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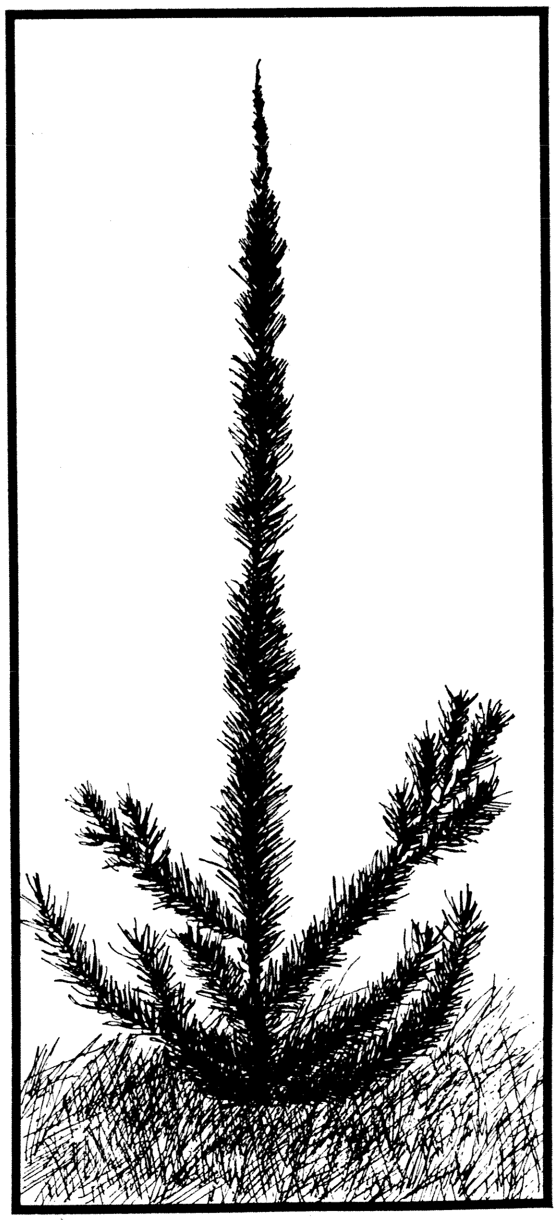
Growth and Site Relationships of *Pinus caribaea* Across the Caribbean Basin

An Institute of Tropical Forestry publication in cooperation with the University of Puerto Rico



ACKNOWLEDGMENTS

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Finally, the contributions of several agency and company administrators are recognized. Without their long-term support and commitment, field and interpretive work conducted by their technical staffs would not have been possible. These administrators are listed at the beginning of individual country reports.

August 1991

Growth and Site Relationships of *Pinus caribaea* Across the Caribbean Basin

Leon H. Liegel, Compiler

This publication is the final report for a science and technology grant from the U.S. Agency for International Development, Project AID/SCI/E2/06: Growth and Site Relationships of Caribbean Pine on Diverse Soils in Costa Rica, Jamaica, Trinidad, and Venezuela. It culminates 5 years of plantation silvicultural research at the Institute of Tropical Forestry, Southern Forest Experiment Station, Forest Service, U.S. Department of Agriculture, Rio Piedras, Puerto Rico. All research was conducted in cooperation with the University of Puerto Rico.

Front Cover: A foxtail tree, typically with a branchless main stem 2 to 10 meters (6.6 to 32.8 feet) long. This unusual phenomenon was observed in the five countries studied; it is one of the few traits common to all countries. Cover drawing by Gretchen Bracher, Corvallis, OR.

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EXECUTIVE SUMMARY

In 1982, the U.S. Agency for International Development funded a project to study growth of Caribbean pine (Pinus caribaea var. hondurensis) in four countries: Costa Rica, Jamaica, Trinidad, and Venezuela. Objectives of the project were to undertake new field research, to complete specific institution building activities, and to improve communication linkages among all cooperator countries. Puerto Rico served as a staging area for the overseas work and was a standard against which to compare growth data from the other countries.

Soil, climatic, and other environmental conditions are quite diverse across the five countries. At one extreme, study sites in Venezuela are located only 50 meters (164 feet) or less above sea level; have deep, droughty, sandy Oxisol soils; and receive only 900 to 1,200 millimeters (35 to 47 inches) of precipitation annually over a 4- to 6-month period. At the other extreme, study sites in Jamaica are located at elevations of 260 to 1,300 meters (858 to 4,290 feet), have deep, clay Ultisol soils, and receive 1,600 to over 3,500 millimeters (63 to 138 inches) of precipitation annually over a 10- to 12-month period.

Over 200 field plots in unthinned plantations provided data to construct site index, survival, and outside-bark-volume and basal-area curves for each country. For rotation age 15 years at an initial outplant density of 1,300 trees per hectare on "best" sites, greatest mean annual wood production was 37 cubic meters per hectare (533 cubic feet per acre) per year in Costa Rica. Puerto Rico and Venezuela average 32 cubic meters (461 cubic feet) per year. Trinidad and Jamaica averaged 26 cubic meters (375 cubic feet) per year.

Laboratory tests showed no major nutrient imbalances in any country. Overall soil fertility was lowest on sandy soils in Venezuela, as measured by agronomic indices. Soil pH values were highly acidic, ≤4.4, in Puerto Rico, Trinidad, and Venezuela. Higher pH values, >6.5, were measured only in Costa Rica and Jamaica. Predicted volume yields were not generally associated with specific soil types, such as clays, sands, and loams, or with life zones. But yields were higher on well-drained and moist sites than on poorly drained and dry sites.

Tree form was poor in all countries. Highest amounts of forked trees, surpassing 50 percent, were in Costa Rica, Trinidad, and Venezuela. Highest amounts of foxtail trees were in Costa Rica, Puerto Rico, and Venezuela, close to or surpassing 60 percent. Least foxtailing, 35 percent, was in Jamaica. (Avoiding seed sources from Poptun, Guatemala, and coastal Honduras will reduce foxtailing.) Most plots had few cones per tree and little evidence of past or recent flowering.

Insect or pathogen damage existed in Costa Rica, Jamaica, and Venezuela. Fires were a frequent hazard in all countries but seldom caused damage unless plantings were young and had thin bark. Wind damage was most severe in Jamaica and Puerto Rico, which are located in the Caribbean hurricane belt.

In moist areas, native shrubs and trees quickly revegetate planted sites and will eventually replace pine plantations unless repetitive weedings or fires reduce their growth. Understory flora and fauna are apparently as diverse within unburned pine plantations as they are within native secondary forests. Native wildlife generally find abundant food and cover in edge areas between pine plantations and native forest.

Chapter 1

1. THE CARIBBEAN PINE PROJECT

by Leon H. Liegel

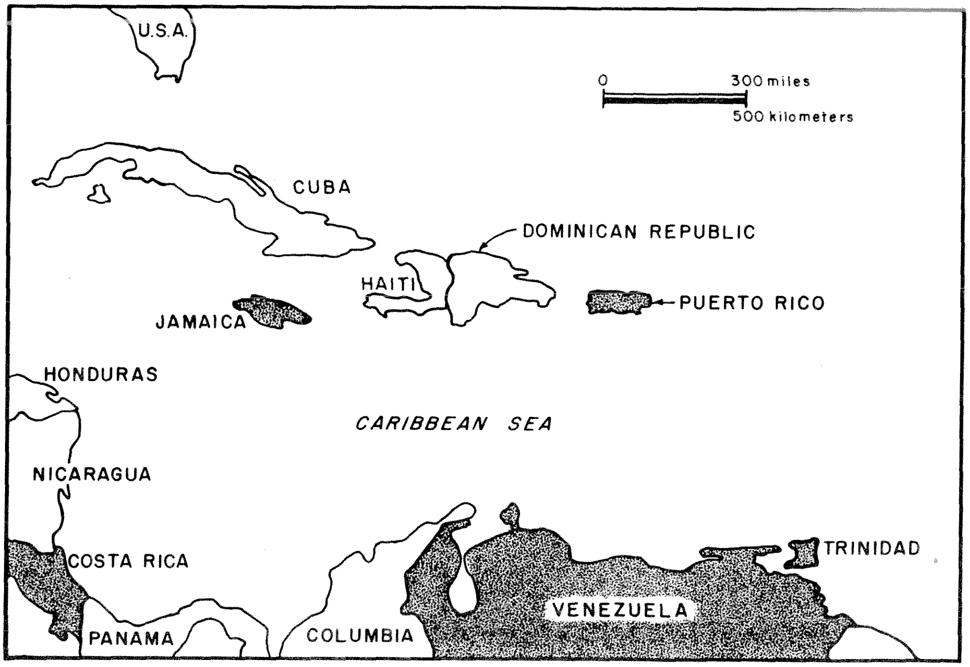

Figure 1.1—*Location of all countries (dark-shaded areas) included in the Caribbean Pine Project.*

Participants in the Caribbean Pine Project 1983–87

United States Agency for International Development

James Hester, chief—Environment, Natural Resources and Energy—Bureau for Latin America and the Caribbean
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1.1 Introduction

1.1.1 *Study Background and Objectives.*—Although Caribbean pine (*Pinus caribaea* var *hondurensis* Barr. and Golf.) has been widely planted in the Caribbean Basin area, the effects of site on tree growth and yield have been documented in only a few countries. Historically, there has been little exchange of technical information among countries of the region. The present study, funded by the U.S. Agency for International Development in December 1982, sought to improve communication and forest research linkages between the cooperator countries of Costa Rica, Jamaica, Puerto Rico, Trinidad, and Venezuela (fig. 1.1). The four specific objectives of the study, called the Caribbean pine project in this report, were to:

- collect and synthesize existing Caribbean pine research data,
- select and complete training activities for forestry staffs of cooperator institutions,
- conduct new field research, and
- publish results from syntheses of old and new research activities.

1.1.2 *Audience.*—This report summarizes project information in nontechnical terms for as large and diverse an audience as possible. Target readers are government officials and managers and local environmentalists who must make decisions about whether Caribbean pine plantings provide sound resource management alternatives. The audience also includes members of local or international donor agencies that could fund forestry development projects in any of the cooperator countries. Therefore, technical jargon is kept to a minimum. Appendix A contains a glossary of abbreviations and definitions of key technical terms used in the report.

1.1.3 *Subject Arrangement.*—This chapter explains project objectives and benefits, data collected, and institution building and training components of the project. Remaining chapters outline overall findings for all cooperator countries. The format is a highly illustrated casebook approach that explains specific findings and implications for individual countries.

Information for each country is presented in the same sequence. First, there is a short history of pine management. Second, a section on geology and soils defines the physical environment in which plantation forestry is practiced. Third, growth data are presented and ranked against results for each of the other cooperator countries. Fourth, general stand conditions are reviewed: percentages of deformed trees (forked stems, foxtail growth habit), cone/seed production, and important disturbances such as fires and wind damage. Fifth, observations on physical and chemical properties are summarized for surface and subsurface soil horizons. Last, suggestions are given for forest management strategies and new research in each country. Some subject overlap is intentional to make each chapter independent of all others.

1.1.4 *Project Benefits and Management Implications.*—The results of this research should enable managers, foresters, ecologists, and economists in cooperator countries to make sound, practical forestry decisions. Other benefits are:

- Identification of sites where trees have abnormal growth characteristics and are susceptible to wind damage,
- assessment of the effects of Caribbean pine plantings on plant understory diversity,
- analysis of past planting practices to determine future plantation establishment activities,
- development of a sound data base for continued cooperative research among forestry institutions within or outside the Caribbean Basin, and
- establishment of a known resource data base that can be used for other forestry development projects in the region.

1.1.5 *Physical Setting.*—In all these countries, pine plantations are mostly unthinned and are usually unmanaged except for basic weed and fire control. Each country has very diverse elevational, rainfall, soil, and geological conditions. For example, sites in Venezuela have sandy soils derived from sedimentary and aeolian sands, are located 50 meters (164 feet) or less above sea level, and receive only 900 to 1,200 millimeters (35 to 47 inches) of precipitation annually. At the other extreme, sites in Jamaica have deep clay soils derived from volcanic and limestone rocks, are located at 260 to 1,300 meters (858 to 4,290 feet) above sea level, and receive 1,600 to over 3,500 millimeters (63 to over 138 inches) of precipitation annually.

1.1.6 *Native Stands*—Natural stands of Caribbean pine exist in Central America, Belize, Guatemala, Honduras, and Nicaragua, from 12° to 18° N. latitude and from about 83° to 89° W. longitude. In Honduras, trees grow at elevations of up to 1,000 meters (3,280 feet); in the other countries, trees grow from coastal lowlands to elevations of 500 to 800 meters (1,650 and 2,640 feet). Few studies have documented soil properties in native stands. Coastal soils are well-aerated sands and silts on former levee banks of rivers; mountain soils are derived from conglomerate, granite, and slate rocks as well as limestone in Guatemala.

Climate is tropical, with no frost throughout the growing season. A winter dry season extends from December through May. Annual rainfall varies from 1,500 to 3,900 millimeters (59 to 154 inches) and is greatest at lowest latitudes along the coast. Interior stands are influenced by rain shadow effects and can receive less than 1,000 millimeters (40 inches).

Disturbances are limited to lightning-caused fires and bark beetle attacks from *Ips* or *Dendroctonus* genera; blowdowns from hurricanes occur infrequently along coastal areas of Honduras and Belize. Before cutting was increased markedly, trees grew to heights of over 30 meters (99 feet) and to outside diameters of over 40 centimeters (16 inches) in 60 to 80 years. Stand density ranged from scattered individuals in grass savannas to pure stands along the coast. (Wood from older native stands is used for sawtimber and cabinet making).

Large genetic variation exists among stands within any individual country and among all countries where Caribbean pine grows naturally. This variation has been characterized over the last 20 years by scientists from the Oxford Forestry Institute, formerly the Commonwealth Forestry Institute, in Oxford, United Kingdom. Results show that progeny of seeds from certain native stands grow well in some countries but not in all. One unusual phenomenon, the foxtail growth habit (see front cover), comprises 10 to over 50 percent of research or operational plantings, yet is rarely seen in native stands. Apparently, it is a result of both genetic and environmental factors.

Trees from some native seed sources are quite wind resistant in environments having high hurricane incidence; those from other sources have higher wood density at early ages. Therefore, knowing the number of cones produced per tree and actual seed viability is very important when considering large reforestation projects. Because most natural stands face tremendous cutting pressures, collecting seeds from older plantations has become very important in the last decade. Unfortunately, trees with large numbers of cones in exotic environments frequently produce few viable seeds. And trees in heavily stocked stands on poor sites produce flowers and cones at later ages and in lesser amounts than do trees growing in less dense stands on fertile soils.

1.2 Project Structure

Various agencies helped support the many activities needed to complete the Caribbean pine project. Key personnel and the kinds of services provided are given at the beginning of this chapter. The specific tasks of each agency are described below.

1.2.1 *U.S. Agency for International Development (USAID)*.—The Caribbean pine project was funded by USAID for $150,000 in late 1982. The grant was part of USAID's competitive grants program that allows United States' scientists and colleagues from developing countries to submit joint research proposals. Emphasis is on allowing other countries to take advantage of emerging but lesser known and perhaps riskier technologies than those used in regular development projects. All proposals undergo rigorous internal and external peer review and evaluation. The four major criteria used in judging them are scientific merit, relevance to development, new and innovative character, and overseas institution building components.

Progress reports were prepared every 6 months for USAID's Bureau for Latin America and the Caribbean and the Bureau for Science and Technology. Protocols regarding limitations on overseas research and travel were handled by these offices.

1.2.2 *U.S. Department of Agriculture (USDA)*.—Funds from USAID were distributed via a Participating Agency Service Agreement administered by the USDA Office of International Cooperation and Development, Worldwide Programs Office, Washington, DC. This office administers various agricultural technical assistance programs in foreign countries that include participating USDA scientists. Its personnel tracked all foreign travel expenditures and handled training costs incurred by foreign nationals within the project.

General technical and overall supervision of the project was provided by USDA Forest Service scientist Leon H. Liegel, the project manager and project principal investigator. Administrative support for day-to-day operations came from the clerical and fiscal staffs at the Institute of Tropical Forestry and the Supervisor's Office, Caribbean National Forest, Rio Piedras, PR. Cooperative agreements for all overseas work were handled by Forest Service personnel at the Southern Forest Experiment Station, New Orleans, LA.

1.2.3 *Cooperator Countries*.—Technical counterparts in each cooperator country acted as coinvestigators for the project. They prepared local budgets for training activities, helped direct field activities, and interpreted final results. More important, each coinvestigator coordinated efforts with local administrators so that project objectives were completed as planned.

1.3 Collecting Growth and Yield Data

1.3.1 *Field Methods*.—Variable-sized rectangular growth plots were established only in plantations where mortality and site disturbance were minimal. The objective was to sample field conditions where plantings were neither too poorly nor too highly stocked. Data from either extreme condition would lead to low or high growth estimates not representative of overall growing conditions.

Diameters were recorded at breast height, 1.3 meters (4.3 feet) from the ground for all trees, usually 30 or more per plot. Total heights in meters were recorded for at least 10 or more trees. Also, heights to 5-centimeter (2-inch) reductions in the outside-bark diameters were measured with a height/diameter gauge (Spiegel relaskope).

1.3.2 *Stand Conditions*.—Other data on stand development were collected. Tree form and stem quality were assessed by counting the number of trees having a crooked bole, forked main stem, leaning main stem, and foxtail growth habit (see front cover and fig. 6.6).

Sawtimber crop trees with forked and crooked stems have 50-percent or less value than those with straight single stems and superior wood quality properties. A high percentage of forking generally indicates past disease, pest, or wind damage. A high percentage of leaning trees indicates past storm damage and perhaps underground pathogens that have weakened tree root systems. Up to a decade ago, wood properties of foxtail trees were thought to be inferior to those of non-foxtail trees. More recent research does not support this idea. When foxtail trees resume normal growth, usually after 6 or 8 years, they produce two to three times more branches than normally grow in a whorl. Over time, normal whorls are produced as the tree grows. However, at the point where excess branches thicken, a weak point develops on the stem that is easily snapped in moderate to high winds.

Understory vegetation was classified into one of five categories, ranging from bare ground covered only with needles to ground covered with profuse grass or shrub cover (fig. 1.2). Understory species usually provide food and cover for a variety of wildlife species. However, some environmentalists feel that pine needles accumulate and prevent an understory from developing. Kinds of understory associations also help predict the need for weeding during early plantation development. Their abundance and composition determine whether a fire hazard will exist from fuels accumulated during a long, dry season.

The objective in taking measurements of stand conditions was to collect baseline stand and ecological data that could be used by land managers, foresters, ecologists, conservationists, and development planners.

1.3.3 *Merchantability and Utilization.*—Each country growing Caribbean pine wood has different cutting and harvesting practices, utilization criteria, and merchantability standards. Small materials from thinnings, less than 15 centimeters (6 inches) outside bark, are sometimes used for fenceposts and rustic fence or building materials. Because juvenile wood content is high in young wood, even chemical treatment will not prolong wood life beyond 10 years. Chemical treatment, either by

Figure 1.2—*Diameter, height, form, and cone production data were recorded for all field plots. Observations were also made on other stand characteristics. For example, some plantations had a profuse understory (left), whereas others (right), disturbed by fire or grazing, had little or no competing vegetation.*

hot-cold-bath or pressure preservative methods, is very expensive because high amounts of chemical are absorbed by low-density juvenile wood.

On good sites, 15-year-old plantings can produce logs with minimum outside diameters of 25 to 30 centimeters (10 to 12 inches) and minimum top diameters of 10 to 20 centimeters (4 to 8 inches). On average sites, however, 20 to 25 years are needed to reach the same merchantability limits. Natural pruning is poor in plantations, and including pruning to 4.9 meters (16 feet), one log height, will improve wood quality for sawlog standards. Properties of good-quality, high-value sawlogs are less juvenile wood, greater strength, and higher specific gravity or density of the wood. Older plantings also produce poles suitable for electrical and telephone lines in 12 to 15 years. Overall form and standing strength may not be equal to commercial pine utility pole standards for the Southern United States. Yet more careful management of planting density and pruning regimes would help improve both factors to meet existing standards.

Volume yields can be expressed with (outside bark) and without bark (underbark), depending on the local customs and products produced. For pines, underbark yields are some 15 to 25 percent less than outside-bark volumes for the same trees. Exact bark percentages are best obtained by felling sample trees and measuring bark thickness at several points along the bole. The method used in this study was to measure bark thickness at breast height only on 10 or more trees per plot. Although bark percentages measured this way are slightly higher than those determined from felled trees, they do provide general values to compare outside-bark yields with underbark yields. Average amounts (percentages) of bark at breast height for Caribbean pine were: Costa Rica, 17; Jamaica, 17: Puerto Rico, 13; Trinidad, 14; and Venezuela, 21.

1.4 Collecting Soils Data

1.4.1 *Field Methods.*—The productivity of crops such as bananas, corn, and sweet potatoes is directly related to fertility of the soils in which they are grown. Similarly, it was assumed that the growth and productivity of Caribbean pine is influenced by the various types of soils on which plantations are established. Therefore, soil samples were collected for all plots where growth and yield data were collected (fig. 1.3).

Two bags of soil, each weighing about 1 kilogram (2.2 pounds), were collected with a bucket auger or shovel. One bag contained soil collected from the surface down to 20 centimeters (8 inches), the other from 20 centimeters to 1 meter (8 inches to 3.3 feet) or rock barriers. Samples in Puerto Rico were taken from the surface to 30 centimeters (12 inches) because of slightly different sampling protocols developed for a doctoral dissertation. Soil samples were collected from three to five spots

Figure 1.3—*Soils were collected from each plot with a bucket auger or shovel. Sampling was often difficult because the soils had high clay content and many rocks.*

within each plot, mixed, and placed in cloth bags. When collecting soils, field crews made notations about:

- soil color,
- amount and kind of rocks,
- depth where rocks occurred,
- depth were drainage was restricted, and
- average depth to which roots grew.

1.4.2 *Laboratory and Office Interpretations.*—Soil samples were forwarded to and analyzed at the Tropical Soils Laboratory, Soil Science Department, North Carolina State University in Raleigh. The following physical and chemical properties that influence soil fertility were measured for all samples:

- amounts of sand, silt, and clay;
- cation exchange capacity (CEC);
- soil reaction (pH);
- aluminum saturation;
- phosphorous fixation potential;
- presence of sticky, plastic, expanding clays;
- presence of free calcium or sodium salts; and
- amount of potassium-weatherable minerals.

Results from laboratory tests were compared with crop and forest fertility indices to detect nutrient imbalances and any fertility deficiencies. Another objective was to determine whether plantations located in the same predetermined soil regions, based on geologic and topographic features, had similar fertility attributes. Soils of the same fertility should demonstrate the same response to fertilizer and other management practices (e.g., site preparation, thinning regimes, or harvest methods) that are used to increase wood volume yields. The fertility indices used were:

Minimal fertility standards

Fertility index	pH	Al saturation	Ca	Mg	K	P
		pct	- - -*meq/100 cm*^{3} - - -			ppm
Crops	<6.0	≤60	0.5	0.1	0.20	10
Pines	4.5–6.5	≤60	0.2	0.2	0.05	4–200

1.5 Institution Building and Training

1.5.1 *Objective.*—An integral part of the Caribbean pine project was completing various institution building and training activities. General training needs were identified in 1983 during planning meetings of the Project Principal Investigator with Forest Department senior level staffs in the cooperator countries. Specific activities and trips were accomplished throughout the project as opportunities developed (table 1.1).The overall objective was to augment existing professional and institutional strengths so that both managerial and technical skills could be improved.

1.5.2 *In-Country Activities.*—Local activities centered on establishing field plots to assess growth and yield of Caribbean pine by:

- supplying forestry equipment needed to conduct actual field work and
- providing training in initiating new field work, including rationale and sampling techniques for taking soil samples in each plot.

Two Spiegel relaskopes, used to take tree heights and outside stem diameters, remained in each country after field work was completed.

1.5.3 *Professional Development.*—Activities for career and professional development were conducted outside the cooperator countries in Chile, Colombia, the United Kingdom, the United States, Puerto Rico, and Venezuela. Attendance at international meetings allowed foreign national professionals to make contacts with their peers from all over the world. It also allowed them to become familiar with research and operational techniques that could be adapted to conditions in their own countries. Training costs were provided from project funds. Specific training accomplishments for each country are listed in appendix B.

Training sessions were very successful as judged by the written comments of those who participated. Of particular importance was the meeting of project counterparts and the Project Principal Investigator in Puerto Rico in September 1986 (fig 1.4). They visited provenance, seed orchard, and spacing trials of Caribbean pine and provenance trials of *Eucalyptus deglupta* and *Pinus merkusii.* Afterwards, the counterparts traveled together to Venezuela where they compared growth and management of Caribbean pine in the eastern savannas with reforestation practices observed in Puerto Rico and used in their own countries. These information exchanges created professional bonds that can be utilized in future forestry development projects within the Caribbean Basin.

Table 1.1—*Summary of activities and expenses involved in acccomplishing organizational work and training goals in the Caribbean pine project, 1983–86*

Cooperator country	Activity	Cost in U.S. dollars
Costa Rica	International travel/training in Colombia, Puerto Rico, United Kingdom, and Venezuela; field equipment and labor	13,956
Jamaica	International travel/training in Puerto Rico, the United States, and Venezuela; field equipment	12,554
Trinidad	International travel/training in Puerto Rico, the United States, and Venezuela; field equipment	16,431
Venezuela	International travel/training in Chile, Puerto Rico, and the United States; field equipment	18,527
Puerto Rico *	International travel for field training exercises and project planning activities in other cooperator countries	16,583
Total		78,051

*Puerto Rico was not a direct recipient of USAID grant funds but served as a staging area for conducting and comparing research in the other countries.

1.6 Data Synthesis and Integration

Synthesis and integration of information collected in all countries were essential to the Caribbean pine project. Kinds of information collected were data on the physical and chemical properties of soils, tree and stand data, and observations about field conditions and forest management practices(fig. 1.5). Additional information came from world literature and from various studies on

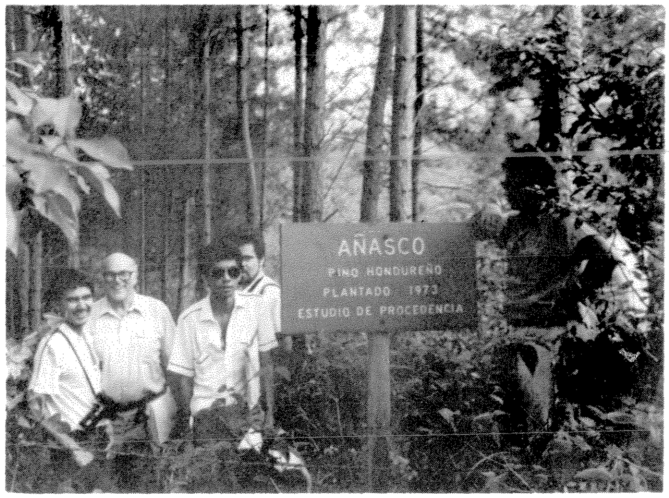


Figure 1.4—*Project technical counterparts from Costa Rica and Venezuela. Photo taken near Anasco, PR, as they discussed prolific natural regeneration of Caribbean pine with foresters from Sri Lanka.*

climate, soil surveys, and forest surveys in each of the countries. Results were summarized for various audiences by special reports, peer-review technical articles, and casebook studies.

1.6.1 *Special Reports.*—These reports (see appendix C) incorporated observations about plantation and nursery management practices used in the cooperator countries. For example, an article by Venator and others (1985) documented how Caribbean pine nursery stock is produced by either bare-root or containerized techniques, depending on available human and monetary resources and environmental conditions. Nursery techniques used by several cooperator agencies were reviewed by text and picture format in the forest nursery guide written by Liegel and Venator (1987). These and other articles alerted forest researchers across the world to the USAID-funded project.

1.6.2 *Peer-Reviewed Technical Articles.*—Specific information about field plot sampling techniques and data analyses will be presented via peer-reviewed journal articles. Such a format is suitable for other forest researchers or quantitative ecologists who are interested in the technical aspects of the project. Writing for this audience is essential to document all techniques by which the field and laboratory data were collected, analyzed, and interpreted. Drafts of technical articles are now being prepared.

