeding arboreta. These three uses are compatible with each other and suitable for the adopted design of the trials. A fourth possible use as seed orchards is not recommended because the test plantations have large plot sizes. Conversion into seed orchards would also conflict with the other three uses.

Some plantations were established using Nelder-Bleasdale systematic spacing designs. They should be measured and analyzed in the future. They may or may not give any useful genetic information. There are very few spacing experiments with loblolly and slash pine in Brazil. Valuable information about spacing can be learned from these systematic grids.

Future Research

A conventional approach of provenance testing was used in loblolly and slash pine trials. Some real contribution to practical tree improvement was achieved for loblolly pine, but not for slash pine. Future trials should follow a different approach, including hundreds of seedlots and sampling several families from each of many stands.

Further improvement can be pursued by using already improved American material or superior provenances or stands in the natural range. Seeds from American seed orchards can be used to establish test plantations for future selections. The choice of a superior provenance of loblolly pine for more intensive sampling trials could be Livingston Parish and surrounding parts of southeastern Louisiana. In slash pine such a region of superiority has not been detected. The sending of a Brazilian team for seed collection in southeastern Louisiana is necessary for an intensive sampling of stands in the region.

Genetic experimentation in Brazil has usually tested a small number of seedlots (2 to 20), using a small number of replications (2 to 5), and large plots (25 to 121 trees). Such procedures have limited the scope of the trials in terms of the material tested, and they have decreased the precision and efficiency of the trials. Another serious limitation has been the limited number of locations tested. Future genetic research should make use of small plots (1 to 10 trees), a greater number of replications (8 to 10), and a greater number of locations (15 to 30).

Future intensive sampling trials should be established in such a way that the test plantations can be converted into seed orchards. Efficient conversion can be accomplished by using a very large number of seedlots (100 to 300), small plot sizes (1 to 4), and a large number of replications (8 to 10). Modifications in design which allow such large tests to be conducted almost as simply as an ordinary provenance test are indicated.

APPENDICES

APPENDIX A

HEIGHT GROWTH DATA OF LOBLOLLY AND SLASH PINE SEEDLOTS TESTED IN SOUTHERN BRAZIL

Table A1.--Location and height growth of loblolly pine seedlots (Series 1) tested in southern Brazil. Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Height when grown at			
	Capão Bonito (cm)	Irati (cm)	Tres Barras (cm)	Pelotas (cm)
6 AL Livingston	645	148	377	231
A FL Marion	630	--	493	--
B FL Jackson	--	--	460	--
11 NC Jones	523	143	397	193
C LA Washington	625	--	407	--
10 MS Stone	588	153	317	220
1 SC Berkeley	615	167	213	214
13 GA Jones	455	134	407	170
5 LA Calcasieu	590	119	323	183
D MS Forrest	585	114	423	157
99 PR Irati, BRAZIL	600	128	370	133
2 FL Marion	705	110	337	138
12 GA Oglethorpe	460	131	327	160
4 MD	--	--	353	--
14 GA Oglethorpe	438	92	310	175
3 MD Worcester	353	110	267	171
7 TX Nacogdoches	575	--	313	138

Table A2.--Location and height growth of loblolly pine seedlots (Series 2) tested in southern Brazil. Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Height when grown at			
	Capão Bonito (cm)	Irati (cm)	Tres Barras (cm)	Pelotas (cm)
9 MS Harrison	135	111	263	240
8 MS Scott & Smith	117	121	275	--
98 PR Klabin, BRAZIL	151	116	233	240
17 SC Charleston	136	105	248	239
18 SC Berkeley	154	90	268	235
11 NC Jones	112	116	255	222
16 MS Scott	125	87	273	232
29 TX Angelina	116	98	255	199
20 NC Robeson	121	102	225	205
30 NC Perquimans	102	104	233	194
27 SC Kershaw	107	91	228	219
13 GA Jones	115	91	230	198
22 MS Chickasaw	101	92	228	201
28 AL Talladega	88	97	200	200
24 NC Pasquotank	97	93	213	192
19 GA Greene	86	67	218	181
25 MD Worcester	56	77	190	189
21 NC Durham	76	80	195	--
23 VA Nottoway	67	80	175	--
26 MD Kent	64	71	175	--

