Fuelwood and Charcoal Research in the Dominican Republic

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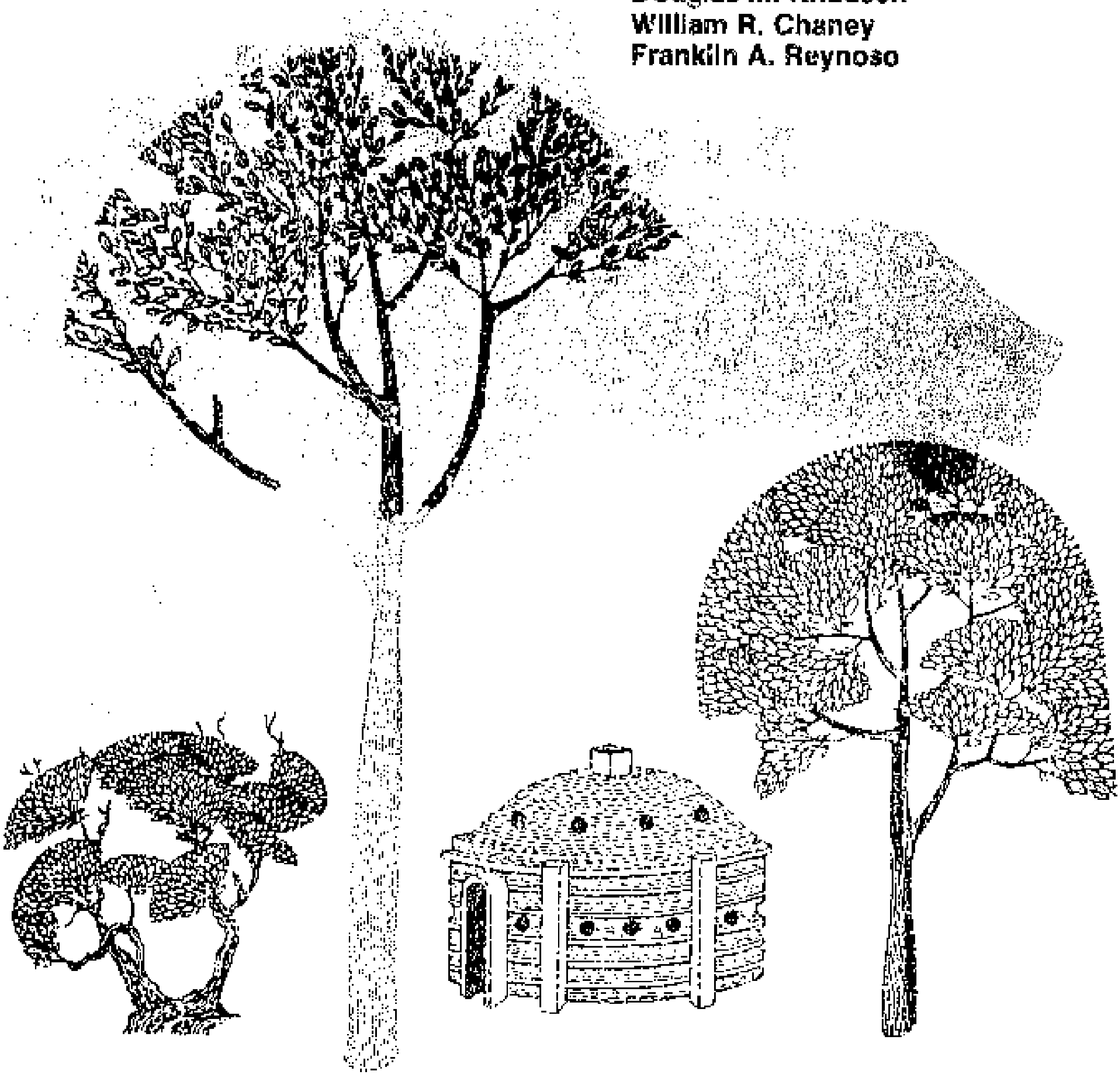

• Instituto Superior de Agricultura
• Comision Nacional de Politica Energetica
• Purdue University
• Agency for International Development

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Results of the
Wood Fuel Development Program

Executor

Coordinator

Advisor

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PREFACE

The Dominican Republic has the physical and biological requisites to be a net exporter of wood products. Instead, it now imports virtually all of its manufactured wood and faces serious shortages of fuelwood and charcoal. Wood-based products are the Dominican Republic's third most costly industrial and agricultural import.

Other serious national and international costs are those derived from the deforested watersheds of this mountainous nation: eroded soil, silted-in reservoirs, irregular water flow in rivers and irrigation canals, nonfunctional hydroelectric plants, as well as businesses and families that must spend increasing amounts of their time or income to attain adequate fuel. Indications are that the problems are just beginning as the population grows and the forest resource declines.

This publication presents results of the first major forestry research effort in the Dominican Republic. Purdue University had the pleasure of collaborating in the effort with the Instituto Superior de Agricultura (ISA) in Santiago under auspices of the National Energy Policy Commission (COENER) and the support of the U.S. Agency for International Development (USAID). Assistance was also provided by the Federal University of Viçosa, Brazil.

Some of the research results presented have not been published previously. Most of the results, however, have been published in Spanish as "Technical Notes" of ISA and distributed throughout the Dominican Republic and elsewhere. During the life of the project, 31 student theses, internal reports, special papers and class materials for short courses were produced.

This publication is Purdue University's interpretation of the research findings. Dominican foresters, represented by co-author F. Reynoso, contributed importantly to this volume. However, responsibility for errors in fact or interpretation rests with the Purdue co-authors.

Forestry research is normally thought of as a long-term enterprise. This research effort demonstrates that certain kinds of important results can be achieved in the relatively short time when appropriate research designs and strategies are executed with the efficiency of the Dominican scientists and their collaborators involved in this research program.

The institutional capacity for sustained research of ISA has been increased substantially by this collaborative effort. The return of several young scientists now in training in Brazil and the U.S. will help accelerate the pace of the research activity at ISA.

The remarkable tree growth rates documented in this report suggest that the Dominican Republic has the potential to become self-sufficient in many essential forest products and to eventually develop forest industries to serve new internal and foreign markets. Future research will produce information on means of obtaining yield increases and will identify other tree species having potential to contribute to the economic development and improved environmental protection of this nation.

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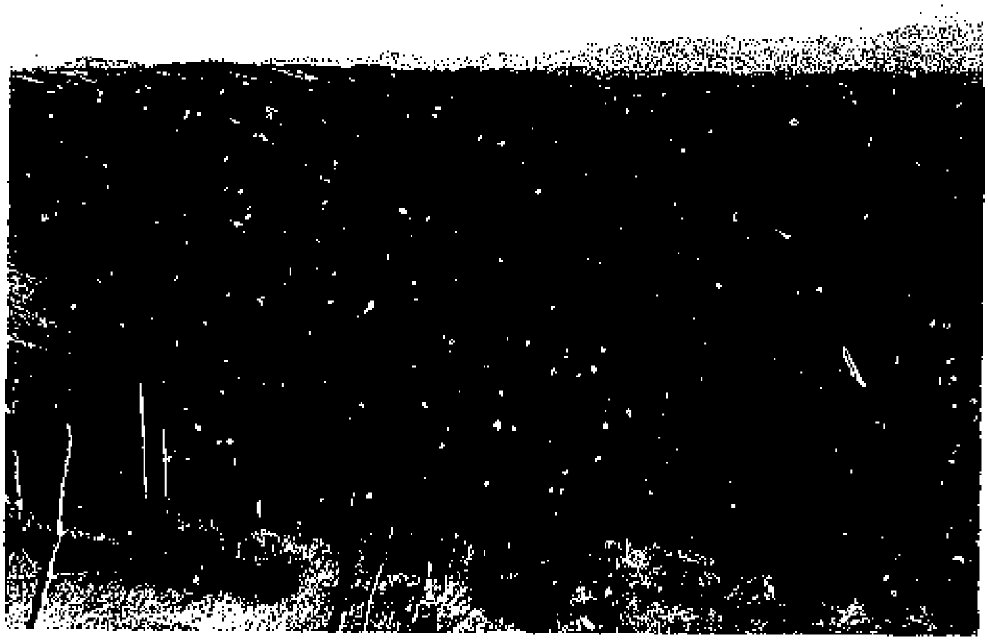

CHAPTER I

INTRODUCTION

The Dominican Republic has adequate land and economic conditions to quickly develop its forest resources. Presently however, a country that is ideally suited for forest production is importing most wood and wood products, creating a heavy burden on the trade balance and a net loss of foreign currency. Petroleum too is all imported and processed at the government refinery. Instead of progressing toward a more prosperous and productive economy, the Dominican Republic has increased its dependence on foreign wood and foreign energy and has allowed its once-vast forest resources to diminish rapidly. Forest lands have been cleared for agricultural crops and pasture and degraded by clandestine cutting for firewood, charcoal and small wood using industries.

The Wood Fuel Development Program described in this document is one of the efforts being made by the Dominican Republic to solve these forest resource problems. The history of the project began with early academic recognition of the importance of the pending fuelwood and charcoal shortage (Jennings and Ferreiras, 1979). For several years before that, government sponsored studies by international consulting groups and technical agencies such as FAO and OAS led to plans for financing research on reforestation that were to be the precursor to active forest planting efforts.

Floods, fires and an official ban on timber harvesting since 1967 dramatized the need to grow more trees, especially for fuelwood and for the protection of soils and water. Recently built reservoirs were, and still are, filling in rapidly with sediments from the denuded mountain slopes. Some of these reservoirs reportedly lost half of their water holding capacity in ten years or less. This endangers the future of agricultural irrigation and hydroelectric projects in which the nation has invested large sums. Perhaps the most vivid example of the environmental deterioration that has resulted from years of deforestation is the brown strip of water that flows in front of the capital city, Santo Domingo, whenever heavy rains upstream wash the soil into the Ozama River. The beautiful blue Caribbean, so attractive to tourists and residents alike, becomes a muddy yellow for several days after each rain. In June 1988, severe power shortages were aggravated by ten of the eleven hydroelectric plants being nonfunctional due to a lack of sufficient stored water.

A Dominican Republic Perspective

The Dominican Republic is located in the Tropical Zone, between the northern latitudes 17° and 20° and longitudes 68° and 71°. Together with Haiti it forms the second largest Antillean island, named Hispaniola (Figure 1).

The climate is subtropical. Mean temperature varies between 22°C and 28°C and rarely exceeds 32°C or falls below 15°C except at high elevations. Precipitation patterns are very complex. In some regions rainfall is evenly distributed throughout the year whereas in other regions two distinct rainy seasons occur. The Northeast and East sections of the country receive the most rainfall (1500-2750 mm/year) whereas the Southwest and Northwest are much drier (350-1000 mm/year).

Topographically, the country is quite variable. It consists of fertile valleys, high and partly deforested and eroded mountains, and desert-like plains. Five mountain ranges traverse the country, four extending in a northwesterly direction in the west of the country and a single range extending east to west in the eastern part. Of these, the Cordillera Central is the most important, with peaks over 3000 m (Sánchez, 1984). Extensive valleys lie between the major ranges. Lowland plains cover most of the eastern end of the island (Figure 2). There are numerous rivers and streams too shallow for navigation but important for irrigation and as hydroelectric power sources.

Figure 1. Map of Antillean Islands. (Source: Rand McNally)

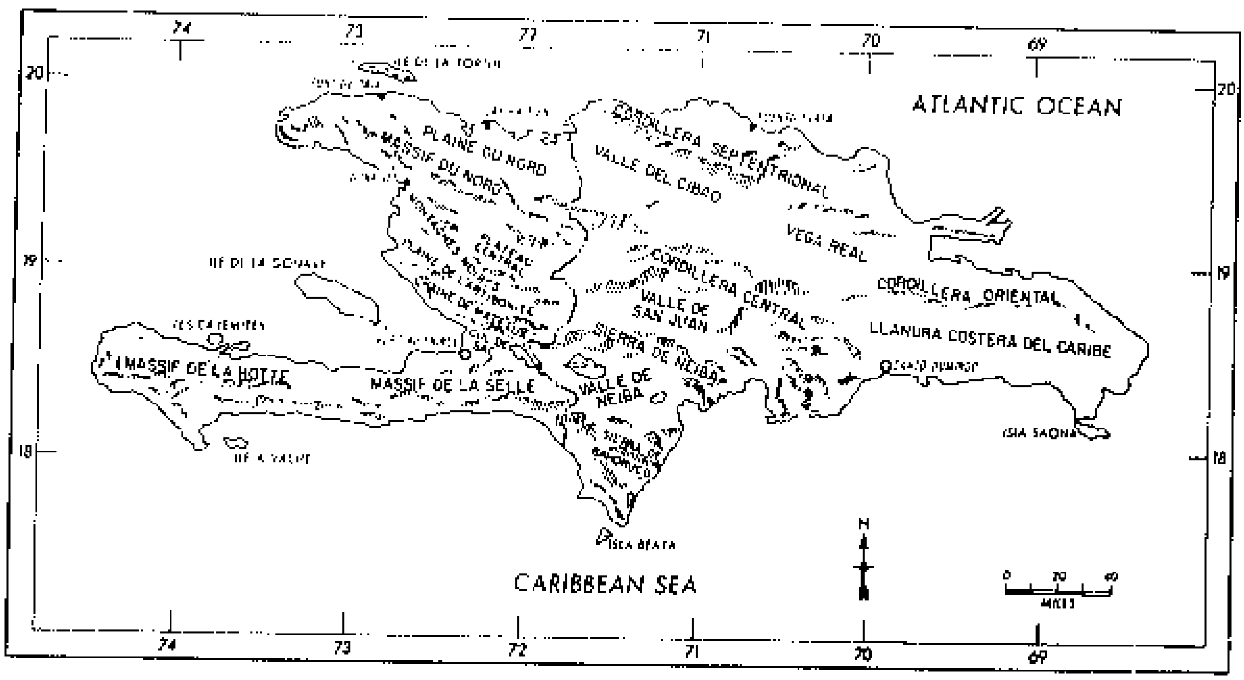

Figure 2. Relief features of the Dominican Republic. (Source: Weil et al., 1982)

The country is ecologically very diverse. Nine life zones of the Holdridge ecological classification occur here (Holdridge, 1982). Two of these cover 68% of the nation; Subtropical Moist and Subtropical Dry Forest (Figure 3). A third zone, the Subtropical Lower Montane Wet Forest, with 7% of the land is critical for a regular supply of water for irrigation and hydroelectric power.

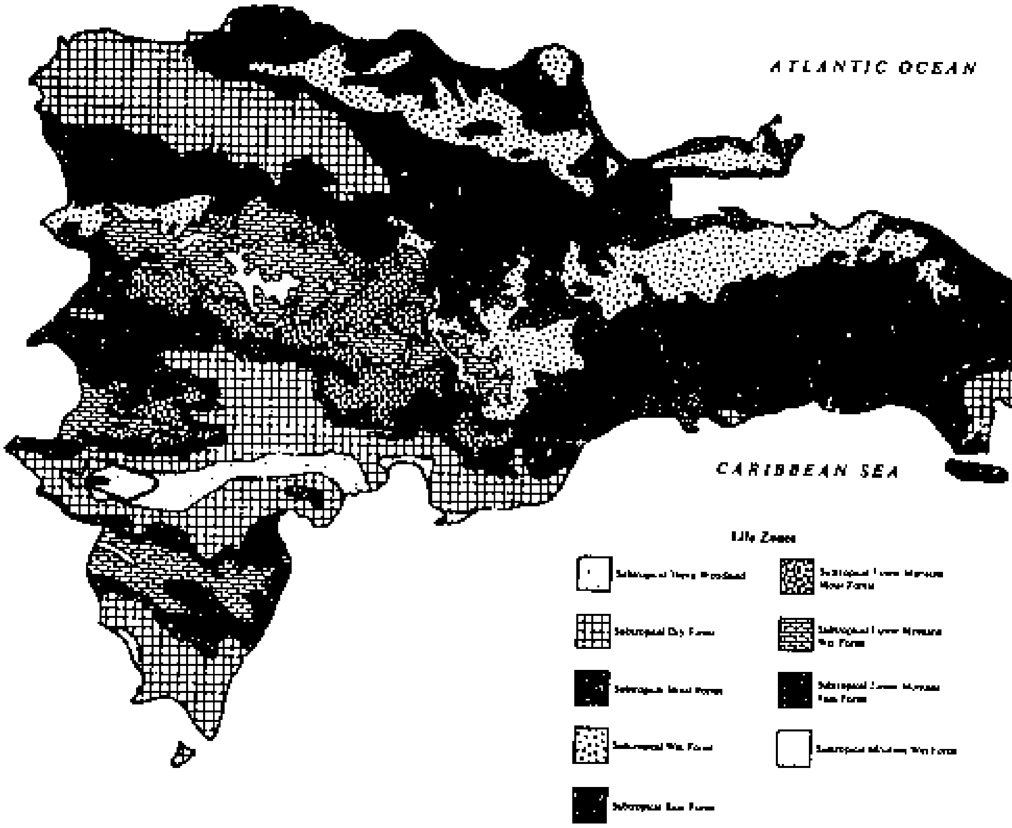

Figure 3. Holdridge Life Zones in the Dominican Republic. (Source: Holdridge, 1982)

Salient socio-geographic information is shown in Table 1. The population is young, nearly 41% being under 15 years of age, and with a significant rural component. The population is growing rapidly at an annual rate of 2.5%. The heaviest concentration of the 6.5 million inhabitants is in the capital city of Santo Domingo and in the Valle del Cibao (Figure 2). The Provinces of the country and the provincial capitals are shown in Figure 4. Almost one million Dominican citizens are resident abroad. The people are descendents of white Spanish settlers and black African slaves whose extensive intermingling produced a rich range of mixes. In 1970 the mulatto group constituted about 70% of the population. The remaining 30% was formed by whites of European descent and by blacks. Unemployment is estimated to be 30% while the level of underemployment is estimated by the World Bank to be much higher (L.A.T., 1984, 1986; Weil et al., 1982; World Population Institute, 1987).

Although the Dominican Republic is the most agricultural of the Caribbean islands, it still has to import a large proportion of its food. The majority of farms are small holdings with less than 15 hectares under cultivation and many occupy only 1 hectare. A large part of the total agricultural land (43%), however, is used by a small number of large landowners who cultivate export crops like sugarcane, coffee, cocoa and tobacco. The government controls about 40% of the land, including large sugarcane, rice and tobacco fields. Export crops are the country's main foreign exchange earner. Only 11% of the agricultural land is cultivated with food crops for domestic use (rice, corn, cassava, beans, yams, and sweet potatoes). The rest (46%) is utilized for animal production.