1.6.3 *Casebook Studies.*—Chapters 2 through 6 in this report evaluate Caribbean pine management practices, including planting, tending, and harvesting techniques, in each cooperator country. Existing markets and processing plants make sawn wood products available in some countries but not in others. Each country also has a unique set of cultural and socio-economic factors that determine the scope and magnitude of future plantation management strategies. Overall results are presented in a country-by-country casebook format.

1.6.4 *Future Cooperative Research.*—End results of the Caribbean pine project are additional regional cooperative research and new forestry projects in each country (fig. 1.5). A wealth of tree and soil data were accumulated in uniform fashion across five countries having very diverse environmental conditions and forest management histories. These baseline data can be used for new intensive studies. Subject areas not investigated in this project that could be studied are:

- assessment of wildlife benefits or losses from pine plantation management,
- quantification of wood density and wood quality across the diverse sites studied,
- development of a regionwide growth and yield model,
- investigation of nontraditional forest products that could be obtained from low-density juvenile wood (such as animal bedding material), and
- determination of differences in soil nutrient status in successive plantations or between plantations and adjacent natural forest and savanna areas.

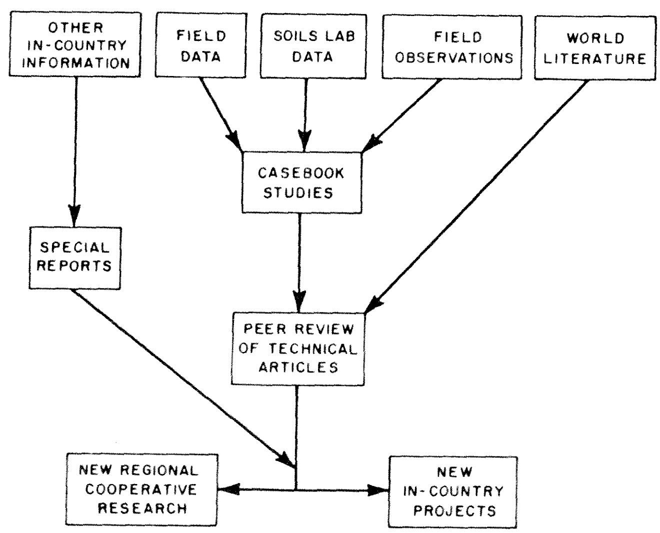
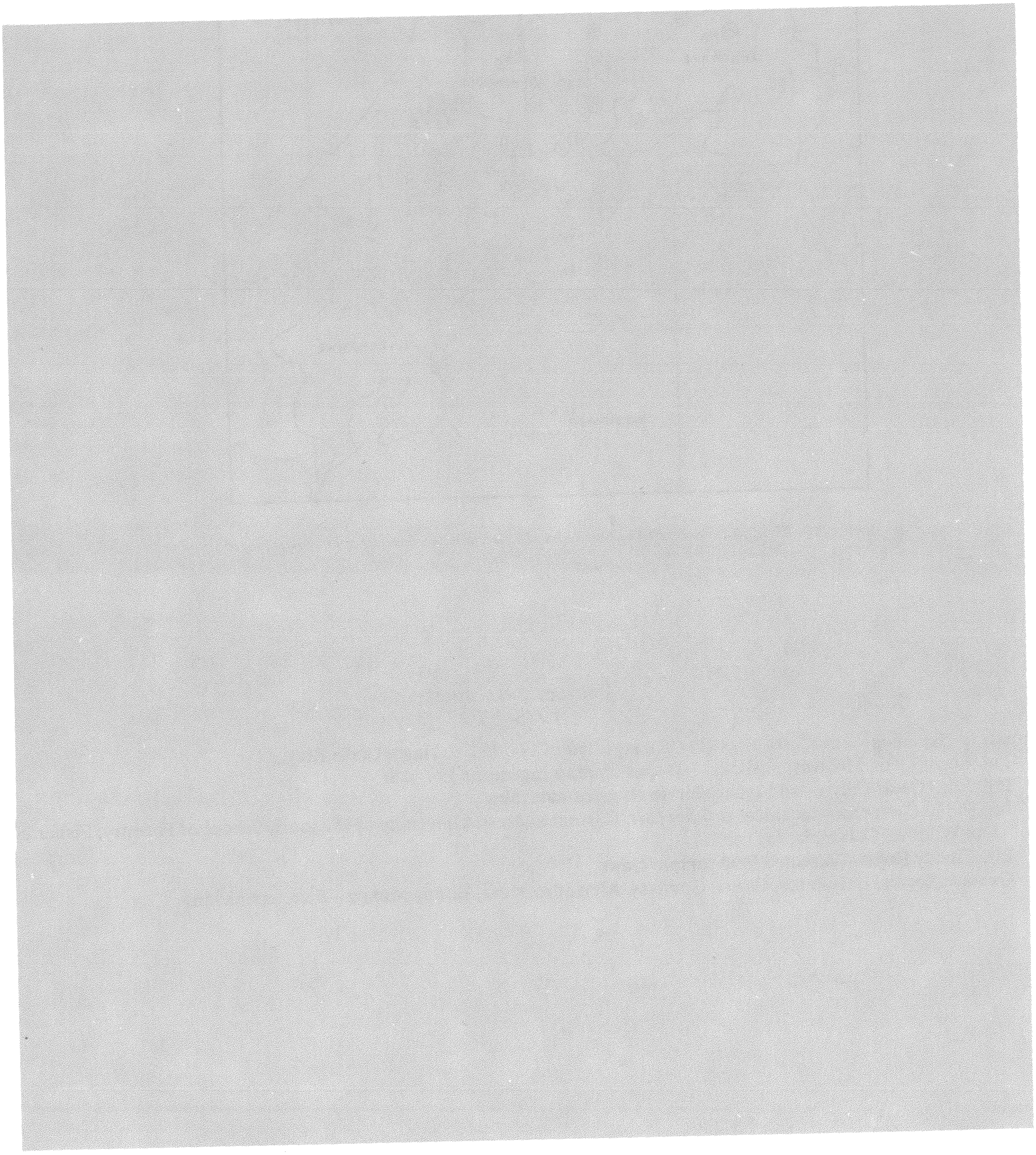


Figure 1.5—*Synthesis and integration of information collected in the Caribbean pine project.*

Chapter 2



2. COSTA RICA

by Leon H. Liegel, Pablo Camacho, and Freddy Rojas

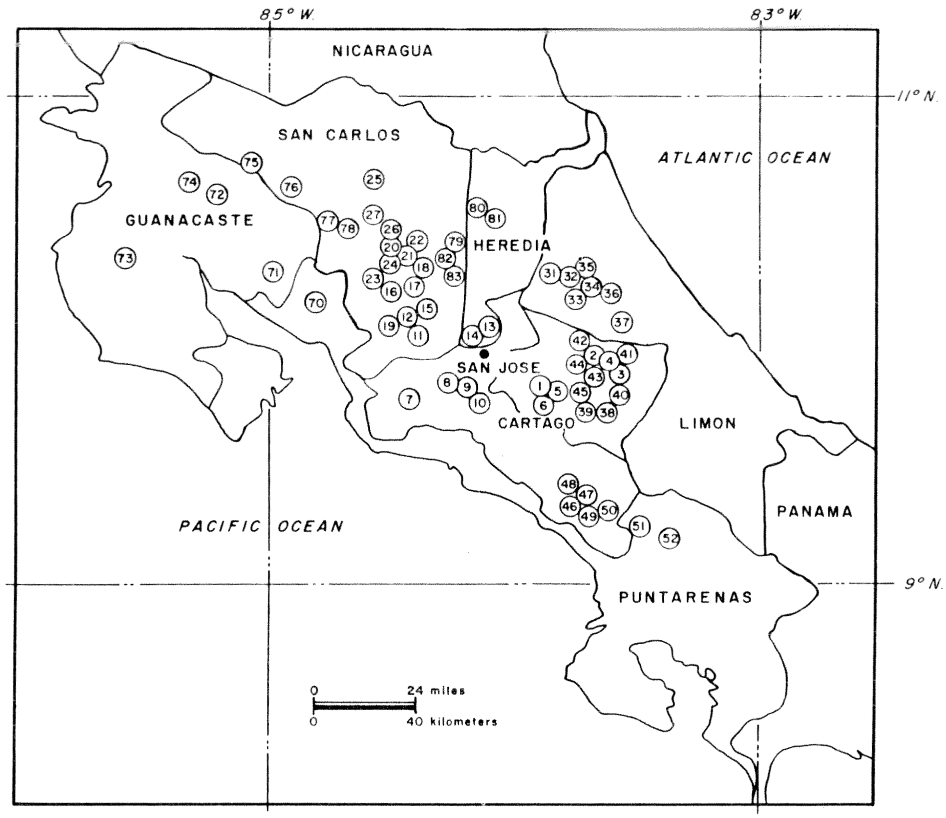


Figure 2.1—*Field plots established in Costa Rica. Circled numbers indicate approximate plot location in particular provinces.*

Project Personnel
1985–87

Instituto Tecnologico de Costa Rica (ITCR). Apartado 159-7050, Cartago, Costa Rica

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Ing. Julio Cesar Calvo—administrador de recursos naturales

Ing. Pablo Camacho—technical counterpart. Current address: University of Missouri, School of Forestry, Fisheries and Wildlife, Columbia, MO 65211.

Ing. Freddy Rojas— directed field sample crews

Gustavo Torres, Luis Perez, Carlos Gamboa, Alejandro Meza, Ronny Munoz—field technicians

2.1 Local Pine Management History

2.1.1 *Initial Introduction.*—Caribbean pine was introduced to Costa Rica almost 30 years ago along with several other exotic forest tree species. The first plantings were used mainly as ornamentals on land owned by small farmers and industrial concerns. Because of its exceptional growth, Caribbean pine was soon planted for commercial wood production.

Small experimental plantings of Caribbean pine were established in Turrialba in 1960. During the first 2 to 6 years, height growth of dominant trees averaged over 2.5 meters (8 feet) per year. Apparently, the only impediments to growth throughout the country are drainage and associated factors such as water table height and depth of soil available for root development. Seed sources for early and subsequent plantings were Guatemala, Honduras, and Mt. Pine Ridge, Belize.

2.1.2 *Silvicultural Practices.*—Outplant density is generally 2.5 by 2.5 meters (8 by 8 feet), or 1,600 trees per hectare (680 trees per acre). In the first year, four weedings are needed on wetter sites of the Atlantic side and three weedings on drier sites of the Pacific side. During the second year, weedings are reduced to two and discontinued thereafter unless trees are growing very poorly or sites are extremely wet all year long.

Thinning is generally precommercial and is done during the fourth or fifth year after planting. Forty to 50 percent of the trees are removed. The second and last thinning is done at 10 years; thinned material is used for posts and poles. For the final cut, 200 crop trees per hectare (85 trees per acre) are left to produce sawtimber at 15 years on good sites and at 20 years on poorer sites.

2.1.3 *General Management Practices and Concerns.*—By 1976, there were 25 plantations of Caribbean pine around Turrialba, varying from 5 to 8 years of age. Most were established by members of the Agricultural Diversification Project in the Canton of Turrialba. Total area planted was about 117 hectares (287 acres). Thinning was not common in these and other, older, plantings.

The first commercial Caribbean pine plantings were made by Celulosa de Turrialba, S. A. in 1977–78. A total of 600 hectares (1,470 acres) was planted to provide pulp material for tissue paper production. By 1985, about 3,000 hectares (7,350 acres) had been established throughout the country in all seven provinces (fig. 2.2).

Nursery practices are labor intensive, using plastic bag containers for seedling production (fig. 2.3). Except for research plantings, primary seed sources now used are those from Honduras.

Generally, growth and performance of Caribbean pine are excellent, but both insects and diseases have destroyed some plantings. Although other species have been introduced successfully in Costa Rica, Caribbean pine has many desirable wood quality traits for producing specific pulpwood and sawn wood products. Thus, Caribbean pine is now one of several forest species used for reforesting both upland and lowland environments. For large-scale commercial reforestation efforts, the most important management concern is predicting, with certainty, growth and yield for the diverse soil and climatic regions in the country.

2.2 Local Environment

2.2.1 *Climate.*—Costa Rica's climate is quite moderate because the country is located in the equatorial zone. In most places, differences between the warmest and coldest months are only about 5 °C (9 °F). Temperatures range from 7 to 35 °C (44 to 95 °F) in the warmest and from 0 to 10 °C (32 to 50 °F) in the coldest months. The Pacific side is considerably warmer and drier than the Atlantic side, having 1,500 to 3,000 millimeters (59 to 118 inches) of rainfall annually versus 3,000 to 6,000 millime-

Figure 2.2—*Small upland plantings of Caribbean pine in Costa Rica. Plantations are usually dispersed among pasture and other croplands.*

Figure 2.3—*Most Caribbean pine plantings in Costa Rica are established with potted stock. Soil preparation, bag filling, seeding, and tending care are all labor-intensive operations that employ local people.*

Figure 2.4—*On steep, overgrazed slopes, Caribbean pine stands protect the soil from erosion. Plantations also modify degraded sites so that native species are more easily established by natural succession.*

ters (118 to 236 inches), because of a central mountain spine that extends the entire length of the country.

2.2.2 *Geology.*—Past and more recent volcanic activity has helped shape Costa Rica's topography. The oldest formations are mesozoic volcanic and sedimentary rocks in the western part of the country, especially on the Nicoya Peninsula. They include old lava flows, tuffs, and some marine sedimentary rocks. Next are the tertiary and cretaceous plutonic rocks comprised of diorite, granodiorite, and granite. These rocks are limited to the Nicoya Peninsula and the eastern edge of the Cordillera de Talamanca. Finally, the most recent sedimentary and volcanic materials are of quarternary age. Large portions of the country covered by these materials are in the eastern coastal lowlands next to the Caribbean; the Central Valley, including San Jose; and the Guanacaste area bordering Nicaragua.

2.2.3 *Soils and Topography.*—Soils in Costa Rica fall into four major groups. The first group includes soils on flat relief along coastal areas and in valleys between major mountain ranges. Most of these soils are moderately to well drained and include Inceptisols, Entisols, and Vertisols (see appendix A). Soils in the second group are on undulating relief and were generally formed from volcanic ash deposited on older materials; the predominant soil orders are Inceptisols and Ultisols. Soils in the third group exist on undulating to hilly relief; the orders are Inceptisols and Alfisols. The fourth group of soils is on steeply dissected and mountainous relief (fig. 2.4). They were derived from shallow residual materials or volcanic ash deposited over residual materials; the soil orders are Inceptisols, Ultisols, Entisols, and Andisols.

Caribbean pine has been planted on most major geological formations of the four soil groups, on either the wetter Atlantic or drier Pacific side of the country (fig. 2.1). Most soils, except those of coastal areas, exist across all three life zones where sample plots were established (table 2.1). Although growth is adequate on infertile sandy coastal sands or on granitic uplands, best growth occurs on deep, wet, and well-drained upland soils.

2.3 Growth and Volume Data

2.3.1 *Growth Model Approach.*—Height and diameter data collected for individual plot trees 3 to 17 years of age (section 1.3) were converted to per-hectare outside-bark volume and basal area. Mathematical equations were then developed to predict per-hectare volumes using three independent variables:

- plantation age,
- average height of tallest trees at age 15 (site index), and
- number of trees per hectare surviving at age of measurement.

The plot data were first grouped by the three life zones studied (table 2.1), and prediction equations were developed for each zone. Appropriate statistical tests showed no differences in predicted volumes and basal areas by life zone. Therefore, growth data from all 58 plots were used to develop predicted volume and basal area curves for planting densities of 1,300, 2,100, and 3,200 trees per hectare (531, 857, and 1,306 trees per acre).

2.3.2 *Stand Volumes.*—At low density of 1,300 trees per hectare (531 trees per acre), predicted total outside-

Table 2.1—*Regions and plots sampled for the Caribbean pine project in Costa Rica, 1985–87*

Life zone	Age class (years)*			
	3–6	7–10	11–14	≥15
	---- Number of plots----			
Tropical wet	6	3	1	...
Tropical rain	12	5	5	1
Premontane rain	7	5	11	2

*Total of 58 plots.

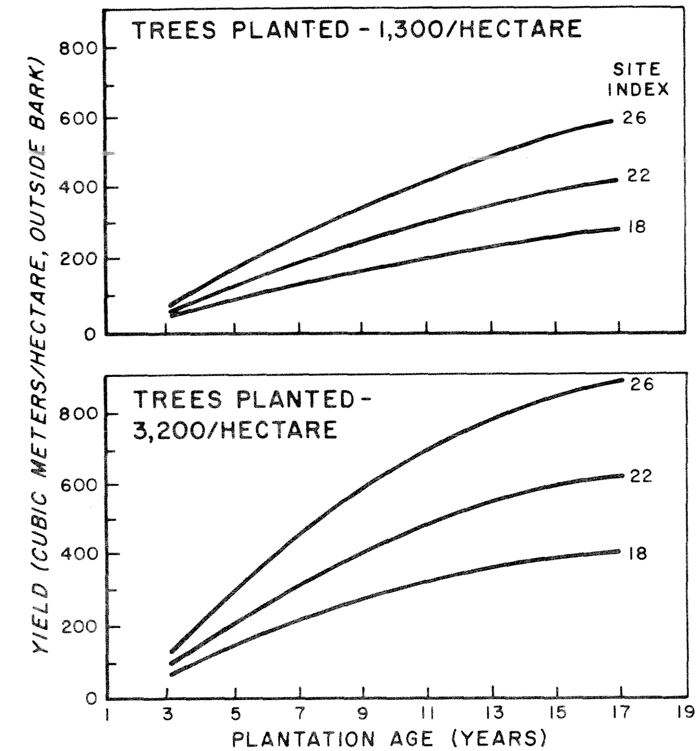


Figure 2.5—*Predicted total outside-bark yield of Caribbean pine plantings in Costa Rica for different plantation ages, site indices, and two outplant densities.*

bark yield on a good site (site index 26) by age 17 is 550 cubic meters (7,924 cubic feet) (fig. 2.5). For the same age on the poorest sites (site index 18), predicted yield is considerably lower, 250 cubic meters per hectare (3,602 cubic feet per acre).

At a high planting density of 3,200 trees per hectare (1,306 trees per acre), predicted yield on a good site (site index 26) is greater at age 17, almost 900 cubic meters per hectare (12,967 cubic feet per acre). However, at high densities, wood volume and basal area are distributed over many small stems. For sawlog production, forest managers prefer that volumes be concentrated on fewer good-quality, high-value stems (section 1.3.3).

2.3.3 *Other Countries.*—Yields in Costa Rica were compared with those of the other countries studied in the Caribbean pine project using three specific criteria:

- a rotation age of 15 years,
- total number of trees planted at 1,300 per hectare (531 per acre), and
- comparisons limited to "best" sites only.

The results are given in table 2.2. Predicted outside-bark yield in Costa Rica was superior to the yields in the other four countries.

For comparative purposes, overbark yields of loblolly pine *(Pinus taeda)* in the Southern United States range from 13 to 16 cubic meters per hectare per year (187 to 230 cubic feet per acre per year). This comparison assumes average commercial planting sites, an initial outplant density of 1,525 trees per hectare (622 trees per acre), and a 25- to 35-year rotation with no thinning.

2.4 Stand Conditions

2.4.1 *Tree Form.*—Most trees in all 58 measurement plots had crooked and leaning stems (fig.2.6). Forking on the plots ranged from 3 to 53 percent, with 23 plots having greater than 20-percent forked trees. Foxtailing on the plots ranged from 8 to 65 percent, with 16 plots having greater than 40-percent foxtail trees (see front cover). These foxtail percentages are higher than those for Puerto Rico, Trinidad, and Jamaica but are similar to the high percentages for Venezuela.

Overall poor tree form is not unusual for Caribbean countries where past planting densities were high, thinnings were not done, and unimproved seeds were used. Converting to genetically superior seeds from known, better formed parents and planting trees at lower densities should improve tree form considerably and also improve the value of harvested logs.

2.4.2 *Cone and Seed Production.*—Cone production on individual trees was poor. Almost half of all plots had no cones, and the other half averaged considerably less than 50 mature or immature cones per tree. Thirty plots showed no sign of past or more recent flowering, 10 plots had active flowering at time of assessment, and the rest showed signs of recent flowering.

Poor cone and flower production (section 1.1.4) is a common characteristic of dense unthinned stands. As long as local reforestation efforts remain limited, seeds can be bought from reputable international seed suppliers. To determine whether seeds can be produced locally

Table 2.2— *Comparison of outside-bark yield of Caribbean pine in Costa Rica with that of other countries for rotation age 15 years and "best" sites only*[*]

Country	Site index	Total yield	Mean annual increment
	m	m^3 */ha*	m^3 */ha/yr*
Well-drained sites			
Costa Rica	26 (85)[†]	550 (7,924)[‡]	35 (504)[§]
Jamaica	24 (79)	400 (5,763)	27 (389)
Puerto Rico	26 (85)	485 (6,988)	32 (461)
Trinidad	22 (72)	360 (5,187)	24 (346)
Moist sites			
Venezuela	21 (69)	475 (6,844)	32 (461)

[*] Trinidad trees planted = 1,330 per hectare (543 per acre); all other countries = 1,300 per hectare (530 per acre).
[†] (ft).
[‡] (ft^3/acre).
[§] (ft^3/acre/yr).

Figure 2.6—*Crooked and leaning stems were common in all measurement plots. Poor form can be reduced in future plantings by using locally collected seeds from superior formed parents and by controlling grazing in young stands that are easily damaged by cattle and other animals.*

via seed stands or seed orchards, country-wide phenological studies spanning several years are needed.

2.4.3 *Damage and Other Conditions.*—Insects or pathogen damage existed in 8 plots and fire damage in 12 plots; in the latter, exuding resin or other visible injury was confined to 6 plots. Because Costa Rica is outside the hurricane belt, wind damage was minimal and limited to plantings on exposed ridge tops. Only nine plots had more than 15-percent wind damage. The most common damage was from careless cutting, vandalism, and uncontrolled grazing. Litter thickness on the forest floor was usually deeper than 50 millimeters (2 inches). Litter composition was both decaying pine needles and hardwood leaves, except where fires had occurred.

Stand conditions in Costa Rica were generally similar to those in the other Caribbean countries. Native shrubs and trees quickly revegetate planted sites and outcompete the pines unless repetitive weedings or fires reduce their growth. Where pine plantings are small, the edge where pine and native forest meet supplies abundant food and cover for native wildlife.

2.5 Soils and Landscape

2.5.1 *Field Observations.*—In all three life zones, plot soils were usually more than 100 centimeters (39 inches) deep, even though they were often on steep hillsides (fig. 2.7). Soil structure was well defined and was predominantly blocky or subangular blocky. In most plots, several indicators showed good soil drainage. Soils in over half the plots felt gritty, and about one-third of the plots had stones in some or all parts of the sampled depth. Roots were distinct and generally found midway or deeper to 100 centimeters (39 inches) or to where parent rock existed. Earthworms were seen in soil samples from the tropical rain and premontane rain but not in the tropical wet life zones.

2.5.2 *Laboratory Analyses.*—Based on percentages of sand/silt/clay, the four major soil texture classes were silt, silt loam, loam, and clay. Classes were distributed across, rather than limited to, any specific life zone. Surface and subsurface textures were often dissimilar, a situation that did not exist in the other countries studied.

The two most common soil fertility limitations, according to crop criteria (section 1.4.2), were high soil acidity plus low potassium and phosphorus at some sites. According to minimum forestry fertility standards for pines, only phosphorus levels were low. Ranges in chemical values for surface horizons were:

Life zone	pH	Al saturation	Ca	Mg	K	P
		pct	-----	meq/100 cm^3	-----	ppm
Tropical wet	4.9–6.5	6	0.5–22.4	0.1–6.0	0.04–0.82	1–32
Tropical rain	4.5–6.2	16	0.4–15.6	0.2–3.6	0.05–1.90	2–9
Premontaine rain	4.6–6.6	18	0.4–14.0	0.1–3.8	0.06–0.78	1–117

Chemical values for subsurface horizons were not consistently lower or higher than those for surface horizons. Similarity in the physical and chemical properties of soils across all plots studied probably contributed to the lack of significant growth differences of Caribbean pine among the three life zones studied. Life zones alone were not effective for modeling the productivity of Car-

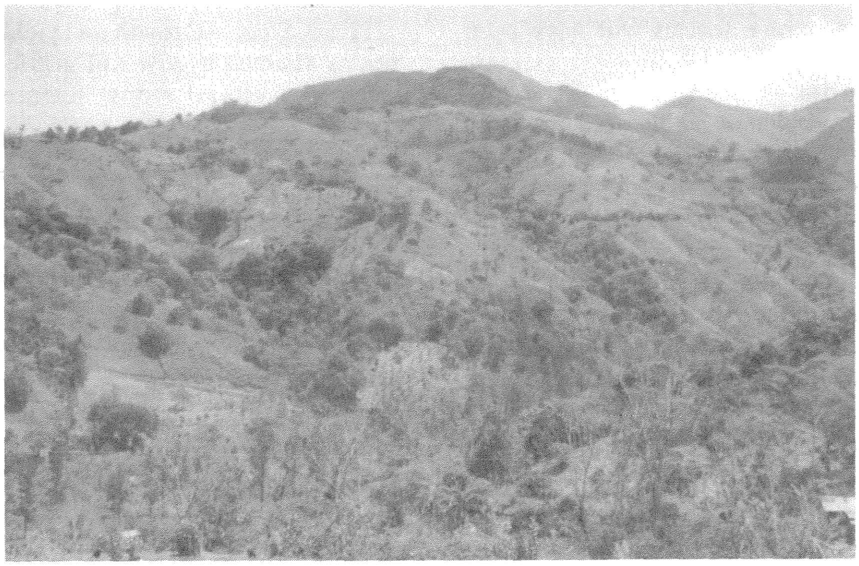


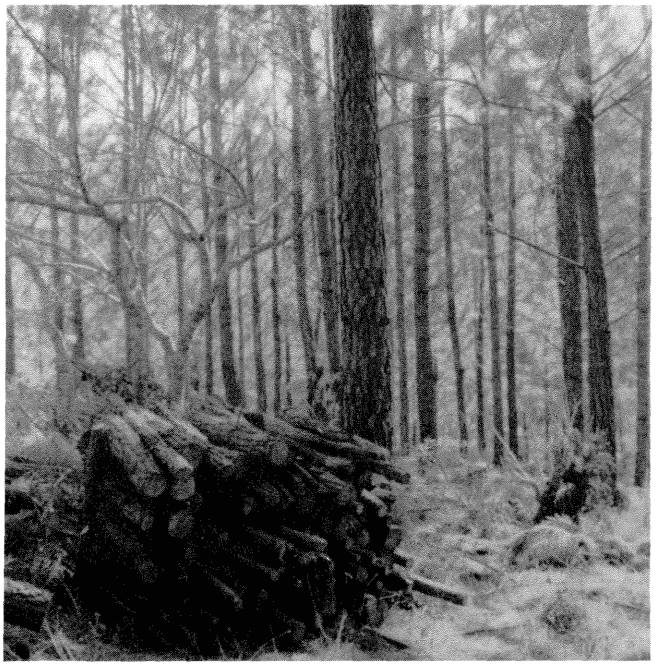
Figure 2.7—*Steep slope landscape typical of lands commonly planted to Caribbean pine in Costa Rica. Trees grow well where soil fertility is too low and soil conservation practices too costly for most agricultural crops.*

ibbean pine in Costa Rica, based on the limited data collected in this project.

2.6 Forest Management Implications

2.6.1 *Growth Data.*—Data on stand growth and yield from small and industrial plantations are very impressive. Even on steep, easily eroded slopes, Caribbean pine plantings produce various wood products (fig. 2.8) at rates greater than those in many tropical countries. Growth rates are two and a half to three times greater than those measured for commercial pine timber producing areas of the Southern United States (section 2.3.3). Even if outside-bark yields are reduced by 25 percent to report volume on an underbark basis (section 1.3.3), resulting underbark yields in Costa Rica are still twice those of the southern pines.