Table A3.--Location and height growth of slash pine seedlots (Series 1) tested in southern Brazil. Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Height when grown at		
	Capão Bonito (cm)	Irati (cm)	Tres Barras (cm)
A FL Levy	--	60	420
D LA Allen	510	52	420
6 FL Calhoun	500	53	400
E MS Covington	--	--	420
2 FL Columbia	488	48	403
1 FL Marion	553	47	378
B FL Flager	545	--	398
4 LA St. Tammany	523	46	368
7 GA Dooly	460	47	378
99 PR Irati, BRAZIL	473	49	338
5 MS Harrison	475	46	338
3 FL Calhoun	465	38	363
C FL Bay	465	--	378

Table A4.--Location and height growth of slash pine seedlots (Series 2) tested in southern Brazil. Seedlots are arranged in decreasing order of their overall ranking.

Seedlot number and state and county (or parish) of origin	Height when grown at			
	Capão Bonito (cm)	Irati (cm)	Tres Barras (cm)	Pelotas (cm)
14 FL Columbia	115	123	228	208
6 FL Calhoun	106	105	212	212
11 MS Harrison	105	112	202	209
99 PR Irati, BRAZIL	102	117	192	210
12 MS Harrison	106	110	192	195
13 SC Hampton	99	103	226	191
10 FL Calhoun	98	110	218	191
8 SC Berkeley	106	92	194	181

APPENDIX B

SAMPLES OF THE RESULTS OF THE STATISTICAL ANALYSIS USING MSU CDC CYBER 750 COMPUTER

Table B1.--Sample of an analysis of variance table for height growth.

Source of variation	Sum of squares	df	Mean square	F	Signif. of F
Main effects	300027.451	18	16668.192	3.023	.003
TRT	232941.176	16	14558.824	2.640	.009
REP	67086.275	2	33543.137	6.083	.006
Explained	300027.451	18	16668.192	3.023	.003
Residual	176447.059	32	5513.971		
Total	476474.510	50	9529.490		

Table B2.--Sample of an analysis of variance table for height growth of the 25% tallest trees.

Source of variation	Sum of squares	df	Mean square	F	Signif. of F
Main effects	224168.627	18	12453.813	2.516	.011
TRT	192800.000	16	12050.000	2.435	.016
REP	31368.627	2	15684.314	3.169	.055
Explained	224168.627	18	12453.813	2.516	.011
Residual	158364.706	32	4948.897		
Total	382533.333	50	7650.667		

Table B3.--Sample of an analysis of variance table for diameter at breast height.

Source of variation	Sum of squares	df	Mean square	F	Signif. of F
Main effects	8277.569	18	459.865	2.273	.021
TRT	7148.039	16	446.752	2.208	.028
REP	1129.529	2	564.765	2.791	.076
Explained	8277.569	18	459.865	2.273	.021
Residual	6475.137	32	202.348		
Total	14752.706	50	295.054		

Table B4.--Sample of an analysis of variance table for forked trees.

Source of variation	Sum of squares	df	Mean square	F	Signif. of F
Main effects	8.471	18	.471	1.855	.062
TRT	6.588	16	.412	1.623	.119
REP	1.882	2	.941	3.710	.036
Explained	8.471	18	.471	1.855	.062
Residual	8.118	32	.254		
Total	16.588	50	.332		

Table B5.--Sample of an analysis of variance table for ant damage.

Source of variation	Sum of squares	df	Mean square	F	Signif. of F
Main effects	252.784	18	14.044	1.784	.075
TRT	172.745	16	10.797	1.371	.217
REP	80.039	2	40.020	5.083	.012
Explained	252.784	18	14.044	1.784	.075
Residual	251.961	32	7.874		
Total	504.745	50	10.095		

Table B6.--Sample of an analysis of variance table for foxtail.

