PROVENANCE TESTING MEXICAN PINES IN THE UNITED STATES AND BRAZIL [1/]

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The flora of Mexico, including many forest tree species, is noted for its great diversity. As a result of a wide variety of environmental conditions, selection forces operating for millions of years in combination with frequent hybridization and introgression have created a wealth of inter- and intra-specific variation. In recent years, forest geneticists have recognized the potential value of this material for use in Mexico and other regions where suitable local tree species are lacking. Consequently, several programs have been initiated throughout the world to evaluate and utilize Mexican tree species, especially the pines. One such project involved the N. C. State Industry Tree Improvement Program. [3/]

In 1961 several cooperators in the industry program became interested in trying to do something with their problem sites where local species have failed or do poorly. Several methods involving selection, hybridization, and the introduction of exotics were proposed, and various combinations of these were selected for trial by certain of the cooperators. The purpose of this paper is to present early results of the study involving the use of Mexican pines as exotics in southeastern United States, Hawaii, and Brazil.

OBJECTIVES

The original intent was to collect material primarily for trial on problem sites scattered throughout southeastern United States. These areas vary from dry sandy sites to those that are excessively wet, and they range from coastal regions near sea level to the natural hardwood sites of higher elevations. Because of the large quantity of seed actually obtained, however, the study was expanded later to include locations in Brazil belonging to two of the cooperators; material was also made available to the U. S. Forest Service for testing in Hawaii.

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In addition to the species-site tests, other less applied objectives were incorporated into the original work plan. One of these was to determine the range of variability in wood qualities that existed both within and between species growing in natural stands under different environmental conditions. Material was also collected for use in studying species relationships, including karyological investigations. Results of the wood study have already been reported (Zobel, 1965), while those from the karyological analysis are being incorporated into a larger study of the genus Pinus which is nearing completion.

METHODS

Collections

Considerable time was spent prior to the trip in planning the collection activities, especially in determining the areas and species to be utilized. Although Mexico and the southern regions of the United States differ considerably in latitude, it was felt that certain areas of somewhat comparable environmental conditions existed where altitudinal differences sufficiently modified temperatures and precipitation. It was recognized, of course, that elevation is never a complete substitute for latitude because of day length, intensity of actinic rays, and other complicating factors.

Collection areas were selected in the cold-temperate and warm-temperate limatic zones of the Sierra Madre Occidental, Sierra Madre Oriental and the Great Cross Range according to site conditions and estimated cone crops. ollections were made in 1962 during the months of November and December from a minimum of five trees per species in each stand. Trees of good phenotypes with a minimum of 100 cones were selected, but occasionally trees of inferior form had to be accepted because of the badly cutover condition of some stands in strategic areas. Along with the cones, two 11 __ increment cores and various samples of vegetative material were obtained from each tree. All material was kept separate for each tree.

Collections were made for 17 species of which 12 had sufficient seed to be included in the provenance tests (Table 1). A wide variety of sites and habitats were sampled from the northern regions of Chihuahua (30 latitude) to south-central Puebla (19 latitude). Elevations ranged from 4,500 to 12,000 feet and soil conditions varied from essentially pure volcanic ash to well developed fertile loams to very poor soils predominantly composed of lay or rock.

Original plans were to have one of the two collection teams concentrate its activities in the northern regions of the Sierra Madre Occidental, but very poor cone crops along with severe insect infestations greatly reduced the collections in these areas. Consequently, the bulk of the seed (approximately 81 percent) was obtained from more southerly areas in the states of Mexico, Puebla and Michoacan. Details of the collection trip can be obtained from the summary by Saylor and McElwee (1963) which includes suggestions for planning and executing such operations.

Nursery Operations

All seeds were extracted in Mexico using a combination of air drying in

Table 1. Summary of cone collections.