Using wider spacings in upland plantings should improve wood quality for sawn wood and pole products; also, landowners should increase their financial returns because planting, tending, and harvesting costs are reduced when fewer trees are planted per hectare. Concentrating high yield on land not needed for agricultural food crops should help reduce an expected wood short-



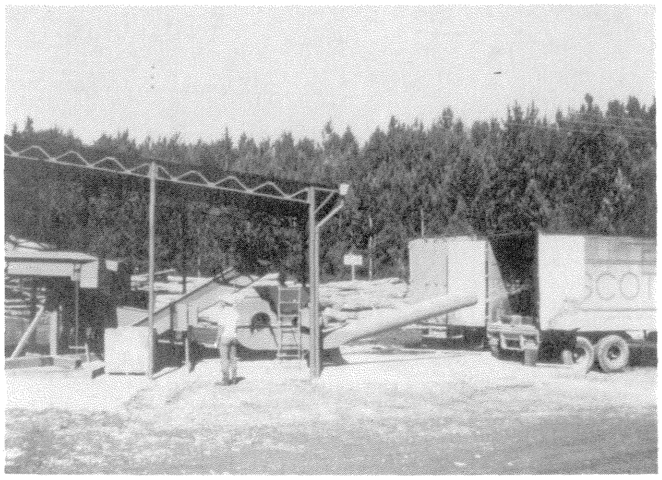


Figure 2.8—*Caribbean pine plantings produce various wood products. (left) At the family level, small Caribbean pine plantings provide firewood, posts, and sawn wood products. (right) Large commercial pine plantations produce long-fiber raw materials that help make cardboard, tissue paper, and other paper products.*

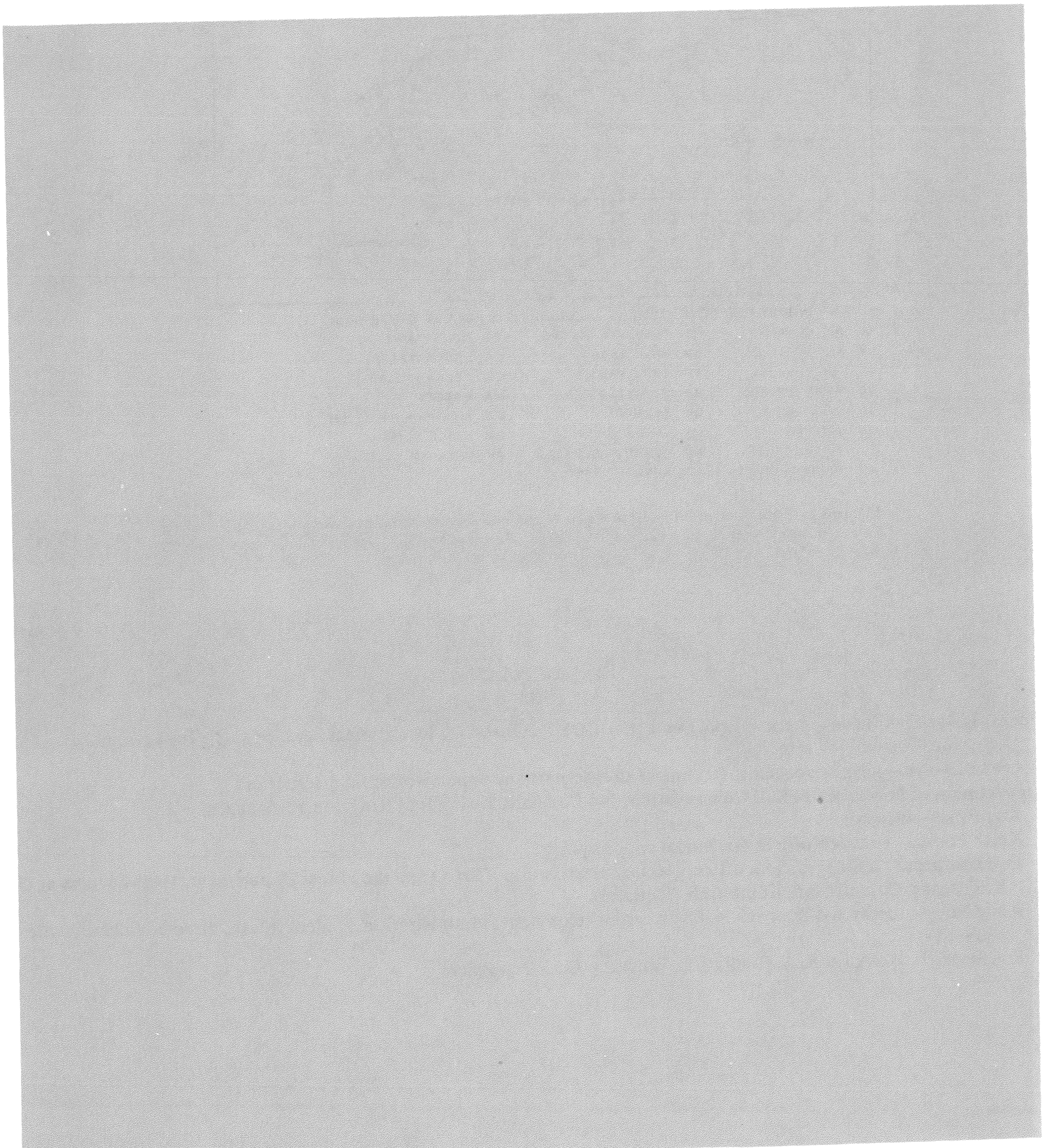
age in 1995, when local native forests will have been completely logged.

2.6.2 *Stand Conditions.*—Localized problems with disease and insects can probably be reduced by using stricter sanitation practices before, during, and after harvesting. Older plantings established at close spacings on moist to wet sites now have few, if any, cones. As long as local reforestation efforts are limited, sufficient high-quality seeds can be bought from international seed vendors. Timber losses from vandalism or fires will probably remain significant management problems if plantings are kept small and dispersed with other farmland uses. Grazing can be used to reduce understory competition in plantations, but the number of animals per unit area of land must be strictly controlled to prevent damage to tree stems from overgrazing. Damaged trunks are entry points for disease and insect pathogens that can spread to adjacent healthy tree. Apparently, understory flora and fauna are as diverse within unburned pine plantations as they are within native secondary forests.

2.6.3 *Soils.*—Growth and yield of Caribbean pine are not as affected by low soil nutrients and low pH as are many agricultural crops. Textural differences between surface and subsurface horizons exist in all three life zones; the causal agent is recent geological imputs of volcanic ash. The superior growth of Caribbean pine in Costa Rica, compared to rates observed in other Caribbean countries, is probably attributable to increased soil fertility that results from these ash inputs.

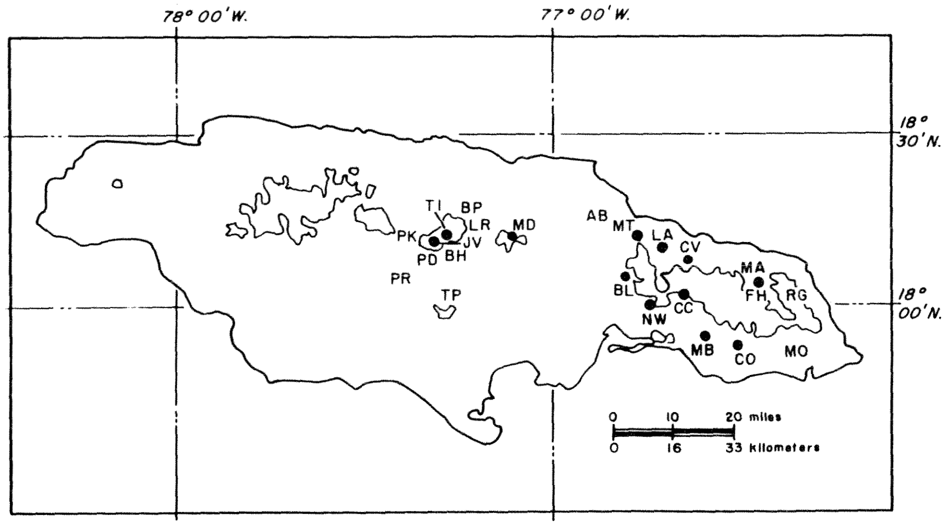
2.6.4 *New Research.*—Future reforestation efforts should include identification of the best seed sources for areas now being planted commercially. Such seed sources should incorporate greater outplant survival, fast growth to overtop weed competition on moist sites, less foxtailing, and less juvenile wood and higher wood density for specified rotation lengths and desired wood products. Bare-root nursery stock might be suitable and cheaper than the potted stock now used, particularly in drier, more level terrain. Lastly, countrywide studies of flowering and cone production, spanning a period of 3 to 5 years, are needed to determine whether local seed orchards are possible.

Chapter 3



3. JAMAICA

by Leon H. Liegel, Owen Evelyn, and Keith Porter



FOREST INDUSTRIES DEVELOPMENT CORPORATION FOREST DISTRICTS:

RG	RIO GRANDE	PD	PENNANTS DOUCES	MT	MOUNT AIRY (4)
NW	NEWCASTLE (2)	BH	BULL HEAD	LA	LANCASTER (1)
CC	CINCHONA (2)	TP	TEAK PEN	CV	CEDAR VALLEY (1)
MB	MAVIS BANK (19)	BP	BARRETTS PEN	MA	MABESS
CO	COLEY (2)	BL	BELMORE (1)	FH	FRIENDSHIP HALL (3)
MO	MORANT	LR	LITTLE RIVER	PR	PEACE RIVER
TI	TINGLEYS (2)	MD	MOUNT DIABLO (2)	PK	PECKHAM
JV	JOHNS VALE (2)	AB	ANNOTTO BAY		

Figure 3.1—*Field plots established in Jamaica. Numbers in parentheses indicate the number of plots within particular Forest Industries Development Corporation (FIDCO) forest management districts.*

Project Personnel 1983–87

Forest Industries Development Corporation (FIDCO). PO Box 631, Twickenham Park, Spanish Town, Jamaica
- Guy Symes—managing director
- Owen Evelyn—logging specialist (technical counterpart and supervisor of field activities)

Department of Forestry and Soil Conservation. 144 Constant Spring Rd., Kingston 10, Jamaica
- Roy Jones—director
- Keith Porter—research officer (technical counterpart)
- D. Thompson—senior research officer (technical advisor to FIDCO and the Forest Department, 1980–85, now at U. K. Forestry Commission, Edinburgh, Scotland)
- Andy Roby—research officer (U. K. Overseas Development Administration, student intern; directed field activities, 1983–84)
- P. Allman, L. Blackwood, A. Findlay, E. Walcott—field technicians

Figure 3.2—*An upland 15-year-old plantation of Caribbean pine from the Mt. Diablo area on limestone soils. A total of 8,000 hectares (19,600 acres) have now been planted in Jamaica.*

3.1 Local Pine Management History

3.1.1 *Species Introductions.*—The first species of the genus *Pinus* were introduced in Jamaica in the late 19th century. These first botanical plantings were established in government botanical gardens at Cinchoma and on private lands. The initial introductions included *P. excelsa, P. muricata, P. palustris,*and *P. patula.*

Honduras, or Caribbean, pine was introduced in 1945 and in 1950–51. The first small plantings failed, largely because of poor nursery practices and a lack of mycorrhizal fungi. Additional plantings established in 1953–54 by H. S. Dears, then acting conservator of forests, were much more successful. Height growth in plots in the Blue Mountains surpassed 1.2 meters (4.5 feet) per year, and the form was excellent. The first commercial planting of Caribbean pine, 122 hectares (300 acres), was established in 1959. Yearly planting increased to a maximum of 942 hectares (2,308 acres) in 1982–83 (fig. 3.2). Early introductions used seeds primarily from Mt. Pine Ridge, Belize; since the mid-1970's, most seeds have come from Honduras.

3.1.2 *General Management Practices and Concerns.*—Potted seedlings are produced in polyethylene (plastic) bags. The pot mixture must provide adequate nutrition, moisture, support, and mycorrhizal fungi inoculum; the beneficial mycorrhizal fungi grow on seedling roots and help supply water and nutrients. Planting density was originally 2.4 by 2.4 meters (8 by 8 feet) or about 1,670 trees per hectare (682 trees per acre). At this spacing, thinnings were needed between 6 and 8 years after planting to remove small stems, allowing the remaining trees sufficient growing space to produce merchantable sawtimber. Most commercial plantings are located on steep uplands where nursery, planting, road building, and logging costs are very high. Thinning of small-size materials having little or no commercial value was eliminated in the late 1970's. Spacing is now 2.7 by 3.0 meters (9 by 10 feet) or greater. The expected rotation age for sawtimber is 18 to 20 years.

At wide spacings, nursery stock (fig. 3.3) must be vigorous and healthy to outgrow competing vegetation. Because the best upland planting areas are those with >2,000 millimeters (≥80 inches) of rainfall, weed con-

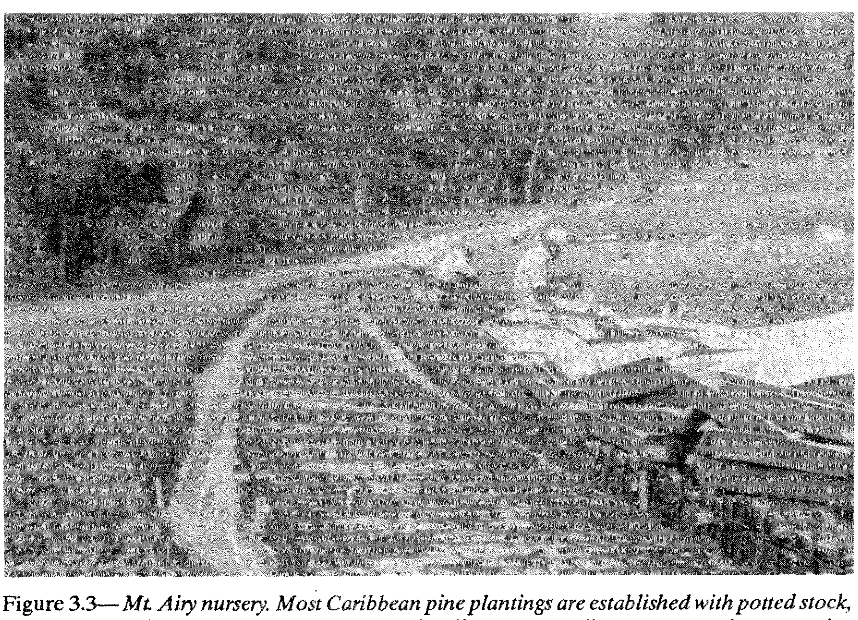


Figure 3.3—*Mt. Airy nursery. Most Caribbean pine plantings are established with potted stock, using high-clay-content alluvial soil. For expanding programs, incorporating lighter textured pot medium materials will improve seedling quality.*

Table 3.1—*Major soils and geology of plots sampled for the Caribbean pine project in Jamaica, 1983–87*

Major soil series or soil type	Geology	Age class (years)*			
		8–12	13–16	17–20	≥20
		---- Number of plots ----			
Halls Delight	Calcareous shales	3	2	2	2
Valda	Newcastle porphyry or volcanic extrusives	2	2	2	2
Cuffy Gully	Conglomerates	2	2	2	2
Several series	Metamorphics and shales	2	2	3	2
Limestone	Red/yellow limestones	1	2	2	2

*Total of 41 plots.

trol is time consuming and expensive. Bamboo eradication is also needed in some very wet areas.

Strict protection measures are needed throughout the management cycle. In the nursery, control is needed for pine tip moth and red spider mites. In the field, sanitation measures are needed to keep logging debris to a minimum, thus reducing bark beetle attacks on adjacent stands.

Nutritional studies have been few and limited to increasing the vigor of nursery stock. The only exception is yellowing of foliage and reduced growth in 6- to 10-year-old plantations on soils that produce bauxite ore for aluminum processing. Trees produced from seed sources in the Bahama Islands that grow naturally on high-calcium marl soils do not generally exhibit yellow foliage symptoms or reduced growth when planted on limestone soils.

Today, harvesting pine plantations means a continual flow of posts, poles, and sawtimber to local tradesmen. Extracting and harvesting techniques are no longer on the purely experimental basis that existed in the late 1970's. Because of limited foreign exchange, a high local demand for pine wood products is expected in the future.

3.2 Local Environment

3.2.1 *Climate and Topography.*—Because of very irregular mountainous topography and prevailing northeast trade winds, Jamaica has a wide range of climatic conditions. Rainfall peaks in May–June and September–October, but its distribution is quite erratic. Lowland coastal areas receive 1,000 to 1,500 millimeters (40 to 60 inches) annually, whereas upland areas receive 2,000 to 5,000 millimeters (80 to 200 inches) or more. Frost does not occur. Maximum temperatures along the coast range from 25 to 32 °C (77 to 89 °F) and in the upper plateaus and mountains from 15 to 20 °C (59 to 68 °F).

3.2.2 *Geology.*—Although about 64 percent of Jamaica has a limestone geological base, much of this land is too dry for commercial forests. Pine plantings for sawtimber and other wood products are concentrated in the central and eastern uplands, including areas of the Blue Mountain range. Based on existing geology and soil maps, five major geological/soil regions were studied in the Caribbean pine project (table 3.1):

- calcareous shales,
- porphyry and volcanic extrusives,
- conglomerates,
- metamorphics and noncalcareous shales, and
- red/yellow limestones.

3.2.3 *Soils.*—Most soils of the uplands are shallow and stony. Soil moisture is generally high throughout the year except in areas lower than 300 meters (1,000 feet). Slopes are steep (fig. 3.4), and erosion is common unless permanent vegetative cover protects the soil surface against the powerful force of raindrop impact.

Because of the steep topography, high rainfall, and wide range in parent materials, upland soils are usually young in development. Inceptisols (see appendix A) are the predominant order for soils derived from calcareous shales, volcanics, conglomerates, and metamorphic rocks. Over limestone rocks, Oxisols and Entisols predominate. Inceptisols and Vertisols are in areas of lower rainfall and gentle relief.

All soils have high clay content; low pH, except the Vertisols; and poor natural drainage. Such soils are not suited for productive long-term agricultural crops, al-

Figure 3.4—*Steep erosive slopes where Caribbean pine stands are commonly established. Long-term tree cover offers better site protection than do agricultural row-crop alternatives. But steep topography poses problems for forestry planting, tending, and harvesting practices.*

though they are often cultivated by small subsistence farmers. Most tree species, particularly Caribbean pine, are very adaptable to these soils. Forestry plantings protect the soil from erosion, provide wildlife cover, and improve downstream water quality. They also afford economic returns when trees are cut and wood products are sold to local markets.

3.3 Growth and Volume Data

3.3.1 *Growth Model Approach.*—Height and diameter data collected for individual plot trees 8 to 25 years of age (section 1.3) were converted to per-hectare outside-bark volume and basal area. Mathematical equations were then developed to predict per-hectare volumes, given three characteristics or parameters:

- plantation age,
- average height of tallest trees at age 15 (site index), and
- number of trees per hectare surviving at age of measurement.

Because availability of data was limited, a regrouping of information into three soil classes was necessary. Prediction equations were then developed for each class. Appropriate statistical tests showed no regional differences in predicted volumes and basal areas. Therefore, growth data from all 41 plots were combined to develop predicted volume and basal area curves for planting densities of 1,300, 2,100, and 3,200 trees per hectare (531, 857, and 1,306 trees per acre).

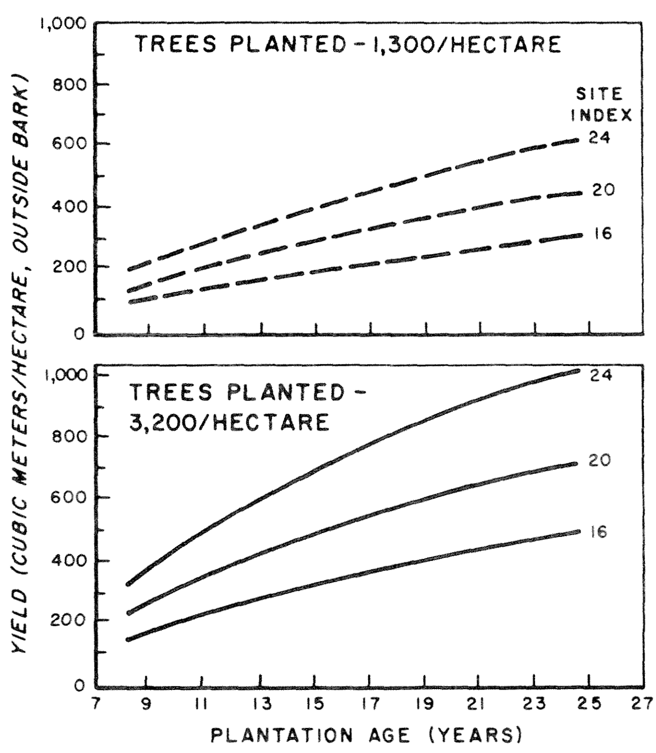


Figure 3.5—*Predicted total outside-bark yield of Caribbean pine plantings in Jamaica for different plantation ages, site indices, and two outplant densities.*

3.3.2 *Stand Volumes.*—At a low density of 1,300 trees per hectare (531 trees per acre), predicted total outside-bark yield on a good site (site index 24) by age 25 is about 600 cubic meters per hectare (8,645 cubic feet per acre) (fig. 3.5). For the same age on the poorest sites (site index 16), predicted yield is considerably lower, about 260 cubic meters per hectare (3,746 cubic feet per acre).

At a high planting density of 3,200 trees per hectare (1,306 trees per acre), predicted yield is greater at age 25, almost 1,000 cubic meters per hectare (about 14,400 cubic feet per acre). However, at high densities, wood volume and basal area are distributed mainly over many small stems. For sawlog production, forest managers prefer that larger volumes be concentrated on fewer but good-quality, high-value stems (section 1.3.3).

3.3.3 *Other Countries.*—Yields in Jamaica were compared with those of the other countries studied in the Caribbean pine project. In doing this, three specific criteria were used:

- a rotation age of 15 years,
- total number of trees planted at 1,300 per hectare (531 per acre), and
- comparisons limited to "best" sites only.

Predicted outside-bark yield in Jamaica was superior to that in Trinidad but less than yields in Costa Rica, Puerto Rico, and Venezuela (table 3.2).

For comparative purposes, overbark yields of loblolly pine *(Pinus taeda)* in the Southern United States range from 13 to 16 cubic meters per hectare per year (187 to 230 cubic feet per acre per year). This comparison assumes average commercial planting sites, an initial outplant density of 1,525 trees per hectare (622 trees per acre), and a 25- to 35-year rotation with no thinning.

Table 3.2— *Comparison of outside-bark yield of Caribbean pine in Jamaica with that of other countries for rotation age 15 years and "best" sites only*[*]

Country	Site index	Total yield	Mean annual increment
	m	m^3ha	m^3ha/yr
Well-drained sites			
Costa Rica	26 (85)†	550 (7,924)‡	35 (504)§
Jamaica	24 (79)	400 (5,763)	27 (389)
Puerto Rico	26 (85)	485 (6,988)	32 (461)
Trinidad	22 (72)	360 (5,187)	24 (346)
Moist sites			
Venezuela	21 (69)	475 (6,844)	32 (461)

[*] Trinidad trees planted = 1,330 per hectare (543 per acre); all other countries = 1,300 per hectare (530 per acre).

† (ft).

‡ (ft^3/acre).

§ (ft^3/acre/yr).

3.4 Stand Conditions

3.4.1 *Tree Form.*—Most trees in all 41 measurement plots had crooked and leaning stems (fig. 3.6). Forking ranged from zero to 26 percent, with five plots having ≥20-percent forked trees. Foxtailing ranged from 5 to 35 percent across all plots; these figures are similar to those for Puerto Rico and most other countries where foxtailing (see front cover) exists on Caribbean pine.

Overall poor tree form is not unusual for Caribbean countries where past planting densities were high, thinnings were not done, and unimproved seeds were used. Converting to genetically superior seeds from known, better formed parents and planting trees at lower densities will improve tree form considerably and result in higher prices for harvested logs.

3.4.2 *Cone and Seed Production.*—Cone production on individual trees was poor. Most plots had considerably less than 50 cones per tree, but three plots had ≥200 cones per tree. Very few plots had immature cones.

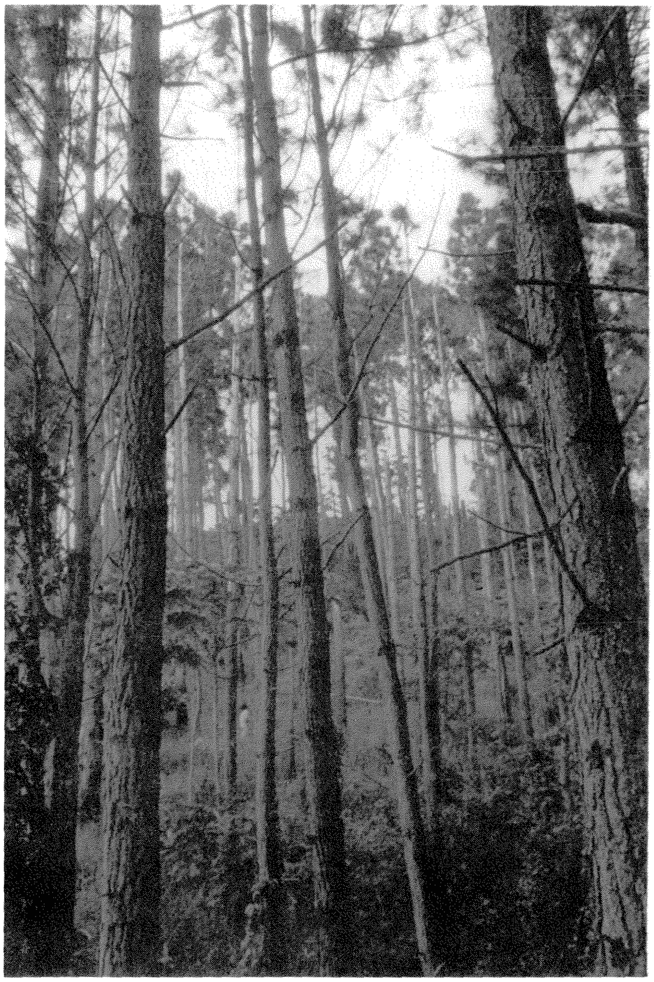


Figure 3.6—*Poor form, including broken-top damage and leaning stems, was common in all measurement plots. However, these defects can be reduced in future plantings by controlling outplant density and by using seeds from superior formed and wind-resistant parent trees.*

Eleven plots had no observable flower production; the rest had a few trees with either existing flowers or evidence of recent flowers.

Poor cone and flower production are a common result of dense overstocked stands (section 1.1.4). This phenomenon also exists in areas receiving high, evenly distributed rainfall throughout the year. Establishing seed orchards on drier sites could produce seeds for local reforestation efforts and for export to other countries, thus earning foreign exchange.

3.4.3 *Damage and Other Conditions.*—Insects or pathogen damage was not observed in any of the measured plots; however, such damage does exist elsewhere in Jamaica. Fire damage was seen in 14 plots, whereas blowdown damage existed in only 6 plots. The most common damage was broken tops, probably caused by strong winds from Hurricane Allan in 1981. The understory of most plots was few to many native shrubs and trees coming in under the pines. Where a shrub understory was absent in 11 plots, fires were the disturbing influence. Litter thickness on the forest floor averaged ≥50 millimeters (≥2 inches). Composition of the litter was both decaying pine needles and native hardwood leaves, except where fires had occurred.

Overall stand conditions in Jamaica are similar to those in other Caribbean islands. Native shrubs and trees quickly revegetate planted sites and will replace the pines unless repetitive weedings or fires keep them back. Where pine plantings are small, the edge where pine and native forest meet supplies abundant food and cover for native wildlife.