Source of variation	Sum of squares	df	Mean square	F	Signif. of F
Main effects	34.784	18	1.932	2.581	.009
TRT	32.745	16	2.047	2.733	.008
REP	2.039	2	1.020	1.362	.271
Explained	34.784	18	1.932	2.581	.009
Residual	23.961	32	.749		
Total	58.745	50	1.175		

Table B7.--Sample of Pearson correlation coefficients among traits in one set of measurements.

	MORT	MEANHT	STDVHT	RANHT	HT25	FORK	ANT
MORT	1.0000	-.2094 p=.070	.0681 p=.317	-.3124 p=.013	-.1805 p=.103	-.1706 p=.116	-.0722 p=.307
MEANHT	-.2094 p=.070	1.0000	.4900 p=.001	.5357 p=.001	.8859 p=.001	-.0014 p=.496	.1085 p=.224
STDVHT	.0681 p=.317	.4900 p=.001	1.0000	.8030 p=.001	.7934 p=.001	-.0030 p=.492	.1812 p=.102
RANHT	-.3124 p=.013	.5357 p=.001	.8030 p=.001	1.0000	.7817 p=.001	.1429 p=.159	.2447 p=.042
HT25	-.1805 p=.103	.8859 p=.001	.7934 p=.001	.7817 p=.001	1.0000	-.0094 p=.474	.1779 p=.106
FORK	-.1706 p=.116	-.0014 p=.496	-.0030 p=.492	.1429 p=.159	-.0094 p=.474	1.0000	.0663 p=.322
ANT	-.0722 p=.307	.1085 p=.224	.1812 p=.102	.2447 p=.042	.1779 p=.106	.0663 p=.322	1.0000

Key: MORT = mortality
MEANHT = mean height
STDVHT = standard deviation of height
RANHT = range of height
HT25 = height of 25% tallest trees
FORK = forked trees
ANT = ant damage

APPENDIX C

THE USE OF NELDER-BLEASDALE DESIGNS IN THE PRODEPEF TRIALS

THE USE OF NELDER-BLEASDALE DESIGNS IN THE PRODEPEF TRIALS

Experimental Considerations

The use of conventional randomized designs is very common in field experiments. Randomized designs provide, when the plot-treatment additivity condition holds, an unbiased estimate of the variance of treatment effects, as well as giving unbiased estimates of the mean.

Randomization may have some disadvantages, however, with spacing experiments. For example, if the spacing is being maintained in a square pattern for all densities, then we may either (a) keep a constant number of plants per plot or (b) keep all plots the same size. In the first case, the plots are all of different sizes and awkward to fit together in a block. In the second case, the close spacings may have an unnecessarily large number of plants in them. In addition, efforts to keep the block size small will lead to a large proportion (perhaps a half or more) of the plants in the trial being used as guards. Where plant material or land is valuable, this is unsatisfactory (Nelder, 1962).

Spacing experiments with forest trees using conventional randomized block designs usually result in carrying out experiments of enormous size. Such large experiments are not statistically desirable and sometimes not practicable with the resources available. Thus, it becomes worthwhile to consider the possibility of using systematic designs for spacing experiments in order to overcome the disadvantage of randomized experiments previously described. If a systematic design is used which consists of a randomized-block type of layout without the element of randomization, then the problem of fitting the plots together may be eased, but the other difficulties remain, particularly that relating to the high proportion of guards (Nelder, 1962).

Bleasdale and Nelder (1960) had an original idea to solve the problem. If crops were planted in rows which radiated from a point, with the distance between plants along a radius approximately equal to the distance between radii at that point, then a large range of plant densities could be grown in a small area. Further, guard plants would only be needed around the outer edge of a group of plants arranged in this systematic manner.