Table 1. Socio-geographic facts and figures about the Dominican Republic.

Surface area (km^2)	48,734
Population	6,500,000
Population density (persons/km^2)	133
Urban population (%)	52
Population growth rate (%)	2.5
Language	Spanish
Religion	Catholic (95%)
Illiteracy (%)	35
Unemployment (%)	30
Average income/capita (US $)	1,200

Source: L.A.T., 1984, 1986; World Population Institute, 1987.

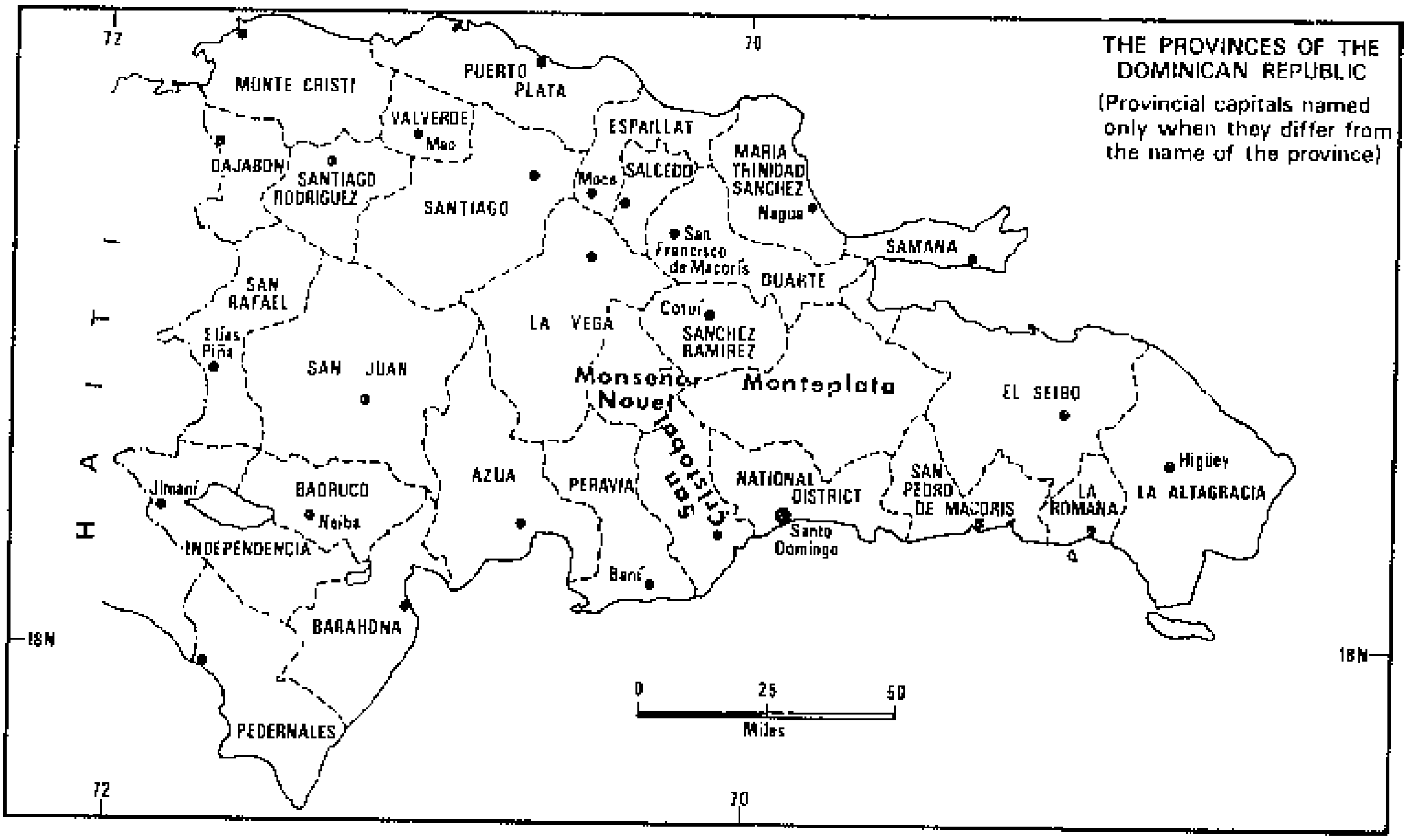

Figure 4. Provinces and provincial capitals of the Dominican Republic. (Source: Bell, 1981)

The economy is strongly dominated by the agricultural sector which employs about 58% of the working population. A small mining industry also exists; nickel, gold and bauxite are the leading minerals. Manufacturing comprises a small number of establishments, some of which are state owned. The food and beverage sector accounts for the largest proportion of manufacturing production and industrial employment. In 1987 a record US$ 1.5 billion in goods and services were imported. Of imports, lumber and other wood products are second only to petroleum products. Exports in 1987 amounted to only US$ 740 million, making the commercial trade deficit about US$ 760 million. Eighty percent of the foreign exchange from exports comes from agricultural products. An important source of income for the country is the almost 900,000 tourists who annually visit the Dominican Republic as well as the remittances to local family members by the large number of Dominicans who reside abroad. Tourism income approaches US$ 600 million yearly while remittances are estimated at US$ 800 million (Santo Domingo News, 1988; Weil et al., 1982).

In 1977, 57% of the land in the Dominican Republic was farmland and about 14% was in forest cover. A land capability classification was prepared by the Organization of American States in 1966 (Table 2).

Table 2. Land capability class for the Dominican Republic.

Class	Area (km^2)	Area (%)	Production capacity
I	537	1.1	Excellent for cultivation
II	2,350	4.9	Very good for cultivation
III	3,122	6.6	Good for cultivation
IV	3,639	7.7	Marginal for cultivation
V	6,071	12.7	Pasture; no erosion hazard
VI	5,611	11.8	Pasture; erosion hazard
VII	25,161	52.7	Forest
VIII	1,202	2.5	Wildlands
Total	47,693*	100.0	

*Does not include 588 km^2 in islands, lakes and other unclassified areas. (From Hartshorn, 1981).

Although almost 53% of the total land area in the Dominican Republic is best suited for forest production, the most recent inventory of land use (CRIES, 1980) indicates slightly less than 7,000 km^2 of forest remain in the country. This represents only 14% of the total land area. This figure may be an underestimation of the forest due to the fact that the study defines forest as having a canopy closure of at least 75%, which excludes the majority of the open pine forests. An earlier study by FAO (1973) found 10,966 km^2 (22.7%) in five forest types (Table 3). However, only about one-third of the forest land was estimated to be undisturbed by fire or slash and burn agriculture. Whatever the exact figure of remaining natural forest may be, it is clear that deforestation has taken place in many parts of the Dominican Republic which at one time was well endowed with pine, hardwood and mixed pine-hardwood forests. The causes of deforestation are uncontrolled cutting, wildfire, grazing, and conversion to agriculture. Subhumid broadleaved forests and mixed pine-hardwood forests in particular have been deforested, probably because of their accessibility for logging and better soils which are attractive for agriculture. Estimations from comparisons of present day forest and the primeval forests predicted from Holdridge Life Zones indicate that 86% of the humid broadleaved forests and 69% of the subhumid broadleaved forests have been cleared (Hartshorn et al., 1981). Especially in the turbulent years following the death of Trujillo in 1961, forests disappeared at an alarming rate.

Some measures have been taken to stem the rate of loss of forest cover. In 1967 a presidential decree closed sawmills and prohibited the cutting of trees. This greatly contributed to the protection of the remaining pine forests, which occur on poor soils in remote and rugged terrain and hence are of little interest to agriculturists. However, deforestation for slash and burn agriculture, as well as for charcoal production and firewood, continued at almost the same rate. The law also discouraged forest management and plantation establishment due to the misconception by the general populace that planted trees could not be harvested, even though a permit system is existent as part of the decree to allow plantation owners to harvest.

Table 3. Area of and percent of total land in different forest types in the Dominican Republic in 1973 according to FAO study.

Forest type	km^2	%
Pine	1,962	4.1
Mixed pine-broadleaved	1,385	2.9
Humid broadleaved	4,135	8.5
Subhumid broadleaved	3,382	7.0
Mangroves	102	0.2
Totals	10,966	22.7

From Hartshorn et al., 1981.

Reforestation activities are necessary for three major reasons; erosion control, fuelwood, and industrial wood products. Soil erosion has reached serious proportions in most of the watersheds. Soil resources in which the nation's food is produced are being lost and sediments are choking the reservoirs which are an important source of irrigation water and hydroelectric power. Covering the soil surface with more permanent crops like trees would help to alleviate the problem.

There is a large and growing demand for wood fuel in the Dominican Republic, in the form of both firewood and charcoal. Its extent is not precisely documented but all estimates are that it is large. According to a 1981 census, 75% of the population use fuelwood or charcoal for cooking. Almost all the charcoal in the country is produced in earthen kilns that give a very poor yield. This yield is considered to be about 1 unit volume of charcoal per 5-7 unit volumes of wood. In addition, the open type cooking stoves used in both rural and urban areas have an efficiency of only 7%. Growth of the population of poor coupled with an increase in price of imported fossil fuel has resulted in an increased use of wood fuel in recent years. Based on an average consumption of 0.45 m^3 of firewood/person/year, this alone means a yearly consumption of 2.9 million m^3 of wood, without considering the additional demands of industry and the conversion to charcoal for use in urban areas. Of the total energy consumption in the Dominican Republic, 67% is derived from imported fossil fuels, 1% from hydroelectric generation and 32% from sugarcane residues, fuelwood and charcoal. Much of the fuelwood and charcoal demand is met by harvest from the native dry forests (COENER, 1985; Moreli and Knudson, 1984). Shortages of wood fuel already occur in certain parts of the country. Management of the existing native dry forest to increase yield and establishment of plantations of fast growing species with good fuelwood value could be part of a solution to the problem.

The Dominican Republic is a net importer of lumber and wood-based products. The potential forest productivity of the country is enormous. It could become self sufficient in wood and support an industrial base that would provide employment, income, and reduce the trade deficit. Before the prohibition against cutting in 1967, there were seventy-five sawmills in the country and domestic production met demand. Since then, most lumber and other wood products have been imported (Ramm, Potter and Rudolph, 1987 and Weil et al., 1982).

The primary agency charged with management and protection of the country's forests is the Dirección General Forestal, more commonly referred to as FORESTA. In 1967, major administrative responsibility was moved from the Secretaría de Estado de Agricultura (SEA) to the Secretaría de Estado de las Fuerzas Armadas, where it resides today. One of the military's principal civic action responsibilities is to supervise FORESTA and to regulate the conservation and restoration of the forests, the transport and commerce of forest products, protection against fires, and to instill in the minds of the population the very serious need for forest conservation. FORESTA is headed by a Director-General who had until 1988 been a high ranking officer in the armed forces. Policy matters are coordinated between FORESTA and CONATEF (Comisión Nacional Técnica Forestal). Operationally FORESTA has 8 districts and 24 subdistricts. Each district has an officer in charge who is responsible to the central office in Santo Domingo. The majority of FORESTA's personnel are occupied with vigilance and fire control and with planning and implementing reforestation projects dealing with the rehabilitation of degraded land. There is no integrated or sustained yield management of native forest land and little utilization except for salvage operations. FORESTA is the most active organization in plantation forestry in the Dominican Republic. However, overall efforts to establish forest plantations in the Dominican Republic have been modest to date (Hartshorn et al., 1981). The two main species planted are the indigenous *Pinus occidentalis* and the introduced *Pinus caribaea* var. *hondurensis*. Both are planted for the dual purposes of watershed stabilization and wood production. Other species planted on a smaller scale are *Swietenia mahagoni*, *Leucaena leucocephala*, *Cassia siamea*, and various eucalypts. A number of other species have been planted in experimental/demonstration plots at FORESTA's nurseries.

Other organizations also are involved in reforestation and product utilization. SEA (Secretary of Agriculture) has long maintained tree nurseries for distribution of seedlings to landowners. In addition, SEA coordinates several land use programs that include forestry components. Among them are MARENA in San José de Ocoa and Project Bao near Janico. SEA also helps to fund Plan Sierra near San José de las Matas, a private extension/demonstration effort that integrates mountain agriculture, forestry, public health and development. The Dirección Nacional de Parques manages national parks. The Subsecretaría de Estado de los Recursos Naturales, a subagency in SEA, is responsible for planning, implementing, and supervising national policy for all natural resources. Many industries, especially mining firms with a government concession, established forest plantations as part of their land reclamation program. The most important were Alcoa Corporation, mining bauxite in the extreme southwest of the country, Falconbridge Dominicana, a ferro-nickel mining firm near Bonao, and Rosario Dominicana, a gold mine operation northeast of Bonao. Gulf and Western Corporation also had established a few experimental tree plots on its sugarcane lands before selling its properties that are now operated as Central Romana.

The main problems encountered in the execution of reforestation programs are 1) insufficient professionally trained foresters, 2) land tenure control, and 3) a lack of forestry consciousness. There is a serious shortage of trained foresters in the Dominican Republic. The general lack of activity and the associated lack of employment opportunities in forestry is a definite disincentive for an individual to seek training in forestry. Although by law FORESTA is empowered to define and manage all forest land, both private and public, government sponsored reforestation has taken place only on lands clearly under government control. There is a real need to define the boundary of public land in the country and to decide which lands can realistically be controlled by FORESTA. As in many other developing countries the native forests are considered as a public resource to be exploited and converted to agriculture or pasture. By fostering a conservation ethic among the populace and by involving the rural people in reforestation and agroforestry programs these attitudes might be changed. There also is a need for pilot plantation establishment, management, and financial analysis to demonstrate to private individuals with capital and land the potential economic gains from investments in forestry.

Description of Project

In recognition of the heavy economic cost of imported petroleum and the potential shortfall of fuelwood, the Dominican Republic instituted a program for the development of domestic sources of energy to provide alternatives to imported oil. As one part of a broad energy project, the Wood Fuel Development Program for the Dominican Republic was initiated in June 1983. The project was sponsored by USAID and the Dominican Republic through its Comisión Nacional de Política Energética (COENER). Purdue University was awarded the competitive contract to serve as technical advisor and to work with the Instituto Superior de Agricultura (ISA) and personnel of COENER who conducted the research work.

The primary objectives of the project were to develop a scientific research program that would address the problems of fuelwood production and conversion to charcoal and at the same time enhance the research experience and expertise of foresters in the Dominican Republic with the aim of sustaining future research efforts in forestry. The original project scope was expanded from a concentration on plantation establishment on arid sites to include plantation establishment on more humid sites as well as management of the remaining native dry forests.

The five-year program successfully coordinated the efforts of public agencies and institutions, industry, and individual landowners who had expertise and interests in fuelwood and charcoal in the Dominican Republic. The Federal University of Viçosa in Minas Gerais, Brazil, provided technical training and advice in the area of charcoal conversion during the project. An outline of the major thrusts and approaches of the project is given below.

I. Basic Studies. This aspect of the project focused on ecology, dendrology, assessment of existing forests and plantations, policy and financial feasibility of native forest and plantation establishment and management. These investigations provided support data for the other phases of the project.

II. Tree Research. Tree species with potential for use in fuelwood plantings were identified and established in plantations and experimental plots. These plantings were designed to yield information concerning adaptation of exotic tree species to specific sites, optimum spacing, fertilizer response, cultural practices for establishment and maintenance, insect and disease problems, growth and yield, and susceptibility to grazing animals. Two existing tree seedling nurseries were expanded and procedures developed for production of large quantities of containerized seedlings of the desirable species. The scope of the tree research program was expanded in the first year of the project to include humid sites in addition to arid sites and to develop techniques and approaches for management of the existing native dry forest.

III. Wood Conversion. The principal objective was to improve the efficiency of conversion of wood to charcoal and thus to stretch the wood resource. Brick kilns were designed and constructed that demonstrated greater efficiency than the traditional earthen kiln technique. Species characteristics, the size of woody material, and moisture content of wood as it related to charcoal conversion were investigated. A research laboratory and analytical procedures and techniques were established.

IV. Training and Institutional Building. Both short- and long-term training programs were important aspects of the project. Long-term academic training was supported at both the MS and Ph.D. degree level at universities in the U.S., Brazil and Venezuela. These training programs were provided with the expectation that the individuals would return to or join the faculty in forestry at ISA. Their experience and training should markedly enhance the quality of the teaching and research programs at this institution. Short-term training was offered within the Dominican Republic and a number of faculty and staff of ISA, COENER, and other agencies attended symposiums, workshops, conventions and educational programs in other parts of the world. The impact of the training efforts is evident from the enhanced appreciation of forestry and forestry research among staff associated with this project. The institutional building aspects of the project will increase even more markedly when the long-term trainees join the faculty at ISA.

This report presents a summary of the research program, the infrastructure developed, the technical results, and the training provided to Dominican foresters in the areas of research planning, tree nursery and forest management, and charcoal production. The information is organized in chapters that deal with the native dry forest (II), plantations (III), charcoal production (IV), and policy (V).