3.5 Soils and Landscape

3.5.1 *Field Observations.*—Soils in all but eight plots were deep (fig. 3.7); shallower soils were generally on limestone sites. Several indicators showed that all plots had good drainage. Over half the plots had gritty soil and/or stones within the material sampled. Soil structure was well defined and was predominantly subangular blocky. Roots were distinct and generally found to 100 centimeters (39 inches) or to where parent rock existed. Earthworms were seen in soils from 15 plots, representing all soil regions sampled.

3.5.2 *Laboratory Analyses.*—Based on percentages of sand/silt/clay, the two major soil texture classes were clay/clay loam and loam/loamy clay. At any one site, textures of surface and subsurface samples were similar. The two most common soil fertility limitations, according to crop criteria (section 1.4.2), were high soil acidity for Halls Delight and potassium deficiency for limestone and Valda soils. According to minimum forestry fertility standards for pines, only phosphorus levels were low for soils of several series and for limestone sites. Soils from only two plots showed gleization, an indication of poor internal drainage. Chemical values for subsurface horizons were not consistently lower or higher than those for surface horizons; ranges in values for surface horizons were:

Major series or soil type	pH	Al saturation	Ca	Mg	K	P
		pct	-----	meq/100 cm^3	-----	*ppm*
Halls Delight	4.6–5.6	26–31	1.5–14.6	0.9–9.0	0.15–0.41	3–10
Valda	4.6–6.0	4–16	0.8–19.0	0.6–2.5	0.12–0.32	3–8
Cuffy Gully	5.0–6.1	2–10	1.7–16.4	0.8–7.1	0.06–0.33	4–18
Several soils	4.8–6.4	4–12	0.9–14.4	0.6–7.9	0.05–0.28	1–6
Limestone	5.1–7.0	1–5	3.0–31.3	0.6–6.0	0.05–0.20	1–6

Figure 3.7—*Soils in most plots were deep, >100 centimeters (>39 inches), as in this roadcut, except in limestone areas. Although soil nutrient status by crop standards was low, overall growth and yield of Caribbean pine was quite good across all regions studied.*

Physical and chemical properties of the soils were generally similar for all plots studied. This similarity probably contributed to the lack of significant growth differences of Caribbean pine across all soil regions studied. The predetermined five soil regions studied (section 3.2.2) were not effective in determining productivity classes of Caribbean pine, as based on the limited data collected in this project.

3.6 Forest Management Implications

3.6.1 *Growth Data.*—Data on stand growth and yield from local plantations are impressive. Even on steep, nutrient-poor sites, Caribbean pine plantings are producing wood volumes at rates comparable or superior to those in other tropical countries. For plantings of similar ages and stockings, overall growth rates in Jamaica are one and a half to two times faster than those measured for commercial pine timber producing areas in the Southern United States (section 3.3.3). Even if outside-bark yields are reduced by 25 percent to report volume on an underbark basis (section 1.3.3), resulting underbark yields in Jamaica are still almost 50 percent higher than those of the Southern pines.

Using wider spacings in upland areas will provide products (fig. 3.8) having improved wood quality and also assure higher financial returns because planting, tending, and harvesting costs will be reduced. Where weed competition is severe and chemical control is too expensive, closer initial spacings may be needed to help control understory species; however, thinning and release of crop trees will be needed between ages 5 and 8 years to avoid loss of volume increment on such sites.

3.6.2 *Stand Conditions.*—Localized problems exist with root rot disease and bark beetles. These can be reduced by using stricter sanitation practices during and after harvesting. Older plantings initially established at close spacings on wetter sites now have few cones. Establishing widely spaced seed orchards on drier sites would produce seeds for local planting programs; eventually, commercial export of seeds to other countries could be possible. Unfortunately, as was shown in 1981 and 1988, periodic hurricanes pose a threat to long-term forestry practices. Incorporating wider spacing and using seed sources that produce wind-resistant trees in local plantings will reduce broken top and blow-down losses.

3.6.3 *Soils.*—Growth and yield of Caribbean pine are not as affected by poor soil fertility and low pH as are many agricultural crops. Apparently, soil flora and fauna are as diverse within unburned pine plantations as they are within native secondary forest. On severely eroded and degraded sites, pine plantations may be a means of establishing permanent native forest. This would be achieved by planted pines acting as nurse trees that would modify harsh soil microclimate and nutrient status such that seedlings of native species could become estab-

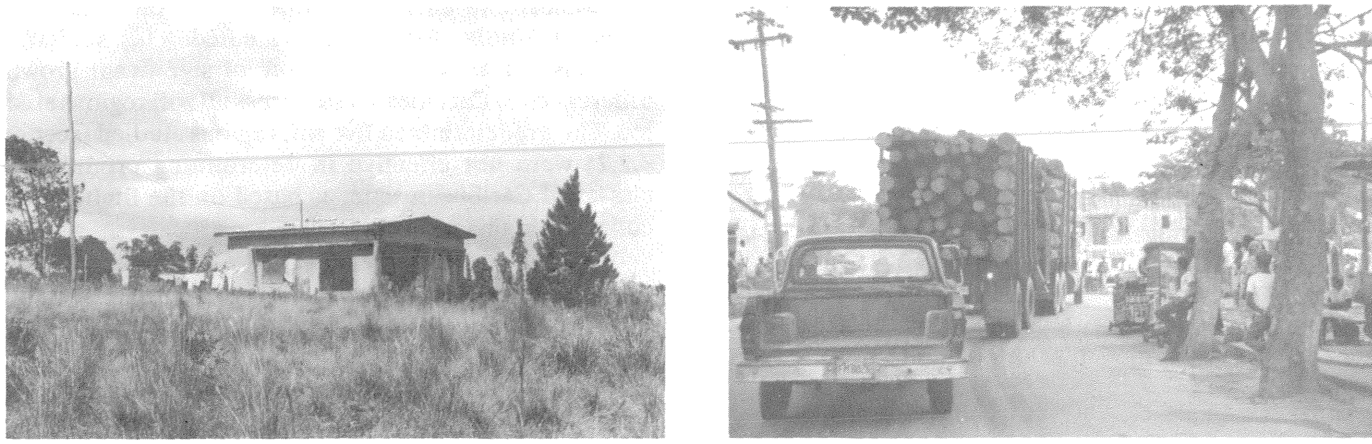


Figure 3.8—*Caribbean pine plantings provide various benefits in addition to producing wood products. (left) At the family-farm level, small Caribbean pine plantings offer shade and protection from drying winds. (right) Obtaining harvestable wood products from older, larger plantations can provide seasonal or permanent jobs for people living in rural and urban areas.*

lished. Soil losses through erosion and downstream siltation of reservoirs can be avoided by proper location, construction, and maintenance of roads. Newer cable harvesting practices have substantially lowered soil erosion and site disturbance common with cable systems used in the late 1970's.

3.6.4 *New Research.*—Older plantings that are being harvested dramatically show the potential of local wood production. However, harvested stands generally represent earlier introduced seed sources that produce trees having poor natural pruning, lower wood density, and slower growth than trees produced from other seed sources now available. Conducting local selections to determine the highest wood density in local stands would provide material for seed orchards produced through vegetative propagation. Gaining membership in the Central America and Mexico Coniferous Resources Cooperative (CAMCORE) would provide access to genetically superior seed and vegetative material that could be incorporated into Jamaica's research and commercial pine planting programs.

Chapter 4

4. PUERTO RICO

by Leon H. Liegel and Zakir Hussain

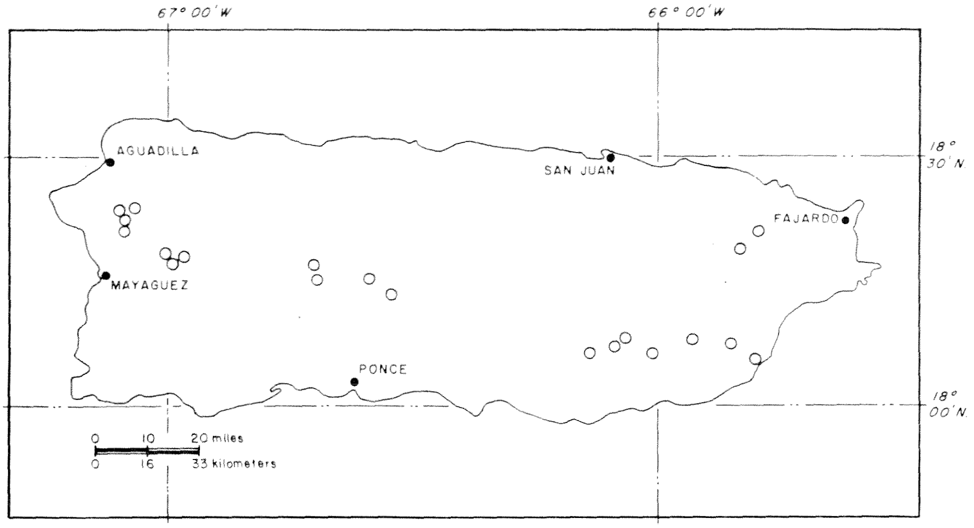


Figure 4.1—*Field plots established in Puerto Rico. Approximate field plot locations are indicated by circles, which sometimes represent more than one plot.*

Project Personnel
1983–87

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4.1 Local Pine Management History

4.1.1 *Initial Introduction.*—Caribbean pine, also known locally as Honduras pine, pino hondureno, or pino caribaea, grows well throughout Puerto Rico (fig. 4.2). The species was added to Island reforestation programs in the mid-1960's after adaptability plantings showed that it outperformed most other pine and hardwood species. Early failure to establish Caribbean and other pine species before the mid-1950's was largely due to lack of native mycorrhizal fungi. Besides protecting soils from erosion, Caribbean pine offered a potential local source of raw material for posts, poles, and sawtimber when planted on land unsuited for crops or other land uses. Through 1970, the seed source was primarily Mt. Pine Ridge, Belize. Thereafter, for small research plantings, seeds for provenance trials were obtained from the Oxford Forestry Institute in Great Britain. For local reforestation programs, seeds were bought from international seed vendors; they were usually collected from native stands in Honduras.

4.1.2 *General Management Practices and Concerns.*—Nursery stock was first produced in plastic bags filled with soil (fig. 4.3). From 1970 to 1978, several kinds of reusable or lightweight container systems and synthetic growth medium formulations were tested to reduce outplant establishment costs. The containers used were polyethylene multipot tubes, Polypot (milk) cartons, Spencer-Lemaire Rootrainers (book planters), and Styroblocks. Pilot bare-root plantings were also successful.

Through the 1970's, reforestation efforts remained small. By 1976, some 70 plantings encompassed only about 128 hectares (314 acres). Most stands were left unmanaged and unthinned; exceptions were small research plantings. Because stands less than 10 years old had high percentages of juvenile wood, suitability for posts and poles was limited.

Figure 4.2—*A small upland planting of Caribbean pine in eastern Puerto Rico, typical of over 1,000 hectares (2,450 acres) now existing on the Island.*

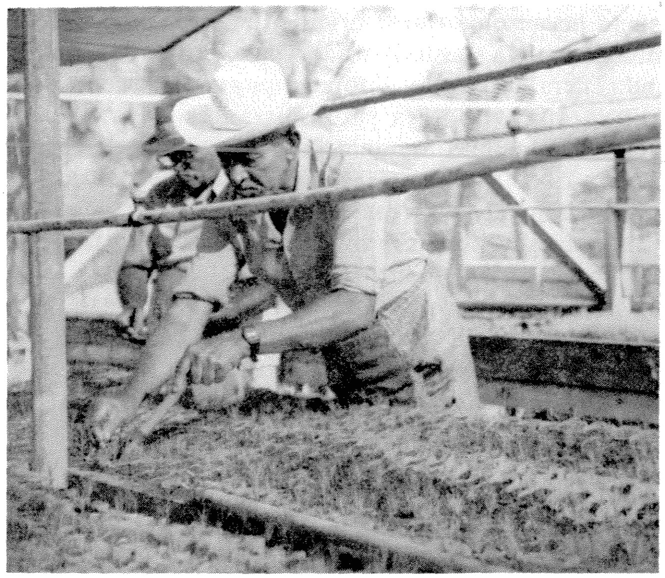


Figure 4.3—*Traditionally, Caribbean pine plantings have been established with potted stock. However, because local labor costs are high, bare-root production systems may be more economical when large reforestation projects are started.*

In 1973, a 10-year program was started to identify specific seed sources most suited to Puerto Rico's diverse lowland and upland soils. Also sought were sources with higher wood density and prolific cone/seed production. Obtaining seeds from local orchards would reduce the cost of imported seeds, which then sold for $100 and now (1989) cost up to $300 or more per kilo (2.2 pounds).

Results from an islandwide inventory in 1975–76 showed that overall growth and yield were quite good in the existing unmanaged stands. About the same time, 13- to 15-year results from four spacing trial sites showed mean annual overbark yields of 30 to 50 cubic meters per hectare (432 to 720 cubic feet per acre); higher specific gravities ($\geq$0.45) were common in these older stands. Except for drier areas where fires were set by vandals, all stands had minimal insect, disease, and windthrow damage. The spacing study also showed that wider spacings of 3.0 by 3.0 meters (10 by 10 feet) in upland environments would reduce nursery, planting, and harvesting costs while providing higher quality, more valuable pole and sawtimber wood products.

4.2 Local Environment

4.2.1 *Climate and Topography.*—About 65 percent of the surface in Puerto Rico is classified as mountains and foothills, with slopes $\geq$45 percent. Below 300 meters (984 feet), a tropical climate prevails, with mean annual temperatures of 24 °C (75 °F) or above. Mountain areas over 300 meters (984 feet) are considered subtropical and have mean annual temperatures lower than 24 °C (75 °F). Frost is absent, and a moderate climate permits an islandwide growing season that lasts all year long. Climatically, semiarid to tropical rain forest conditions exist across the

Island because east-west oriented mountains intercept moist, incoming easterly trade winds. Rainfall extremes and general broken local topography contribute to high soil variability within short distances. Most of the Island's rainfall is orographic in nature. Mountain areas receive 2,000 to over 5,000 millimeters (80 to over 200 inches) annually, whereas drier coastal plains and foothills in the south and southwest receive only 800 to 1,500 millimeters (32 to 60 inches).

4.2.2 *Geology.*—Despite Puerto Rico's small size, geological and soil diversity are great. Much of this diversity was caused by several periods of volcanism followed by submergence and uplifting. Parent material for the lowland and highland sands are:

- granodiorite,
- quartz diorite, or
- residuum of plutonic rocks

Soils in the other three regions were derived from residuum or colluvium of basic volcanic rocks. Although limestone materials cover about 15 percent of the Island, limestone areas were excluded from the study. Shallow depth renders limestone soils unsuitable for forestry.

4.2.3 *Soils.*—Over 160 soil series have been described in Puerto Rico; they represent 9 of the 11 soil orders recognized in the USDA Soil Taxonomy classification system. Inceptisols and Ultisols (see appendix A) are the principal soil orders within the study areas (table 4.1).

Table 4.1—*Regions and plots sampled for the Caribbean pine project in Puerto Rico and their associated soils, 1983–87*

Region	Number of plots	Predominant soil: Series	Predominant soil: Order
Lowland sands (<300 m)	4	Pandura, Teja, Utuado, Lirios	Inceptisols
Highland sands (>300 m)	4	Pandura, Teja, Utuado, Pellejas	Inceptisols
Shallow clays (<300 m)	2	Caguabo, Malaya, Mucara	Inceptisols
Lowland deep clays (<300 m)	8	Consumo, Daguey, Humatas	Ultisols
Highland deep clays (>300 m)	9	Consumo, Daguey, Humatas	Ultisols
Total	27		

Soils in all regions have high amounts (≥70 percent) of clay in both surface and subsurface horizons. Depth of A and B horizons together is usually ≥50 centimeters (≥20 inches). Soil reaction is low, usually pH 4.5 to 5.0 or lower. Despite high clay content, drainage and permeability are generally good to moderate. Slopes are steep (fig. 4.4), and erosion is common unless permanent vegetative cover protects the soil surface against the powerful force of raindrop impact.

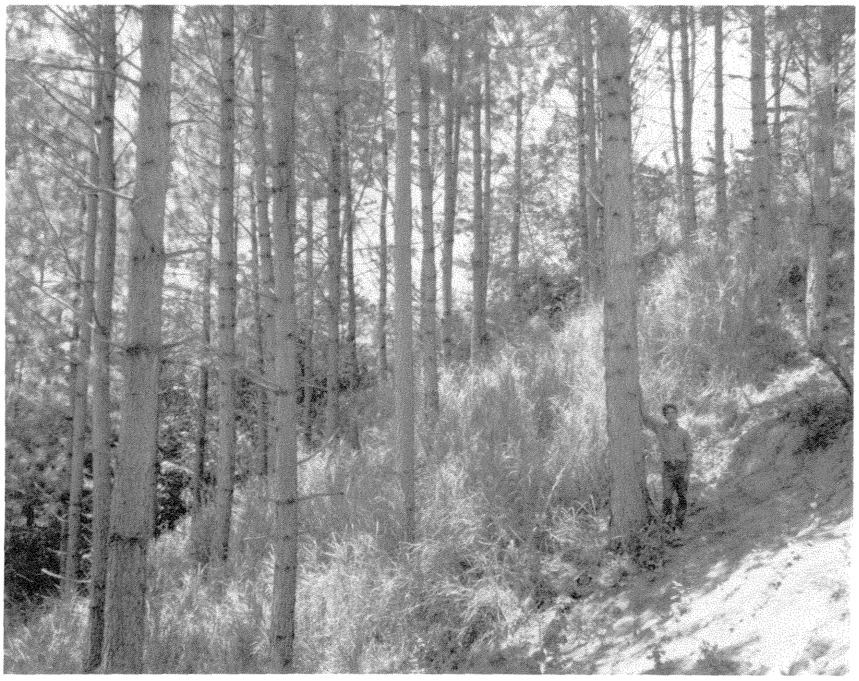


Figure 4.4—*A 12.5-year-old Caribbean pine stand on steep, erosive highland sandy soils. Long-term tree cover offers better site protection than row-crop agricultural land use alternatives. But steep topography poses problems for planting, tending, and harvesting practices.*

4.3 Growth and Volume Data

4.3.1 *Growth Model Approach.*—Height and diameter data collected for individual plot trees 8 to 25 years of age (section 1.3) were converted to per-hectare outside-bark volume and basal area. Mathematical equations were then developed to predict per-hectare volumes, given three characteristics or parameters:

- plantation age,
- average height of tallest trees at age 15 (site index), and
- number of trees per hectare surviving at age of measurement.

Because availability of data was limited, a regrouping of information from five to three soil classes was necessary: sands; deep clays, more than 300 meters (984 feet); and shallow to deep clays, less than 300 meters. Prediction equations were then developed for each class. Appropriate statistical tests showed no significant class differences in predicted volumes and basal areas. Therefore, growth data from all 27 plots were combined to develop predicted volume and basal area curves for planting densities of 1,300, 2,100, and 3,200 trees per hectare (531, 857, and 1,306 trees per acre).

4.3.2 *Stand Volumes.*—At a low density of 1,300 trees per hectare (531 trees per acre), predicted total outside-bark yield on a good site (site index 26) by age 24 is 550 cubic meters per hectare (7,924 cubic feet per acre) (fig. 4.5). For the same age on the poorest sites (site index 18), predicted yield is considerably lower, about 375 cubic meters per hectare (5,403 cubic feet per acre).

At a high planting density of 3,200 trees per hectare (1,306 trees per acre), predicted yield on good sites (site index 26) is greater at age 24, 700 cubic meters per hectare (10,086 cubic feet per acre). This high yield is attainable by age 18 on some sites. However, at high densities, wood volumes and basal area are distributed mainly over many small stems. For sawlog production, forest managers prefer that larger volumes be concentrated on fewer good-quality, high-value stems (section 1.3.3).

4.3.3 *Other Countries.*—Yields in Puerto Rico were compared with those from other countries studied in the Caribbean pine project. In doing this, three specific criteria were used:

- a rotation age of 15 years,
- total number of trees planted at 1,300 per hectare (531 per acre), and
- comparisons limited to "best" sites only.

Results are shown in table 4.2. Predicted outside-bark yield in Puerto Rico was superior to that in Jamaica and Trinidad and equal to that on moist sites in Venezuela. Only predicted yield in Costa Rica surpassed that in Puerto Rico.

For comparative purposes, overbark yields of loblolly pine *(Pinus taeda)* in the Southern United States range from 13 to 16 cubic meters per hectare per year (187 to 230 cubic feet per acre per year). This comparison assumes average commercial planting sites, an initial outplant density of 1,525 trees per hectare (622 trees per acre), and a 25- to 35-year rotation with no thinning.

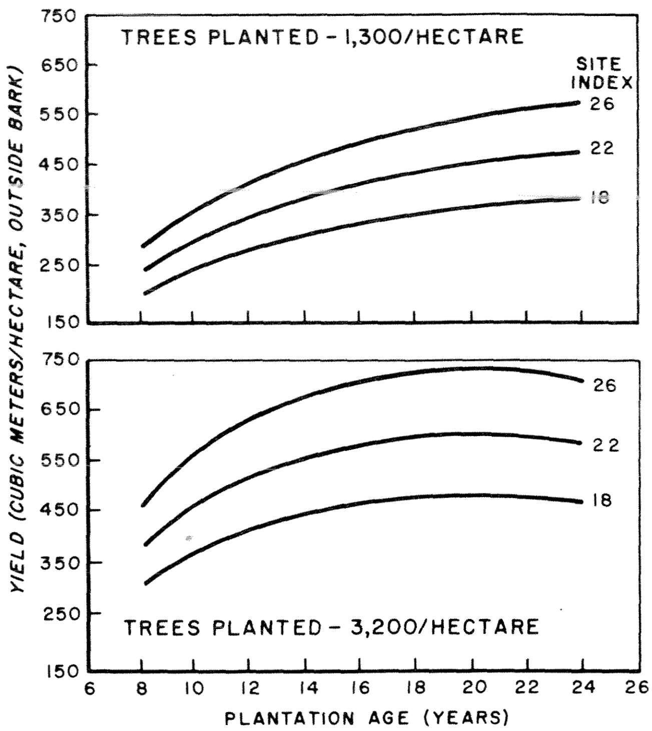


Figure 4.5—*Predicted total outside-bark yield of Caribbean pine plantings in Puerto Rico for different plantation ages, site indices, and two outplant densities.*

Table 4.2—*Comparison of outside-bark-yield of Caribbean pine in Puerto Rico with that of other countries for rotation age 15 years and "best" sites only**

Country	Site index	Total yield	Mean annual increment
	m	m^3 /ha	m^3 /ha/yr
Well-drained sites			
Costa Rica	26 (85)†	550 (7,924)‡	35 (504)§
Jamaica	24 (79)	400 (5,763)	27 (389)
Puerto Rico	26 (85)	485 (6,988)	32 (461)
Trinidad	22 (72)	360 (5,187)	24 (346)
Moist sites			
Venezuela	21 (69)	475 (6,844)	32 (461)

*Trinidad trees planted = 1,330 per hectare (543 per acre); all other countries = 1,300 per hectare (530 per acre).

†(ft).

‡(ft^3/acre).

§(ft^3/acre/yr).

Figure 4.6—*Examples of poor tree form and good cone production on study plots. (left) Poor form, including crooked, forked, and leaning stems, was common in all measurement plots. (right) Good cone crops existed only on trees along the edges of plantings where greater light, nutrients, and moisture were available.*

4.4 Stand Conditions

4.4.1 *Tree Form.*—Most trees in all 27 measurement plots had crooked and leaning stems (fig. 4.6). Forking ranged from 2 to 21 percent, with only one plot exceeding 20-percent forked trees. Foxtailing ranged from 2 to 61 percent, with seven plots having more than 20-percent foxtail trees (see front cover). These foxtail percentages are lower than those for Costa Rica and Venezuela but are comparable to those for Jamaica and Trinidad.

Overall poor tree form is not unusual for Caribbean countries where past planting densities were high, thinnings were not done, and unimproved seeds were used. Converting to genetically superior seeds from known, better formed parents and planting trees at lower densities will improve tree form considerably and result in higher prices for harvested logs.

4.4.2 *Cone and Seed Production.*—Cone production on individual trees was poor. Only four plots averaged ≤50 mature or immature cones per tree; the rest showed no cone production. Active or recent flowering was not observed. However, edge trees in the plantation perimeter generally had high quantities of mature and immature cones (fig. 4.6). In the absence of grazing and fire disturbance, areas outside plantations had natural reproduction on sandy and clay soils.

Poor cone and flower production is a common result of dense overstocked stands (section 1.1.4). This phenomenon also exists in areas receiving high, evenly distributed rainfall throughout the year. As long as local reforestation efforts remain limited, seeds can be bought from reputable international seed suppliers. To determine whether seeds can be produced locally via seed production stands or seed orchards, countrywide phenological studies spanning several years are needed. Establishing seed production areas in some existing plantations that have a predominance of straight, well-formed trees is another alternative.

4.4.3 *Damage and Other Conditions.*—Almost half the plots were burned, but only two showed severe damage. No plots showed insect or disease damage. Six plots had windthrow damage greater than 15 percent; the rest had none. Prior observations on the plots suggested that this damage occurred in 1979 when two cyclonic storms passed over Puerto Rico. The predominant damage was from vandalism and fires set by man.

Four previously burned plots had an understory of pine needles, three others had a grass understory, and the rest had scattered to many shrubs. Litter thickness was generally less than 60 millimeters (2.4 inches).

Overall stand conditions in Puerto Rico are similar to those in other Caribbean countries. Native shrubs and trees quickly revegetate planted sites and replace the pines unless repetitive weedings, grazing, or fires keep them back. Where pine plantings are small, the edge where pine and native forest meet supplies abundant food and cover for native wildlife.

4.5 Soils and Landscape

4.5.1 *Field Observations.*—Soils in all plots except one were deep (fig. 4.7). Structure was well defined and was predominantly blocky or subangular blocky. In most plots, several indicators showed good drainage. Soils in most plots felt gritty and/or had stones in limited or all parts of the sample depth. Roots were distinct and generally found midway or deeper to the lowest depth sampled. Earthworms were seen occasionally, especially in more moist, high-elevation deep clay soils.

4.5.2 *Laboratory Analyses*—Based on percentages of sand/silt/clay, soil textures were predominantly clay at both upper and lower depths. Textures for the sandy soils were loam over loam. Four plots in the shallow clay region had a clay surface horizon over a loamy subsurface horizon. Similarity between surface and subsurface textures existed in the other countries studied, except in Costa Rica.

The two most common soil fertility limitations, according to crop criteria (section 1.4.2), were high soil acidity plus potassium and phosphorus deficiency. However, according to minimum forestry fertility standards, the only limitations were high soil acidity and potential phosphorus deficiency for clay soils at more than 300 meter (984 feet) elevation. Except for pH, chemical values for subsurface horizons were not consistently lower or higher than those for surface horizons. Ranges in chemical values for surface horizons were:

Soil region	pH	Al saturation	Ca	Mg	K	P
		pct	----- *meq/100 cm*^{3}	-----		*ppm*
Sands	4.6–5.7	13–24	0.67–11.2	0.22–6.74	0.07–0.14	2–8
Clays (≤300 m)	4.4–5.6	19–26	1.06–17.8	0.63–9.95	0.07–0.27	1–6
Clays (>300 m)	4.4–5.5	24–48	1.15–4.7	0.40–4.77	0.05–0.16	1–7

Observed growth rates of Caribbean pine were probably not related to soil fertility or predetermined soil regions for two reasons. First, the physical and chemical properties of the soils across all plots, generally in moist to wet climates, were very similar. Second, only 27 plots were sampled; including more plots or limiting the upper soil sample to zero to 20 centimeters (0 to 8 inches) Section 1.4.1) may change future growth and yield interpretations.

Figure 4.7—*Soils in most plots were deep, >100 centimeters (>39 inches), as in this abandoned burrow pit near Anasco, PR. Although soil nutrient status was low by crop standards, overall growth and yield of Caribbean pine was quite good across all regions studied.*

4.6 Forest Management Implications

4.6.1 *Growth Data.*—Data on stand growth and yield from local plantations are impressive, even on steep, nutrient-poor sites. For the same age and similarly stocked stands, annual overbark volume growth rates are comparable or superior to those in other tropical countries. Overall growth rates in Puerto Rico are two to two and a half times faster than those measured for commercial timber producing areas in the Southern United States (section 4.3.3). Even if outside-bark yields are reduced by 25 percent to report volume on an underbark basis (section 1.3.3), resulting underbark yields in Puerto Rico are still twice those of the Southern pines. Using wider spacings will provide products having improved wood quality and also assure higher financial returns because planting, tending, and harvesting costs will be lowered.