Descriptions of the Designs

Nelder (1962) suggested five designs, four based on polar coordinates and one on a rectangular logarithmic grid (Figure C1). Namkoong (1966) proposed that all may be made suitable to silvicultural experiments, and two are of interest to tree breeders. Of these two, design "1a" varies plant spacing while design "1b" varies shape of the growing space. Design "1b" is useful for studying the effects of growing space shape, a factor that may be of critical importance when trees are to be planted and harvested in rows. However, if interest lies primarily in spacing and restrictions are placed on plant numbers and plot size, only design "1a" is suitable.

PRODEPEF trials utilized basically design "1a." The components of design "1a" are angles of arc turned by successive spokes of an imaginary wheel which intersect successive rims or circumferences at

Legend:

(a) Design 1a. Shape fixed, area increases with r.

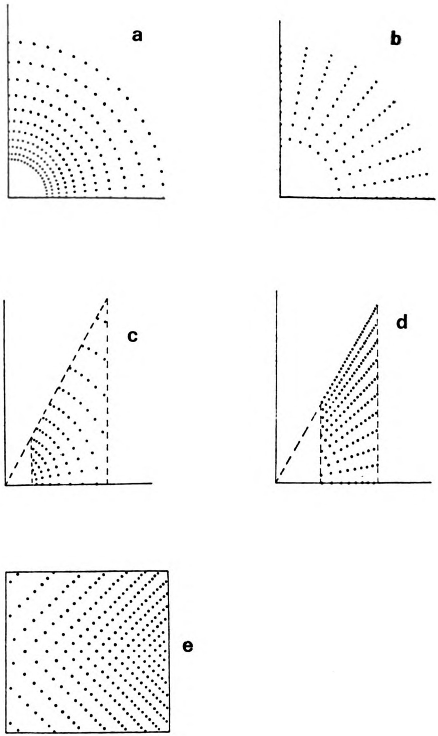
(b) Design 1b. Area fixed, shape changes with r.

(c) Design 1c. Equal-area contours = vertical lines.
Equal-shape contours = radii.

(d) Design 1d. Equal-area contours - radii.
Equal-shape contours = vertical lines.

(e) Design 2. Equal-area contours = vertical lines.
Equal-shape contours = horizontal lines.

Figure C1.--The five original Nelder designs.
(From Nelder, 1962.)


a
b
c
d
e

specified radial distances. The intersections of spokes and radial distances are the planting point locations. For example, a circular block of 100 trees can be laid out on 10 spokes at successive angles of 36°, with 10 trees planted along each spoke (Namkoong, 1966).

For design "la" Nelder (1962) specified two conditions:

1. The shape of the growing space available for each plant is to be the same throughout the whole circular plot, and

2. Plants at different spokes but at the same radius shall have equal spacing.

Based on these conditions he derived the relations:

$$r_n = r_o \alpha^n$$

$$\tau = \text{constant, and}$$

$$\theta = \text{constant.}$$

where n is the number of plants in each spoke (number of radii); $n = 0, 1, 2, \ldots, N, N+1$. 0 and N+1 are the guard plants and N is the number of densities (arcs, plants) we intend to test;

r_n is the radial distance of the n^{th} plant in the spoke or the radius of the n^{th} arc;

r_o is the radial distance of the starting plant in each spoke;

α is the constant determining the rate of change in growing space;

τ is the rectangularity of plant arrangement; and

θ is the angle between adjacent spokes, in radians.

In this design the rectangularity is constant over the whole grid, and it is measured by the ratio of within-spoke spacing to between-spoke spacing. The area per plant increases as we go outwards from the center.

The design is defined by the constants and variables previously described. Nelder (1962) presented all the mathematics required to the calculation of his designs. The condensed and perhaps too mathematical form in Nelder's paper has been found by some as difficult. Bleasdale (1967) presented an easier, step-by-step procedure to calculate the dimensions needed to construct the design. Namkoong (1966) suggested some changes in the original formulas to calculate design "1a" as well as his proposed modification of it.