Species [1/]	Number of Trees	Number of Stand Locations	Total Cones
1. *P. montezumae* Lamb.	22	5	7,549
2. *P. teocote* Schiede & Deppe	10	2	4,857
3. *P. hartwegii* Lindl.	5	1	1,200
4. *P. leiophylla* Schiede & Deppe	12	3	3,263
5. *P. patula* Schiede & Deppe	10	2	3,782
6. *P. rudis* Endl.	5	1	1,543
7. *P. pseudostrobus* Lindl.	10	2	3,238
8. *P. tenuifolia* Benth.	11	2	3,229
9. *P. lawsonii* Roezl	10	2	5,899
10. *P. oocarpa* Schiede	11	2	2,985
11. *P. michoacana* Martinez	18	4	3,314
12. *P. arizonica* Engelm.	3	1	523
13. *P. chihuahuana* Engelm.	1	1	10
14. *P. herrerai* Martinez	1	1	100
15. *P. durangensis* Martinez	1	1	36
16. *P. lumholtzii* Robins. & Fern.	2	1	8
17. *P. lutea* Blanco	1	1	5
	133	32	41,541

[1/] The following quantities of bulk seed of undetermined sources were also obtained: (a) *P. michoacana* - 1 1/2 lbs.; (b) *P. douglasiana* Martinez - 1 1/2 lbs.; and (c) *P. leiophylla* - 1 lb.

the sun and kiln extraction. In 1963 the seeds were sown in nurseries located in Tennessee (Vonore), North Carolina (Lumberton), Alabama (Childersberg), Hawaii, and central and southern Brazil. All seedlings for a given company's test plantings were grown in one nursery to avoid extraneous variation caused by nursery effects.

In general the techniques used in growing the Mexican **pines were** similar to those used for the southern pines (e.g., loblolly and shortleaf pines) of the United States. However, certain problems were encountered that are worthy of discussion at this time because of the effects they had on the condition of the planting stock.

For some species certain seed lots germinated very poorly, and in one case, P. lawsonii, none of the seeds germinated. The primary cause for this was associated with insect damage, although other undetermined factors are also suspected for P. lawsonii. In at least two nurseries, severe damping-off occurred in several locations; this was eventually controlled with the **use** of such fungicides as Captan and Hydro-oxyquinoline, but some retardation in development did occur.

Severe cold damage was the most serious problem encountered in. the nurseries located in southern United States. The damage varied among species, but all except those from the highest elevations (e.g., P. hartwegii, P. rudis, P. arizonica) were affected to some degree. For example, even in the most southerly location (Alabama), P. oocarpa was completely eradicated and P. michoacana was badly damaged by the first hard freeze in October. The problem is related to an inability of the Mexican pines to go dormant before the severe freezes occur in the fall and to remain dormant during the winter months as do the native pines. In addition to the initial damage, most lots suffered from repeated freezes that alternated with warm periods. Pines native to southeastern United States require at least two weeks of warm weather before breaking dormancy, but Mexican pines break dormancy with 4-5 days of warm weather. Consequently, injury was added to injury and this reduced the overall vigor of the planting stock.

Because it was quite evident that the seedlings in the Tennessee nursery were not going to "harden-off" for the winter, and because the seedlings were in such good condition regarding size and vigor, it was decided to lift during the fall rather than the following spring and to then store the seedlings under refrigeration during the winter. Unfortunately, severe mold problems developed during storage, so most of the seedlings were removed and "heeled-in" in holding beds. Again this combination of circumstances tended to adversely affect the condition of the stock.

I n Hawaii problems were encountered with damping-off, wind erosion, rodents, birds, flooded beds, high soil pH levels, lack of suitable mycorrhiza, and transplanting shock. All of these contributed to nursery mortality and reduction in vigor of planting stock. On the other hand, most species developed well in the nurseries in Brazil.

The results of the 1963 nursery operations were such that a high percentage of inferior planting stock was produced for most species. Because of the loss of several species immediately after planting and because of the early poor performance of the planted stock that did live, a supplementary planting was made in 1966, This material was grown in a nursery in Statesboro, Georgia. Some freeze damage was experienced again, but in general, the seedlings obtained from this nursery were quite good.

It is important to recognize that the native pines (loblolly, longleaf, shortleaf and virginia pines) used as checks in the plantings in southern United States were in better condition than much of the Mexican stock at the time of planting. This influenced the early performance and must be considered in evaluating the results.

Planting Design

The same basic pattern, a randomized block design, was used by all participants. In 1964 at least two plantings were established by all but two cooperators. Each planting consisted of four Blocks which were divided into Species Groups which in turn were divided into as many Plots as there were mother trees (families). Two species checks were randomly placed in each Block. Row Plots of 15 seedlings were established using a 9 ft. x 9 ft. spacing. When material was available, border trees were planted completely around each Species Group extending the rows to 17 trees.