One nontraditional use of low-density juvenile wood from young trees could be wood shavings for horse stall bedding. In flat terrain, plantings for bedding material (wood shavings) could be stocked at higher outplant densities and be harvested in 5 to 8 years rather than 15 to 20 years as are plantings for sawn wood products (fig 4.8).

4.6.2 *Stand Conditions.*—Lack of insect or disease problems is attributable to the small size of local plantings and the very scattered nature of plantings throughout the countryside. As the size of planting blocks

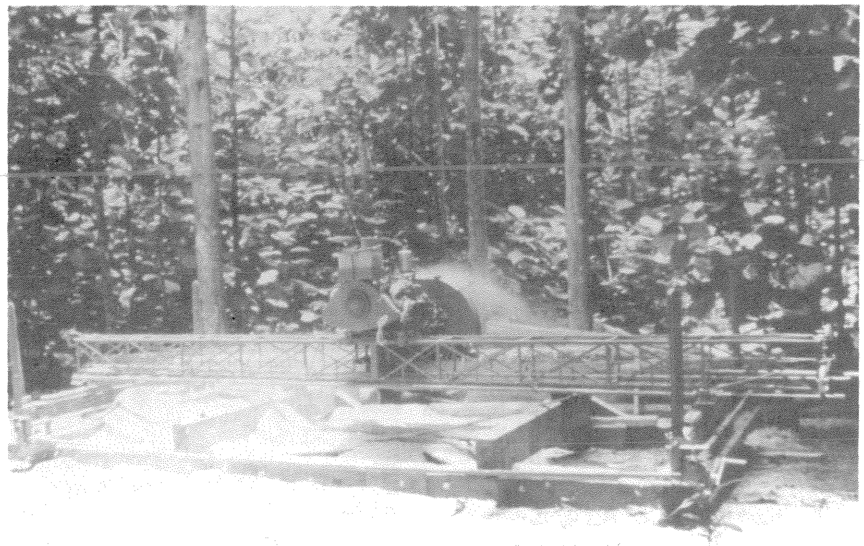


Figure 4.8—*Caribbean pine plantings provide posts and poles, as well as sawn wood products. The use of portable sawmills in Puerto Rico now allows cutting of lumber on rural landowner property rather than at distant processing centers in urban areas.*

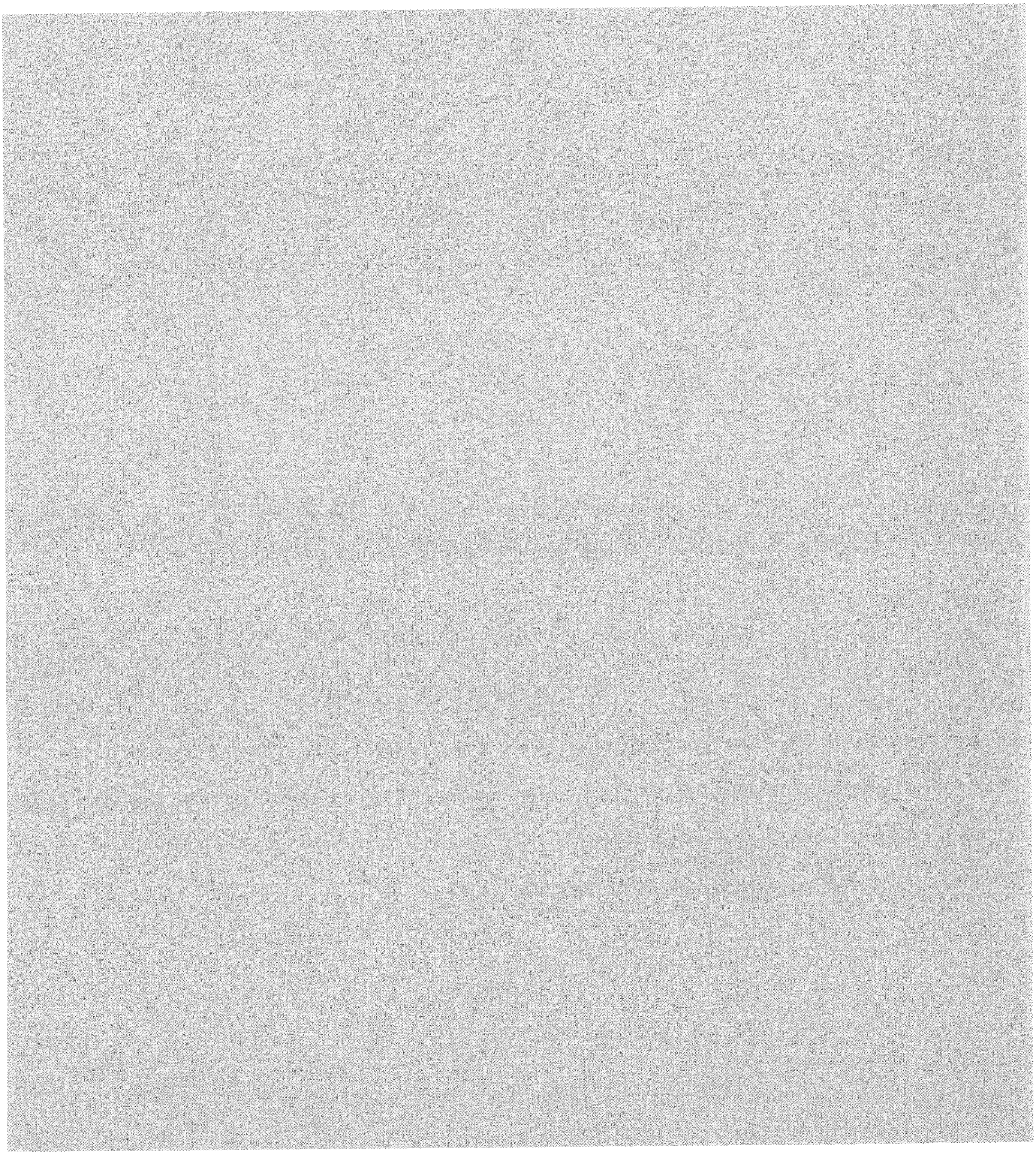
increases, strict sanitation practices before, during, and after harvesting should be maintained for insect and disease control.

As long as local reforestation efforts remain limited, sufficient high-quality seeds can be bought from international seed vendors. Use of improved seeds and wider spacing would improve tree form. Long-term reforestation efforts must also incorporate seed sources that are wind resistant because hurricanes are periodic threats to completing desired rotations. Timber losses by vandalism and fires will remain significant management problems in the future if plantings are kept small and dispersed with other farmland uses in highly populated rural areas.

4.6.3 *Soils.*—Growth and yield of Caribbean pine are not as affected by low soil nutrient status and low pH as are many agricultural crops. Annual wood volume yields on clay soils and sandy soils in Puerto Rico are greater than those of similarly aged and stocked pine stands in the Southern United States that supply most commercial sawn wood products. Apparently, understory flora and fauna, including earthworms, are as diverse within unburned pine plantations as they are within native forests.

4.6.4 *New Research.*—New research should quantify yields obtainable from the drier southern coast foothills where sugarcane was once produced. Although excluded as commercial forestland in the past, these areas now have closer access to main roads, large blocks of land in unproductive pasture, and fewer small farms that preclude managing large contiguous blocks of land. Finally, integrated cultural-economic studies should be conducted to determine how local perceptions can be changed to make large-scale forestry projects environmentally and economically attractive for long-term development in Puerto Rico.

Chapter 5



5. TRINIDAD

by Leon H. Liegel, Seepersad Ramnarine, and Kenny Singh

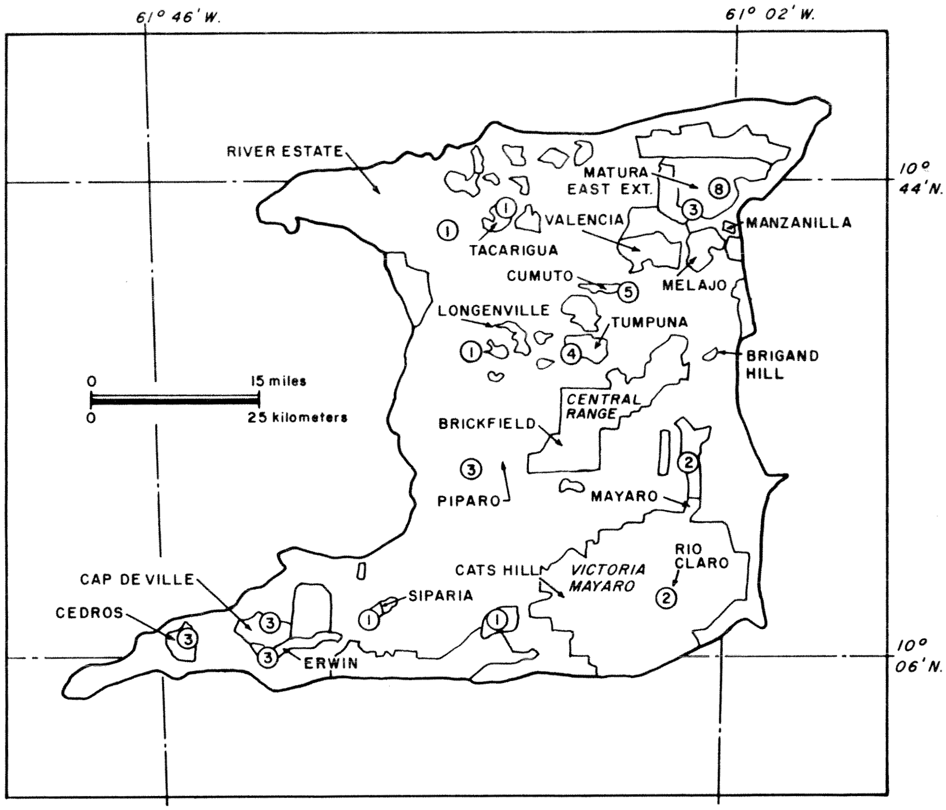


Figure 5.1.—*Field plots established in Trinidad. Circles indicate number of plots and their approximate location.*

Project Personnel
1983–87

Ministry of Agriculture, Land, and Food Production—Forest Division. Private Bag 30, Port-of-Spain, Trinidad

Bal S. Ramdial—conservator of forests

Seepersad Ramnarine—assistant conservator of forests—research (technical counterpart and supervisor of field activities)

Kenny Singh (directed south field sample crews)

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C. Roberts, F. Ramsaroop, M. Malabir—field technicians

Figure 5.2—*A typical Caribbean pine planting, almost 20 years old, on poorly drained lowland soils.*

5.1 Local Pine Management History

5.1.1 *Initial Introduction.*—Honduras or Caribbean pine was first planted in Trinidad on an experimental scale in 1948 when two small plots were established in the Arena Reserve. Encouraged by the success of early plantings, the first large-scale plantations, totaling 40 hectares (102 acres), were established in 1956. Subsequently, planting was steadily increased and had peaked at 300 hectares (762 acres) annually by the late 1970's. The current rate of establishment is under 200 hectares (490 acres) annually. At the end of 1986, over 6,000 hectares (15,240 acres) had been established (fig. 5.2).

5.1.2 *General Management Practices and Concerns.*—Through the early 1970's, seeds were obtained from sources in Belize. More recently, however, the main international suppliers have collected seeds primarily from Honduras and Guatemala. Original mycorrhizal inoculum was obtained from Belize. The beneficial mycorrhizal fungi grow on roots of seedlings and adult trees and help supply water and nutrients to the plant.

Most seedlings are planted as potted stock (fig. 5.3). Many proportions of sand, soil, rice hulls, sawdust, and other materials have been tested for pot-mix growth medium. Because of geographical proximity, Trinidad supplied eastern Venezuela with mycorrhizal inoculum for the first savanna pine plantings in the mid-1960's (section 6.1.1).

Before the early 1980's, most plantations were established by the taungya system: planting trees between agricultural row crops, then leaving the trees after harvesting the food crop at maturity. However, there is now little interest in this system. Weed control is practiced during the first 5 years after establishment, and plantings are given some protection from fires.

Research efforts have been directed towards understanding the growth and management of Caribbean pine. Tree improvement work has focused on identifying genetically superior trees and establishing a seed orchard to produce seeds locally. Imported seeds cost 180–300 U.S. dollars per kilo (quoted price is for 1989). Caribbean pine also plays an important role in Trinidad's watershed management program; it is widely used in reforesting denuded hillsides, especially in the Northern Range. No major pest or disease problems have been detected.

5.1.3 *Stocking and Utilization.*—Some experimental plots were analyzed by A. D. Miller, who published the "Provisional Yield Table for *Pinus caribaea* var. *hondurensis* in Trinidad" in 1969. This study recommended a spacing of 2.1 by 2.1 meters (7 by 7 feet) if there was a good market for small thinnings, and 3.6 by 3.6 meters (12 by 12 feet) if the objective was to produce sawlogs as quickly as possible. Because there was no local market for pulp, the Forest Division continued to plant at 2.7 by 2.7 meters (9 by 9 feet), a practice that was and still is practiced in many countries. Although no formal study on an optimum rotation age for Caribbean pine in

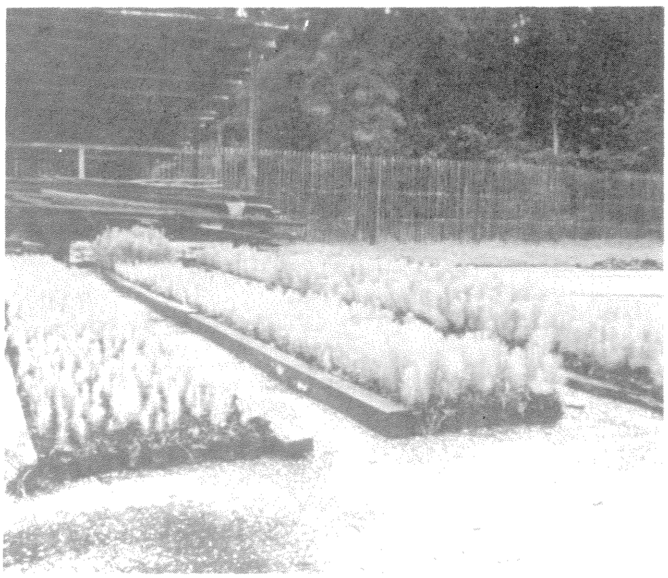


Figure 5.3—*Most Caribbean pine plantings are established with potted stock obtained from the Comuto nursery. The nursery is also used as a demonstration and experimental area for testing new nursery production techniques.*

Trinidad has been conducted, a rotation age of 25 to 30 years is anticipated for the better sites.

Most local pine plantations have remained unthinned because of initial indecision about whether to manage for sawlogs or for pulp. Currently, however, some older pine plantings are being harvested and utilized for electricity cable transmission poles, sawtimber, and lumber to manufacture pallets.

5.2 Local Environment

5.2.1 *Climate and Topography.*—The climate is tropical, with two distinct seasons: a dry season from January to May and a wet season from June to December. The average daily temperatures are 29 °C (84 °F) in the day and 23 °C (73 °F) at night. Annual precipitation varies from about 3,300 millimeters (130 inches) in the north and northeast to ≤1,700 millimeters (67 inches) in the western and southern portions of the Island. Topographically, there are three ranges of hills running east to west across the Island plus two intervening lowland areas, comprising terraces, alluvial plains, and swamps. Elevations in the foothills and mountains range from 150 to slightly over 900 meters (459 to over 2,970 feet); lowland elevations seldom exceed 60 meters (198 feet).

5.2.2 *Geology.*—Unlike other West Indian Islands that are volcanic or coralline in nature, Trinidad has a geologic base that is almost entirely sedimentary (table 5.1). This phenomenon exists because Trinidad is structurally related to the South American continent rather than to the West Indian Islands. Rock materials are quite variable, consisting of:

- fine grain quartz sand,
- clay shale,
- soft marl, and
- hard limestone.

In the Northern Range, predominant rocks are clay slates, metamorphic schists, marbles, and phyllites. The Central and Southern Ranges have rocks consisting of shales, limestones, and sandstones.

5.2.3 *Soils.*—Over 120 soil series have been described; most are in the Inceptisol order (see appendix A). These soils are characterized by low base saturation and low pH, generally below 5.5.

Most soils in Trinidad tend to have restricted internal drainage, even those on intermediate or high upland topographic positions. Soils with good drainage are limited to areas of the Northern Range (fig. 5.4) and portions of the Caroni Plain and Southern Range. The poorly drained soils are not suited for most agricultural crops except rice. Caribbean pine has been planted extensively on lowland and upland poorly drained soils. When left untended and unthinned for many years, pine plantings on poorly drained sites are quickly invaded and eventually replaced by local secondary shrub and tree species.

5.3 Growth and Volume Data

5.3.1 *Growth Model Approach.*—Height and diameter data collected for individual plot trees 6 to 26 years of age (section 1.3) were converted to per-hectare outside-bark volume and basal area. Mathematical equations were then developed to predict per-hectare volumes, given three characteristics or parameters:

- plantation age,
- average height of tallest trees at age 15 (site index), and
- number of trees per hectare surviving at age of measurement.

Because availability of data was limited, a regrouping of information from five soil groups to two soil drainage

Table 5.1— *Regions and plots sampled for the Caribbean pine project in Trinidad and their associated geology and soils, 1983–87*

Region	Number of plots	Land capability classes	Geology	Predominant soil: Series	Predominant soil: Order
High uplands, good drainage	4	III, IV, VI, VII	Limestone, micaceous	Maracas Matelot	Ultisols
Terraces, good drainage	4	IV, V, VI	Porcillanite, sand, phyllites	Las Lomas	Ultisols
Intermediate uplands, poor drainage	12	IV, V, VI, VII	Clay shales, sandstone	Ecclesville Talparo	Vertisols Vertisols
Terraces, poor drainage	15	V, VI, VII	Sand, clay, mixed shale	Piarco Valencia	Ultisols Spodosols
Alluvial lowlands, poor drainage	6	IV	Clay, mixed shales, and clay alluvium	l'Ebranche St. John	Inceptisols Alfisols
Total	41				

Figure 5.4—*Steep erosive slopes on the Northern Range, outside Port-of-Spain, where Caribbean pine stands have been established.*

classes was necessary: poorly drained (22 sites) and well-drained (19 sites). Appropriate statistical tests showed significant growth differences between the two drainage classes. Also, the poorly drained soils had only one and the well-drained sites had three outplant densities. Therefore, predicted volumes and basal areas were developed for a single planting density of 1,330 trees per hectare (543 trees per acre).

5.3.2 *Stand Volumes.*—On a well-drained site (site index 22) by age 20, total predicted outside-bark yield is about 430 cubic meters per hectare (6,196 cubic feet per acre). For the same age and drainage class on a poor site (site index 14), predicted yield is considerably lower, only 175 cubic meters per hectare (2,521 cubic feet per acre) (fig. 5.5). On poorly drained sites (site index 22) by age 20, total predicted outside-bark yield is only 315 cubic meters per hectare (4,539 cubic feet per acre). Observed differences in total predicted yields between site indices of the same drainage class are similar to differences observed in other countries for a particular planting density.

5.3.3 *Other Countries.*—Yields in Trinidad were compared with those from other countries studied in the Caribbean pine project. In doing this, three specific criteria were used:

- a rotation of 15 years,
- total number of trees planted at 1,300 per hectare (531 per acre), except 1,330 per hectare (543 per acre) for Trinidad, and
- comparisons limited to "best" sites only.

Results are shown in table 5.2. Predicted overall yield in Trinidad, even on relatively well-drained sites, was the lowest of all five countries studied.

For comparative purposes, overbark yields of loblolly pine *(Pinus taeda)* in the Southern United States range from 13 to 16 cubic meters per hectare per year (187 to 230 cubic feet per acre per year). This comparison assumes average commercial planting sites, an initial outplant density of 1,525 trees per hectare (622 trees per acre), and a 25- to 35-year rotation with no thinning.

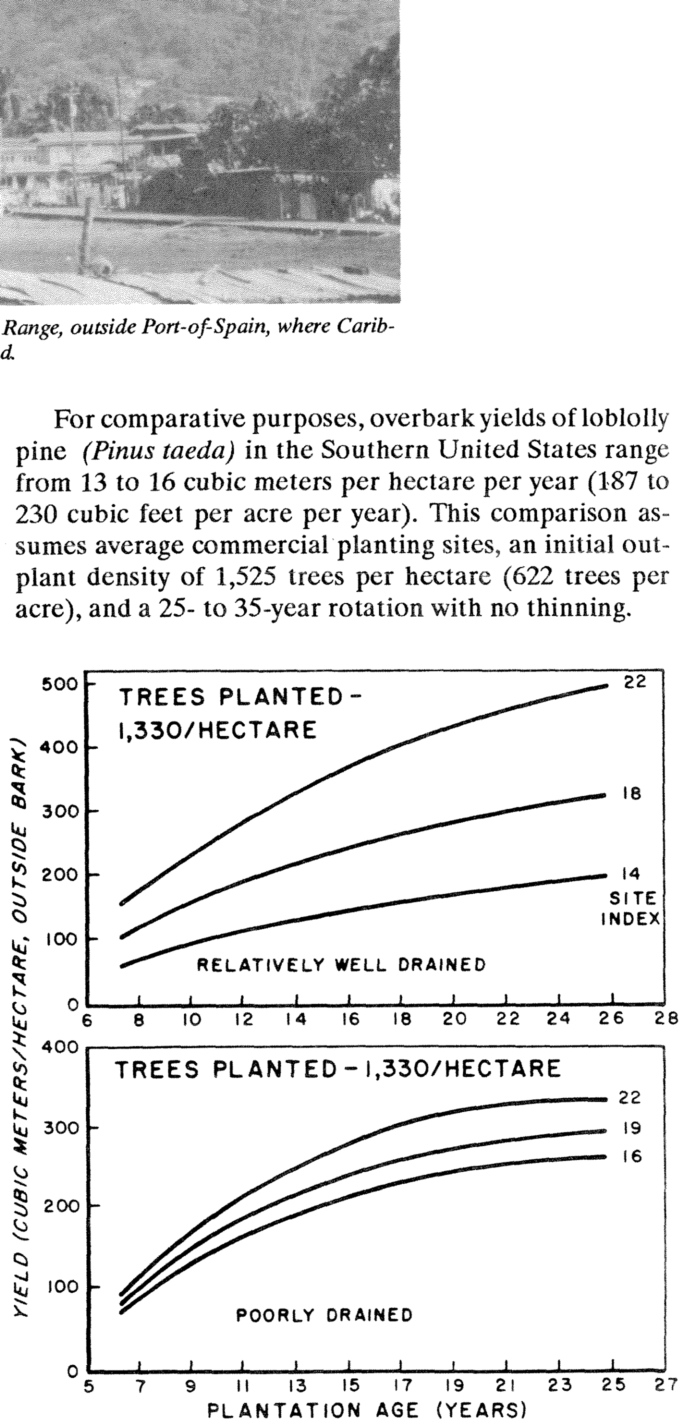


Figure 5.5—*Predicted total outside-bark yield of Caribbean pine plantings in Trinidad for different plantation ages, site indices, and two drainage classes.*

Figure 5.6—*Examples of poor tree form and high tree mortality in study plots. (left) Leaning trees, crooked boles, and forked stems (background) were much more common than straighter, large-diameter stems (foreground). (right) Mortality has been high in this 10-year-old stand in drier southwestern Trinidad where vandals frequently set forest fires.*

5.4 Stand Conditions

5.4.1 *Tree Form.*—Most trees in all 41 measurement plots had crooked and leaning stems (fig. 5.6). Forking ranged from 2 to 61 percent, with 21 plots having ≥20-percent forked trees. Foxtailing ranged from 2 to 43 percent, with 10 plots having ≥20-percent foxtail trees. These foxtail percentages are similar to those for Jamaica, Puerto Rico, and Venezuela but are lower than those for Costa Rica.

Table 5.2—*Comparison of outside-bark yield of Caribbean pine in Trinidad with that of other countries for rotation age 15 years and "best" sites only**

Country	Site index	Total yield	Mean annual increment
	m	m^3*/ha*	m^3 */ha/yr*
Well-drained sites			
Costa Rica	26 (85)†	550 (7,924)‡	35 (504)§
Jamaica	24 (79)	400 (5,763)	27 (389)
Puerto Rico	26 (85)	485 (6,988)	32 (461)
Trinidad	22 (72)	360 (5,187)	24 (346)
Moist sites			
Venezuela	21 (69)	475 (6,844)	32 (461)

*Trinidad trees planted = 1,330 per hectare (543 per acre); all other countries = 1,300 per hectare (530 per acre).

†(ft).

‡(ft^3/acre).

§(ft^3/acre/yr).

Overall poor tree form is not unusual for Caribbean countries where past planting densities were high, thinnings were not done, and unimproved seeds were used. Converting to genetically superior seeds from known, better formed parents and planting trees at lower densities will improve tree form considerably and result in higher prices for harvested logs.

5.4.2 *Cone and Seed Production.*—Cone production on individual trees was poor. Thirty-four plots averaged considerably less than 50 mature or immature cones per tree. Nine plots showed active flowering, and 25 plots had recent flowering.

Poor cone and flower production is a common result of dense overstocked stands. This phenomenon also exists in areas receiving high, evenly distributed rainfall throughout the year. As long as local reforestation efforts remain limited, seeds can be bought from reputable international seed suppliers. To determine whether seeds can be produced locally via seed stands or seed orchards, countrywide phenological studies spanning several years are needed.

5.4.3 *Overall Stand Conditions.*—Only 10 plots showed no signs of burning; 10 of the burned plots had trees with profusely exuding resin. Only two plots showed significant windthrow damage. Trinidad is at the fringe of the Caribbean hurricane belt, and wind damage is not frequent. The most common damage was from undermanagement of the stands, disallowing full growth potential to be realized. Litter thickness on the forest floor was usually ≤60 millimeters (≤2.4 inches). Litter composition was primarily mixed pine needles and hardwood leaves, except where fires had occurred.

Overall stand conditions in Trinidad are similar to those in other Caribbean countries. Native shrubs and trees quickly revegetate planted sites and replace the pines unless repetitive weedings or fires keep them back (fig. 5.6). Where pine plantings are small, the edge where pine and native forest meet supplies abundant food and cover for native wildlife.

5.5 Soils and Landscape

5.5.1 *Field Observations.*—Most of the plot soils were ≥100 centimeters(≥39 inches) deep; only nine plots had shallower soils. Soil structure was quite variable, as follows:

	Number of plots
No structure	21
Granular	9
Blocky	2
Subangular blocky	9

Soils in 31 plots lacked stones in either the upper or lower horizons; 21 plots had gleization. These two conditions indicate poor drainage. Consequently, except in sandy or sandy loam soils, tree roots were confined to the upper soil horizons. Earthworms were seen in almost half the plots.

5.5.2 *Laboratory Analyses.*—Based on percentages of sand/silt/clay, the three major soil texture classes were clay, loam, and sand. For 24 plots, surface and subsurface textures were the same. For the other 17 plots, textures of surface and subsurface horizons were dissimilar, usually a loamy surface underlain by poorly drained clay (fig. 5.7).

The most common soil fertility limitations, according to crop criteria (section 1.4.2), were high soil acidity, potassium and phosphorus deficiency, and high aluminum saturation. According to minimum forestry fertility standards for pines, only calcium levels were deficient in most poorly drained soils. Ranges in chemical values for surface horizons were:

Soils	pH	Al saturation	Ca	Mg	K	P
		pct	------	*meq/100 cm³*	-----	ppm
Poorly drained	4.4–5.3	43–61	0.26–4.75	0.18–5.6	0.04–0.23	5–12
Well-drained	4.4–5.7	14–38	0.55–3.47	0.19–1.2	0.03–0.16	4–12

Chemical values for subsurface horizons were not consistently lower or higher than those for surface horizons. The differences in aluminum saturation, calcium levels, and drainage status between poorly drained and well-drained sites probably account for the significant growth differences of Caribbean pine across planting sites in Trinidad.