Adaptations of the Designs

Modifications of the basic designs are possible and may be used to achieve specific objectives. Nelder (1962) pointed out two adaptations, one to test triangular spacing and the other to study competition of two species. Bleasdale (1967) discussed the "fan design," basically an adaptation of type "1a" design extended to fill a rectangular plot. A step-by-step procedure for the additional calculations was given as well as the method of calculating similar design when some restrictions are imposed.

Namkoong's (1966) proposed modification of design "1a" allows limited variability to the shape of growing space, but improves the sampling of densities and are even more economical of space than Nelder's original designs. He calculated several different planting plans and all information required for field layout was given.

For the PRODEPEF trials two planting plans were calculated. Plan A was essentially design "la" (Table Cl and Figure C2) testing 47 provenances of four pine species: loblolly, slash, longleaf, and shortleaf. Plan B followed the adaptation of design "la" (Table C2 and Figure C3) as suggested by Namkoong (1966), testing 21 provenances of loblolly and slash pines.

Field Layout

The marking out of the designs in the field presents no great problem. A transit and nonstretching and flexible wire are the most convenient aids to marking out. A picket is set up at the center (origin) and a transit placed over it. The wire is attached to the central picket. This wire is marked with paint at the points corresponding to the distances r_n required, and fitted with a cane at the other end to allow it to be stretched tightly along the ground. Seedlings or stakes are put in against the appropriate marks. The transit gives the angle θ between two adjacent spokes at the origin. The wire is then moved to the next position and the second spoke is marked out. This process is repeated until the whole area is covered. An average of 3 hours were usually spent laying out one Nelder-Bleasdale circular plot in the PRODEPEF trials.

Table C1.--Parameters of Nelder-Bleasdale design--Plan A.

Radius	Planting points from center (m)	Approximate spacing (m)	Equivalent density (trees/ha)
r_0	12.21	--	--
r_1	13.74	1.63	3,751
r_2	15.47	1.84	2,950
r_3	17.42	2.12	2,227
r_4	19.71	2.39	1,751
r_5	22.20	2.64	1,435
r_6	25.00	2.97	1,134
r_7	28.14	3.34	895
r_8	31.69	3.77	704
r_9	35.68	4.24	556
r_{10}	40.18	4.78	437
r_{11}	45.24	--	--