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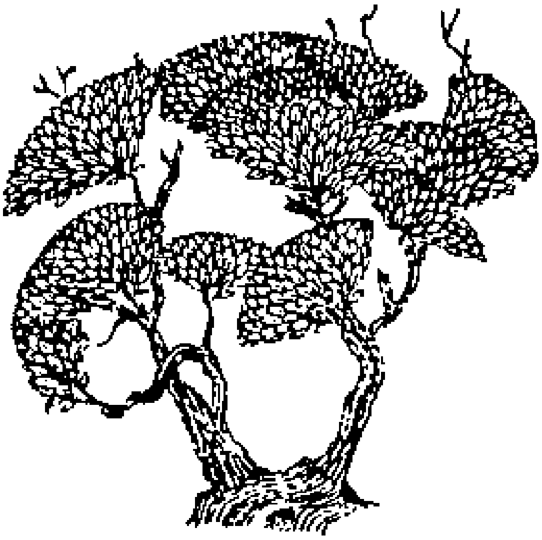
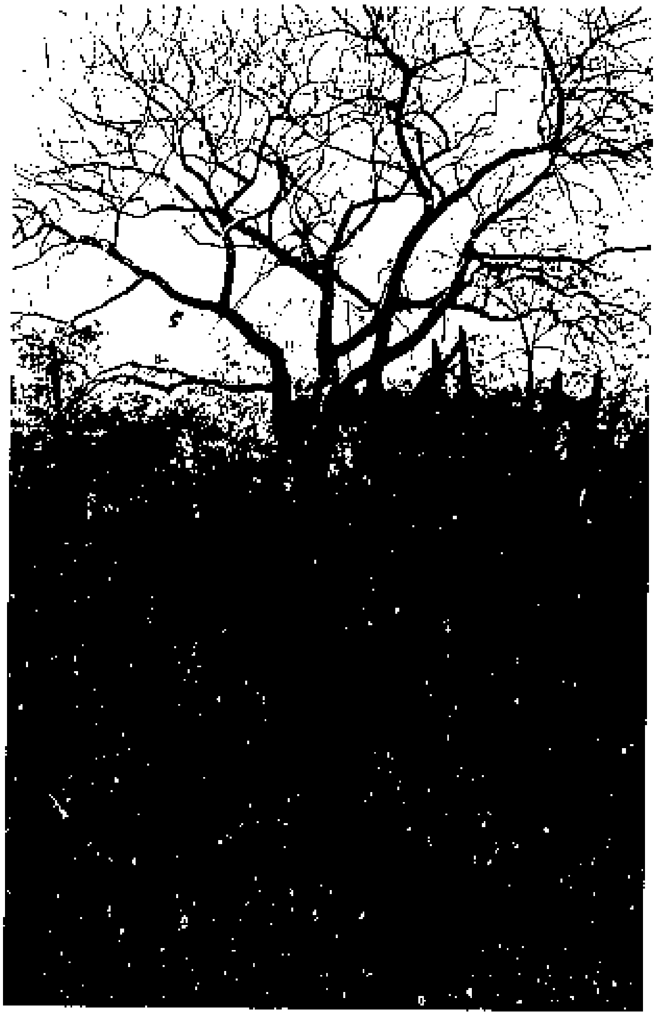




Native Dry Forest

CHAPTER II

CHARACTERIZATION AND MANAGEMENT OF NATIVE DRY FORESTS

The Dry Forests

The native dry forests of the Dominican Republic are important resources that have been reduced in extent and quality by centuries of fuelwood harvesting and livestock grazing. These forests are defined as either Subtropical Dry Forest or Subtropical Thorn Woodland according to the Holdridge Classification System of Life Zones (Holdridge, 1982). This classification system does not take into account the floristic composition, but rather elevation and climatic factors.

Subtropical Dry Forest

The Subtropical Dry Forest includes areas with an altitudinal range of 0-700 m, annual precipitation of 500-1000 mm, biotemperature of 18-24°C, and a coefficient of potential evapotranspiration of 1.0-2.0. This Life Zone occupies 9,962 km^2 in the country, representing 20.7% of the total surface area. Intensive use of the land has reduced the native dry forest vegetation so that today only about 3,000 km^2 remain. These forests are located on undulating land in the western Cibao, the area around Yuma Bay in the province of Altagracia, the area of the Baoruco peninsula, the San Juan and Neiba valleys and the Azua and Bani plains. These lands are unsuitable for irrigation and are too dry for non-irrigated crops (Hartshorn et al., 1981; Jennings and Ferreiras, 1979) (Figure 5).

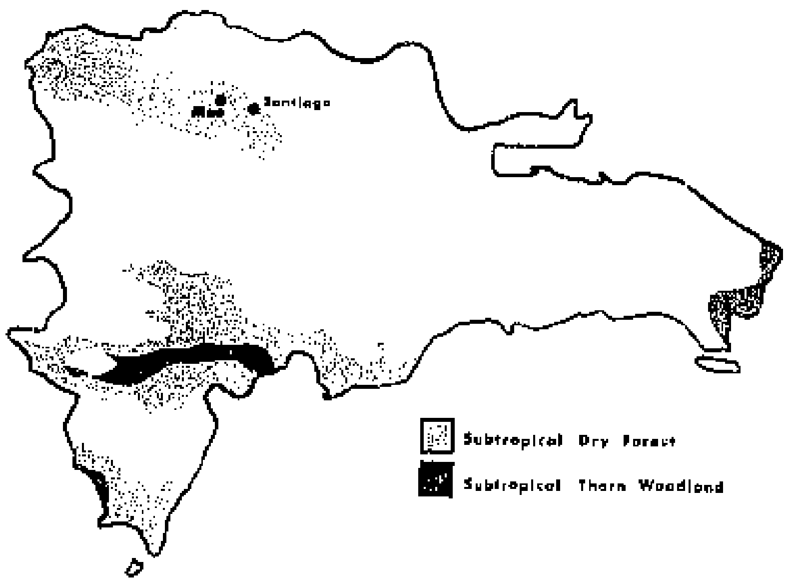


Figure 5. Location of Subtropical Dry Forest and Subtropical Thorn Woodland in the Dominican Republic.

The main use of these forests is as a source of firewood and charcoal and browse for goats. These two uses constitute the two biggest problems in the dry forests. Uncontrolled and indiscriminate cutting of trees for charcoal and fuelwood and a free ranging approach to grazing goats has led to significant degradation and exploitation. The importance of goats in the rural economy has led to intensive pressure on the dry forest and energy needs of the increasing population continue to have a negative effect on it. Of the total energy consumed in the Dominican Republic, 32% is derived from sugarcane residues, fuelwood and charcoal (Morell and Knudson, 1985). Much of the fuelwood and charcoal originates from the Subtropical Dry Forest.

Subtropical Thorn Woodland

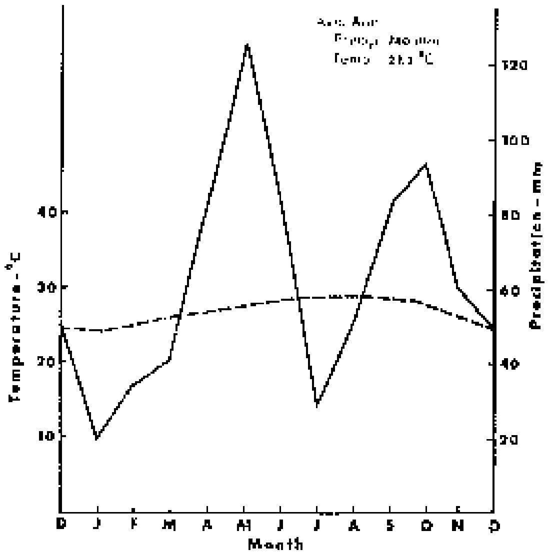
This Life Zone occurs in the driest part of the Dominican Republic, particularly in the southwest where it extends from Lake Enriquillo to Puerto Viejo at elevations less than 300 m. Other small areas of the Life Zone border Honda Bay (near Cabo Rojo), Ocoa Bay and Calderas Bay (near Punta Salinas). Another small area is found at the base of the Aguacate Hills in the northwest of the Cibao (Figure 5). It occupies only 1,001 km^2, representing 2% of the country (Hartshorn et al., 1981).

The climatic conditions are characterized by less than 500 mm of rain annually and an annual bio-temperature of 18-21°C. This combination of high temperature and little precipitation results in a coefficient of potential evapotranspiration of 2.0 to 4.0. The natural vegetation of the zone consists principally of spiny shrubs and cactus. The cacti include *Opuntia antillana* (guazábara) and *Neoabbottia paniculata*. Also common are *Copernicia berteroana* (Yarey palm), *Prosopis juliflora* (cambrón) and species of *Capparis*. These forests also provide a source of fuelwood and charcoal. It is often difficult to distinguish the thorn forest from the dry forest, particularly when the subtropical dry forest has been intensively utilized.

Description of Study Area

An experimental forest of approximately 1000 ha was established through cooperation of ISA and COENER near the city of Mao. The Finca de Investigaciones Forestales de Mao is located in the western part of the Cibao Valley (19°35'N and 71°4'W) and is included in the Subtropical Dry Forest Life Zone. The region is semi-arid with average annual precipitation 740 mm, temperature 27.2°C and potential evaporation 1,243 mm (coefficient of evapotranspiration 1.7). Precipitation is quite irregular with rainy seasons in March-June and September-December. Average annual temperature is more uniform (Figure 6). Elevation of the area is 78-175 m.

Figure 6. Average monthly precipitation and temperature in Mao. (Data from Mao Meteorological Station, Secretary of Agriculture, Santo Domingo.)



The soils are alluvial deposits derived from calcareous rock, are highly susceptible to erosion and have a pH of 7.8 to 8.4. Moisture retention is low with a field capacity of 13.9% (Rodríguez et al., 1982). The area encompasses a variety of sites from level terrain with deep soils to steep slopes with shallow soils. Hartshorn et al. (1981) describes the vegetation as a low forest (average height 6-8 m) with an abundance of xermorphic species that are widely spaced and intermixed with cactus and other desert plants. In general, the Finca Forestal is representative of the Subtropical Dry Forest in the Dominican Republic (Figure 7).

Figure 7. Subtropical Dry Forest vegetation in Finca Forestal at Mao as viewed from the kiosk near the center of the property.

A map of the Experimental Forest showing the various compartments, roads and structures is shown in Figure 8. During this project the entire area was fenced to provide protection from cattle and goats. A system of roads which subdivides the area into compartments and provides access has been constructed. A small nursery has been expanded, and a work shelter and office building constructed (Figures 9 and 10). A pond for retention of irrigation water has been completed. A kiln area with experimental kilns and a building to house equipment and an analytical laboratory to support the charcoal research aspect of the Project have been located at the northwest edge of the property (Figure 11).

Research Objectives

The principal long term objective of research in the native dry forest is to integrate ecological, silvicultural and economic information to develop management models for the enhancement of growth and yield of fuelwood and charcoal from the native forest. Six hundred hectares of the 900 plus that constitute the Finca de Investigaciones Forestales de Mao have been dedicated to these studies and as a preserve for future studies and observations of the native forest. The remaining 300 hectares are for plantation trials.

Specific research projects were installed to:

1) Identify the species that occur in the native dry forest.
2) Document the composition and ecological dynamics of the forest.
3) Determine the rate of growth of the existing forest.
4) Determine the response of the forest to silvicultural treatments such as control of ground cover and brush competition, thinning, coppicing, and enrichment planting.

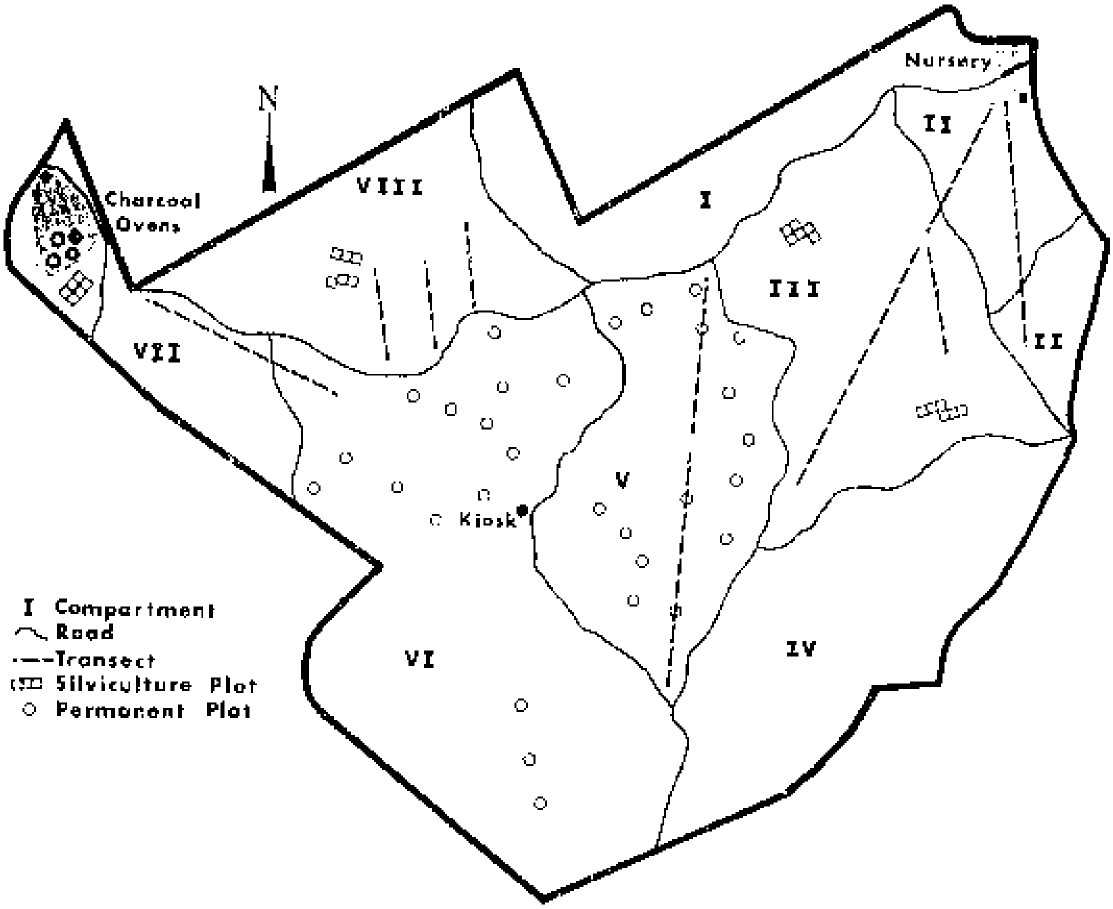


Figure 8. Map of the Finca Forestal in Mao.

Experimental Approach and Procedures

Woody Plant Identification

The trees and shrubs of the native dry forest in the Finca Forestal were first identified by common name or names through consultation with local residents and charcoal producers who had experience with the trees and their uses. Scientific names of the species were determined if possible from existing books and lists of trees known to exist in the native dry forest. The standard used for nomenclature was Liogier (1974). Growth habit, leaf, flower, fruit and bark characteristics were used for identification when they were available. However, many of the species do not flower frequently or the flowers exist for a short time, often only a few days. Since the most pronounced identification feature of plants is the flower, specific identification has not yet been possible for some of the trees and shrubs. A booklet was prepared that included a dichotomous key for identification using only leaf and spine characteristics, common names and scientific names when known, and a brief description and drawing of the leaf characteristics of each tree and shrub (van Paassen, 1986).

Forest Composition and Ecological Dynamics

Based on study of recent aerial photographs, 8 transects were established to sample distinct sections of the native forest in the Finca Forestal at Mao (Figure 8). Each transect consisted of 6 to 14 sections that were 4 m wide x 100 m long (Figure 12). A total of 7,600 linear meters and 30,400 m^2 were sampled. The number of trees of each species and the number of stems with a diameter at breast height of 2.5 cm or greater were recorded. Trees without stems greater than 2.5 cm were considered part of the groundcover and were not recorded. The number of stems with dbh greater than 15 cm was noted. Percent groundcover was estimated visually to within 10% (Powell and Mercedes, 1986).

Figure 9. Planting tree seeds in containers at nursery in Finca Forestal.

Ten superior phenotypes of each of the tree species most desired for fuelwood and charcoal were identified and located in the Mao Experimental Forest as sources of seeds. The trees were carefully selected to represent the various microenvironments and sites. Each parent tree was tagged and located on a map. Phenological observations were recorded to develop an operational knowledge of species behavior, especially time of seed availability.

In 1984, 30 circular permanent plots were established throughout the Finca Forestal to represent the diversity of sites (Figure 8). These were aggregated in 10 groups of 3 plots so that within a group of 3 plots similar sites and microenvironments occurred. Each plot was circular in shape with a diameter of 13.8 m and an area of 600 m^2. Ten of the plots were randomly assigned as controls. Ten were clearcut, providing data on tree dimensions and weights, as well as future information on natural regeneration processes. The third set of 10 plots was left intact except for treatments of the understory vegetation. The ten control plots were to serve as comparisons for experiments in the treated plots and as a means for monitoring long-term growth and ecological changes. These 10 plots were inventoried and each of the trees identified and measured (Hernández and Disla, 1987). The number of stems/ha, diameter at breast height (1.3 m), diameter at knee height (50 cm), and total height were recorded. Average basal area was calculated for each tree and total basal area/ha compiled. The intent was to avoid any interference with the vegetation in the control plots except occasional non-destructive measurements. Thus, the 6000 m^2 that they constitute, spread over the variety of conditions in the forest, should give a good long-term indication of the forest's dynamics and productivity. On the ten clearcut plots, Maxfield (1985) conducted mensurational studies on the central 200 m^2 with the collaboration of the Dominican native forest research team. These plots also were used for sprouting studies (Disla, 1987a,b,c; Disla, Gómez and Mercedes, 1986).

Figure 10. Forest researcher José Hernández with secretary Milagros Almánzar in front of the office building constructed at the Finca Forestal in Mao.

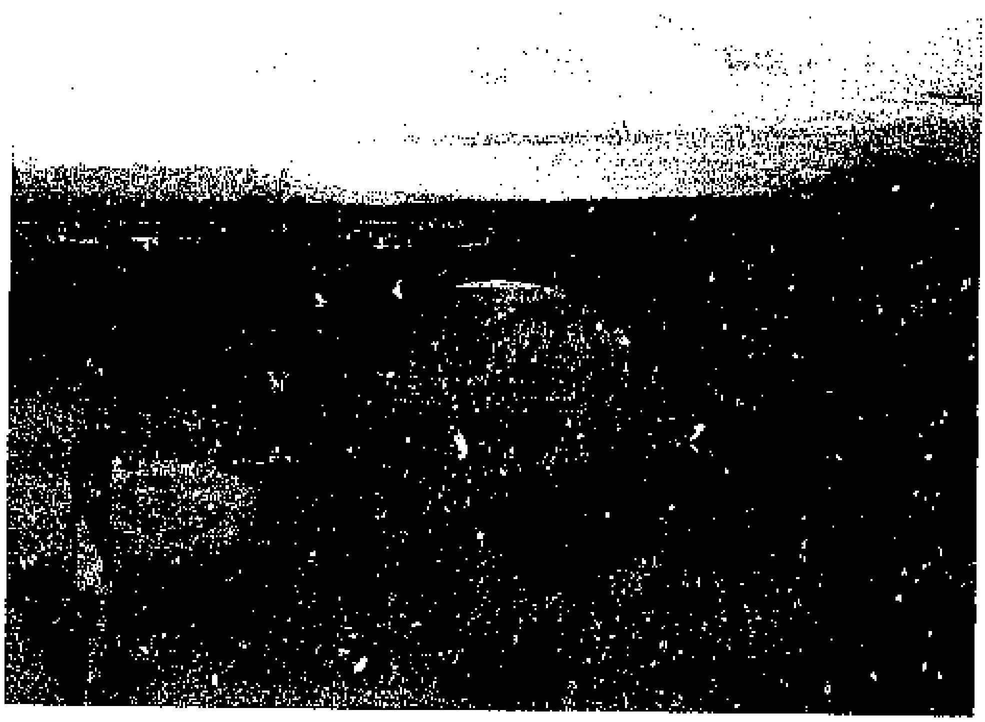


Figure 11. Charcoal kilns located in the Finca Forestal in Mao.