Figure 5.7—*Soils in most plots were poorly drained. This is indicated by gray and whitish color in the bottom row of soil samples. Although nutrient status by crop standards was relatively poor, growth and yield of Caribbean pine was fair for unthinned dense stands.*

5.6 Forest Management Implications

5.6.1 *Growth Data.*—Data on stand growth and yield from local plantations are generally higher than those on coniferous plantings of similar age from temperate areas (section 5.3.3). Even if outside-bark yields are reduced by 25 percent to report volume on an underbark basis (section 1.3.3), resulting underbark yields in Trinidad are still slightly higher than those of the southern pines. However, Caribbean pine plantings of similar age in other tropical countries are producing wood products (fig. 5.8) and volumes at rates superior to those in Trinidad. Using wider spacings in upland and lowland plantings and planting on better drained soils will improve yields and wood quality. Reducing outplant densities will also assure greater financial returns because planting, tending, and harvesting costs will be lowered.

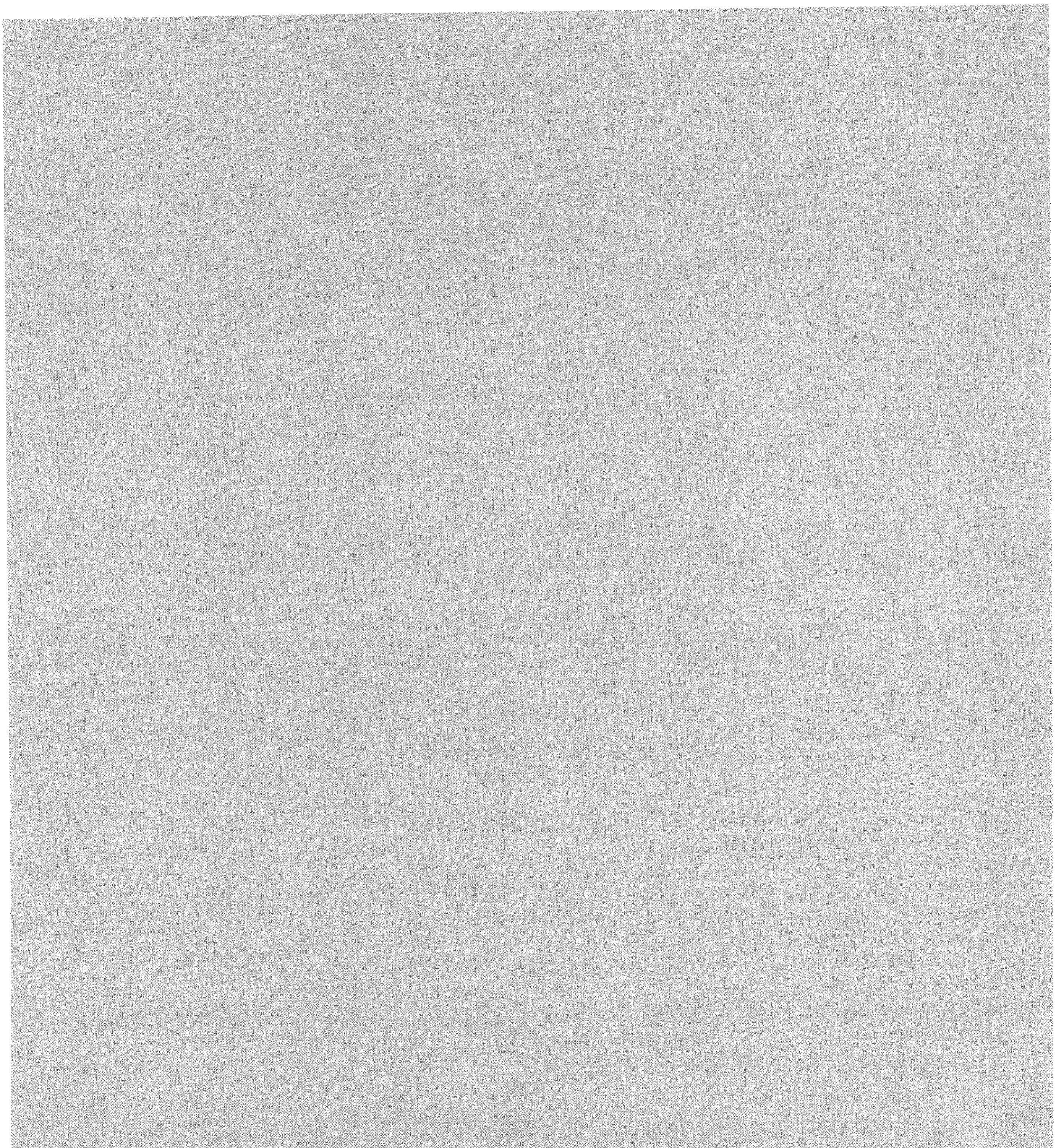
5.6.2 *Stand Conditions.*—Only localized problems with diseases and insects existed. Poor cone and flower production observed in Trinidad were also observed in other Caribbean countries. Seed production in Trinidad has been consistently low. As long as local reforestation efforts remain limited, sufficient high-quality seeds can be bought from international seed vendors. And, as long as plantings are dispersed with other farmland uses, timber losses by vandalism and fires will remain significant management problems in the southwest portion of the Island. With intensive fire protection and prescribed burning, growth rates, especially in southwestern Trinidad, would be comparable to those in eastern Venezuela where sandy soils also predominate. Experimental bareroot plantings should be tried because of the sandy soils and gentle relief in this area. Efforts should be made to determine the most financially advantageous rotation age for sawlogs, and thinning regimes need to be developed and implemented. Mechanical site preparation should be investigated as an alternative because of high hand-labor establishment costs.

5.6.3 *Soils.*—Poor soil drainage and associated nutrient properties had significant effects upon the growth and yield of Caribbean pine. Higher yields can be obtained by limiting plantings to better drained sites and by using lower densities. Planting on well-drained sites only should also reduce expected sawlog rotation length by 5 to 8 years. Apparently, soil flora and fauna are as diverse within unburned pine plantings as they are within native secondary forests.

Figure 5.8—*Pine plantings currently produce posts and poles. One future and nontraditional use of low-density absorbent pine fibers could be wood shavings for horse stall bedding material.*

5.6.4 *New Research.*—New studies should investigate the natural variation in wood density across local stands, both for well-drained and poorly drained sites. Vegetative cuttings of individual trees having lower percentages of low-density juvenile wood can be incorporated into existing seed orchards. Nontraditional use of low-density pine fibers for animal bedding material should be investigated for supplying local and export markets. Container cargo ships from the United States frequently return empty after leaving cargo in Trinidad. The economic feasibility of using returning ships to transport high-quality sacked or baled bedding material to other Caribbean islands and the United States should be studied via cost-benefit and marketing strategies possible under the current Caribbean Basin initiative.

Chapter 6



6. VENEZUELA

by Leon H. Liegel and Ricardo Bellandi

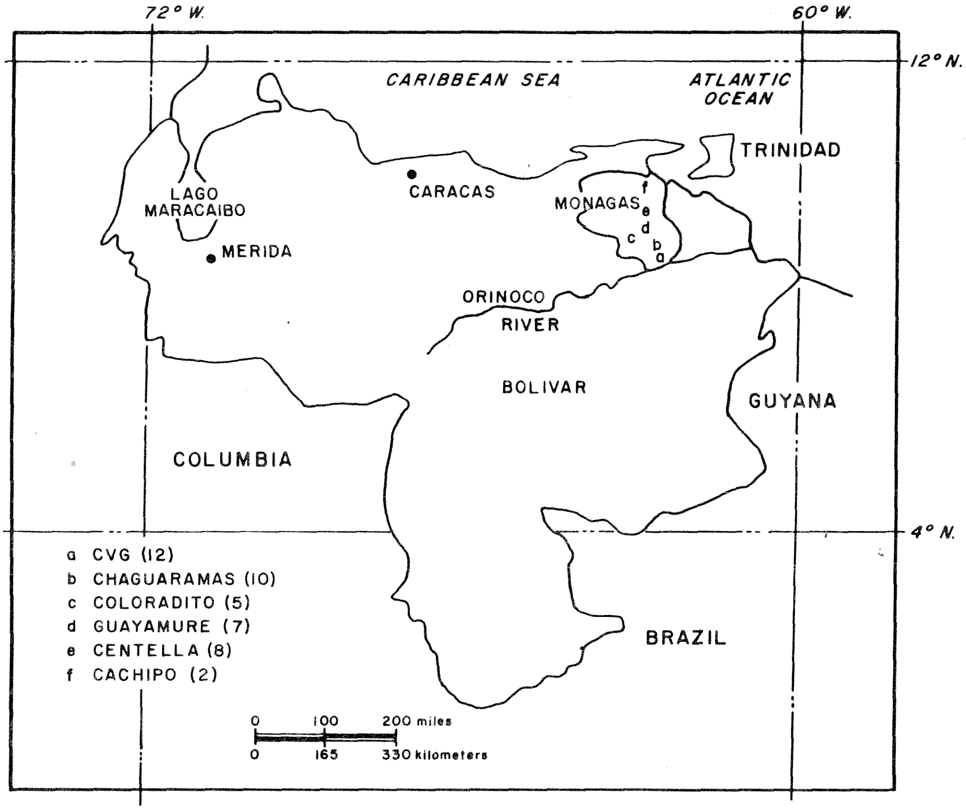


Figure 6.1—*Field plots established in Venezuela. Letters specify approximate location by ownership; total number of plots is indicated within parentheses.*

Project Personnel 1983–87

Compania Nacional de Reforestacion (CONARE)[1]. Apartado Postal 17017, El Conde-Zona Postal 101, Caracas, Venezuela

Anibal Luna—president
J. J. Cabrero Malo—past president
Ricardo Bellandi (technical counterpart, Chaguaramas Field Office).
Victor Fernandez—field crew leader
Juan Serpa—field technician
Pedro Gomez—forester

Corporacion Venezolana de Guayana (CVG)[1]. Edificio Seguros Orinoco, 3rd Piso—Puerto Ordaz, Estado Bolivar, Venezuela

Ing. For. Arquimedes Rodriguez—general manager

[1]In late 1988, separate operations of CONARE and CVG were combined into a single management entity called Productos Forestales de Oriente, C. A. (PROFORCA), for which Ing. For. Arquimedes Rodriguez is the general manager.

6.1 Local Pine Management History

6.1.1 *Initial Plantings.*—Planting of Caribbean pine in Venezuela's eastern savannas (Estado Monagas) began in 1968. About 700 hectares (1,715 acres) were established by the Corporacion Venezolana de Guayana (CVG). Four years later the Ministry of Agriculture and Husbandry, Division of Renewable Natural Resources (MAC-RNR), also began planting Caribbean pine. In 1973, existing MAC-RNR plantings were placed under the administration of the Compania Nacional de Reforestacion (CONARE), which continued to plant a few thousand hectares annually along with CVG. By 1983, total area planted by both CVG and CONARE was almost 150,000 hectares (367,500 acres) (fig. 6.2).

6.1.2 *General Management Practices and Concerns.*—All early plantings were established with nursery stock produced in polyethylene or asphalt-roofing-paper pots. Survival was poor during the first few years because bags were not slit or removed in the field. Through 1979, seeds were imported almost exclusively from Guatemala. The genetic composition of these seeds plus local environmental factors in Venezuela combined to produce high percentages of foxtail trees in most plantings (see front cover). After 1979, imported seeds came mostly from high-elevation inland sources in Honduras, and subsequent foxtailing was reduced by more than half.

To reduce hand-labor costs associated with producing potted seedlings, a trial bare-root planting of about 500 hectares (1,225 acres) was established in the late 1970's. Survival was so high that operational bare-root-produced stock was used thereafter by CVG and CONARE (fig 6.3). Because plantings rose to 12,000 hectares (29,400 acres) or more annually, other mechanized nursery and planting techniques were quickly adapted from operational practices used in the Southern United States.

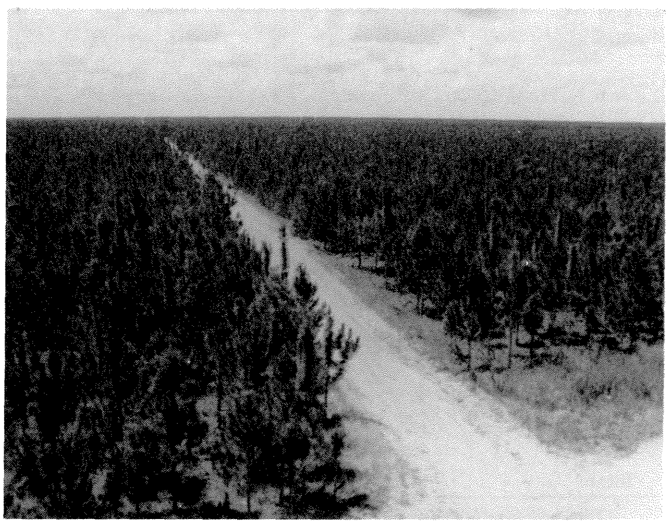


Figure 6.2—*A typical 4-year-old savanna planting of Caribbean pine in eastern Venezuela. Total area planted since 1968 is about 200,000 hectares (490,000 acres).*

As the early plantings matured, local volume tables were produced. Site studies showed that seemingly flat terrain contained at least three kinds of soil that could affect growth and yield. Tree improvement and breeding programs were initiated so that local seed orchards could eventually supply the rising need for seeds. Because of uncertainty for marketable wood products, all stands were left unthinned until 1982. Lack of thinning, high stocking, dry climate, and sandy soils eventually created conditions that caused scattered dieback on both CVG and CONARE holdings from 1979 to 1983. However, overall growth in the dry savanna region has been so good that an integrated pulpmill/sawmill operation is now planned for the Orinoco River area, close to Puerto Ordaz.

6.2 Local Environment

6.2.1 *Climate.*—Climate in the eastern savannas is strongly seasonal with distinct dry and moist periods. Rainfall averages about 1,000 millimeters (40 inches) and falls mostly in June through August, with another peak in November. Warmest months are September to November, and coolest months are December to February. Daily temperatures rise to between 30 and 33 °C (86 and 91 °F), and those at night fall between 20 and 22 °C (68 and 72 °F). Mean monthly differences in maximum and minimum temperatures vary by only 2 to 4 °C (3 to 7 °F).

6.2.2 *Geology and Topography.*—The three main geologic formations of the savanna area, from oldest to youngest, are:

- La Pica, which is of marine origin;

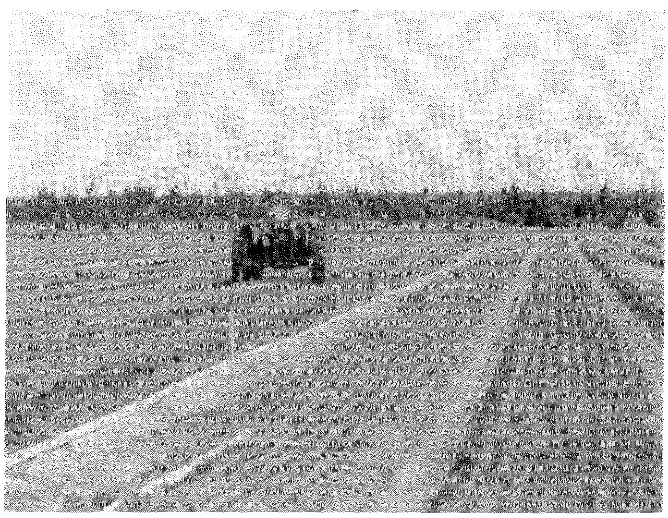


Figure 6.3—*Since 1980, operational field plantings have been made exclusively with bare-root stock, using mechanized production techniques. From 1968 to 1979, the first plantings of Caribbean pine were established with potted nursery stock.*

- Las Piedras, which was laid down in a semisaline environment; and
- the Mesa formation, from which most soils in the region were derived.

The Mesa consists of very fine to coarse sands derived from alluvial deposits. Sources of these materials were the Guayana shield to the south and the Coast Range to the north. In recent times, aeolic forces have substantially rearranged these materials so that resulting formations are quite complex, despite uniformity to the casual observer (fig. 6.2). Thus, the major Mesa formation features are channels and fans, with fans occupying the larger area.

6.2.3 *Soils.*—Soils of the area are Oxisols to Oxisol-Ultisol intergrades (appendix A), with soil reaction or pH ranging from 4.7 to 5.5. They have little structure, excessive internal drainage, and little water-holding capacity. Natural fertility is low, with the sum of the bases and aluminum less than 2.0 milliequivalents per 100 grams (0.4 ounce) of soil.

Three major kinds of soil exist according to topographic position (fig. 6.4). Best Class I soils for afforestation are those with clay accumulations above 60 centimeters (23.6 inches). Clay materials near the surface trap water in the wet season and provide a source of moisture to plant roots during the dry season. Poorest Class III soils are those with sands and no clay above 100 centimeters (39.4 inches) or those where drainage is impeded above 40 centimeters (15.7 inches). These soils are too dry during the long dry season or too wet during the rainy season. Class II soils are intermediate and have clay accumulations between 60 and 100 centimeters (23.6 and 39.4 inches). Moisture conditions are adequate in these soils except during exceptionally dry years. Newly planted seedlings are at great risk in Class II and Class III soils until root systems reach deeper layers having adequate moisture.

Figure 6.4—*Early plantings had poor survival. Failures were caused primarily by several management practices, including poor planting techniques, poor quality seedlings, planting outside optimum wet season, and planting on poor (Class III) sites.*

6.3 Growth and Volume Data

6.3.1 *Growth Model Approach.*—Height and diameter data collected for individual plot trees 4 to 15 years of age (section 1.3) were converted to outside-bark volume and basal area per hectare. Mathematical equations were then developed to predict per-hectare volumes, using three independent variables:

- plantation age,
- average height of tallest trees at age 15 (site index), and
- number of trees per hectare surviving at age of measurement.

Because availability of data was limited, a regrouping of information from six ownership (table 6.1) into four soil and climatic groups was necessary. Prediction equations were developed for each soil/climatic group. Subsequent statistical tests showed significant differences in predicted volumes and basal areas between two combined soil/climatic groups, representing 12 dry and 32 moist sites. Therefore, growth data from these two groups were kept separate when developing predicted volume and basal area curves for a planting density of 1,300 trees per hectare (531 trees per acre).

6.3.2 *Stand Volumes.*—Predicted total outside-bark yield on a good moist site (site index 21 by age 10 years is 300 cubic meters per hectare (4,322 cubic feet per acre). On dry sites having 1,300 trees per hectare (531 trees per acre), predicted yield on a good site (site index 18) at 10 years is 115 cubic meters per hectare (1,657 cubic feet per acre) (fig. 6.5). At higher planting densities, similar yield differences existed between moist and dry sites.

Table 6.1—*Holdings and plots sampled for the Caribbean pine project in Venezuela, 1983–87*

Ownership or area	Age class (years)						Total
	4–5	6–7	8–9	10–11	12–13	≥14	
	*Number of plots**						
Cachipo	......	......	......	......	......	2	2
Chaguaramas	2	2	2	4	......	......	10
Coloradito	1	4	......	......	......	......	5
Guayamure	1	2	2	2	......	......	7
Centella	2	2	2	2	......	......	8
CVG	2	2	2	2	2	2	12
Total							44

*Data not available for certain age classes because of past planting history and/or differences in timing of land acquisition.

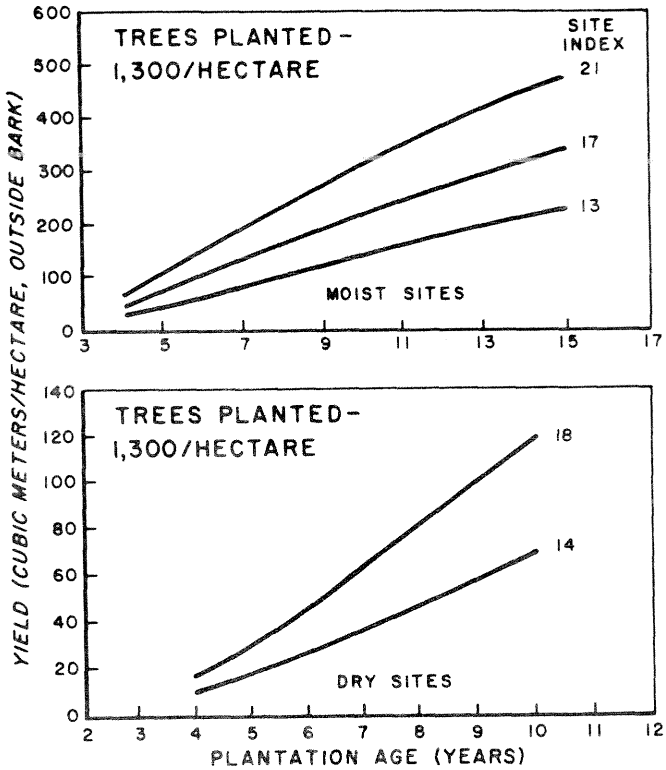


Figure 6.5—*Predicted total outside-bark yield of Caribbean pine plantings in Venezuela for different plantation ages and site indices in two climatic regions.*

For pulp production, higher outplant densities are used. At high densities, however, wood volume and basal area are mainly distributed over many small stems. For sawlog production, forest managers prefer that larger volumes be concentrated on fewer good-quality, high-value stems (section 1.3.3).

6.3.3 *Other Countries.*—Yields in Venezuela were compared with those from other countries studied in the Caribbean pine project using three specific criteria:

- a rotation of 15 years,
- total number of trees planted at 1,300 per hectare (531 per acre), and
- comparisons limited to "best" sites only.

Predicted yield for Venezuela's moist sites is equal to that in Puerto Rico, higher than yields in Jamaica and Trinidad, but less than the yield in Costa Rica (table 6.2)

For comparative purposes, overbark yields of loblolly pine *(Pinus taeda)* in the Southern United States range from 13 to 16 cubic meters per hectare per year (187 to 230 cubic feet per acre per year). This comparison assumes average commercial planting sites, an initial outplant density of 1,525 trees per hectare (622 trees per acre), and a 25- to 35-year rotation with no thinning.

6.4 Stand Conditions

6.4.1 *Tree Form.*—Most trees in all 44 measurement plots had crooked stems. The range was 43-to 100-percent crooked trees on moist sites and 12 to 100 percent on dry sites. Percentages of leaning trees were much less in Venezuela than in the other four countries: zero to 3 percent on wet sites and zero to 14 percent on dry sites. The low percentages in Venezuela are the result of fewer cyclonic or orographic storms than occur in the other countries studied. Forked trees ranged from 13 to 43 percent on moist sites and 6 to 63 percent on dry sites. Trees with foxtailing (fig. 6.6) ranged from 18 to 40 percent on moist sites and 10 to 54 percent on dry sites. These figures are slightly higher than those for the other countries except Costa Rica.

6.4.2 *Cone and Seed Production.*—Cone production for individual trees was poor on both moist and dry sites. Most plots had considerably less than 50 mature cones per tree; 10 plots had no mature cones. All but the plots on dry sites had a similar number of immature cones. Only four plots showed active flowering at the time of assessment: three on moist sites and one on a dry site. Five of the moist sites and four of the dry sites showed signs of recent flowering. Over 70 percent of all plots on the dry sites, however, exhibited no signs of active or recent flowering.

Poor cone and flower production were also observed in the other countries studied. In Venezuela, the cause is probably long periods of low soil moisture, poor nutrient supply, and high outplant density. In the other countries, however, the cause is dense, overstocked stands and high rainfall that disrupt normal flower developmental processes. For long-term plantation forestry in the savannas, grafted seed orchards located elsewhere in Venezuela could produce seeds for local afforestation and reforestation efforts.

Table 6.2—*Comparison of outside-bark yield of Caribbean pine in Venezuela with that of other countries for rotation age 15 years and "best" sites only**

Country	Site index	Total yield	Mean annual increment
	m	*m^3/ha*	*m^3/ha/yr*
Well-drained sites			
Costa Rica	26 (85)†	550 (7,924)‡	35 (504)§
Jamaica	24 (79)	400 (5,763)	27 (389)
Puerto Rico	26 (85)	485 (6,988)	32 (461)
Trinidad	22 (72)	360 (5,187)	24 (346)
Moist sites			
Venezuela	21 (69)	475 (6,844)	32 (461)

*Trinidad trees planted = 1,330 per hectare (543 per acre); all other countries = 1,300 per hectare (530 per acre).

†(ft).

‡(ft^3/acre).

§(ft^3/acre/yr).

Figure 6.6—*A 3.5-year-old Caribbean pine planting with a high percentage of foxtail trees. Improved form and a reduction in numbers of foxtail trees can be achieved by using seeds from superior formed parent trees that do not come from Guatemala.*

6.4.3 *General Stand Conditions.*—The most common damage was defoliation caused by ants on a total of 29 plots. Damage was equally destructive across moist and dry sites. Only one plot showed fire damage. However, fire damage was quite severe in a few other areas outside the measurement plots. In one plot, cattle had trampled and browsed young trees when grazing. An unknown pathogen in one plot that had dieback symptoms was probably *Diodiplodia*. In 1981 and 1983, outbreaks of this pathogen were documented on holdings owned by CONARE and CVG. High stand densities and consecutive droughts allowed the blue stain fungi to attack both root and top portions of stressed trees.

Unlike the well-developed understory in plantations of the other countries studied, that of plantings in Venezuela consists primarily of pine needles and a few shrubs. Poor soils and low soil moisture conditions cause this phenomenon. (Within large clearings or between plantings, native grass predominates.) Litter thickness is generally less than 60 millimeters (2.4 inches).

6.5 Soils and Landscape

6.5.1 *Field Observations.*—Soils in all plots were deep. Because of their sandy textures, most soils had poor structure and excessive drainage. Exceptions were those soils in which development had caused clay accumulation between the surface and 100 centimeters (39.4 inches). Within the clay horizon, structure was generally well defined, and drainage was moderate to poor. Roots were distinct and usually penetrated to the lowest depths sampled. In many of the plots, channelization by ants had caused considerable mixing of surface and subsurface horizons (fig. 6.7).

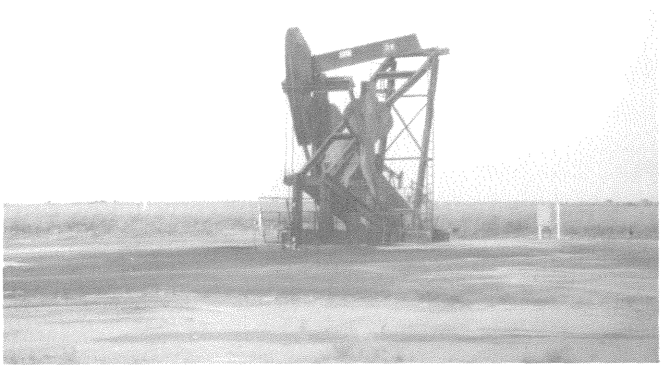
6.5.2 *Laboratory Analyses.*—Soil reaction (pH) was usually higher in subsurface than in surface horizons. The most common soil fertility limitations, according to crop criteria and forestry fertility standards for pines (section 1.4.2), were high soil acidity, high aluminum saturation, and low levels of all nutrients in surface and subsurface horizons. Ranges in values for chemical properties of the soils across moist and dry sites were:

Site and horizon	pH	Al saturation	Ca	Mg	K	P
		pct		*meq/100 cm^3*		*ppm*
Moist						
Surface	4.2–5.0	71–89	0.13–0.45	0.01–0.46	0.01–0.04	1–9
Subsurface	4.3–5.5	55–69	0.13–0.43	0.00–0.46	0.00–0.04	0–9
Dry						
Surface	4.2–4.8	62–74	0.17–0.27	0.03–0.15	0.01–0.03	1–6
Subsurface	4.5–5.3	58	0.19–0.31	0.03–0.27	0.01–0.03	1–11

A great similarity exists in the physical and chemical properties of the surface and subsurface horizons of the moist and dry sites. Significant growth differences between the two kinds of sites can probably be attributed to variation in total annual rainfall and resultant soil moisture.