Number of experimental spokes = 47

Number of experimental densities = 10

Arcs r_0 and r_{11} are guards

Radial angle = θ = 7.65°

Rectangularity = τ = 1:1

Rate of change of spacing = α = 1.1259

Chord at r_{11} between adjacent spokes = 6.04 m

Total area of trial = 0.828 ha

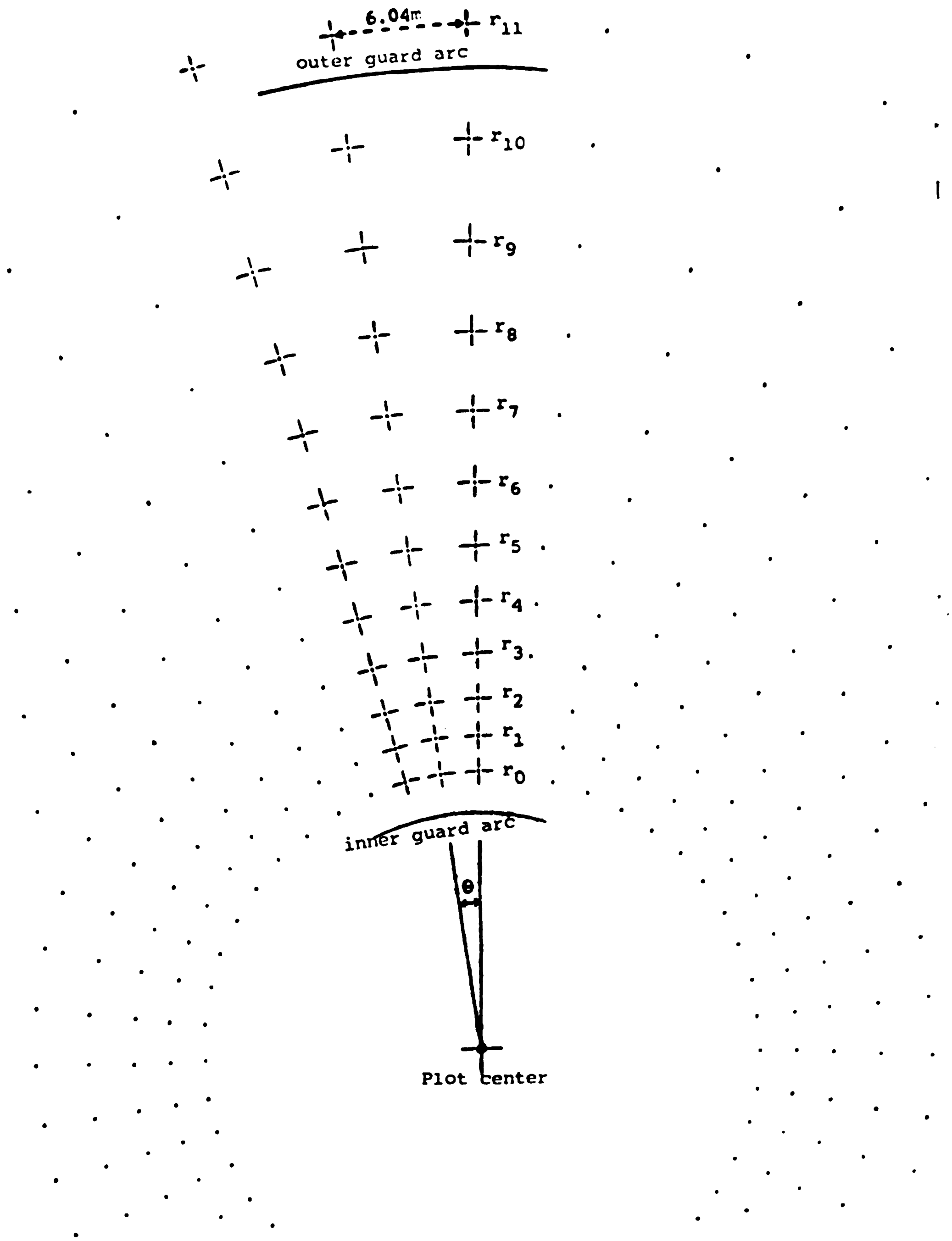


Figure C2.--Layout of PRODEPEF's plan A.

Table C2.--Parameters of Nelder-Bleasdale design--Plan B.

Radius	Planting points from center (m)	Equivalent density (trees/ha)
r_0	7.83	--
r_1	9.10	3,089
r_2	10.36	2,718
r_3	11.62	2,347
r_4	12.97	1,977
r_5	14.40	1,606
r_6	16.03	1,234
r_7	17.97	865
r_8	20.57	494
r_9	24.83	247
r_{10}	31.85	124
r_{11}	42.43	--