Figure 12. Wolfgang Arand and Beato Abréu establishing a transect in the native forest at Mao.

One problem that has confronted workers in the dry forest is the calculation of wood volume or weight as a measure of growth and eventual productivity. The twisted, multi-stemmed trees defy easy measurement. Foresters have typically developed their volume equations based upon single stems with more or less cylindrical sections or conical shapes. This does not function well for the complex and varied forms of trees that grow in the dry forest.

Maxfield (1985) collaborated with the Dominican dry forest researchers to test methods of estimating woody biomass from simple field measurements. He recommended using basal area calculated from the diameter at knee height (0.5 m) (dkh) as the independent variable and weight as the dependent variable, using simple linear regressions for each of 19 species. These equations were developed from measurements of 556 sample trees. A minimum of 20 trees of each species and a representation of the various diameter classes were measured. Diameter at knee height, diameter at breast height, crown diameter, total height, green weight of the harvested trees, and weight of the usable biomass after non-commercial twigs and leaves were removed to 2.5 cm diameter were determined.

For purposes of comparison, basal area and yield also were sampled on an area of approximately 15 ha that was cleared in Compartments II and III of the Finca Forestal (Figure 8) for establishment of plantations of exotic species. The wood was piled and the volume measured in steres. The actual volume of solid wood in a stere (1x1x1 m) was determined by measuring the diameter and length and calculating the volume of each stem in each of 10 steres. The ratio of actual solid volume per stere was a coefficient for conversion of piled wood to solid wood (Hernández, 1986b).

__Forest Management__

__Control of Understory Vegetation__ A sample area of 12,000 m^2 in 20 of the permanent circular plots described above was defined in the Finca Forestal at Mao. Three treatments were imposed as follows:

1) 10 plots - No treatment of understory or ground cover.
2) 5 plots - Complete removal to bare soil of shrubs and weeds with a hoe.
3) 5 plots - Chopping or cutting of shrubs and weeds with a machete.

Treatments were repeated as needed according to regrowth of the vegetation. Parameters monitored for trees greater than 2.5 cm dbh were diameter at knee height (50 cm) and breast height, and total tree height. The data were analyzed to compare tree growth in response to the method of understory control.

A study to identify and determine the importance of weeds in the dry forest was installed. Fifty circular sample plots of 100 m^2 each were randomly established. Each plot was divided into quadrants using the cardinal points of the compass. All the weeds, large trees, tree seedlings and epiphytes were identified and counted, and the bare soil areas estimated in one of the quadrants. In the remaining quadrants, only the trees and seedlings were counted (Burgos, Diloné and Mercedes, 1986).

Enrichment Planting Studies were initiated to investigate the feasibility of the enhancement of the native forest through planting of both native and exotic species that have desirable wood qualities and growth rates. This management strategy is justified when the forest is poorly stocked with commercial species or when natural regeneration is not occurring following previous harvesting for fuelwood and charcoal. Although enrichment trails in high forests have usually failed due to competition, they have rarely been tried in the open dry forest.

Enrichment plantings can take two forms: 1) Planting in cleared strips from 1 to 5 meters wide that are separated by strips of undisturbed forests. 2) Planting in natural openings in the forest. Planting in strips has the potential of transforming the natural irregular and heterogeneous forest to one of greater homogeneity and value. The native forest between the strips is still retained and the potential value of its trees is not lost. In case of failure of some of the planted trees, the native forest continues its development with minimal disturbance.

An experiment has been installed in the Mao Experimental Forest to monitor growth of trees planted in cleared strips and small openings. The strips are 3 m wide x 50 m long and spaced so that an area of 5, 10 or 20 m wide of undisturbed vegetation is left between the strips (Figure 13). Narrow strips only 50 cm wide that provide easy access lanes to random spot openings also have been cleared. Along these access lanes, natural openings were widened to 60 cm. Both native and exotic species will be planted. Thus far, only *Leucaena leucocephala* variety K-8 has been successfully planted. This exotic species was selected for investigation because of its known rapid growth and adaptability to poor and shallow soils. *Azadirachta indica* and *Cassia siamea* seedlings fared poorly because their planting was followed by an 8-month drought.

Thinning Twenty-four plots that are 50 x 50 m (2500 m^2) were delineated in the Finca Forestal at Mao between October, 1985 and January, 1986 (Figure 8). The experimental design was four randomized complete blocks. Each block consisted of 6 contiguous plots. Within each 2500 m^2 plot, 5 permanent circular plots of 100 m^2 each were defined. A total inventory of each circular plot was made, resulting in an inventory of 500 m^2 per plot. The inventory consisted of identification of each tree by species and measurement of its height and diameter at both 50 cm and dbh. Following the inventory the plots were randomly assigned a target thinning treatment of 0, 20, 40, 60 and 80%. Two control plots (0%) were randomly assigned to each block (Figure 14).

The plots were thinned in January, 1986. Four criteria were used in the thinning process.

1) Favor the species most desired for charcoal.
2) Try to maintain species diversity.
3) Select trees of good form.
4) Strive for uniformity of spacing among trees.

Figure 13. Cleared strip in native forest for enrichment planting.

Thus, there was not a strict adherence to mathematical criteria for thinning but rather a professional judgment to produce a quality, varied and healthy residual stand.

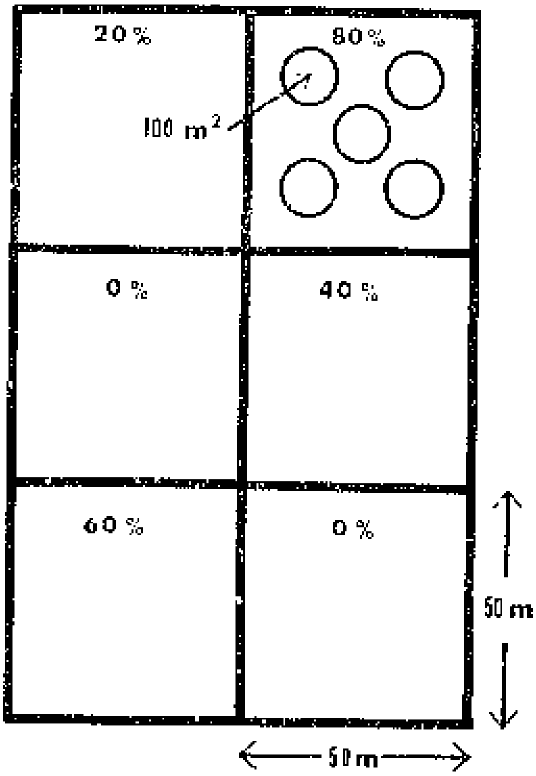


Figure 14. Experimental plot layout for study of response of native dry forest to thinning. Sample of 1 of 4 replications.

The actual number of trees that originally occurred in each plot, the theoretical residual after thinning and the actual residual after thinning are shown in Table 4. In reality, then, the thinnings represent three levels plus a control, one very light thinning of about 10%, two in which about one-third of the trees were removed and one in which two-thirds were cut. The thinning levels were calculated on the basis of averaging the number of trees per hectare for transects, permanent plots and thinning plots.

Table 4. Average actual and theoretical number of trees in the experimental thinning plots.

		Target thinning level			
	Control	20%	40%	60%	80%
Original No. trees	1863	1955	1995	2090	1785
Theoretical residual	1863	1564	1197	836	357
Actual residual	2017	1820	1395	1380	675
Actual % thinning		7%	30%	34%	62%
Comparative % thinning (Based on trees in control)		10%	31%	32%	67%

Following thinning, the plots were reinventoried at 6 months (June 1986) and again after 1.5 years (June 1987). The height and diameter (dbh and dkh) by species were recorded. Analysis of future data will eventually allow determination of the growth response of the entire stand and of individual species to thinning.

<u>Sprout Management</u> Several studies have been installed to investigate the potential of native dry forest species to sprout from stumps after harvesting as a means of regeneration. Ten of the 600 m^2 circular permanent plots described above were used for some of these studies. Within each circular plot, five 4 x 4 m sample plots were uniformly located (Figure 15). The total area sampled was 80 m^2/circular plot for a total of 800 m^2 in all 10 replications. Following clear cutting of the entire circular plot, all the stumps greater than 4 cm in diameter were identified by species, tagged and the diameter and height recorded. Five months later the total number of sprouts and the length of the 5 best developed were measured and their point of origin recorded (i.e. side of stump, stump crown, root collar, stump wound, or root). These observations and measurements were made again at 8, 11, 14 and 26 months following clear cutting (Disla, 1987b and Disla, Gómez and Mercedes, 1986).

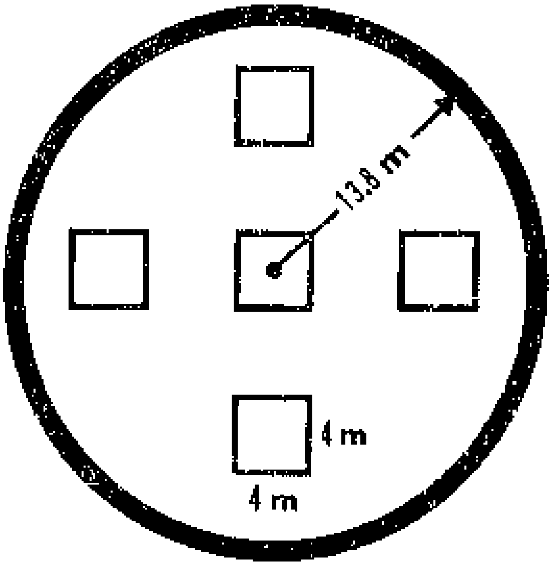


Figure 15. Representative replication (1 of 10) and plot layout for study of sprout production on stumps following tree harvesting.

The objectives were:

1) Determine the number and length of sprouts per species with respect to diameter and height of the stump for each species.
2) Determine the number and length of sprouts with respect to site of origin on the stump.
3) Determine the longevity and number of sprouts retained over time.
4) Compare root and stump sprouts.

In another study the number of sprouts on stumps was controlled such that stumps retained only 1, 2, 3 or 4 sprouts. The growth of these was compared with unpruned stumps. The study was done in the same clearcut circular plots described above. However, only four 4 x 4 m subplots were examined in 4 randomly selected plots (Figure 16). The area sampled was 256 m^2. Only stumps greater than 4 cm were considered (Disla, 1987a).

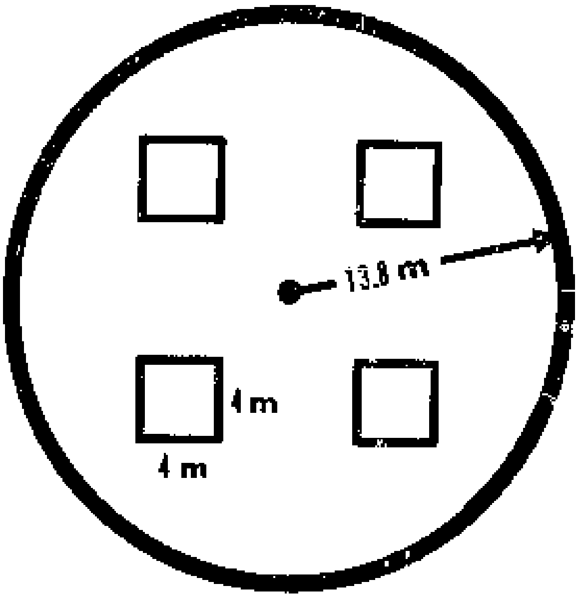


Figure 16. Representative replication and plot layout (1 of 4) for sprout pruning study.

Sprouting in relation to thinning was monitored in the plots thinned to 20, 40, 60 and 80%. Four sample plots of 32 m^2 (8 x 4 m) were established in each of the 50 x 50 m thinning plots described above. There were 16 subsamples at each thinning level and a total of 2048 m^2 sampled (Figure 17). The number and growth of sprouts was monitored for a year after thinning (Disla, 1987c).

Results

The results presented here are only a brief summary of the salient findings of some of the experiments conducted in the native dry forests. Emphasis is placed on research done in the Experimental Forest in Mao; however, other studies also were conducted in the dry forest areas on the ISA campus and in the southwest part of the country. More detailed information and results can be found in the references that are cited in the text and in the publications listed in the Project Summary.

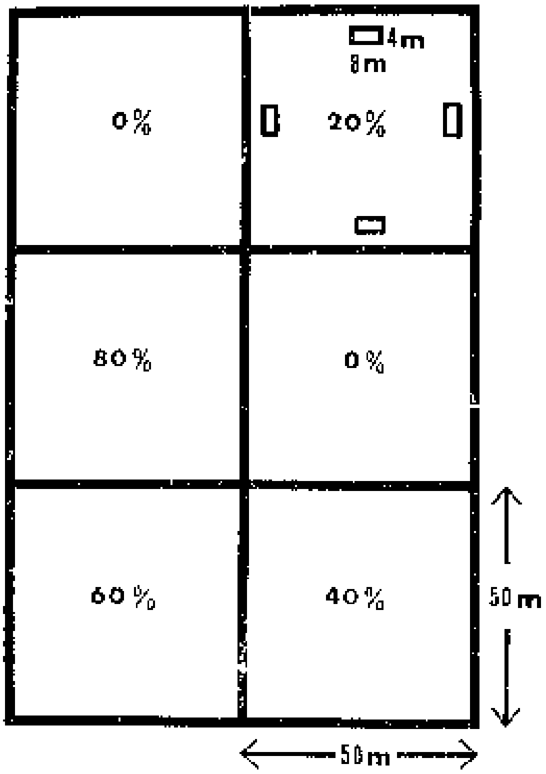


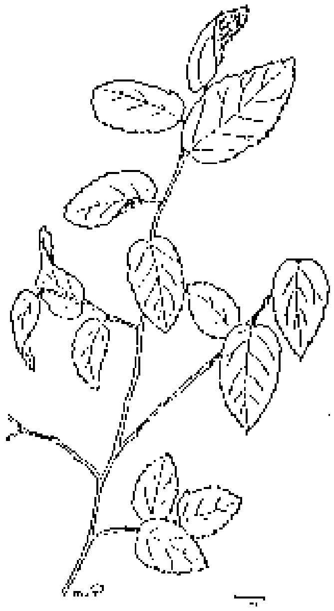
Figure 17. Representative replication and plot layout (1 of 4) for study of sprouts in relation to thinning.

Trees of the Dry Forest

Ninety-eight species of trees and shrubs were found to exist in the native dry forest. An illustrated guide that includes a dichotomous key for identification based only on leaf and spine characteristics was prepared (van Paassen, 1986). The tree and shrub species identified are in 21 different families. A significant number of trees and shrubs are known only by a common name since the scientific name has not yet been reliably determined. Lists of the woody species found in the Experimental Forest at Mao organized according to common names are given in Table 5.

A brief description of 9 of the most common and valuable trees in the native dry forest and a drawing of the leaf and twig are given below. The drawings were done by Marianne van Paassen and were taken from the Guide she prepared (van Paassen, 1986).

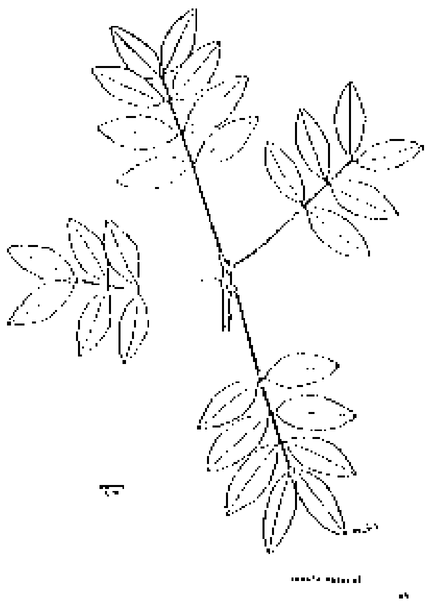
Baitoa. *Phyllostylon brasiliensis* Capanema. Ulmaceae.



A deciduous tree that averages 10 meters tall with a stem diameter of 22 cm. The form is erect with a single trunk. Branches grow upward and produce a crown of about 6 meters diameter. The leaves are simple and alternate, somewhat oval shaped with serrated margins and have pubescence on both sides. Spines are absent. Flowers usually appear the end of January and the fruit, which is a samara, begins to fall in April. The trunk is ashen colored, the bark furrowed and peels off in strips. Because the wood does not crack or split, bends easily and is durable, it is used for cabinets and furniture. It is moderately desired for fuelwood and charcoal. The fruit is edible.

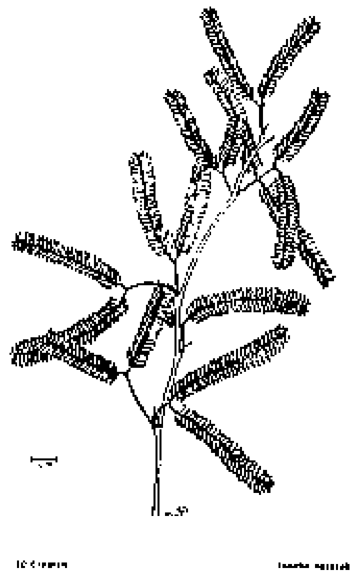
Brucón. *Cassia emarginata L.* Leguminosae.

A deciduous tree that averages 6 meters tall and 9 cm in diameter. Its form is erect and it usually produces two trunks of equal size. The crown is rounded and reaches a diameter of 6 meters. The leaves are pinnately compound and alternate, leaflet margins are entire and both surfaces have hairs. Flowers and fruits are produced almost all year. The flowers are simple and a bright yellow. The fruit is a legume that turns brown when mature. The bark is smooth and ashen colored. The wood is yellow and used for fuelwood, to make charcoal and for fence posts. A dye is extracted from the heartwood. The fruits are fed to livestock.



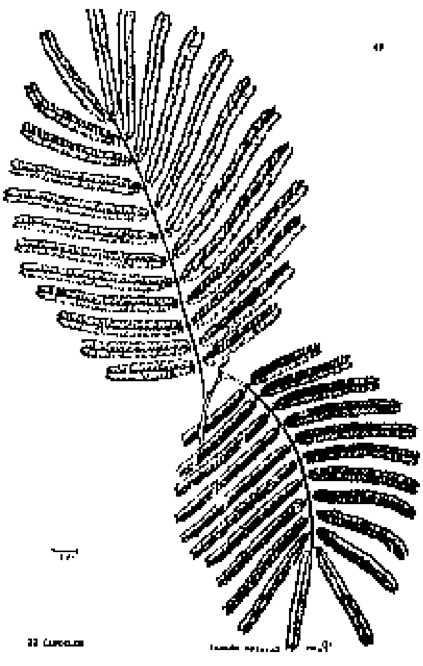
Cambrón. *Prosopis juliflora* (Sw.) DC. Leguminosae.