New areas to be afforested should be mapped first; only Class I and Class II soils (section 6.2.3) should be planted. Additional soil mapping work may be needed where early plantings had high mortality. A key manage-

Figure 6.7.—*Soils in most plots were sandy and deep, >100 centimeters (>39 inches). In many areas, excavation by ants had mixed surface and subsurface horizons.*



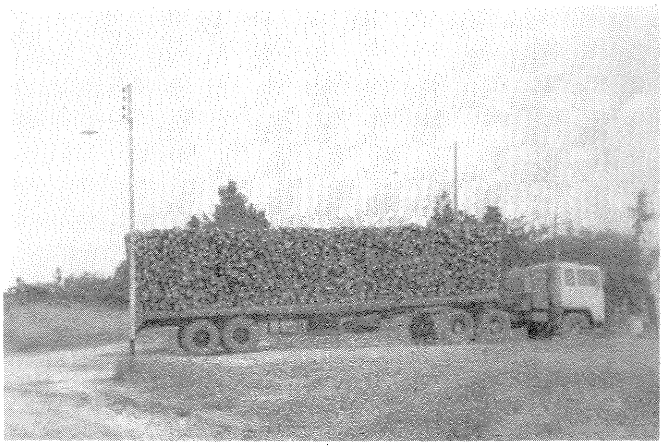


Figure 6.8—*Examples of savanna area above oil deposits and Caribbean pine logs loaded for shipment. (left) Oil underneath the savanna soils is of short-term economic benefit. (right) Large Caribbean pine plantings provide renewable resources: posts, poles, and sawn wood products. Commercial plantations also produce long-fiber materials from thinnings that are used to make cardboard, tissue paper, and other paper products.*

ment issue is whether high mortality in early plantings resulted from poor soils, poor management practices such as using poor quality nursery seedlings, drought effects during the first 6 to 18 months after planting, or a combination of these factors.

6.6 Forest Management Implications

6.6.1 *Growth Data.*—Data on stand growth and yield from the eastern grasslands are impressive. Even on deep, dry, nutrient-poor sandy sites, Caribbean pine plantings with good survival can produce wood volumes at rates comparable or superior to those in other tropical countries (fig. 6.8). Overall growth rates in Venezuela are two to two and a half times faster than those measured for commercial timber producing areas in the Southern United States (section 6.3.3). Even if outside-bark yields are reduced by 25 percent to report volume on an underbark basis (section 1.3.3), resulting underbark yields in Venezuela are still about twice those of the southern pines. Using slightly wider spacing with high-quality nursery seedlings will improve wood quality and result in lower nursery, planting, and harvesting costs. Another alternative is earlier thinning of young stands if markets can be found for the thinned material.

6.6.2 *Stand Conditions.*—Localized problems exist with dieback, which is attributed to blue stain fungi attack, and defoliation caused by ants. Dieback should be controlled by using wider spacings or thinning before trees start competing for scarce water and nutrients. More effective ant control measures are also being studied and implemented. Constant vigilance is needed to protect dry grass, understory accumulation of needles, and overstory foliage from fires. Low-intensity prescribed fires may be an alternative to control understory and litter buildup. Establishing grafted seed orchards from local disease-free, ant-and drought-resistant parent trees will guarantee sufficient quantities of seeds for afforestation and reforestation planting programs. Maximum seed and cone production will be obtained in more moist, high-elevation sites away from the lowland savanna sites. Foxtailing can be reduced by using seed sources outside Guatemala.

6.6.3 *Soils.*—Growth and yield of Caribbean pine are not as restricted by poor soil fertility and low pH as are many agricultural crops. As long as excessively drained soils, those lacking a moisture-holding clay horizon within 60 centimeters (23.6 inches) of the surface, are not planted to pine, survival and tree growth will be satisfactory unless several drought years occur in succession. Many widespread planting failures in the 1970's were erroneously attributed to "poor soils." These early afforestation program failures are now generally believed to have been the result of poor planting techniques in the field, poor-quality nursery seedlings, and planting after summer rains had started.

6.6.4 *New Research.*—Additional studies are needed to quantify wood quality variation in young stands having high amounts of juvenile wood. Individual trees and seed sources resulting in higher wood specific gravities should be identified; their genetic makeup can be included in clonal tests and seed orchards, then in operational planting programs. Testing other species such as *P. oocarpa* on very dry sites should continue. Finding species or provenances adaptable to Class II and Class III soils will greatly extend the area over which plantation forests can be established. Changes in soil fertility in plantations and in native savanna should be monitored to evaluate the long-term ecological implications of plantation management on local biological diversity.

Appendix A

Glossary of Important Abbreviations and Definitions of Key Terms

AGENCY ABBREVIATIONS

CAMCORE—Central America and Mexico Coniferous Resources Cooperative
CONARE—Compania Nacional de Reforestacion, Venezuela
CVG—Corporacion Venezolana de Guayana, Venezuela
FIDCO—Forest Industries Development Corporation, Jamaica
ITCR—Instituto Tecnologico de Costa Rica
MAC-RNR—Ministerio de Agricultura y Cria—Recursos Naturales Renovables, Venezuela
USAID—United States Agency for International Development
USDA—United States Department of Agriculture

COMMON SOIL NUTRIENT ABBREVIATIONS

Ca—Calcium—Ca, Mg, and K are measured in millequivalents per 100 cubic centimeters (meq/100 cm^3).
CEC—Cation exchange capacity: the number and weight of nutrients, especially Ca, Mg, and K cations, that a given weight or volume of soil can hold in available form. Fertile soils have higher values for major nutrients.
K—Potassium
Mg—Magnesium
P—Phosphorus—is measured in parts per million (ppm).
pH—Soil reaction: the concentration of hydrogen and hydroxyl ions in the soil. Acidic soils have a pH value <7.0; basic soils have a pH value >7.0. Soils with a pH value of 7.0 are neutral, neither acidic nor basic.
Al—Aluminum—Al saturation is a measure of what percentage of exchange sites in a given volume of soil are filled with Al rather than beneficial cations such as Ca, Mg, and K.

DEFINITIONS FOR SELECT FORESTRY AND SOIL RESEARCH TERMINOLOGY

Afforestation—Planting trees on savanna grasslands or other areas where forest vegetation does not occur naturally—contrasts with the definition for reforestation.

Best sites—Those sites having the highest site index and most optimum growing conditions; the only sites used when comparing growth rates between countries.

Basal area—The computed cross-sectional area of tree stems per unit area of land. It is usually expressed as square meters per hectare or square feet per acre. In older stands, basal area serves as a measure of stand density—the higher the value, the more cross-sectional area (of wood volume) concentration in a given area of land.

Base saturation—The extent to which the adsorption sites in a given volume of soil are saturated with ions other than hydrogen and aluminum. Usually, it is expressed as a percentage of the total cation exchange capacity (CEC).

Clone bank—A special planting made by vegetative reproduction techniques (e.g., grafting) designed to preserve certain high-value genetic traits such as disease resistance, high cone production, and good adaptability to dry or wet sites.

Cone/seed production—A measure of whether trees in a plantation are producing mature cones (and presumably seeds) that can be used for afforestation and reforestation efforts. Cone production assessment is subjective and usually specified as a certain number of cones being visible or actually collected from individual trees.

Cubic meter (or cubic foot)—A volumetric measurement (m^3 or ft^3) specifying the amount of wood material (with or without bark) having dimensions of 1 by 1 by 1 meter in a unit area of land. The higher the value, the better the site productivity, assuming all other conditions of moisture, climate, and management are the same for the areas being compared.

Forking—A stem defect on trees that lowers wood quality for processed wood products. Instead of one straight stem, two or more stems are present.

Foxtail(ing)—A growth phenomenon exhibited when conifer trees are planted outside their native ranges. Instead of whorls being produced normally as the main stem grows, the whorls are not produced for 2 to 6 years. The resultant branchless area resembles a fox's tail—all needles are concentrated on the tree's main stem.

Gleization—A term associated with poorly drained soils, lacking oxygen. Instead of bright red, yellow, brown soil color, gley soils are bright or pale grey, blue-grey, or white in color.

Hectare (or acre)—A unit of land area, 100 meters (327 feet) on a side, used to express site productivity. Examples are cubic meters (m^3) per hectare (total volume) and square meters (m^2) per hectare (total basal area) (see mean annual increment).

Mean annual increment—A site productivity measurement unit obtained by dividing total basal area or total volume in a stand of trees by the age since outplanting.

Milliequivalents per 100 grams—The unit of measurement (meq/100g) for determining base saturation and cation exchange capacity. For example, if a clay has cation exchange capacity of 1 milliequivalent, it is capable of exchanging 1 milligram of hydrogen, or its equivalent, for every 100 grams of clay. Fertile soils have higher values than nutrient-poor soils.

Outside-bark yield (or overbark yield)—Total or mean annual volume increment, which includes the outside bark. For thin-bark species such as eucalyptus, outside- and inside-bark figures are almost identical. For thick-bark species such as Caribbean pine, outside-bark yield will surpass inside-bark yield by 10 to 20 percent or more.

Outplant density—The total number of trees planted per unit area of land. High densities (3,200 trees per hectare or 1,306 trees per acre) are used for small-size products such as posts or pulp and can be grown in 10 to 20 years or less. Lower densities (≤2,100 trees per hectare or 857 trees per acre) are used to produce larger size trees that are utilized for utility poles and sawtimber.

Choosing the correct density or stocking is dependent upon a species' ability to grow in crowded conditions, which products can be sold at the end of a selected rotation age, and expected financial return after discounting costs of planting, tending, and harvesting.

Planting density—The total number of trees per unit area (hectare or acre) planted. Nursery and planting costs increase as planting density increases.

Provenance—The source or origin of seeds or vegetative material used in reforestation work. Seed origin is important because seeds from some sources result in trees having greater foxtailing, better growth, better wood quality, and higher wind resistance than others of the same species. Seed source differences exist between countries and between regions of individual countries.

Reforestation—Replanting trees on lands that were once covered with trees, established either by natural succession or by planting—contrasts with afforestation.

Rotation—The total number of years that trees are left to grow for a particular product; e.g., rotation age 15 years for sawlogs, 8 years for pulp, or 5 years for posts.

Seed production stand—Existing stands that are thinned heavily to reduce competition among remaining stems for nutrients and moisture so that seed production is favored; fertilizers can be applied to improve site fertility.

Site index—The expected height of the tallest trees on a given site at a specified (base) age, usually 25 or 50 years for temperate species. For fast-growing tropical species, the base age is usually 15 to 20 years or less.

Soil structure—The natural combination or arrangement of soil particles. Common types of structure are:

blocky/subangular blocky—common in heavy clay surface and subsurface horizons, particularly in humid areas.

granular—rounded aggregates easily shaken apart; subject to wide and rapid changes dependent upon soil management practices.

no structure—individual sand grains or particles not held together by organic matter and humus.

Soil taxonomy—A classification system designed to characterize and name soils for predicting their behavior regarding agricultural, silvicultural, and engineering properties—it reflects levels of detail similar to the botanical system for the plant kingdom. The recognized 11 soil orders are:

Entisols—young soils with only A and C horizons. Soil development is limited by highly resistant minerals or erosion and deposition forces that continually create new land surfaces.

Inceptisols—young soils having greater development than Entisols—most have a B horizon. They exist in all climatic regions except deserts.

Aridisols—desert soils that are dry almost all year. Some contain salt, and most have high amounts of calcium carbonate because leaching is minimal.

Mollisols—represent very productive agricultural soils formed under native prairie pasture. Base status is very high.

Vertisols—dark, clay-rich soils that exist in both warm temperate and tropical areas. In summer, soils shrink to form large cracks; when wet, cracks swell shut and water is repelled from the surface.

Spodosols—sandy soils common to glacial outwash areas of the boreal forests and to coastal marine deposits of tropical areas. A distinct whitish, bleached A_2 horizon exists between an overlying acid humus layer and an underlying dark spodic horizon rich in humus and/or iron oxides.

Alfisols—high-base-status soils usually existing under temperate hardwood forests and more stable landscapes in tropical areas. Once cleared, these soils are productive and respond well to fertilizers.

Ultisols—low-base-status soils existing in warm temperate and tropical regions. Bases are lower than in Alfisols because bedrock material has little calcium and is sometimes lacking in other nutrients due to abundant rainfall and leaching.

Oxisols—highly weathered soils that are extremely infertile. Very granular structure favors high infiltration and easy tillage, yet added nutrients are not tightly held by inert clays.

Histosols—characterized by high accumulation of organic matter. These soils develop in situations where conditions are either too cool and/or too wet for decomposition rates to exceed plant biomass production rates.

Andisols—Dark colored soils derived from volcanic ash, comprising the newest order in soil taxonomy. They contain high amounts of organic carbon ($\leq$25 percent)/volcanic glass, and aluminum and can become quite infertile upon weathering.

Survival density—The actual number of trees surviving per unit area at a given measurement age. Mortality is usually rapid when trees are young but gradually stabilizes as trees become older. By measuring survival at different ages, one can construct survival curves showing the number of surviving trees at any age.

Tallest trees—These are generally referred to as the dominant and codominant individuals in a planting. Dominants are those whose crowns overtop those of the general canopy; codominants are those whose crowns represent the general canopy level of a stand.

Thinning—Cutting a specified portion of a growing stand of trees to reduce competition. This allows crop trees more nutrients and water and concentrates future wood increment on fewer, more valuable stems. Where labor is expensive and markets are not available for thinned wood material, outplant density is generally reduced to avoid thinning before final harvest.

Appendix B

Training Accomplishments of Forestry Staffs in Cooperator Countries

Table B-1.—*Specific activities and expenses involved in accomplishing organizational work and training goals in Costa Rica, 1985–86*

Name/affiliation	Date	Activity or expense item	Project cost in U.S. dollars
Technological Institute of Costa Rica	March 1985	Training in new growth and yield techniques and soil sampling activities	....
	March 1985	Field equipment for growth and yield work	1,632
	March–April 1985	Per diem, lodging, and contract labor costs associated with completing field work	6,034
P. Camacho	June–Sept. 1985	Airfare from Costa Rica to Oxford Univ., United Kingdom, for a tropical forestry course	1,400
P. Camacho	Sept.–Oct. 1986	Attendance at a 1-week meeting in Puerto Rico on the forests of tropical America; review of forestry research techniques with Caribbean pine in eastern Venezuela	2,140
Freddy Rojas	Sept.–Oct. 1986	Attendance at a 1-week meeting in Puerto Rico on the forests of tropical America; review of forestry research with native forest and plantation species in Colombia	2,750
Total			13,956

Table B-2.—*Specific activities and expenses involved in accomplishing organizational work and training goals in Jamaica, 1983–86*

Name/affiliation	Date	Activity or expense item	Project cost in U.S. dollars
FIDCO field crew and Forest Dept. staff	Oct.–Nov. 1983	Training in new growth and yield techniques and soil sampling activities	....
FIDCO/Forest Dept.	Oct.–Nov. 1983	Field equipment for growth and yield work	2,869
Lecia Foster, Forest Dept.	June–July 1984	Attendance at 1-week meeting on forest pest management in Athens, GA; visit to USDA Forest Service insect and disease research installations in North Carolina, Florida, and Louisiana	2,818
Keith Porter, Forest Dept.; Cedric George, FIDCO	Aug. 1986	Participation in 1-week training on field/lab determination of wood density for pine and hardwood species	2,822
Keith Porter, Forest Dept.; Owen Evelyn, FIDCO	Sept.–Oct.1986	Attendance at 1-week meeting in Puerto Rico on forests of tropical America; review of research, operational planting, and harvesting techniques with Caribbean pine in eastern Venezuela for 1 week	4,045
Total			12,554

Table B-3.—*Specific activities and expenses involved in accomplishing organizational work and training goals in Trinidad, 1983–86*

Name/affiliation	Date	Activity or expense item	Project cost in U.S. dollars
Trinidad Forest Division	Oct. 1983	Training in new growth and yield techniques and soil sampling activities	....
Trinidad Forest Division	Oct. 1983	Field equipment for growth and yield work	1,303
One officer	April 1984	Three-week training in tropical plantation management, North Carolina State Univ., Raleigh	2,785
Two officers	Sept.–Oct. 1986	Attendance at 1-week meeting in Puerto Rico on forests of tropical America; review of research, operational planting, and harvesting techniques with Caribbean pine in Venezuela	3,714
One officer	Sept.–Oct. 1986	Attendance at 1-month seminar on forest management, sponsored by Univ. of Michigan, Ann Arbor	4,829
Two officers	Oct. 1986	Attendance at 1-week IUFRO meeting on tree improvement in Virginia and participation in postmeeting tour of private and state forestry land holdings in the South	3,800
Total			16,431

Table B-4.—*Specific activities and expenses involved in accomplishing organizational work and training goals in Venezuela, 1983–86*

Name/affiliation	Date	Activity or expense item	Project cost in U.S. dollars
CONARE, Chaguaramas field station personnel	Oct.–Nov. 1984	Training in new growth and yield techniques and soil sampling activities	....
		Field equipment for growth and yield work	1,832
		Slide projector	395
Ricardo Bellandi	Jan.–July 1984	Special graduate program in tree improvement	4,774
Omar Lonsartt, Victor Itanare, Pedro Gomez	March 1985	Training in harvesting techniques for *Pinus radiata* plantations in Chile	9,750
Ricardo Bellandi	Sept.-Oct. 1986	Attendance at 1-week meeting in Puerto Rico on forests of tropical America; review of research and harvesting techniques for Caribbean pine with other technical counterparts in eastern Venezuela for 1 week	1,776
Total			18,527

Appendix C

Various Reports Prepared for the Caribbean Pine Project

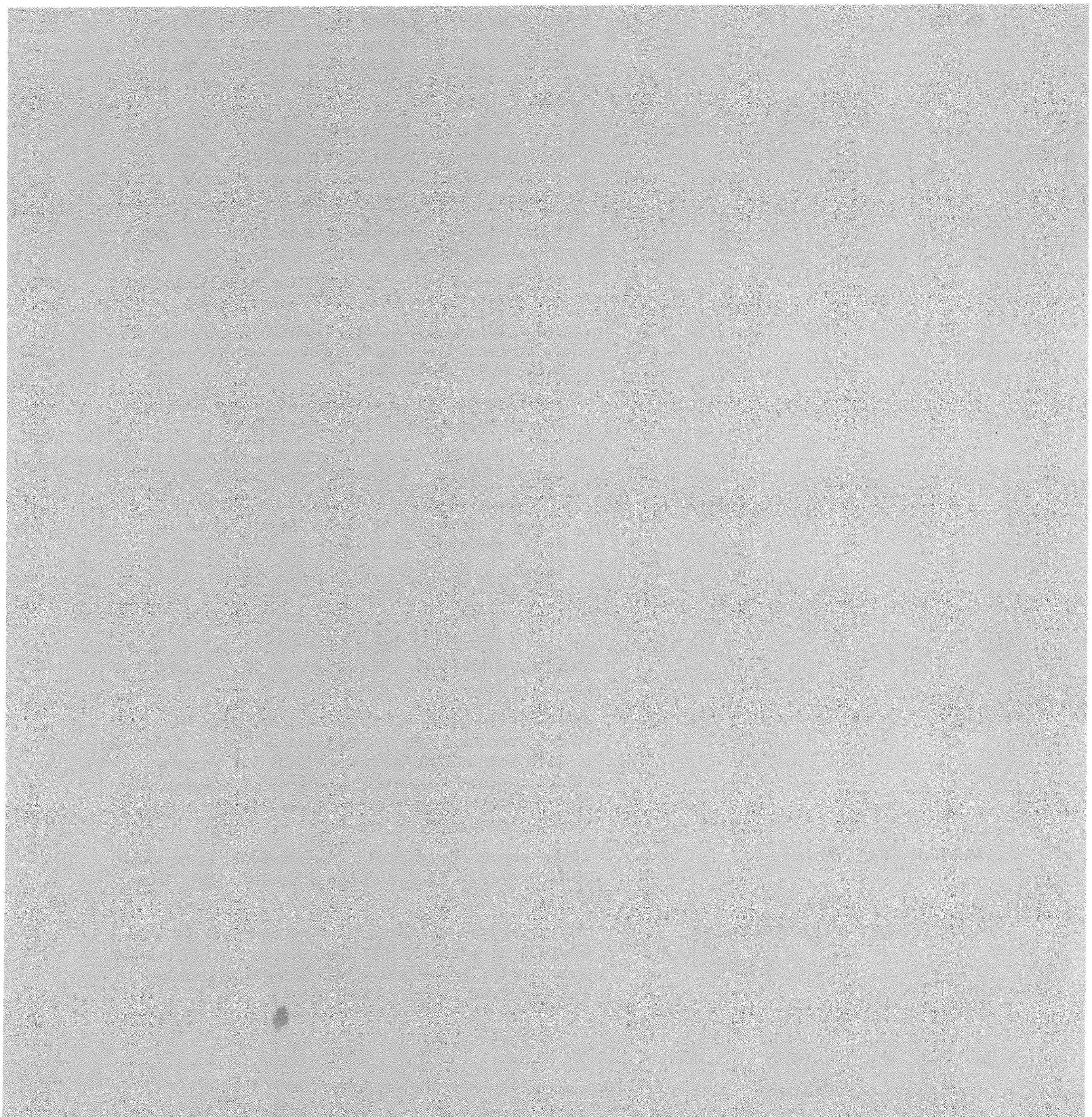
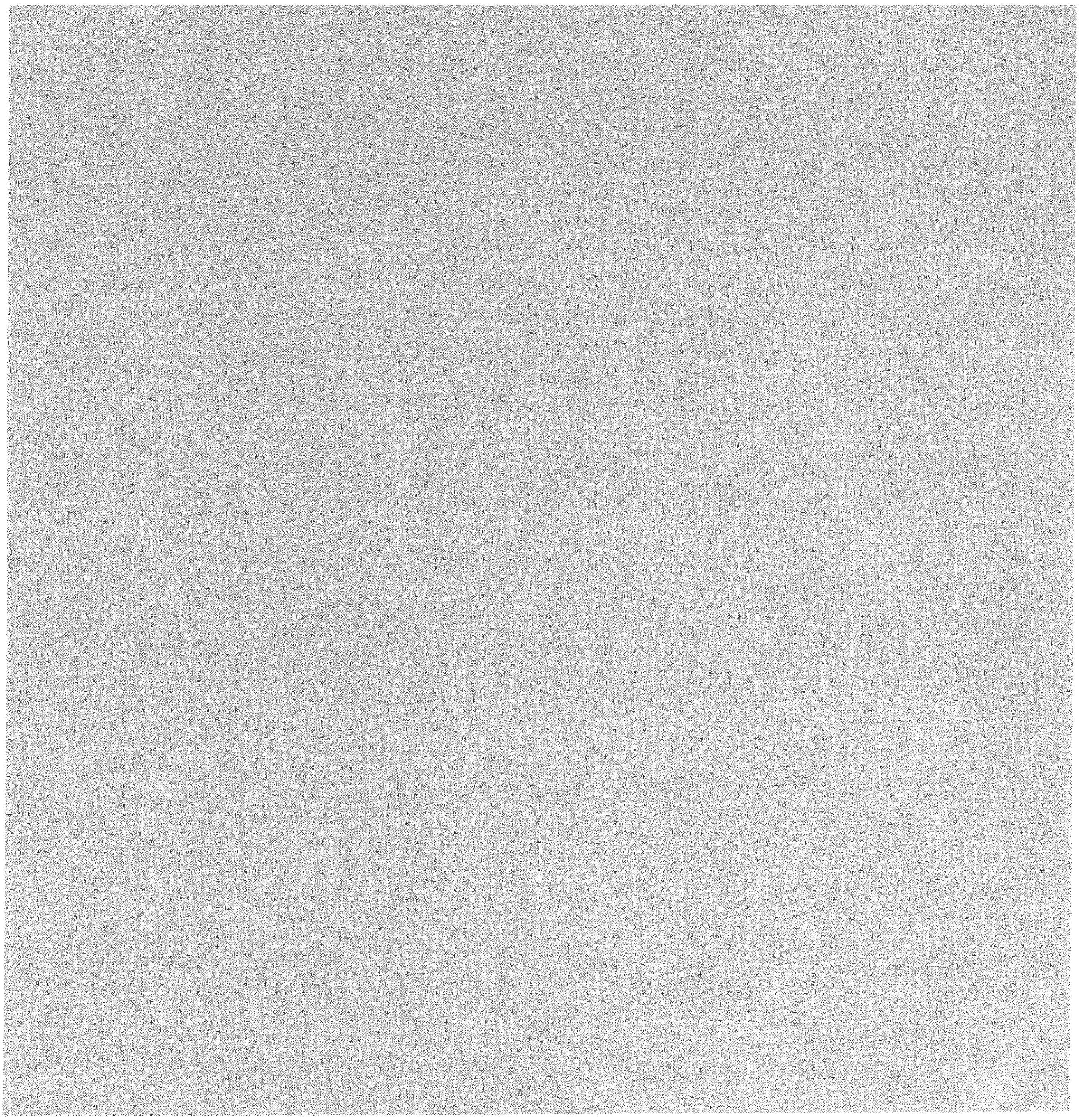


Table C-1.— *List of papers that incorporate field data and/or observations from the Caribbean pine project*

Authors	Publication information
Leon H. Liegel	Issues of plantation forestry in watershed management on small Caribbean islands in the 1980's. 1985. In: Lugo, A E.;Brown, Sandra, eds. Watershed management in the Caribbean: Proceedings, second workshop of Caribbean foresters; 1984 March 19–23; Kingstown, St. Vincent. Rio Piedras, PR: U.S. Department of Agriculture, Forest Service, Institute of Tropical Forestry, and Man and the Biosphere: 147–154.
Leon H. Liegel, Roy Jones, Guy Symes, Bal Ramdial, and J. J. Cabrera Malo	USAID supports study of Honduras pine in the Caribbean. 1985. Journal of Forestry. 83(6): 376–377.
Charles R. Venator, Leon H. Liegel, and James P. Barnett	Bare-root versus container production of pines in the American tropics. 1985. In: South, David, ed. Proceedings, international symposium on nursery management practices for the southern pines; 1985 August 4–9; Montgomery, AL. Auburn, AL: School of Forestry, Alabama Agricultural Experiment Station, Auburn University: 72–82.
Leon H. Liegel	The following papers in: Barnes, R. D.; Gibson, G. L., eds. 1984. Provenance and genetic improvement strategies in tropical forest trees; 1984 April 9–14; Mutare, Zimbabwe. Oxford, United Kingdom; Commonwealth Forestry Institute. 663 p.
	Density effect on *Pinus caribaea* growth at 18–20 years in Puerto Rico: 560–561.
	Growth and selection traits of Mt. Pine Ridge, Belize, plus-tree progeny in Puerto Rico at 11.6 years: 554–555.
	Height and diameter growth correlations with soil variables for normal-branched and foxtail *Pinus caribaea* provenances in Puerto Rico: 322–323.
	Hurricane susceptibility of *Pinus caribaea* and *Pinus oocarpa* provenances in Puerto Rico: 318–319
	Normal-branched and foxtail *Pinus caribaea* height and diameter growth correlations with several foliage variables in Puerto Rico: 358–359.
	Overall growth of early-distributed Mountain Pine Ridge *Pinus caribaea* seed sources in Puerto Rico: 562–563.
	Regional assessment of *Pinus caribaea* growth and yield on diverse soils in selected countries of the Caribbean Basin: 356–357.
Leon H. Liegel	Growth, form, and flowering of Caribbean pine families in Puerto Rico. 1985. Commonwealth Forestry Review. 64(1):67–74.
Charles R. Venator and Leon H. Liegel	Manual de viveros mecanizados para planatas a raiz desnuda; y sistema semi-mecanizado con recipientes de volumenes menores a 130 cc. Ministerio de Agricultura y Ganaderia, Programa Nacional Forestal y Agencia para El Desarrollo Internacional del Los Estados Unidos. [Proyect: Apoyo al sector Forestal del Ecuador 518-0023] Quito, Ecuador.
Mohammed Zakir Hussain	Growth studies of plantations of *Pinus caribaea* var. *hondurensis* in Puerto Rico. Ph.D. dissertation. Yale Univ., New Haven, CT. 118 p.
Leon H. Liegel and Charles R. Venator	A technical guide for forest nursery management in the Caribbean and Latin America. 1987. Gen. Tech. Rep. SO-67. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 156 p.