Number of experimental spokes = 21

Number of experimental densities = 10

Arcs r_0 and r_{11} are guards

Radial angle = θ = 16°

Rectangularity = τ = 1:2 through 1:2.6 up to 1:1

Total area of trial = 0.569 ha

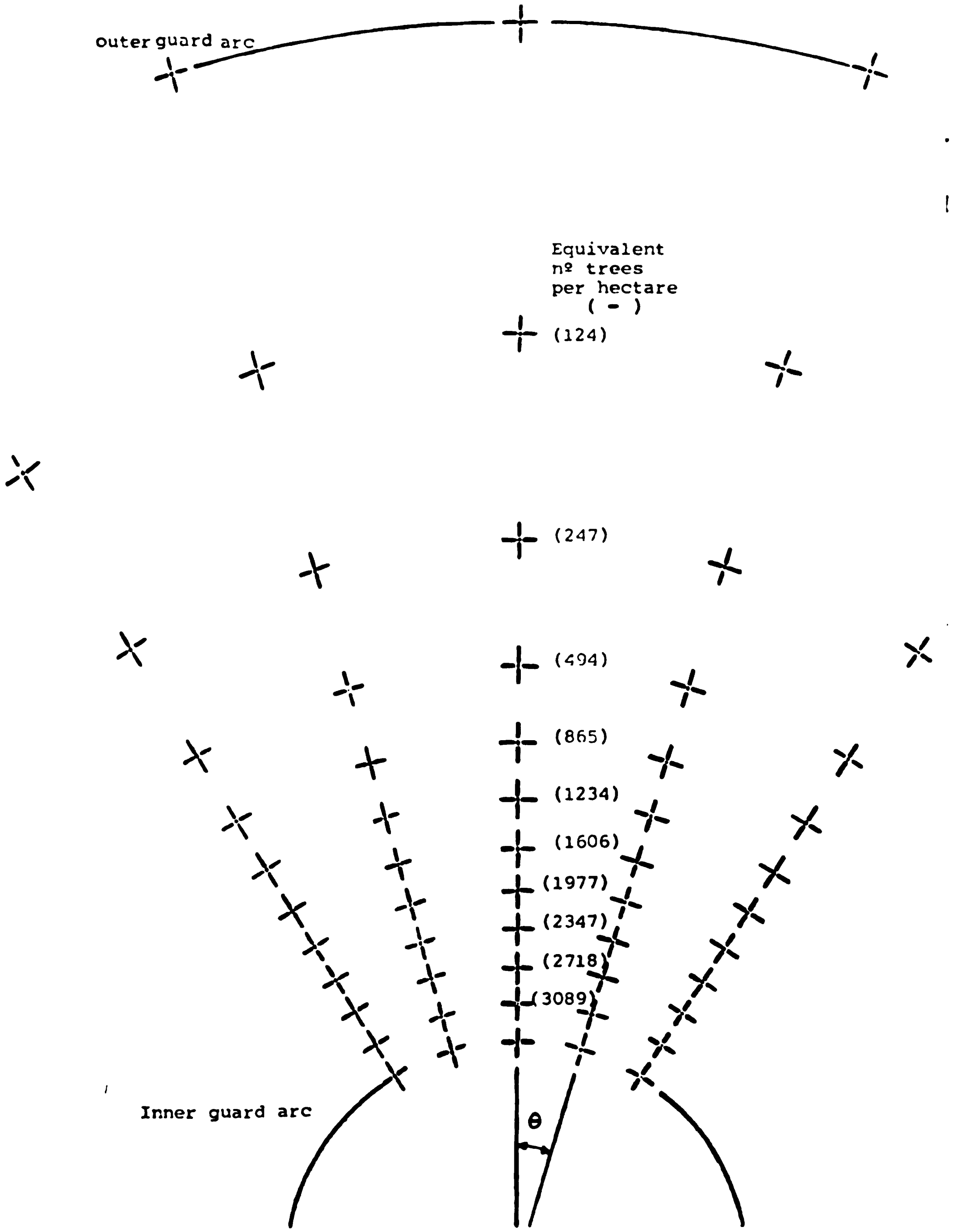


Figure C3.--Layout of PRODEPEF's plan B.

Analysis

Nelder (1962) discussed the main principles underlying the analysis of growth traits from systematic designs. He recommended:

1. to express the trait-density-rectangularity relation by a suitable function and estimate the unknown parameters in it for each "grid" (circle, or sector or replicate),

2. to analyze the parameter values from the individual grids as if they constituted a random sample.

Treating the parameter values from the grids as if they were a random sample from some population is an important assumption to be justified. Nelder affirmed that the assumption was clearly analogous to that of taking a centric systematic area-sample (Milne, 1959) and treating it as random. The main danger in this procedure lies in the possibility that certain kinds of unsuspected periodic variation may be present. Milne concluded from an examination of 50 populations that this danger was negligible, provided that the experimenter takes certain precautions in laying out his experiment to avoid any risk of unwanted periodicity from known sources. Nelder agreed in assessing the risk from unknown sources as negligible.