Planting Sites

On the United States mainland, plantings were established over a wide variety of sites in West Virginia, North Carolina, Georgia, Florida, Alabama, and Louisiana. Site conditions ranged from excessively wet to very dry, from low elevations near the coast to higher elevations (3,000 feet) in the mountains, and from soils high in organic content to those that are mostly sand. In one instance a planting area was selected because it provided especially good conditions to test resistance to *Fomes annosus.* Site preparation varied from minimal operations using only burning to those involving maximum preparation by discing and harrowing. Most of the planting was done by hand.

For the Hawaiian operation, plantings were established on the islands of Maui and Molokai at elevations of 3,200 and 6,000 feet, respectively. The areas were previously covered with grass and/or shrubs, and the soils consist of deep loams (Maui) and silty clays (Molokai). Rainfall averages 40-50 inches annually in these areas.

In Brazil, plantings were located on two very different sites. U. S. Plywood-Champion, Inc. selected an area in the state of Sao Paulo with well drained, sandy soil that was sparsely covered with scrub vegetation prior to planting. Although freezing temperatures do not occur in this area, severe winter droughts are common. The second area, developed by Westvaco Corporation (Rigesa), is a bottomland site located in the state of Parana. The soil is a fertile, silt loam that historically had been covered with dense vegetation. Rainfall (approximately 60 inches annually) occurs uniformly throughout the year; light frost does occur in this area.

RESULTS

United States Mainland

Initial survival rates of the Mexican pines determined one to six months alter planting ranged from approximately 30 to 50 percent for the plantings that were measured. In comparison, results for the native species included as checks averaged 80-100 percent.

Considerable variation in survival occurred among species and between locations. For example, early survival for three species (P. leiophylla, P. patula, and P. pseudostrobus) in one block of a planting in the mountains of West Virginia was above 90 percent, while it was only 22 percent for P. teocote in the same block; across three of the blocks, survival varied from 15 to 100 percent for P. leiophylla. In contrasting areas, one planting in the Cumberland Plateau with somewhat similar conditions to those for the West Virginia planting had an initial survival rate of less than 10 percent; this was rather suprising because only species with some known tolerance to low temperature were selected for this planting.

At the end of one complete year in the field, survival rates dropped to less than 12 percent for the plantings that were sampled; slightly higher rates possibly occurred in a few areas that were only spot checked. By the end of two years, performance was so poor that essentially all plantings were abandoned as failures. Certainly in overall performance (i.e., survival and height growth) the Mexican pines were quite inferior to the native species checks. Even when special attempts were made to preserve individual species for demonstration purposes, most Mexican pines failed to survive.

Hawaii

The performance of the Mexican pines on both islands was considerably better than that on the mainland. Growth after three years in the field (Table 2) was good enough for 8 of the 12 species tested to indicate that there may be some potential value for a few of them. Two other species (P. rudis and P. hartwegii) have grass stages and thus cannot be properly evaluated in such a short time; because these two species had the highest survival of any species on the island of Maui, they also may be of value. These species also survived better than the others on the mainland, but growth was so slow they were suppressed by the natural vegetation.

Although survival in general was disappointing in that half of the species had a survival rate lower than 33 percent at the end of the third growing season, the pattern of mortality indicates these data may be misleading. Most of the mortality took place within eight months of planting; differences between the first and third year measurements were eight percent or less for every species. This suggests that either poor planting stock or poor planting conditions or both may have affected the initial performance of these species so adversely that a meaningful evaluation cannot be made without making additional tests.