An evergreen tree that grows to an average height of 6 meters and diameter of 10 cm. The foliage becomes very thin at times, but the tree is normally never without some leaves. The trunk usually divides into several main stems near the ground. The crown is flat and extends to a diameter of 6 meters. The bark is striated and brown colored. A pair of coarse spines occurs at the base of the leaves. Leaves are bipinnately compound, alternate and smooth. Small pale yellow flowers occur in January. Fruit, a legume, appears in February and is mature in March. The wood is hard and makes excellent fuelwood and charcoal. It also is used for fence posts and cabinetry. The bark is high in tannin and a gum collected from the trunk has medicinal value.

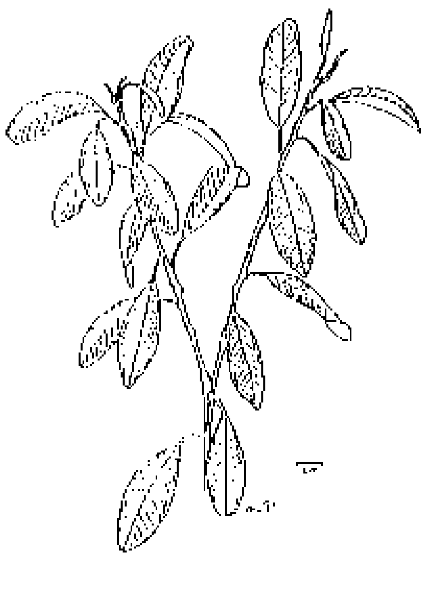


Candelón. *Acacia scleroxyla* Tuss. Leguminosae.

A deciduous tree that averages 8 meters in height and 17 cm in diameter. The greyish, cylindrical trunk grows erect. Branching is dichotomous. The bark is shed very slowly. Spines are absent. The crown is rounded and dense with an average spread of about 7 meters. The leaves are bipinnately compound and alternate with entire margins and smooth surfaces. Pale yellow flowers develop into a legume fruit that appears in April. Fruits are retained on the tree until the end of November when they begin opening to release seeds in December and January. Defoliation is complete by the end of July and the tree refoliates with the rain in September and October. The wood is very hard and is used in cabinetry and carpentry, for fuelwood, charcoal and fence posts.

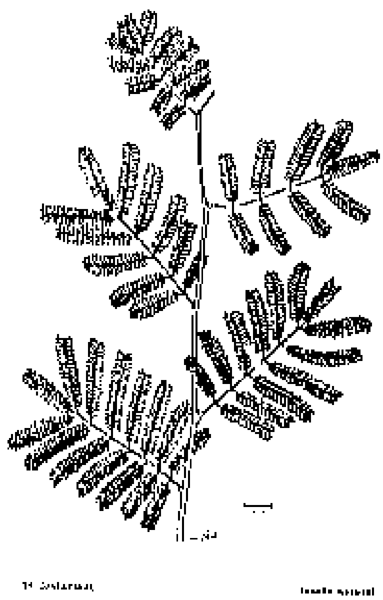


Frijol. *Capparis cynophallophora L.* Capparaceae.



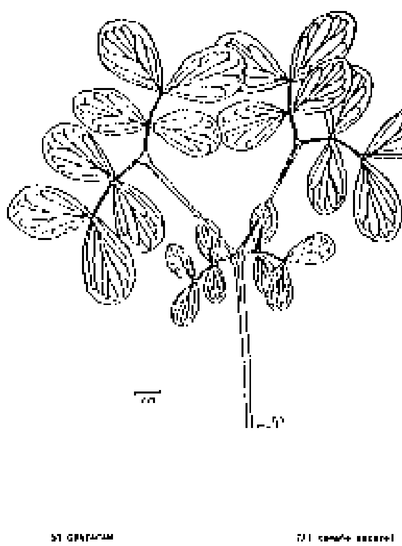
An evergreen tree that grows to an average height of 8 meters and diameter of 20 cm. The tree grows erect and may be single or multiple stemmed. The bark is dark grey with small white spots, rough and slightly furrowed. The canopy is rounded. Leaves are simple and alternate. The upper surface is smooth and brilliant and the lower surface is densely covered with dark grey scales. Purple, fragrant flowers appear in April and fruit pods containing bright brown seeds mature in May. The wood is dense and used as fuelwood and charcoal. Root extracts are used as insect repellent and bark and leaf extracts are used to treat certain nervous conditions.

Guatapanal. *Caesalpinia coriaria* (Jacq.) Willd. Leguminosae.



An evergreen tree averaging 5 meters tall and 11 cm diameter. The trunk is normally twisted, not always erect and sometimes dividing into two or more stems. The brown bark is rough and furrowed. The canopy is irregularly shaped and wide spreading, reaching a diameter of 6 meters. The leaves are compound and alternate with entire margins and smooth surfaces. Young leaves are reddish and then turn a dull green. Aromatic flowers appear in June. Dark twisted fruit pods begin to ripen in November. The tree and wood have many uses. The reddish colored wood is prized for fuelwood and charcoal and is used in turnery and ornate furniture. Bark and fruit are rich in tanin and a dye is extracted from the fruit. Most parts of the tree are thought to have medicinal value.

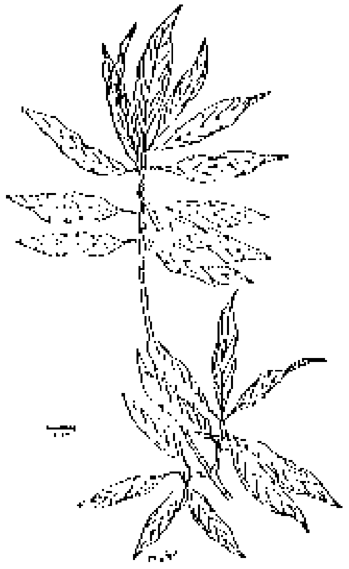
Guayacán. *Guaiacum officinale L.* Zygophyllaceae.



An evergreen tree that averages 4 meters tall and 5 cm in diameter. The trunk is short and slightly inclined. The bark is green with greyish mottling and is shed in scales. The canopy is more or less rounded and dense with a diameter of about 3 meters. The leaves are pinnately compound with entire margins and rough textured surfaces. Purple flowers are usually borne in March to April. The fruit is bright yellow, heart shaped, flat and contains one bright red seed. The wood is strong, dense and resinous. It is used for fuelwood and charcoal and for making implements and tools. Extracts from the wood, bark and seeds have numerous medicinal uses.

Quina. *Exostema caribaeum* (Jacq.) Roem. & Schult. Rubiaceae.

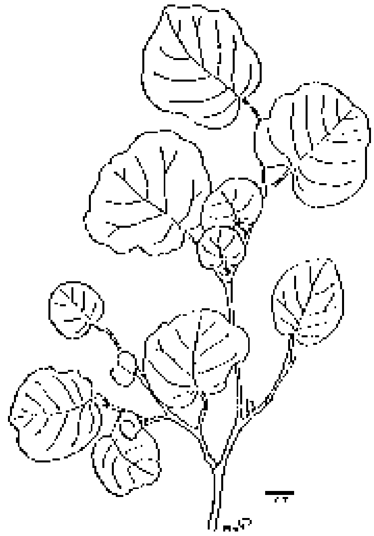
A deciduous tree averaging 6 meters tall and 6 cm in diameter. Its trunk is cylindrical and divides dichotomously. The bark is rough, white with black mottling and is not shed. The crown is small and reaches a diameter of only 2 meters. The leaves are simple, have entire margins, smooth surfaces and are shed the end of October. It flowers in May and fruit matures in July. The wood burns easily and is used for torches, as fuelwood to make charcoal, and for turnery. The bark is a source of quinine.



QUINA

Uvero. *Coccoloba leoganensis*. Jacq. Polygonaceae.

A deciduous tree with average height of 6 meters and diameter of 7 cm. The trunk is irregular and produces many stems near the ground. The bark is rough and is shed abundantly in large thick bluish scales. The leaves are simple and alternate with entire margins and smooth surfaces. As leaves age, they develop holes so that eventually only a skeleton formed by the veins is left. The tree flowers principally in March and fruits in April. Leaves are shed in September and the tree refoliates again in November. The wood is used for fuelwood and charcoal.



UVERO

Table 5. Common and scientific names of trees in the Experimental Forest at Mao.

Common Name	Scientific Name	Common Name	Scientific Name
abey cimarrón		frijolillo	Capparis ferruginea
aleli	Plumeria sp.	garbanzo	Karwinskia calonestra
algodón		gri-grí	
almácigo colorado	Bursera simaruba	guacimilla	
almácigo blanco	Bursera sp.	guácima	Guazuma ulmifolia
almendrillo		guaconejo	Amyris sp.
alpargata	Consolea moniliformis	guamacho	
amarra carnero	Reynosia uncinata	guamachito	Zanthoxylum sp.
anón de breña		guao	Comocladia sp.
arbolito		guatapanal	Caesalpinia coriaria
aroma	Acacia farnesiana	guayacán	Guaiacum officinale
aroma blanca	Acacia macracantha	guayacán de sierra	
aroma extranjera	Parkinsonia aculeata	hueso de chivo	
arrajón	Eugenia ligustrina	jaiquí	
asajaí de breña		jobo de puerco	Spondias sp.
azota petranca		jobobán	Trichilia hirta
baitoa	Phyllostylon brasiliensis	limoncillo	Melicoccus bijugatus
bayahonda	Acacia tortuosa	limoncillo cimarrón	
brucón	Cassia emarginata	limoncillo de avispa	
cabra	Bunchosia glandulosa	lino criollo	Leucaena leucocephala
cabrilla		mata becerro	
cafetán	Lasianthus lanceolatus	mostazo	Capparis flexuosa
cambrón	Prosopis ju... ora	ojo de paloma	
campeche	Haematoxylon campechianum	palo amargo	Trichilia pallida
candelón	Acacia scleroxyla	palo amarillo	
canela	Cinnamomum zeylanicum	palo blanco	
canelilla		palo de burro	Leucaena trichodes
carga agua		palo de caimán	
caimito	Chrysophyllum sp.	palo de cigua	
carmoní		paría	Thouinia trifoliata
caya		penda	Citharexylum sp.
cayuco	Lemaireocereus hystrix	pinillo	
cerecilla		pino macho	Zanthoxylum martinicense
cereza	Malpighia sp.	pionía	
chicharrón	Casearia ilicifolia	quiebra hacha	Atelia microcarpa
chicharroncito		quina	Exostema caribaeum
ciguamo	Krugiodendron ferreum	ramón de burro	Capparis frondosa
cinazo	Pithecellobium circinale	roble	Catalpa longissima
cinazo del grande	Pithecellobium sp.	sangretoro	Maytenus buxifolia
ciruela cimarrona		saona	Ziziphus reticulata
clavellina de la grande		sopaipo	Ziziphus rignonii
clavellina pequeña	Calliandra haematomma	tabacuelillo	
copey	Clusia rosea	tabacuelo blanco	Pictetia spinifolia
copeyito	Clusia sp.	tabacuelo negro	
coral		tamarindo	Tamarindus indica
coralito		trejo	Rheynosia unicinata
corazón de paloma		tremolina gigante	
córbano	Pseudalbizia berteroana	uña de gato	
cuabilla		uña de guaraguao	
cuerno de buey		uvero	Coccoloba leoganensis
escobón		vera	Guaiacum sanctum
escobón blanco	Eugenia monticola	vidrio	Scolosanthus triacanthus
escobón morado		violeta	Melia azedarach
frijol	Capparis cynophallophora		

Source: van Paassen, 1986; Disla, 1987a; Rodriguez, Arand and Villanueva, 1982.

Forest Composition and Ecological Dynamics

Analysis of transect data indicated that 74 species of trees were encountered, 20 for which the scientific name was unknown or undetermined (Powell and Mercedes, 1986). The average number of species per transect was 32. Many of the species had spines. The stand structure varied from short and open to tall and closed. The average number of trees per hectare was 2848 and the average number of stems per hectare was 4,475. There were 38.8 trees/ha with a diameter greater than 15 cm; this represented only 1.4% of the trees. Species that had the greatest relative importance based on number of trees and number of stems/tree were baitoa (26.6%), cayuco (8.8%), quina (8.6%), guayacán (6.8%), and candelón (5.1%) (Table 6).

Table 6. Relative importance of tree species determined from transects.

Species	Relative Importance	Species	Relative Importance
	%		%
Baitoa	26.61	Cereza	0.51
Cayuco	8.87	Chicharron	0.45
Quina	8.60	Ciguamo	0.33
Guayacán	6.83	Carga de agua	0.30
Candelón	5.11	Trejo	0.21
Sangretoro	3.60	Quiebra hacha	0.18
Almácigo	3.46	Guabilla	0.17
Cinazo	3.19	Cafetán	0.16
Brucón	3.07	Palo de caimán	0.16
Cambrón	2.98	Campeche	0.15
Tabacuelo	2.90	Guayabilla	0.13
Canela	1.84	Cuerno de buey	0.12
Guatapanal	1.83	Penda	0.12
Uvero	1.25	Amarra carnero	0.08
Cabrilla	1.17	Anón de breña	0.06
Mostazo	1.06	Uña de gato	0.05
Bayahonda	1.05	Hueso de chivo	0.05
Palo de burro	1.00	Tamarindo	0.04
Frijol	0.99	Cascahueso	0.03
Desconocido	0.94	Gri-grí	0.03
Paría	0.88	Clavellina	0.03
Alpargata	0.84	Palo blanco	0.03
Palo amargo	0.78	Abey	0.02
Aroma	0.73	Roble	0.02
Sopaïpo	0.60	Guamacho	0.01
Ojo de paloma	0.58	Palo amarillo	0.01
Escobón blanco	0.53	Córvano	0.01
Guaconejo	0.52		

Source: Hernández and Disla, 1987.

The most common woody species found in the permanent plots according to the number of trees/ha were baitoa, candelón, almácigo, cambrón and quina (Table 7). These results were similar to the occurrence of species noted from the transect inventory except that almácigo and cambrón were among the five most common species in the permanent plots, whereas cayuco and guayacán were among the five most common from the transect data. Many of the trees are multiple stemmed so that there are 2418 trees/ha and 3682 stems/ha with an average diameter, height and total basal area of 5.9 cm, 5.0 m, and 11.86 m^2/ha, respectively. The canopy appears stratified in three layers; superior (5.6 m and higher), medium (4.6 to 5.5 m) and lower (less than 4.5 m). Of the species encountered, 23.8% had crowns in the superior layer 50% in the medium and 26.2% in the lower strata (Table 7). It remains to be determined through continued observations of the permanent plots if this stratification represents growth and form characteristics of the trees or effects of selective harvesting for fuelwood and charcoal (Hernández and Disla, 1987).

A comparison of dry forest in the northwest part of the country in Mao with the dry forest in the southwest is shown in Table 8. The dry forest in the southwest generally has the same species composition and topography as that in the northwest around Mao. However, the southwest is somewhat drier and warmer and this partially accounts for the fewer trees/ha and lower basal area.

The average basal area/ha of approximately 15 ha in Compartments II and III (Figure 8) that were cleared for establishment of plantations was 8.78 m^2/ha. The average diameter, height and number of trees/ha were 5.6 cm, 5.3 m and 2,555 trees/ha, respectively. Two species, almácigo and baitoa accounted for 47% of the total basal area. Candelón and quina made up another 14%. The yield per hectare of wood was 42.8 steres (Figure 18). Applying the conversion coefficient of 0.42 derived in this study for solid wood/stere, the yield was 18 m^3/ha of solid wood (Hernández, 1985b).

Figure 18. José Mercedes with wood harvested from native dry forest.

Table 7. Average number of trees and stems per hectare diameter, height, and basal area for tree species in three canopy levels in the permanent plots.

Tree Species (common name)	No. Trees per ha	No. Stems per ha	dbh (cm)	Height (m)	Basal Area per ha (m^2)
		Superior Canopy Level			
Parfa	33	33	7.1	6.6	0.13
Almácigo	167	167	12.4	6.4	2.02
Aruma	33	67	9.9	6.2	0.25
Candelón	167	217	7.0	6.0	0.54
Palo blanco	33	50	6.0	6.0	0.14
Quina	100	117	5.5	5.9	0.29
Bayahonda	17	17	4.9	5.8	0.03
Cinazo	50	133	4.6	5.7	0.22
Brucon	50	50	5.8	5.7	0.13
Bañoa	478	550	6.3	5.6	1.72
		Medium Canopy Level			
Anón de breña	50	283	7.3	5.5	1.19
Cambrón	133	166	5.8	5.5	0.44
Palo de hueso	33	33	6.3	5.5	0.10
Frijol	50	67	9.8	5.5	0.51
Palo amargo	33	50	5.0	5.2	0.10
Cafetán	100	283	4.8	5.2	0.51
Ojo de paloma	33	33	5.7	5.1	0.08
Ciguaaro	33	33	4.4	5.1	0.05
Roblillo	50	50	6.5	5.0	0.17
Cereza	33	50	5.3	5.0	0.11
Uña de gato	17	17	3.8	5.0	0.02
Usero	33	50	4.6	4.9	0.04
Sopalpo	33	33	8.5	4.9	0.19
Guacuncjo	33	50	6.1	4.9	0.15
Arbolito	33	50	8.1	4.9	0.26
Palo de cigua	17	17	6.5	4.9	0.06
Trejo	33	50	4.7	4.9	0.09
Mostazo	33	50	4.4	4.8	0.08
Ciruela cimarrona	17	33	5.0	4.7	0.06
Guatapanal	33	50	7.0	4.6	0.19
Amarra carnero	17	17	5.1	4.6	0.03
		Lower Canopy Level			
Canelilla	33	33	5.0	4.4	0.06
Canela	33	50	5.7	4.4	0.13
Palo caimán	83	100	5.1	4.3	0.20
Clavellina	17	33	4.9	4.3	0.06
Hueso de chivo	33	50	3.9	4.1	0.06
Sangretoro	33	67	5.2	3.9	0.14
Guayacán	83	117	4.8	3.9	0.21
Cabrilla	33	67	6.7	3.9	0.24
Escobón	17	33	4.0	3.8	0.04
Limoncillo de avispa	11	183	5.0	3.7	0.36
Tabacuelo	67	83	4.6	3.5	0.14
Total	2418	3682	-	-	11.86
Average	-	-	5.9	5.0	-

*Table 8. Comparison of dry forest in Mao (northwest) and the southwest part of the Dominican Republic.**

Parameter	Mao			Southwest Provinces		
	Transects	Permanent plots	Silvi-culture plots	Independencia	Bahoruco	Pedernales
Trees/ha	2,848	2,418	2,017	983	1,770	1,797
Mean diameter at 50 cm (cm)		5.9	5.5	6.8	6.6	6.7
Mean height (m)		5.0	4.42	5.97	4.76	4.53
Basal Area/ha (m^2)		11.86		3.05	10.81	4.88

*Composite of data from Hernández and Disla, 1987; Luciano and Checo, 1986.