Appendix D

Plot Data Summaries for Countries Included in the Caribbean Pine Project



Sheet codes	Code explanation
Vol_HA	Total outside-bark yield: cubic meters per hectare
BA_HA	Total basal area: square meters per hectare.
TREES_HA	Total number of trees surviving per hectare at time of measurement.
HDC	Mean plot height (meters) of dominant and codominant trees.
SI	Site index: estimated plot heights (meters) to a given base age, 15 years, for all countries.
AGE	Age in years since outplanting.
TP	Number of trees originally planted: outplant density.
GROUP	Predetermined soil, geology, or life zones used to stratify plantings before sampling started—plots within the same group were assumed to have the same physical and chemical soil properties.

COSTA RICA

OBS	STUDY	PLOT	VOL_HA	BA_HA	TREES_HA	HDC	SI	AGE	TP	GROUP
1	507	901	350.465	51.2278	1986.10	17.6500	22.7876	9	2114.16	PRE-MONTANE RAIN FOREST
2	507	902	213.504	39.0299	1437.30	14.0455	21.1056	7	1904.76	TROPICAL RAIN FOREST
3	507	903	117.633	21.6223	1055.17	14.9375	20.6581	8	1992.83	TROPICAL RAIN FOREST
4	507	904	355.968	56.2196	1253.13	14.7500	22.1643	7	1904.76	TROPICAL RAIN FOREST
5	507	905	617.976	67.6099	1499.32	25.6000	27.3226	13	2415.46	PRE-MONTANE RAIN FOREST
6	507	906	158.652	32.2982	2368.42	11.9500	19.9045	6	2770.08	PRE-MONTANE RAIN FOREST
7	507	907	95.999	25.6860	1904.12	9.2500	17.5900	5	2506.27	PRE-MONTANE RAIN FOREST
8	507	908	188.684	35.2489	1485.51	12.2500	20.4042	6	2164.50	TROPICAL WET FOREST
9	507	909	240.302	42.3705	1921.18	13.9500	16.1635	11	2267.57	PRE-MONTANE RAIN FOREST
10	507	910	130.612	22.8200	1370.37	13.1500	19.7600	7	2380.95	PRE-MONTANE RAIN FOREST
11	507	911	256.043	39.4725	1345.76	16.4583	19.0698	11	1481.48	TROPICAL WET FOREST
12	507	912	462.340	62.2252	1329.33	21.5000	22.1728	14	2066.12	PRE-MONTANE RAIN FOREST
13	507	913	594.754	75.0098	1728.33	20.1000	20.1000	15	1893.94	PRE-MONTANE RAIN FOREST
14	507	914	439.468	63.0823	1975.31	17.6500	20.4506	11	2500.00	PRE-MONTANE RAIN FOREST
15	507	915	275.605	49.6159	1563.18	14.8500	22.3146	7	1893.94	TROPICAL WET FOREST
16	507	916	32.135	10.2663	1721.66	4.7500	9.0327	5	2173.91	PRE-MONTANE RAIN FOREST
17	507	917	415.956	53.1490	1366.12	20.5500	21.9328	13	1893.94	PRE-MONTANE RAIN FOREST
18	507	918	345.984	53.7059	1793.25	14.8000	22.2394	7	2016.13	PRE-MONTANE RAIN FOREST
19	507	919	93.483	23.1405	1511.28	9.4583	27.9973	3	1811.59	PRE-MONTANE RAIN FOREST
20	507	920	182.989	29.8608	1075.94	15.0000	16.6378	12	1194.74	TROPICAL RAIN FOREST
21	507	921	356.786	46.5906	1215.94	18.4000	21.3196	11	1602.56	PRE-MONTANE RAIN FOREST
22	507	922	568.941	54.1683	621.52	27.1364	25.7289	17	1149.43	TROPICAL RAIN FOREST
23	507	923	652.021	67.7807	1184.48	22.5909	24.1110	13	1600.00	PRE-MONTANE RAIN FOREST
24	507	924	167.784	33.0488	2298.85	9.6000	18.2556	5	2500.00	TROPICAL RAIN FOREST
25	507	925	156.147	30.4943	1142.86	11.4000	13.2089	11	1231.53	TROPICAL RAIN FOREST
26	507	926	231.127	34.1304	1150.31	16.8000	20.4646	10	1250.00	TROPICAL RAIN FOREST
27	507	927	75.929	19.1712	2222.22	7.8500	17.8627	4	2631.58	TROPICAL RAIN FOREST
28	507	931	59.784	15.2302	1445.31	8.6000	19.5693	4	2923.98	TROPICAL RAIN FOREST
29	507	932	111.840	24.2775	2062.50	10.8500	24.6891	4	2272.73	TROPICAL RAIN FOREST
30	507	933	129.612	22.3132	1134.10	13.3500	15.4683	11	1250.00	TROPICAL RAIN FOREST
31	507	934	132.532	25.9636	991.78	11.4000	18.9884	6	1082.25	TROPICAL RAIN FOREST
32	507	936	37.723	10.9987	1193.97	6.8000	20.1285	3	1428.57	TROPICAL RAIN FOREST
33	507	937	163.239	32.7452	1619.94	12.6364	21.0477	6	1666.67	PRE-MONTANE RAIN FOREST
34	507	938	561.197	70.7008	1539.39	22.6500	23.3588	14	2000.00	PRE-MONTANE RAIN FOREST
35	507	939	324.005	52.2585	1410.26	16.3636	21.1268	9	1538.46	PRE-MONTANE RAIN FOREST
36	507	940	100.449	22.0081	1441.63	10.8500	20.6326	5	1818.18	PRE-MONTANE RAIN FOREST
37	507	941	377.117	38.8600	837.84	28.2000	29.0825	14	1379.31	TROPICAL RAIN FOREST
38	507	942	268.121	36.3121	1111.11	20.2000	21.5592	13	1538.46	PRE-MONTANE RAIN FOREST
39	507	943	293.290	38.6034	1127.23	20.1500	23.3473	11	1428.57	PRE-MONTANE RAIN FOREST
40	507	944	665.301	76.3424	1295.24	25.6000	24.2722	17	1602.56	PRE-MONTANE RAIN FOREST
41	507	945	572.627	67.0379	1250.00	24.4545	28.3348	11	1538.46	PRE-MONTANE RAIN FOREST
42	507	946	136.539	28.0456	1426.10	13.0000	19.5346	7	1602.56	TROPICAL WET FOREST
43	507	948	384.289	55.3577	1972.39	18.6000	22.6572	10	2267.57	TROPICAL WET FOREST
44	507	950	90.111	18.7262	770.98	11.7000	16.1808	8	816.99	TROPICAL RAIN FOREST
45	507	970	86.420	19.1531	1555.10	9.3000	17.6851	5	2380.95	TROPICAL WET FOREST
46	507	971	105.883	26.0108	2068.01	10.1000	22.9825	4	2380.95	TROPICAL WET FOREST
47	507	972	85.749	19.1444	999.47	10.0909	16.8079	6	1041.67	TROPICAL WET FOREST
48	507	973	27.754	7.7398	1383.84	6.8000	15.4734	4	2500.00	TROPICAL WET FOREST
49	507	974	19.130	5.9198	1512.20	5.3333	10.1420	5	2173.91	TROPICAL WET FOREST
50	507	975	130.545	29.1903	1862.98	9.9000	18.8261	5	2506.27	TROPICAL RAIN FOREST
51	507	976	145.812	36.7121	2096.86	8.7000	13.0732	7	2173.91	PRE-MONTANE RAIN FOREST
52	507	977	57.723	15.5135	1887.46	8.1000	23.9766	3	1976.28	PRE-MONTANE RAIN FOREST
53	507	978	167.395	36.4171	2050.26	10.6667	31.5741	3	2801.12	TROPICAL RAIN FOREST
54	507	979	103.080	19.8739	1168.89	11.2727	21.4365	5	1298.70	TROPICAL RAIN FOREST
55	507	980	90.334	19.0573	1370.23	10.2000	19.3966	5	1642.04	TROPICAL RAIN FOREST
56	507	981	555.745	58.3730	1401.45	22.5455	26.1228	11	1602.56	TROPICAL RAIN FOREST
57	507	982	171.165	28.3406	1354.30	15.2000	28.9047	5	1602.56	TROPICAL RAIN FOREST
58	507	983	125.058	26.2713	1505.89	10.7500	20.4425	5	1602.56	TROPICAL RAIN FOREST

JAMAICA

OBS	STUDY	PLOT	VOL_HA	BA_HA	TREES_HA	HDC	SI	AGE	TP	SOILS
1	507	2	294.99	40.219	1676.57	19.9000	17.7585	18	3086.42	CUFFY GULLY
2	507	7	712.25	88.766	1505.97	25.5000	20.3065	22	1736.11	SEVERAL SERIES
3	507	9	620.57	69.557	1402.14	25.4500	20.7879	21	1736.11	VALDA
4	507	11	438.33	61.571	1755.56	20.5500	18.3385	18	2267.57	VALDA
5	507	12	457.29	45.381	1147.20	22.7273	19.6464	19	1736.11	VALDA
6	507	22	381.14	54.998	1073.54	22.3500	20.6467	17	3086.42	VALDA
7	507	23	367.92	67.439	3381.99	15.0500	15.0500	15	4444.44	VALDA
8	507	25	366.62	46.398	1036.24	26.8182	23.1827	19	3086.42	HALLS DELIGHT
9	507	28	291.45	35.590	1165.97	20.6923	19.8513	16	1736.11	HALLS DELIGHT
10	507	31	247.27	35.157	1058.60	16.5909	20.6571	11	1736.11	VALDA
11	507	32	133.26	22.302	655.92	16.8000	17.5885	14	1736.11	SEVERAL SERIES
12	507	33	537.11	62.702	1408.23	21.8455	20.1806	17	1736.11	SEVERAL SERIES
13	507	35	325.85	49.849	1154.68	20.7000	18.4724	18	1736.11	SEVERAL SERIES
14	507	36	299.86	32.614	703.81	23.1500	19.4320	20	1736.11	SEVERAL SERIES
15	507	37	362.70	50.803	1575.30	22.7222	17.2821	24	1736.11	SEVERAL SERIES
16	507	42	342.84	37.435	848.80	24.7917	22.9023	17	1736.11	SEVERAL SERIES
17	507	43	304.51	47.443	1434.63	16.8846	22.6484	10	1736.11	HALLS DELIGHT
18	507	50	171.44	37.841	1469.24	12.5000	18.2833	9	1736.11	SEVERAL SERIES
19	507	51	271.21	57.846	2078.61	13.7500	20.1116	9	3086.42	SEVERAL SERIES
20	507	60	627.57	58.443	1115.41	27.9286	20.8032	25	1736.11	CUFFY GULLY
21	507	83	682.84	61.154	934.32	28.5500	22.2025	23	1736.11	CUFFY GULLY
22	507	106	173.62	33.881	1330.49	13.3333	19.5021	9	1736.11	VALDA
23	507	122	906.89	112.315	2226.56	22.3636	20.6593	17	3086.42	VALDA
24	507	143	227.21	37.904	1067.26	14.5833	19.5615	10	1736.11	HALLS DELIGHT
25	507	301	533.83	72.728	1758.53	22.6500	19.0123	20	3086.42	CUFFY GULLY
26	507	302	252.30	52.101	1385.04	14.0500	20.5504	9	1736.11	CUFFY GULLY
27	507	307	323.68	29.589	331.12	28.6818	24.0754	20	1736.11	LIMESTONE
28	507	310	248.90	56.655	2561.98	11.5500	15.4927	10	3086.42	HALLS DELIGHT
29	507	313	437.82	39.613	723.92	25.6000	20.9104	21	1736.11	HALLS DELIGHT
30	507	317	356.39	43.108	859.02	22.1000	20.4157	17	1736.11	LIMESTONE
31	507	320	1235.67	139.285	1916.85	24.4500	19.0140	23	3086.42	HALLS DELIGHT
32	507	321	269.70	31.509	503.90	18.9545	14.1187	25	1736.11	LIMESTONE
33	507	322	497.22	73.955	1161.27	22.5500	16.7968	25	1736.11	VALDA
34	507	325	277.24	34.116	680.53	20.5833	18.3683	18	1890.36	LIMESTONE
35	507	326	649.76	64.894	1384.44	25.8000	23.8337	17	1736.11	HALLS DELIGHT
36	507	328	559.51	51.956	1004.25	26.7727	26.7727	15	1736.11	CUFFY GULLY
37	507	330	83.37	19.555	1275.51	11.0000	17.8229	8	1736.11	CUFFY GULLY
38	507	334	129.54	21.650	1265.77	13.6000	14.2383	14	1736.11	LIMESTONE
39	507	621	370.05	58.340	1892.30	17.8182	17.8182	15	3086.42	CUFFY GULLY
40	507	625	374.02	40.955	595.09	24.5250	23.5282	16	1736.11	HALLS DELIGHT
41	507	630	214.37	37.466	1107.27	15.3000	22.3787	9	1736.11	LIMESTONE

PUERTO RICO

OBS	STUDY	PLOT	VOL_HA	BA_HA	TREES_HA	HDC	SI	AGE	TP	GROUP
1	474	1	434.011	46.1479	812.77	20.8182	18.1915	22	1890.36	SANDS
2	474	4	472.843	42.2853	762.89	22.8889	20.9970	19	1736.11	SANDS
3	474	5	216.910	21.1882	596.17	20.6429	22.6173	12	1371.74	SANDS
4	474	6	708.450	62.0066	1129.22	22.8333	21.3445	18	1890.36	SANDS
5	474	8	329.908	35.5668	1724.73	18.6818	17.1377	19	3086.42	SHALLOW TO DEEP CLAYS
6	474	9	553.998	50.1438	938.18	25.5455	23.4340	19	3086.42	SHALLOW TO DEEP CLAYS
7	474	10	556.303	47.8550	1009.47	25.5000	22.9886	20	4444.44	SHALLOW TO DEEP CLAYS
8	474	11	531.788	47.1887	1070.21	25.0455	22.2170	21	3460.21	SHALLOW TO DEEP CLAYS
9	474	15	610.761	56.8261	938.18	22.9167	21.8657	17	1736.11	SHALLOW TO DEEP CLAYS
10	474	16	488.222	47.1903	1467.80	23.6818	21.7244	19	3086.42	DEEP CLAYS GT 300M
11	474	17	565.580	50.5616	1113.98	24.6154	22.1911	20	3086.42	DEEP CLAYS GT 300M
12	474	18	904.776	79.0988	1532.91	22.6364	21.5982	17	3086.42	DEEP CLAYS GT 300M
13	474	20	770.267	71.4612	1386.51	23.3182	21.0216	20	1736.11	DEEP CLAYS GT 300M
14	474	24	547.853	46.5783	968.70	26.2727	23.6852	20	1736.11	DEEP CLAYS GT 300M
15	474	25	515.240	68.7111	2258.28	15.7500	17.2564	12	3460.21	DEEP CLAYS GT 300M
16	474	26	742.886	91.8295	2522.07	17.9167	18.9752	13	3460.21	DEEP CLAYS GT 300M
17	474	27	313.101	42.9685	1108.57	17.4600	15.7404	20	3086.42	SHALLOW TO DEEP CLAYS
18	474	28	547.729	43.7080	835.38	29.5455	25.8177	22	1736.11	SHALLOW TO DEEP CLAYS
19	474	29	418.704	40.1251	1267.13	23.2500	20.9602	20	2267.57	SANDS
20	474	30	448.170	37.7437	720.32	28.7500	25.1226	22	2267.57	SANDS
21	474	31	462.198	45.4235	1221.17	26.7917	23.4113	22	2267.57	SANDS
22	474	33	435.227	30.7530	556.72	32.0625	29.4124	19	3086.42	SANDS
23	474	40	526.406	52.3477	1079.30	21.1250	21.7067	14	1736.11	DEEP CLAYS GT 300M
24	474	41	236.216	31.0434	1267.33	17.7273	23.5920	8	1736.11	SHALLOW TO DEEP CLAYS
25	474	42	278.301	33.8714	1487.11	16.6875	22.2082	8	1736.11	SHALLOW TO DEEP CLAYS
26	474	43	293.809	36.9327	1306.93	17.0500	22.6906	8	1736.11	SHALLOW TO DEEP CLAYS
27	474	50	704.565	58.1030	969.83	25.5357	21.4482	25	3086.42	DEEP CLAYS GT 300M

TRINIDAD

OBS	STUDY	PLOT	VOL_HA	BA_HA	TREES_HA	HDC	SI	AGE	TP	GROUP
1	507	701	90.261	15.6139	784.40	13.6273	17.2096	10	1371.74	WELL DRAINED
2	507	702	205.472	35.0348	1102.07	14.7923	16.7213	12	1371.74	POORLY DRAINED
3	507	703	216.667	29.2759	633.83	19.0929	17.4412	18	1371.74	POORLY DRAINED
4	507	704	219.985	27.2064	746.31	20.7818	17.3414	22	1371.74	WELL DRAINED
5	507	705	61.335	13.2022	875.42	10.9100	17.6613	7	1371.74	WELL DRAINED
6	507	706	269.720	37.3638	821.20	19.9800	19.9800	15	1371.74	WELL DRAINED
7	507	707	353.264	42.4698	919.63	20.2786	18.0618	19	1371.74	WELL DRAINED
8	507	708	308.249	39.2722	935.55	20.7600	17.6763	21	1371.74	WELL DRAINED
9	507	709	46.811	12.4544	1215.28	7.9643	10.7742	9	1371.74	WELL DRAINED
10	507	710	151.127	23.6549	840.34	15.6167	18.5885	11	1371.74	WELL DRAINED
11	507	711	373.271	40.7931	943.07	23.1667	20.6342	19	1371.74	WELL DRAINED
12	507	712	279.126	29.6198	742.86	22.2222	17.8786	24	1371.74	WELL DRAINED
13	507	713	246.120	32.2885	758.57	20.6333	20.6333	15	1371.74	POORLY DRAINED
14	507	714	336.160	40.6674	783.99	22.1846	19.3032	20	1371.74	WELL DRAINED
15	507	715	391.079	46.5287	1096.49	23.4900	18.8986	24	1371.74	POORLY DRAINED
16	507	717	67.579	13.3600	893.02	11.1250	20.3421	6	1371.74	POORLY DRAINED
17	507	718	164.521	26.6129	807.60	15.9462	18.9807	11	1371.74	POORLY DRAINED
18	507	719	54.518	12.0487	815.87	9.6545	17.6534	6	1371.74	POORLY DRAINED
19	507	720	194.917	29.3351	646.41	18.5091	19.1962	14	1371.74	POORLY DRAINED
20	507	723	213.359	32.8172	891.47	16.5308	17.8544	13	1371.74	WELL DRAINED
21	507	726	324.635	36.7187	1028.57	22.3500	20.4165	18	1371.74	POORLY DRAINED
22	507	727	384.544	42.0921	926.32	25.6500	21.8399	21	1371.74	POORLY DRAINED
23	507	730	337.890	37.5426	850.00	23.0000	20.4857	19	1371.74	POORLY DRAINED
24	507	732	302.798	38.1951	979.17	19.8750	19.8750	15	1371.74	POORLY DRAINED
25	507	733	343.303	40.8843	1020.41	20.7083	18.9169	18	1371.74	POORLY DRAINED
26	507	734	421.766	47.5480	1000.00	23.3000	18.7457	24	1371.74	POORLY DRAINED
27	507	737	307.615	38.0753	733.45	21.7000	20.9961	16	1371.74	POORLY DRAINED
28	507	739	273.047	40.4548	2133.33	15.8000	17.8604	12	6944.44	WELL DRAINED
29	507	740	94.297	18.8190	809.72	11.8000	19.1021	7	1371.74	POORLY DRAINED
30	507	741	126.533	16.1260	575.00	17.0000	20.2350	11	1371.74	POORLY DRAINED
31	507	742	249.835	28.9182	558.31	20.5417	19.2875	17	1371.74	POORLY DRAINED
32	507	743	273.398	31.1117	722.50	24.0000	20.4350	21	1371.74	POORLY DRAINED
33	507	744	156.338	28.4391	950.41	13.1000	21.2065	7	1371.74	WELL DRAINED
34	507	746	310.071	39.4227	1238.39	20.0500	18.8259	17	4444.44	WELL DRAINED
35	507	747	240.817	31.1841	483.87	21.0833	17.2645	23	1371.74	POORLY DRAINED
36	507	748	83.928	19.2183	1201.47	9.6231	11.4543	11	1371.74	WELL DRAINED
37	507	750	314.608	34.9822	705.47	22.5909	17.8762	25	1371.74	POORLY DRAINED
38	507	752	342.126	38.8871	729.79	25.2111	21.4662	21	1371.74	WELL DRAINED
39	507	753	412.056	49.3125	1129.20	22.4500	19.1153	21	1371.74	WELL DRAINED
40	507	754	449.072	57.5122	905.35	22.3500	17.4115	26	1371.74	WELL DRAINED
41	507	755	266.297	31.0643	609.52	22.7000	19.3281	21	1371.74	POORLY DRAINED

VENEZUELA

OBS	STUDY	PLOT	VOL_HA	BA_HA	TREES_HA	HDC	SI	AGE	TP	GROUP
1	507	801	367.932	42.0121	980.39	22.9091	22.9091	15	2267.57	WET CLIMATE
2	507	802	249.504	35.0609	1157.89	18.4500	18.4500	15	1642.04	WET CLIMATE
3	507	803	111.440	23.8183	845.41	12.1000	14.5891	11	1851.85	(G2) BETWEEN CLIMATE
4	507	804	73.645	15.6816	776.52	11.3333	14.5615	10	1424.50	(G2) BETWEEN CLIMATE
5	507	805	169.149	29.9645	928.57	13.9545	13.9545	15	1189.06	(G1) BETWEEN CLIMATE
6	507	806	34.313	10.2377	1111.11	6.5500	12.5227	6	1424.50	(G1) BETWEEN CLIMATE
7	507	807	182.521	31.3183	928.57	15.6818	15.6818	15	1388.89	(G1) BETWEEN CLIMATE
8	507	808	78.569	16.8189	666.67	11.2500	13.5643	11	1231.53	(G1) BETWEEN CLIMATE
9	507	809	120.850	22.7439	794.87	11.7000	14.1068	11	1543.21	(G1) BETWEEN CLIMATE
10	507	810	129.699	21.5113	423.34	14.9091	16.1947	13	1538.46	(G1) BETWEEN CLIMATE
11	507	811	186.107	31.2541	880.95	16.5833	18.0134	13	1424.50	(G1) BETWEEN CLIMATE
12	507	812	130.414	23.1121	994.32	12.5500	16.1247	10	1481.48	(G2) BETWEEN CLIMATE
13	507	813	14.398	4.5528	1554.62	4.8000	13.6396	4	.	(G1) BETWEEN CLIMATE
14	507	814	43.974	11.4230	1170.57	7.4000	14.1477	6	1481.48	(G1) BETWEEN CLIMATE
15	507	815	30.151	10.2892	1250.00	5.9444	16.8916	4	1543.21	(G2) BETWEEN CLIMATE
16	507	816	37.127	11.9975	1363.64	6.1000	17.3336	4	1666.67	(G2) BETWEEN CLIMATE
17	507	817	81.166	19.0133	1030.30	10.0000	13.8335	9	1538.46	(G1) BETWEEN CLIMATE
18	507	818	62.883	14.1692	555.56	10.2083	14.1217	9	1602.56	(G1) BETWEEN CLIMATE
19	507	819	15.116	4.9186	1133.33	5.1000	14.4920	4	1666.67	(G1) BETWEEN CLIMATE
20	507	820	20.556	6.8207	777.78	5.4000	12.6175	6	1642.04	DRY CLIMATE
21	507	821	47.202	14.6022	1138.46	7.7000	17.9916	6	1400.56	DRY CLIMATE
22	507	823	9.613	2.7867	1290.32	3.4000	13.3486	4	1424.50	DRY CLIMATE
23	507	826	97.267	21.3211	1200.00	10.9000	15.1345	10	1589.83	DRY CLIMATE
24	507	827	96.874	20.9905	972.22	10.4091	14.4529	10	1589.83	DRY CLIMATE
25	507	828	43.845	11.0757	791.86	8.0000	13.7188	8	1683.50	DRY CLIMATE
26	507	829	71.110	15.9374	1043.96	8.7273	14.9660	8	1547.99	DRY CLIMATE
27	507	830	98.106	19.8774	1000.00	11.8333	16.3697	9	1275.51	WET CLIMATE
28	507	831	91.043	18.8052	686.27	12.5000	17.2919	9	1371.74	WET CLIMATE
29	507	832	129.182	27.6350	1174.24	11.9500	14.4083	11	1322.75	WET CLIMATE
30	507	833	107.165	22.3014	944.44	12.9000	15.5537	11	1234.57	WET CLIMATE
31	507	834	50.073	12.4043	700.76	8.2000	18.5506	5	1373.63	WET CLIMATE
32	507	835	36.229	8.5356	496.45	9.1000	20.5867	5	1152.07	WET CLIMATE
33	507	836	66.692	14.2341	879.63	10.2500	17.1939	7	1234.57	WET CLIMATE
34	507	837	34.260	8.6630	952.38	8.2000	13.7551	7	1373.63	WET CLIMATE
35	507	840	46.777	11.1147	685.19	9.8500	19.3922	7	1240.69	DRY CLIMATE
36	507	841	94.174	20.7696	1292.52	9.7500	19.1953	7	1683.50	DRY CLIMATE
37	507	842	54.231	15.2360	1030.30	8.1000	18.9262	6	1488.10	DRY CLIMATE
38	507	843	32.820	8.7763	1250.00	6.1000	14.2531	6	1488.10	DRY CLIMATE
39	507	844	34.762	10.1280	1465.20	6.1091	17.7938	5	1538.46	DRY CLIMATE
40	507	850	66.983	18.0272	1355.31	8.0500	15.3905	6	1479.29	(G2) BETWEEN CLIMATE
41	507	851	105.161	19.7475	656.66	11.9167	15.3110	10	1322.75	(G2) BETWEEN CLIMATE
42	507	852	85.952	18.7716	1037.04	10.1500	15.3224	8	1379.31	(G2) BETWEEN CLIMATE
43	507	853	102.168	22.3676	1043.77	10.8889	16.4379	8	1424.50	(G2) BETWEEN CLIMATE
44	507	854	73.480	16.8033	1000.00	10.4167	19.9152	6	1424.50	(G2) BETWEEN CLIMATE

Appendix E

Important Metric/English Unit Conversions

Metric units	Approximate English units
1 cubic meter	35.3 cubic feet or 424 board feet
1 square meter	10.9 square feet
1 meter or 100 centimeters	39.4 inches or 3.3 feet
1 centimeter or 25.4 millimeters	2.54 inches
1 hectare or 10,000 square meters	2.45 acres or 106,722 square feet
0.41 hectare	1 acre or 43,560 square feet
degrees Celsius (C) (degrees F-32) (5/9)	degrees Fahrenheit (F) (degrees C) (5/9) + 32
1.6 kilometers	1 mile or 5,280 feet
1 kilo	2.2 pounds

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Liegel, Leon H., Compiler. 1991. Growth and site relationships of *Pinus caribaea* across the Caribbean Basin. Gen.Tech. Rep. SO-83. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 70 p.

Summarizes results of growth, volume, basal area, and stand conditions for *Pinus caribaea* var. *hondurensis* in five countries. Past pine management practices are reviewed for all countries. Implications of new forestry and soils research are discussed in terms of their impact on future local reforestation and afforestation strategies. Also discussed are institution building and training accomplishments conducted along with field research activities.

Keywords: Caribbean pine, Costa Rica, foxtailing, Jamaica, Puerto Rico, site index, soil-site studies, Trinidad, Venezuela.