Brazil

The plantings in Brazil were unquestionably the most successful of any of

Table 2. Survival and height measurements of three year old plantings in Hawaii.[1/]

Species	No. of Families[3/]	Island of Maui[2/] Height (ft.) Species Average	Island of Maui Height (ft.) Family Range	Island of Maui Survival (%) Species Average	Island of Maui Survival (%) Family Range	No. of Families	Island of Molokai[2/] Height (ft.) Species Average	Island of Molokai Height (ft.) Family Range	Island of Molokai Survival (%) Species Average	Island of Molokai Survival (%) Family Range
P. patula	7	6.5	5.0-7.5	24	20-27					
P. tenuifolia	4	6.5	5.5-8.0	21	15-30	2	5.5	5.5-6.5	72	33-82
P. pseudostrobus	10	6.0	4.0-7.0	29	22-47	8	6.0	4.0-7.0	31	7-47
P. montezumae var. *macrocarpa*	1	5.5		18						
P. leiophylla	9	3.5	3.0-4.5	48	27-70	6	5.0	4.0-6.0	63	36-85
P. teocote	4	3.5	3.0-4.5	39	18-57					
P. montezumae	13	3.5	2.0-4.5	18	0-44	7	3.0	1.5-3.5	14	0-31
P. michoacana var. *cornuta*	9	3.0	2.0-4.0	22	7-38	5	4.5	2.5-7.0	25	10-42
P. michoacana	3	2.5	2.0-3.5	11	5-23					
P. rudis	3	2.5	2.5-3.0	62	50-70					
P. hartwegii	2	2.0		65	63-67					
P. oocarpa	5	2.0	1.5-2.0	20	13-23					

1/ Data supplied by Craig Whitesell, U. S. Forest Service, Honolulu, Hawaii.

2/ Each planting is composed of four replications (Blocks).

3/ 14 or 15 open pollinated progeny were planted for each family in all replications.

the 20 that were established. Survival was outstanding in the state of Parana with eight out of nine species having survival rates of 80 percent or greater (Table 3). On the more droughty sites in Sao Paulo, survival was somewhat poorer, ranging from 6 to 79 percent; 7 of the 11 species had rates greater than 50 percent (Table 4).

Considerable variation in growth occurred between species in both locations. Third year height measurements ranged from 4 to 14 feet in Sao Paulo and from 0.5 to 12 feet in Parana; more than half of the species tested had growth rates of two feet per year or greater. As in Hawaii, P. patula was the most outstanding species in both areas; the freezing temperatures in Parana appeared to be no problem because the plants apparently were dormant when they occurred.

The plantings in Sao Paulo were the only ones other than those on the United States mainland in which non-Mexican pines were included as species hecks. In this case P. elliottii and P. taeda were used, and both were appreciably better than any of the Mexican pines (except perhaps P. patula) when both growth rate and survival are combined (Table 4). These results are in close agreement with those from other plantations of pines from south-eastern United States that have been established in Brazil.

DISCUSSION AND CONCLUSIONS

Much of the material planted in southeastern United States was established with guarded optimism,because it was felt that differences in environmental conditions between the test sites and the collection sites were too great. However, complete failure of all species within two years was not anticipated; undoubtedly the poor condition of much of the planting stock was an important cause of this early mortality. The single most important factor influencing mortality and growth was associated with freeze damage. Injury by freezing was repeatedly inflicted on the seedlings of most species, including several that are known to withstand quite low temperatures in their native habitat. The problem was associated with an inability to become dormant before freezing temperatures occur in the fall and to remain dormant during the winter. On the other hand, the few species that were not damaged by the cold weather did appear to be affected adversely by the high summer temperatures.

Because these results are so similar to those reported by Zobel (1969) in areas throughout the South, it appears that most Mexican pines have very limited value, if any, for commercial use in the southern and southeastern regions of the United States. Without question, if they are to be used, very detailed information on growth patterns, site conditions, environmental stress factors, etc. will have to be obtained to permit the selection of species or strains better adapted to this part of the world.

In both Hawaii and Brazil, the growth and survival data are impressive enough to indicate that some species of Mexican pines may have value as a source of coniferous wood needed so badly in these areas. Although not greatly superior to other pines being tested (e.g., P. elliottii and P. taeda), species such as P. patula, P. iciophylla, P. pseudostrobus, P. tenuifolia, and P. oocarpa have certainly done well enough to warrant further

Table 3. Survival and height measurements of a three year old planting in Parana, Brazil.[1/]

Species	No. of Families[2/]	Height (ft.)		Survival (%)	
		Species Average	Family Range	Species Average	Family Range
P. patula	5	12.0	10.0-13.5	98	93-100
P. leiophylla	7	12.0	10.0-14.0	99	98-100
P. oocarpa	3	12.0	11.0-13.5	98	93-100
P. pseudostrobus	7	6.5	5.0-7.5	99	98-100
P. tenuifolia	2	6.0	5.5-6.5	100	
P. michoacana	3	4.0	3.0-4.5	99	97-100
P. michoacana var. cornuta	4	4.0	3.0-5.0	99	97-100
P. montezumae	7	2.0	1.5-2.0	80	65-90
P. rudis	2	0.5	0.5-1.0	58	55-61

1/ The data were provided through the courtesy of Westvaco Corporation; the planting was composed of four replications (Blocks).