Simple linear regression equations with natural logarithmic transformations were developed for each of 19 species of trees in the dry forest at Mao to predict the green weight of the total above ground live biomass and the live biomass usable for fuelwood (Maxfield, 1985). The equation and regression coefficients for predicting green weight of usable biomass are given in Table 9. It is recommended that for inventorying a forest of mixed species, the biomass regression equations having basal area at knee height as the independent variable should be used since only one measurement is needed for each stem. Diameter at knee height accounted for the major part of the variability of the dependent variable for the species considered.

Maxfield (1985) found moisture content on a dry weight basis to range from 25 to 186 percent with 12 of 19 species having moisture contents between 40 and 50 percent. At 14 percent moisture (air-dry), the energy values averaged 7320 Btu/lb. Oven-dry energy values ranged from 7750 to 9250 Btu/lb. There were 45.6 metric tons per hectare of total biomass and 32.5 metric tons per hectare of usable biomass. This converted to 592, 508 and 314 Btu/ha at oven-dry, air-dry and field moisture contents, respectively, which is the equivalent of 102, 88 and 54 barrels of oil per hectare.

Forest Management

Control of Understory Vegetation Two years after initiation of treatment, complete removal of weeds and shrubs with a hoe tended to result in better diameter and height growth of trees than chopping of competing vegetation with a machete (Table 10), although the differences were not statistically significant due to the variation among the different species (Hernández and Disla, 1987).

Species demonstrating the best response in diameter to control of competing vegetation were almácigo (*Bursera simaruba*), aroma (*Acacia farnesiana*), cuerno de buey, guatapanal (*Caesalpinia coriaria*), and sopalpo (*Ziziphus rignonii*). In terms of height growth the best response occurred in tabacuelo (*Pictetia spinifolia*), guatapanal (*Caesalpinia coriaria*), clavellina, ciguamo (*Krugiodendron ferreum*) and quina (*Exostema caribaeum*).

Table 9. Simple linear regression coefficients and statistics for predicting green weight of the usable biomass of selected dry forest species in Mao with the regression model ln (usable weight) = $b_o + b_1 + ln(X_i)$[1].

Specie[2]	Coefficients b_0	Coefficients b_1	X_i	Statistics n	$S_{y.x}$[3]	r^2	DKH Range (cm)
Bursera simaruba Almacigo	7.191616	1.110368	X_2	36	0.146939	.9898	4.0-34.0
Acacia macracantha Aroma	7.633640	1.043212	X_3	23	0.183606	.9831	4.0-30.0
Phyllostylon brasilensis Baitoa	7.096829	1.038230	X_2	56	0.144541	.9849	4.0-29.0
Cassia emarginata Brucon	10.008309	1.208762	X_1	26	0.178667	.9574	4.0-16.0
Policurea alpina Cafetan	9.592580	1.125651	X_1	18	0.277910	.8287	4.0-12.0
Prosopis juliflora Cambron	7.318781	0.999669	X_4	22	0.168407	.9827	4.0-30.0
Acacia scleroxyla Candelon	7.762502	1.112649	X_4	46	0.173730	.9854	4.0-29.0
Pithecellobium circinale Cinazo	8.804170	1.315341	X_4	23	0.213858	.8732	4.0-8.0
Capparis spp. Frijol	7.334954	1.033208	X_2	21	0.116870	.9880	4.0-19.0
Amyrys spp. Guaconejo	7.661575	1.111198	X_2	21	0.111727	.9759	4.0-11.0
Caesalpinia coriaria Guatapanal	7.882536	1.079668	X_5	24	0.184299	.9822	4.0-24.0
Guaiacum officinale Guayacan	11.386864	1.464382	X_1	24	0.201363	.9156	4.0-10.0
Exostema caribaeum Quina	4.797134	0.820955	X_6	29	0.166601	.9528	4.0-14.0
Maytenus buxifolia Sangretoro	7.850758	1.120838	X_2	22	0.180072	.9516	4.0-14.0
Pictetia spinifolia Tabacuelo	7.390734	1.088975	X_2	13	0.177935	.8886	4.0-7.0
Coccoloba leoganensis Uvero	5.701871	0.974551	X_6	26	0.189499	.9657	4.0-18.0
Others	6.480793	1.157791	X_7	11	0.285666	.8381	4.0-8.8

[1] X_i = independent variable where:

X_1 = DKHBA
X_2 = DKHBA * TH
X_3 = DKHBA * CD
X_4 = DBHBA * TH
X_5 = DBHBA * CD
X_6 = DKHBA * TH^2
X_7 = DBHBA * TH^2

[2] Common name of species as referred to in northwestern Dominican Republic

[3] Standard error of the estimate in natural log (ln) form.

Table 10. Annual diameter, height and basal area growth over two years of trees in the native dry forest in response to control of competition.

Growth Parameter	Treatment		
	Control	Complete Removal	Chopping
Diameter (cm)	0.27	0.52	0.29
Height (m)	0.45	0.60	0.49
Basal area (m^2/ha)	0.59	0.96	0.83
Total volume (m^3/ha)	3.13		5.12

Source: Hernández and Disla, 1987.

Fifty-six species of weeds were found in the native dry forest. Ten of these accounted for 56% of the total number. The most common were two species of escobilla (*Melochia* sp.), two species of juana la blanca (*Borreria* sp.), four species of tremolina (*Croton* sp.) and yerba de ovejo (scientific name unknown). Of the 56 different weeds found, 20 were climbing vines. Epiphytes, principally bromeliads and orchids were common on trees with rough and striated bark. The relative percent of the surface area in the native forest occupied by weeds, trees, seedlings and bare soil is shown in Figure 19.

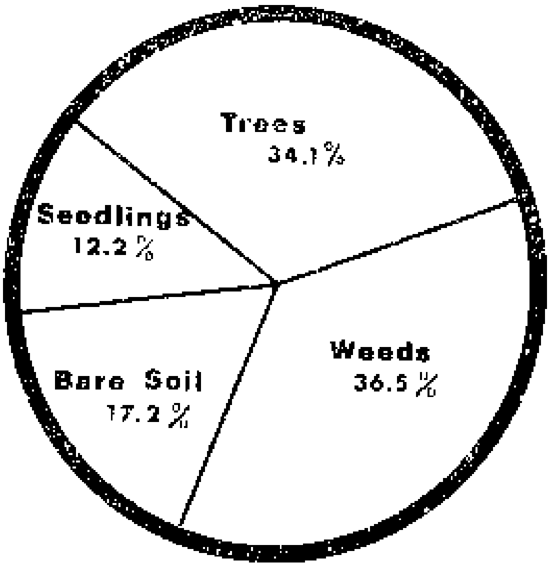


Figure 19. Percent of surface area in native dry forest accounted for by trees, seedlings, weeds and bare soil. (Burgos, Diloné and Mercedes, 1986.)

Weeds cause the greatest damage during the early growth of trees and climbing vines are the most serious problem causing poor form and often mortality through strangulation (Burgos, Diloné and Mercedes, 1986).

Enrichment Plantings Preliminary results of growth from enrichment planting of *Leucaena leucocephala* and *Azadirachta indica* in the native dry forest indicate that initial tree growth is best in the narrow strips. A drought following the planting caused considerable mortality. Replanting has been done and future observations are called for. The 60 cm spots are much more economical to install, less susceptible to erosion and obviously less disruptive of the native vegetation. These results are only preliminary, however, and plans are to continue monitoring tree growth and development.

<u>**Response to Thinning**</u> Thinning did not result in any significant changes in height or diameter of residual trees during a one year period (Table 11). However, there appears to be a trend toward greater amounts of growth at the higher levels of thinning. These results are based on only one year's growth. Subsequent measurements of the treatment plots after additional growth periods are needed to accurately assess tree growth responses to thinning. The initial tree measurements made in January 1986 at the time treatments were imposed were made of all trees in the plots before thinning. Hence, the June 1986 measurements are used as the baseline data for the residual trees.

The response to thinning of seven important species of the dry forest are given in Table 12. The trends suggest that the higher level of thinning results in larger increases in tree size among some of the species, but the results are not statistically different. Data should be collected over a longer period of time for these individual species too.

Table 11. Height and diameter change after one year in trees of the dry forest in Mao in response to January 1986 thinning.

Parameter		Thinning treatment (% removal)				
		0	20	40	60	80
Height (m)	June 1986	4.63	4.49	4.49	4.27	4.48
	June 1987	5.65	5.65	5.62	5.65	5.85
	Change	1.02	1.16	1.13	1.37	1.38
Diameter knee height (cm)	June 1986	5.5	5.8	5.6	5.7	6.5
	June 1987	6.2	6.3	6.2	6.2	7.5
	Change	0.7	0.5	0.6	0.5	1.0

Table 12. Change in height and diameter one year after thinning of selected tree species in the dry forest.

Parameter	Species	Thinning treatment (% removal)				
		0	20	40	60	80
Height (m)	Baitoa	1.1	1.4	1.5	1.1	1.4
	Brucón	1.0	1.1	1.2	1.4	0.5
	Cambrón	1.2	1.0	0.9	2.5	1.3
	Candelón	1.3	1.1	1.0	1.3	0.1
	Guatapanal	0.4	1.2	1.0	1.1	1.3
	Guayacán	1.2	1.2	1.1	1.6	1.3
	Quina	1.1	1.2	0.9	1.5	1.4
Diameter knee height (cm)	Baitoa	0.3	0.3	0.6	0	0.3
	Brucón	0.4	0.4	1.0	0.7	0
	Cambrón	0.4	0	0.4	0	1.7
	Candelon	0.3	0.6	0.5	1.6	0
	Guatapanal	0.6	1.1	0	0.1	2.7
	Guayacán	0.8	0.7	0.4	1.4	0.2
	Quina	0.4	0.3	0.1	0.4	0

Sprout Management Sprouts were common and in some cases prolific among trees native to the dry forest. Of the species observed only cuabilla, clavellina de la grande and paría did not sprout at all. This result is not conclusive however, since the number of stumps of these species was very small. For the majority of species, the number of sprouts increased with the diameter of the stump up to about 24 cm. Larger stumps had few or no sprouts. As a general rule, more sprouts originated from the stump than from the roots (Disla, 1987b and Disla, Gómez and Mercedes, 1986) (Table 13).

With time, there was an autoselection of sprouts in some species such that the most vigorous survived. Twenty-six months after cutting, the number of sprouts retained was still too numerous for best growth and eventual good stand density. Additional observations of these study plots indicated further autoselection; however, the research needs to be continued to substantiate the continuation of the autoselection process (Hernández and Disla, 1987).

In some species such as baitoa and tabacuelo, the autoselection process is slow or does not occur (Table 13). In these cases it is recommended to manually select no more than 2 of the most vigorous sprouts and to cut the excess ones. Pruning of sprouts indicated that longitudinal growth was better when only 1 or 2 sprouts were retained instead of even 3 to 4 (Disla, 1987a). It is important to select sprouts to leave so that they are equally spaced on the stump. It is best not to retain sprouts near the surface of the cut because they are very susceptible to collapse. Weed competition, particularly from vines, is a problem that can cause deformation and even death of sprouts. Weed control that does not damage the stumps or sprouts is recommended.

Table 13. Mean number of sprouts from stumps and roots, retention over time and length after 26 months in some trees native to the dry forest in Mao.

Species	Number of Sprouts				Sprout length after 26 months (m)
	Stump			Roots	
	5 months	14 months	26 months	14 months	
Almácigo	16	13	6	6	1.41
Baitoa	21	16	16	8	1.58
Cafetán	23	12	20		0.65
Cambrón	16	13	8		2.93
Candelón	8	6	6	1	1.31
Guayacán	20	15	11		0.80
Tabacuelo	10	15	17		0.92
Quina	70	41	25	9	0.92

The height of the cut did not influence the number or vigor of sprouts. However, it is recommended to make the cut so that the stump is about 10 cm high and made at an inclination to reduce the risk of decay. When stump mortality occurred in species that sprouted, it could usually be attributed to mechanical damage that allowed insects and decay fungi to invade the stump (Disla, Gómez and Mercedes, 1986).

Sprout production and growth in length on stumps in plots thinned to 20, 40, 60 or 80% of the stem generally was greatest in plots that were heavily thinned or totally cleared (Disla, 1987c). These results are very preliminary at this stage and further observations are needed to substantiate any effect of the degree of thinning on sprout response.

Management Recommendations

There are nearly 100 woody species in the native forest near Mao. About 20 of these are common enough to be of economic value. Baitoa (*Phyllostylon brasiliensis*) and almácigo (*Bursera simaruba*) dominate in frequency and volume, respectively, probably because they were not popular with charcoal cutters who had intervened earlier in this forest. Observations of ecological changes in the composition of the forest are expected to provide valuable information and guidelines for forest management. Hence, continued protection of the Finca Forestal in Mao from local pressures to graze livestock and harvest trees is of great scientific and practical importance.

Most of the remaining dry forests in the Dominican Republic have been grazed and at least lightly cut for fuelwood and charcoal. These forests appear to respond quickly and positively to management. Wherever native dry forest exists, it should be managed by protecting it from livestock and by improving its condition and growth potential through weed control and thinning of less desirable species. Soil compaction by livestock is a major factor limiting penetration of water into the soil. Undisturbed litter fall reduces erosion and improves nutrient cycling and soil porosity. Regeneration studies indicate that most of the useful species will sprout from stumps, thus allowing foresters to easily maintain species composition. Recommendations regarding control of stand density and enrichment planting must await further long term analysis of experimental results.

The Dominican Republic has so little forest remaining that it is not in the national interest to deforest these sites to establish plantations. The potential yield of fuelwood and charcoal from the native dry forest is good and the landowners can be more assured of success, lower cost, and net benefits from managing and protecting the existing native forest. Ecological diversity also is assured. Many of the wood properties and alternative medical and pharmacological values are yet unknown for many of the species.

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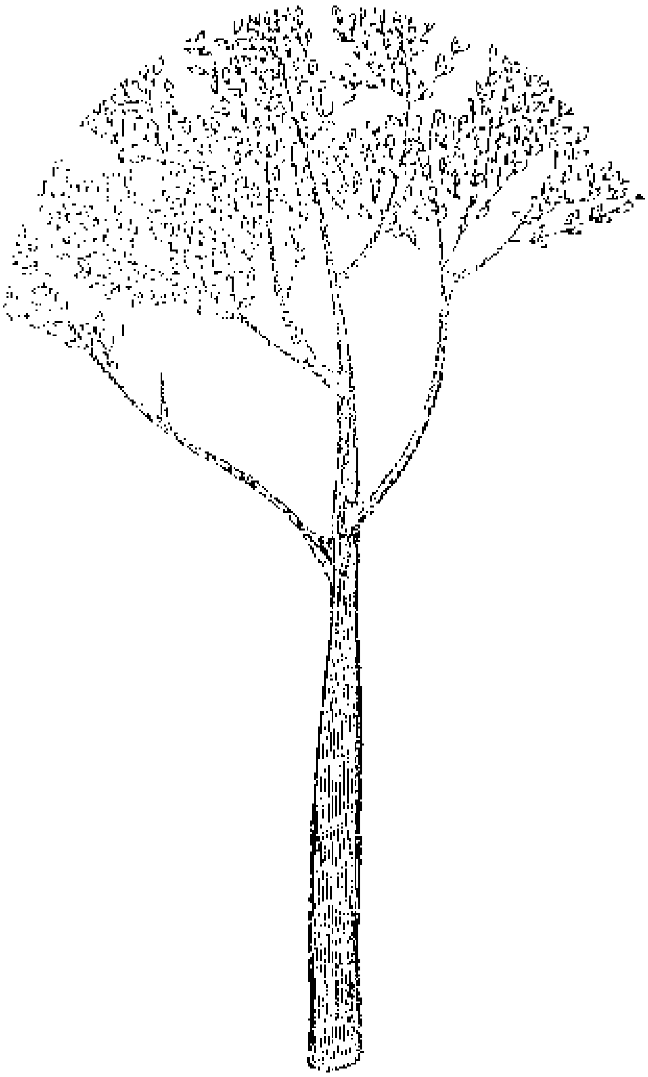


Plantation Establishment and Management

CHAPTER III

PLANTATION ESTABLISHMENT AND MANAGEMENT

This long chapter is divided into six major sections:

A. General description of the research strategy and designs used in the plantation experiments.

B. A general review of the results of the species selection experiments.

C. Analysis of the leading species and several experiments particularly relevant to them.

D. Discussion of various silvicultural problems, results of experiments and recommendations of practices.

E. Mixing forestry and agriculture.

F. Cost projections and profit potential of plantations.

Synopsis of the Findings

The plantation research program established about 100 experiments in the nurseries and in over 20 locations around the country, testing about 40 species of native and exotic trees. A wide variety of sites, ranging from dry to humid climates, basic to acid soils (pH = 8.5-4.5), and rocky subsoil to very deep alluvial soils were used. Results from the trials plus observations on several other plantations provided a selection of six species that seem to have a very high probability of success when planted and managed appropriately.

The six lead species are *Azadirachta indica*, *Leucaena leucocephala*, *Cassia siamea*, *Eucalyptus camaldulensis*, *Eucalyptus robusta*, and *Calliandra calothyrsus*. Another six or eight species are very likely to be added to the list as Dominican researchers continue their measurements and expand the ecological range of their trials. Careful matching of the species to the different site conditions of the nation will reduce the possibility of failure.

Two silvicultural management practices that are vital to the success of all of these species on all sites are 1) fencing and patrolling to prevent the entry of livestock into the plantation and 2) prompt and repeated weeding at the start and throughout the early years of the plantation. On some sites, fertilization and irrigation may be important to commercial growth. On others, it has no practical effect on early growth. Inoculation of roots with microflora is important for some species to prosper; in other cases, there is adequate natural inoculum in the field.

Cost and income analysis by the research program indicated that on reasonably productive sites it is possible to earn an internal rate of return of 20 percent from fast growing tree plantations. Although the estimates of costs and benefits used in these analyses will vary considerably by location and product sold, the returns are consonant with other cases from tropical areas with similar growth rates. Practical experience with plantations in the Dominican Republic by the few early investors who have started harvesting young trees for poles and charcoal indicates very high income ratios, far above the 20 percent rate of return. They dramatize the simple fact that there is a strong seller's market for wood produced in the Dominican Republic.