Yield-density functions for fixed rectangularity have been discussed by Bleasdale and Nelder (1960), Namkoong (1966), and others. They presented the following relationship:

$$G^{-x} = a + bD$$

where G is growth rate, D is the plant density, and x, a, and b are constants.

The mathematical treatment of the data, although of value, is not essential to the interpretation of the results for practical purposes. Meaningful curves can often be drawn through the series of points on a graph, plotting the growth trait against density. The data from each grid should be examined separately before combining the data from several grids (Bleasdale, 1967).

A suggested analysis of variance table for PRODEPEF's plan A design considering the whole grid is:

Source of variation	Degrees of freedom
Distance (density)	9
Spoke (provenance)	46
Error	414
Total	469

It is desirable to consider separately each sector (species) of the circle. The analysis of variance for an individual sector is similar to the analysis for the whole grid. For loblolly pine (16 provenances), for example, it is:

Source of variation	Degrees of freedom
Distance (density)	9
Spoke (provenance)	15
Error	135
Total	159

ANOVA tables for other species in the grid and for plan B can be constructed in a similar manner, taking into account the number of provenances under test. Provenances were not replicated in Series 1, so if the F value for spoke (provenance) is significant, this means that the spokes are different from each other because of either position or provenance effect. Likewise, if the F value for distance (density) is significant, this means that the distances are different from each other because of either position or density effect.

A very meaningful part of the analysis would be calculating the mean for each density, plotting those means against distance, and inspecting the graph. Another method would be to choose an equation that seems to fit the curve the best and calculate the variances due to regression and error.

Analyzing the same design (Plan A) and accounting the four plantations (locations) as replicates, then the ANOVA table is:

Source of variation	Degrees of freedom		F-test
Spoke	187		
Provenance		46	use A
Plantation		3	use A
(A) Plant. X Provenance		138	
Distance (Density)	9		use B
Distance X Spoke	1683		
Distance X Provenance		414	use B
Distance X Plantation		27	use B
(B) Dist. X Plant. X Prov.		1242	
Total	1897		

In Series 2 plantations, provenances were replicated. When two or more species were tested in the same circle, different species were confined to sectors of it. Within each sector (species) at least three replicates were planted as subsectors. Position of each provenance within replicates was randomly assigned. The ANOVA table for a species represented by 5 provenances, 3 replicates, and 10 densities within spokes is:

Source of variation	Degrees of freedom		F-test
Spoke	14		
Provenance		4	use A
Replicate		2	use A
(A) Provenance X Replicate		8	
Distance (Density)	9		use B
Distance X Spoke	126		
Distance X Provenance		36	use B
Distance X Replicate		18	use B
(B) Dist. X Replicate X Prov.		72	
Total	149		

Discussion and Conclusions

The desirability of including density in experimental designs as an important variable of the cultural environment is obvious. Nelder-Bleasdale circular grids make it possible. They avoid the difficulties of the rectangular plots and still study density response over a wide range. Circular grids, however, have the disadvantage of not being fit to easy mechanical planting, cultivation, and maintenance.

Nelder-Bleasdale circular designs, used in PRODEPEF trials, achieved their original purpose of demonstration of another type of experimental design which can be employed in forest trials. They certainly are appropriate for silvicultural experiments, and especially advantageous for spacing experiments.

Two of the basic Nelder-Bleasdale systematic designs can be used for genetic experiments. They are designs "1a" and "1b" (and their adaptations). I do not believe, however, that they could in a satisfactory manner replace the traditional randomized complete block designs for most genetic experiments. Those systematic designs have the disadvantages that the estimates of means might be biased and that there may be no satisfactory estimate of error variance. These difficulties may to some extent be met by orienting the replicates differently and by having enough replications that analyses of parameters estimated from each replication may provide suitable estimates of error. Replication, randomization, and orientation of replicates should consequently be factors of careful consideration when using systematic designs.

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