2/ Fifteen open pollinated progeny were planted for each family in all replications.

Table 4. Survival and height measurements of three year old plantings in Sao Paulo, Brazil.[1/]

Species	No. of Families[3/]	Planting I [2/] Height (ft.) Family Average	Range	Planting I Survival (%) Family Average	Range	No. of Families	Planting II [2/] Height (ft.) Family Average	Range	Planting II Survival (%) Family Average	Range
P. patula	4	14.0	13.5-15.0	72	68-88	2	14.0	13.5-14.0	63	57-68
P. leiophylla	9	9.0	7.0-10.0	76	65-87	8	10.5	10.0-12.5	79	59-94
P. pseudostrobus	7	7.5	3.0-9.5	79	72-85	7	8.5	3.5-10.0	77	65-87
P. teocote	6	7.0	6.0-8.0	52	20-82					
P. douglasiana[4/]		7.0		38			9.5		48	
P. tenuifolia	2	6.0	5.5-7.0	81	70-91	1	7.0		73	
P. durangensis	2	4.5	4.0-5.0	72	59-84					
P. michoacana	13	4.0	3.0-6.5	48	15-73	7	4.0	3.5-5.0	41	20-87
P. montezumae	11	4.0	3.5-5.0	53	23-82	8	4.0	3.5-5.0	33	3-59
P. oocarpa	5	4.0	3.0-5.0	17	5-38	2	8.0	8.0-8.5	50	48-51
P. hartwegii	2	4.0	1.5-6.0	6	3-9					
P. taeda[4/]		11.5		95			12.0		94	
P. elliottii[4/]		10.0		82			10.5		92	

1/ The data were provided through the courtesy of U. S. Plywood-Champion Papers, Inc.; values are determined from plot means of individual families.

2/ Each planting is composed of four replications (Blocks).

3/ Fifteen open pollinated progeny were planted for each family in all replications.

4/ Seeds used were from a commercial seed lot.

evaluation. However, because the results are so variable, any large scale introduction should be done cautiously until further assessments are made. Again great care should be exercised in selecting any material to be established.

In many ways the results in Brazil are comparable to those found in other regions of the Southern Hemisphere. For example, in their review of forest tree introduction in Rhodesia, Barrett and Mullin (1968) noted that at least 11 of 21 species of Mexican pines being tested were worthy of further consideration and study. Approximately 44 percent of the 36 pines being tested showed some promise; interestingly, three of the most impressive species (P. patula, P. elliottii, and P. khasya) come from quite disjunct areas. In all cases, but especially the Mexican pines, the importance of proper seed source was emphasized.

The results of this study as well as those from several others underscore problems associated with provenance testing in general that are especially critical when working with the Mexican pines. The most important of these involves properly matching seed source and potential planting site to provide the greatest possible chance for success; in the present study this was improperly done in several areas and consequently this was a major cause of failure. Because conditions (e.g., temperature, moisture, soil, etc.) in many areas of Mexico vary considerably within short distances, it seems imperative that some system using climatic analogues be employed. This will not ensure success, because it is difficult to predict such things as changes in growth cycles, and it is still difficult to get accurate data for some areas in Mexico. It is important, however, if for no other reason than to force a critical evaluation and comparison of important environmental factors.

Another important problem common in Mexico involves proper delineation of species. The extent of natural variation is poorly known for most species, although it is generally recognized that many of them are extremely variable as a result of strong selection pressures and frequent hybridization; this has created populations in many areas that are extremely difficult to identify taxonomically.

It is apparent, therefore, that if the potential of the Mexican pines in plant introduction is to be fully realized in the future, considerable effort must be expended to strengthen our knowledge of the biology, ecology, and taxonomy of this group of species.

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