Planting trees in association with crops and livestock has already proven to be a successful activity for several owners of very small farms in the middle of the country. Trials at the ISA farm led to incorporating more legume trees into the pasture and cut feed operations of the university livestock herds. There is a requirement for strong and intelligent management of this mixed enterprise, however. Introduction of livestock into plantations of fuelwood trees is not recommended under the present general level of livestock management. This would produce dead or badly damaged tree plantations.

In brief, based upon the findings of this research program, very careful matching of species to sites and management of the species presents strong economic development opportunities for the rural sectors of the country. Investors in large-scale plantations can achieve very good profits. Small-scale farmers have already begun taking advantage of the soil, nutrient, forage and firewood benefits of agroforestry. The data presented allow a new level of confidence in the potential of plantation forestry for profitable investment.

Research Strategy and Designs

Objectives

In the plantation experiments, the major objectives were to: 1) determine which species of fast-growing fuelwood trees could be used for different ecological conditions in the Dominican Republic and 2) determine appropriate silvicultural and management procedures for profitable plantations of these species.

Strategy

To accomplish the objectives in the few months allotted for the research program, a research strategy was developed to permit efficient and rapid observation of species performance using field trials in the Dominican Republic as the basis for recommendations. Careful research of the literature and plantations in other tropical countries helped to determine the species to be tried. A program to visit and measure the major experimental plantings of fuelwood-type species in the Dominican Republic also provided basic data on species behavior and potential (Morell and Knudson, 1984).

The selected native and exotic species were planted in compact designs that allowed an early screening. Some of these same species were planted in longer-term yield plots and silvicultural trials that offered early indications of growth potential but that also will continue to produce data for many years to come. In the short run, these plots gave comparative data on heights, diameters and survival in the first years. Continuing measurements will produce data on volume yields and management impacts on net income.

The selected species offer an initial choice of trees for different sites. Many other excellent species are available for future trials and they should be tested. The very short duration of this research program did not allow exhaustive testing of any more than the most accessible species.

Because of the urgent need for fuelwood and charcoal plantations, relatively underused productive lands could be used for plantations. Therefore, planting experiments were scattered throughout the country, on submarginal to moderately productive soils in wet and dry zones.

Although ideal research conditions include complete control of the land where the trees are planted, this was not possible on any of the sites. To get trees growing even before full funding became available in February 1984, several private and public landowners offered sites for experiments. These collaborative arrangements were key support to the more complex installations at the ISA campus near

Santiago and ISA's Experimental Forest at Mao. A total of about 300 ha were occupied by plantations and their fire breaks on the ISA properties and another 80-100 ha on collaborators' lands, primarily at their expense.

Designs

The study of plantations is of great importance to future investors, since much of the country is denuded of native forests and the lands close to the fuelwood markets will have to be planted soon to meet the immediate needs of the nation. The plantation research program consisted of four main types of experiments, two of which allow rapid results and two which are of longer term consequence (Montero, Knudson and Reynoso, 1984).

1. Initial growth trials (I.G.) were designed to give species selection answers within two years. They use single tree plots with 16 or more replications (Figure 20). On less than 1,000 square meters, 10 to 15 species can be compared without the problem of major variations in soil. When these trees begin to compete with each other, the measurements are terminated and the best trees can be left as examples or seed sources. The information on height growth and survival in the early years is important to investors and managers. It is this very compact experiment that has allowed the program to produce species recommendations for many different ecological conditions within 3 or 4 years, selecting from over 40 species.

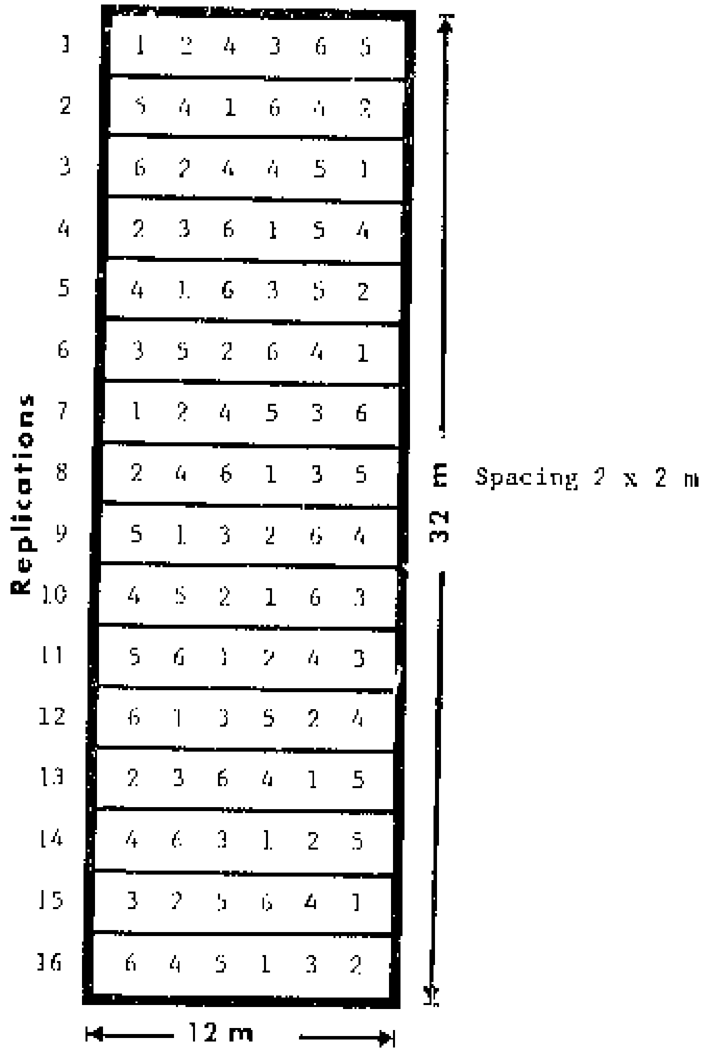


Figure 20. Experimental design for initial growth trials.

2. While initial growth trials gave only information on early growth, yield plots (Y.P.) are designed to compare two to eight species in small parcels of 81 trees of each species in randomized complete blocks with four replications (Figure 21). The 25 central trees are measured for height, diameter, and survival. The relative productivity of the plantations can be estimated at various ages; the most valuable volume comparisons will be at harvest age, normally seven to ten years after planting. The fact that a few species died in yield plots in the first year clearly and rather inexpensively demonstrated the unsuitability of the species for the site in some cases or the need for better site protection and management in other cases.

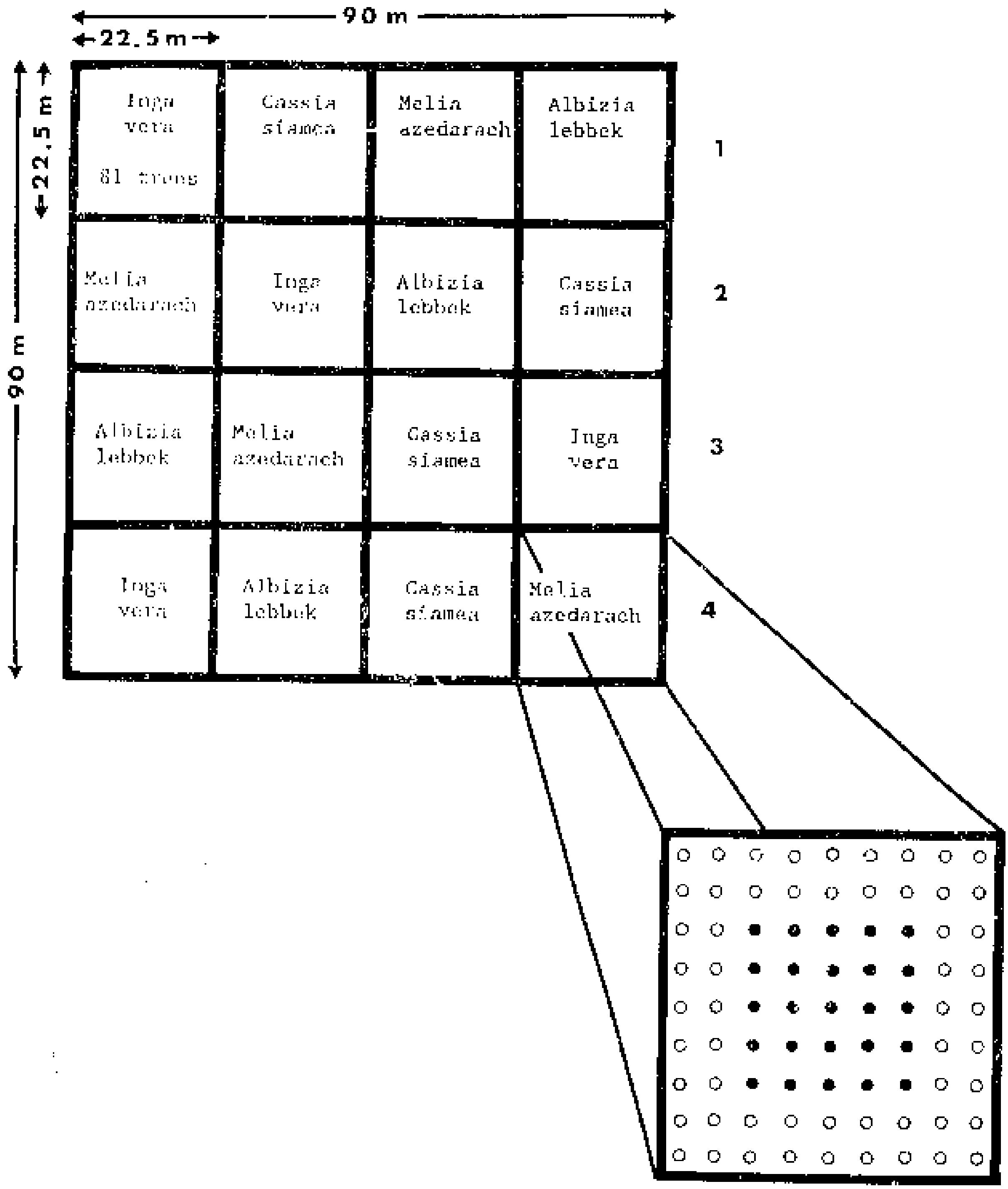
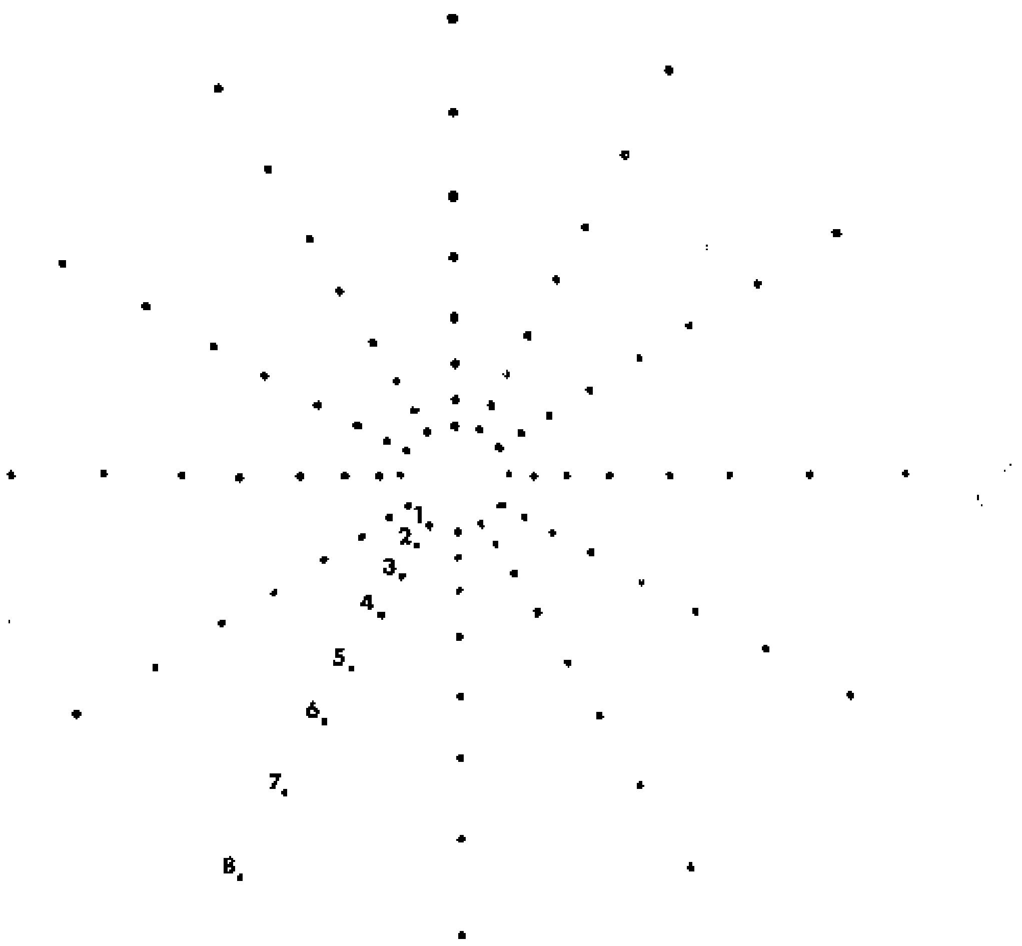


Figure 21. Experimental design for yield plots.

3. Spacing trials help to determine which distance between trees produces the greatest net economic return at harvest time. This is a question of great theoretical debate; answers are a function of the costs of plantation establishment and the markets for small materials, as well as some biological characteristics of individual tree species.

The research program used both the compact Nelder wheel design (Figure 22) and the larger blocks of trees at four different spacings (Figure 23). The Nelder design allows an evaluation of spacing on a very small area. Its validity depends on careful alignment and maintenance of the trees in the plot. It uses as few as 108 trees, 96 of which are measured. The measurements are most useful as the trees approach harvest age or as they stagnate in growth due to crowding.



Each dot represents one tree. Spacing area/tree is trapezoidal.

Angle = 30°

0 2 4 6 8 10
Scale in meters

Distance of points from center		Area/tree
1	1.87 m	Border
2	2.93	1.82 m²
3	4.20	3.13
4	5.73	5.13
5	7.57	8.13
6	9.77	12.59
7	12.42	19.19
8	15.59	Border

Figure 22. Nelder wheel spacing study design.

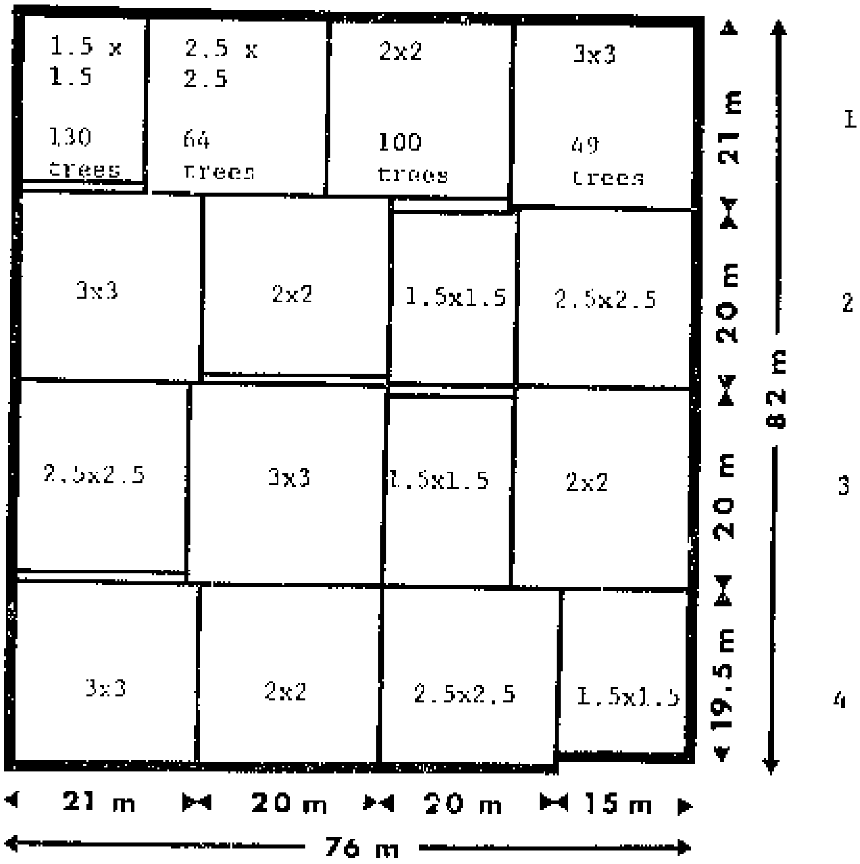


Figure 23. Spacing blocks.

On the other hand, the blocks used in square or rectangular design are compact, but require many more trees per trial and much more land than the Nelder wheel. The design shown uses 1,372 trees for four spacing treatments and four replications. This fits onto an area of about 6,200 m^2. The blocks of closely-spaced neem (*Azadirachta indica*) in ISA-Rio have already shown some remarkable synecological effects that are scientifically interesting. Of greatest interest is the long range productivity of different spacings and to find if the high costs of close spacing are compensated by reduced tending costs and increased yield and income. The value of these spacing plots will increase greatly over the next three years, if they are measured each year.

4. Pilot plantations is a category in which many different silvicultural and economic studies were conducted on different sized parcels. The program has conducted experiments with herbicides, fertilizers, and irrigation, made cost comparisons of site preparation and planting methods, tested bacterial root inoculation, tried different species combinations, water conservation measures and pruning. Most of these experiments used randomized block design with four replications. As the plantations mature, other trials should be implemented on thinning, harvesting and regeneration methods. The program has benefited from pilot plantations established by several private investors.

The general characteristics of the four types of experiments are summarized in Table 14.

Table 14. Plantation experiment dimensions and characteristics.

Type of Experiment	Replication	Measurements	Area Required
Initial Growth	16, 24, 32	Every 3-6 months Final at 2 years	$\leq$ 1000 m^2
Yield Plots	4	Every year Major at 7, 13, 19 years	784-2025 m^2 per species
Spacing			
Blocks	4	Every year after 3;	6000 m^2/Spp.
Nelder	12	Final at 7-10 yrs.	$\leq$ 300 m^2
Pilot Plantations	4	Variable by experiment	Variable

Species Selection Experiments and General Results

This section provides a general overview of the initial growth trials (I.G.) and part of the yield plot experiments (Y.P.). After describing the locations and distribution of species, the general results are presented.

__Locations and Conditions__

Table 15 lists 23 locations where the experiments were installed. These locations are indicated on the map in Figure 24. The range of ecological conditions is from a droughty area south of Azua, where virtually no rain fell for 9 or 10 months after the experiment was installed to three sites with about 2000 mm of rain per year. Soils were limiting factors to the success of several species that were planted. In El Valle, an acid soil was shown to be unsuitable for *Leucaena leucocephala* and *Cassia siamea*. Lack of fertility was a limiting factor to the other species except when commercial fertilizer was added. Very shallow soils at La Celestina and Los Montones Arriba apparently limited plant growth severely; at the latter site, the owner said nothing had grown on the site for 80 years or more. Altitudes tested ranged from near sea level to 700 m. Only a small portion of the country lies above 700 m and most of this is covered with pine forest. Most of the fuelwood plantations close to small or large cities will be at altitudes of sea level to 500 m, although there is an urgent need to reforest severely denuded watersheds in the mountains at elevations of 300-1000 m. Pine is probably the best alternative for reforesting burned or cutover areas at higher elevations.

Of the 23 locations, Mao and ISA (Santiago) contain the most experiments. Including the nursery trials, agroforestry tests and short-term field experiments, these two sites were home for over half of the research effort of the program. For future followup on yield plots and pilot plantations, these two sites plus Cementos Nacionales at San Pedro de Macorís are the major locations of continuing experiments.

Table 15. Locations of experimental plantations.

Location	Province	Rainfall	Soil Limits	Altitude	Kinds of Experiments				
					Init Gr.	Yield	Spacing	Plant'n	
		(mm)		(m)					
El Valle-Pvt	Hato Mayor	2000	pH 4.5 infertile pan at 60 cm	40	5 spp	5 spp	4 spp	5 spp	
Monte Plata-Pvt	M. Plata	1900	pH 5.9	70	6 spp	--	--	4 spp	
La Guázuma-Pvt	Santiago	1200	pH 5.6 shallow eroded	700	8 spp	--	--	--	
Los Montones-Pvt	Santiago	1200	pH 6.1, very shallow, rocky infertile	700	(2) 15 spp	--	--	--	
Jánico-Pvt	Santiago	1000	pH 7.9, rocky	450	6 spp	--	--	--	
La Celestina	Santiago	1250	very shallow, eroded, rocky infertile	550	18 spp	6 spp	--	--	
La Cejita-Pvt	Santiago	1200		600	spp	--	--	4 spp	FL
Suero, Juanillo	Altagracia	1000		20	9 spp	--	--	--	
Mao	Valverde	740	pH 6.8, dry compact	100	(3) 14 spp	10 spp	4 spp	10 spp	
ISA	Santiago	950	pH 7.0-7.7 deep clay, surface rock dry	200	(2) 22 spp	4 spp	3 spp	8 spp	
Villa Bao (Gúzman) Pvt	Santiago	930	pH 7.3, dry	200	--	6 spp	--	2 spp	
Jacagua-Pvt	Santiago	1000	heavy clay	220	10 spp	4 spp	--	--	FL
Monción-Pvt	S. Rodrgz	1150	shallow compact	400	10 spp	--	--	--	FL
S. Pedro de Macorís-Pvt	SPM	1400	rocky	40	12 spp	6 spp	--	2 spp	
Muñoz-Pvt	P. Plata	1800	pH 7.0	25	7 spp	--	--	--	
Manaclar-Pvt	P. Plata	2000		620	10 spp	--	--	--	
Playa Grande-Pvt	MT Sanchez	2000	compact	20	7 spp	--	--	2 spp	FL
La Vega ISA	La Vega	1500	eroded, compact	200	11 spp	--	--	4 spp	FL
Jarabacoa ENF	La Vega	1500	acid	590	12 spp	6 spp	--	--	
Esc. Agronómica-Pvt	La Vega	1400	--	120	--	--	--	1 spp	
Azua	Azua	650	dry	0-20	(2) 10 spp	--	--	--	FD
CIMPA-Navarette	Santiago	800	dry, eroded	160	7 spp	--	--	--	FD
Sabaneta	S. Rodrgz	1300	compact, infertile	150	--	5 spp	--	--	FL

F = Plantation failed before final results, due to drought (D) or livestock (L).

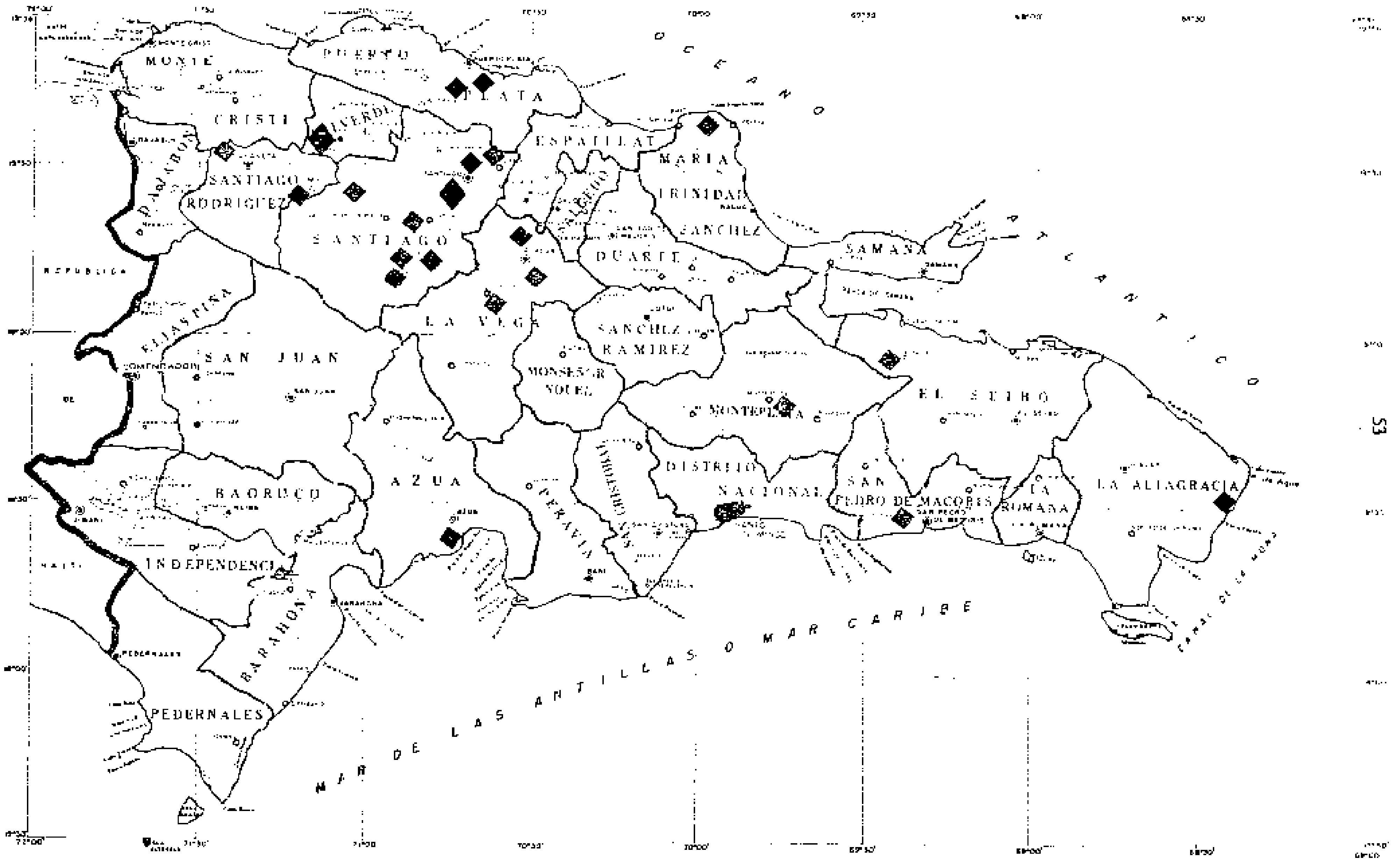


Figure 24. Map showing location of experimental plantations.

Experiments were established in 11 provinces. In many of these, the trials have terminated. In most, the trees remain as a reference and seed source for neighbors or owners to expand their forest area. In addition to the experimental areas, the program stimulated or assisted tree planting by providing advice, seedlings, seeds, or demonstration plantings in about 15 other locations.

Despite the success of the program's collaboration with many landowners, eight of the locations are indicated as having failed before the two-year initial growth trials were complete. These are cases of drought in Azua and CIMPA, where the trees were never well established. On the other six sites, cattle, goats or horses damaged most of the trees, invalidating the experiments.

Table 16 lists 42 species that were installed in one or more experiments. Actually, several other species were tried but were lost before meaningful results could be derived. Fourteen of the species used are listed as native or naturalized. Others that have long been in the country and appear as escapes or perhaps naturalized are *Tamarindus indica*, *Melia azedarach*, *Gliricidia sepium*, and *Albizia lebbek*.

In addition to the plantings listed, the research program benefitted from several independent private plantations, most notably two 1983-84 plantings of *Leucaena leucocephala* near Puerto Plata and the 8 hectare planting in 1984 of *Eucalyptus citriodora* in Santiago. All three of these had yielded a substantial net profit to the owners by the spring of 1988, according to personal interviews and published newspaper accounts. Older experimental plantations at Falconbridge Dominican, Alcoa, and former Gulf – Western properties also were visited and measured by members of the research and advisory team early in the program, providing a basis for species selection and growth projections.

The nursery and plantation experience of FORESTA, the federal forestry agency, Plan Sierra; and the private corporation, "Los Arbolitos", also provided useful background for determining research needs and operating practices used in the program.

<u>General Results</u>

The program researchers do not suggest the cutting of existing native forest to put in plantations. Results of this program offer no indication that it would be wise to deforest in order to reforest. Wherever there is native forest, it should be maintained and/or managed so that it will continue to regenerate the natural mix and vigor of species. To expand the nation's forest base old fields, pastures, bare soils and other unforested lands should be planted with fast-growing species.

For each of the initial growth trials, height and survival were measured two to three times in the first year and twice in the second year. In the yield plots, heights, diameters and survival were measured once per year for the general information they offer, but the yield figures will only be meaningful at about age 5 and on to harvest.

The specific results of each trial were reported in "Notas Técnicas" published and distributed by the Instituto Superior de Agricultura, or in "Informes Internos" kept in Program files at ISA. Table 17 contains heights at 2 years of several species, showing the wide variation in productivity of different sites.

Examples of results from initial growth and yield plots in Mao are summarized in Tables 18, 19, and 20. The values shown in these tables, especially in Table 20, indicate the variation in performance of the same species on different sites, even within the same property.

The information in these trials leads to the conclusions that three species should not be planted in Mao, due to high mortality: *Eucalyptus urophylla*, *Casuarina equisetifolia* and *Casuarina cunninghamiana*. Two others did not grow fast enough to be interesting: *Tamarindus indica* and *Pithecellobium saman*. The best species of the test group on this site will probably be *Leucaena*

Table 16. Lists of species established in experimental plantations.

Species	ISA	NAO	Celestina	Guazuma	L. Montones	Janico	Munoz	M. Plata	El Valle	SP Macor.	Caramacta	Mahaclar	Suero	Jaragua
Azadirachta indica	1,2,3,4	1,2,3,4	1	-	1	1	1	-	-	1	-	1	-	1,2
Calliandra calothyrsus	1,2,4	-	1,2	1	1	-	1	-	-	-	-	1	-	-
Cassia siamea	1,2,4	1,2,3,4	1,2	1	1	1	1	2,4	1,2,3,4	1,2	-	1	1	1
Eucalyptus camaldulensis	1,2,3,4	1,2,3,4	1	1	-	1	-	-	-	1	1,2	1	-	1
Eucalyptus robusta	-	-	1	-	1	-	-	2,4	1,2,3,4	1,2,4	1	-	-	-
Leucaena leucocephala (giant)	1,2,3,4	1,2,3,4	1	1	1	1	1	1	1,2,4	1,2	-	1	1	1
n- Acacia scleroxyla	2,4	1,2,4	1*	-	-	1	-	-	-	-	-	-	-	-
n- Calophyllum calaba	-	-	1	1	1	-	-	-	-	-	-	-	1	-
n- Cassia emarginata	1,2	1,2	-	-	-	-	-	-	-	-	-	-	-	-
n- Cedrela odorata	-	-	1	-	-	-	-	-	-	-	-	-	-	-
n- Colubrina arborescens	-	-	1	-	1	-	-	4	-	1,2	-	-	1	-
n- Guarea guidonea	-	-	-	-	1	-	-	-	-	-	-	-	-	-
n- Guazuma ulmifolia	-	3,4	-	-	-	-	-	-	-	-	1,2	-	-	-
n- Haematoxylum campechianum	-	1,2	-	-	-	-	-	-	-	-	-	-	-	-
n- Inga vera	-	-	1	1	1	-	-	-	-	-	1,2	-	-	-
n- Parkinsonia aculeata	-	1	-	-	-	-	-	-	-	-	-	-	-	-
n- Pithecellobium saman	1	-	1	-	1	-	-	-	-	-	-	-	1	1
n- Prosopis juliflora	1,4	1,2	-	1	1	-	-	-	-	-	-	-	-	-
n- Simarouba glauca	2	-	-	-	-	-	-	-	-	-	-	-	-	1,2
n- Swietenia mahogani	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Albizia lebbek	1	-	-	-	-	-	-	-	-	-	-	-	1	-
Caesalpinia velutina	1	4	-	-	-	-	-	-	-	-	-	-	-	-
Casuarina cristata	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Casuarina cunninghamiana	1,2	1,4	-	-	-	-	-	-	-	-	-	1	-	-
Casuarina equisetifolia	1,4	1,2,4	1,2	1	1	1	-	1	1,2,3,4	1,2	1,2	-	1	1
Casuarina stricta	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Eucalyptus citriodora	4	-	1	-	-	-	-	1	1,2,3,4	1,2,4	1	-	-	-
Eucalyptus cloeziana	1	-	-	-	-	-	-	-	-	-	1	1	-	-
Eucalyptus globulus	-	-	1	-	1	-	-	-	-	-	-	-	-	-
Eucalyptus grandis	-	-	-	-	-	-	-	-	-	-	1,2	-	1	-
Eucalyptus maculata/saligna?	-	-	1	-	1	-	-	-	-	-	1	-	-	-
Eucalyptus sideroxylon	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Eucalyptus tereticornis	4	1,3	-	-	-	-	-	-	-	-	-	-	-	-
Eucalyptus torelliana	1	-	1	-	-	-	1	-	-	-	-	1	-	-
Eucalyptus urophylla	1	1	-	-	-	-	1	-	-	1	-	1	-	-
Gliricidia sepium	1,4	-	-	-	-	-	1	-	-	1	2	-	-	1,2
Gmelina arborea	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Leucaena diversifolia	4	-	-	-	-	-	-	-	-	-	1	1	-	-
Melia azedarach	1,2,4	-	-	-	-	-	-	-	-	1	-	-	-	1
Mimosa scabrella	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Moringa oleifera	-	-	-	-	-	-	-	-	-	-	-	-	1	-
Tamarindus indica	1	-	-	-	1	-	-	-	-	-	-	-	-	1

*Probably Adenanthera peregrina, but originally identified as Acacia scleroxyla
n = native or naturalized species
1 = Initial Growth Trials 2 = Yield Plots 3 = Spacing Trials 4 = Plantations Experiments

Table 17. Heights of selected species in Initial Growth Trials at age 2 years.

Species	Mao	Monte Plata	ISA-1	Guazuma + Montones	La Celestina
Cassia siamea	5.52 m	3.8 m	1.93 m	0.92 m	0.60
Eucalyptus camaldulensis	5.10	--	1.89*	2.10	1.39
Leucaena leucocephala	4.81	4.4	2.52*	2.03	0.27*
Calliandra calothyrsus	--	--	(X)	3.73	1.11
Casuarina equisetifolia	3.32(X)	5.3	(X)	1.41	0.47
Azadirachta indica	3.71	--	1.94	0.61	0.32
Prosopis juliflora	2.02	--	0.42*	(X)	--
Eucalyptus robusta	--	4.5	--	1.05	0.94

*Damaged trees; some were resprouts.
(X) - all trees died.

Table 18. Average heights (m) of live trees in six experiments in Mao.

Species	Experiment and Age (years)					
	IG-1 (2.4)	IG-2 (2)	IG-3 (1.5)	YP-1 (2.4)	YP-2 (2)	YP-3 (1.5)
Leucaena leucocephala K-8	5.68	4.81	2.40	5.74	4.48	2.11
Eucalyptus camaldulensis	5.55	5.10	2.14	5.00	--	--
Cassia siamea	5.23	5.52	2.72	4.90	4.35	3.02
Azadirachta indica	4.33	3.71	1.76	3.72	3.17	2.28
Eucalyptus sideroxylon	--	3.06	1.58	--	--	--
Parkinsonia aculeata	--	2.66	--	--	--	--
Cassia emarginata	2.79	2.18	0.84	2.84	2.18	1.31
Prosopis juliflora	2.74	2.02	0.89	1.64	1.66	--
Acacia scleroxyla	2.48	2.22	--	2.44	--	--
Haematoxylon campechianum	--	--	1.75	--	--	1.45
Eucalyptus urophylla*	4.79	--	--	--	--	--
Casuarina equisetifolia*	3.39	3.32	1.35	0	0	0
Casuarina cunninghamiana*	--	2.17	1.29	--	0	0
Pithecellobium saman	--	1.97	--	--	--	--
Tamarindus indica	2.01	--	--	--	--	--

*Starred species suffered mortality of 50% or more, so are not considered as useful on this site.
IG = Initial growth trials, planted May 1984, September 1984, May 1985.
YP = Yield plots.

Table 19. Average heights, diameters and percent survival in 3 year old yield plots in Mao and Santiago.*

Species	Height m	Dbh cm	Survival %
	Mao		
Leucaena leucocephala	6.20	6.0	99
Eucalyptus camaldulensis	5.34	4.4	62
Cassia siamea	4.86	N/A	80
Azadirachta indica	4.84	3.9	98
Cassia emarginata	2.78	2.3	90
Acacia scleroxyla	2.29	N/A	48
Prosopis juliflora	1.62	N/A	89
Casuarina equisetifolia	Dead	Dead	0
	ISA-1, Santiago		
Leucaena leucocephala	6.79	6.32	96
Azadirachta indica	4.92	5.07	97
Cassia siamea	4.22	3.86	81

*Mao trees were planted May 1984 and measured May 1987; ISA trees were planted September 1984, measured January 1988. *Cassia emarginata* was also planted in the ISA experiment, but suffered almost total mortality in the first year.

Table 20. Heights of young trees in Mao yield plots.

Species and Yield Plot No.	Ht. (m)	Survival (%)
Yield Plot 4 - 14 mo. old		
Cassia siamea	0.21	80
Caesalpinia velutina	0.31	99
Leucaena leucocephala K-8	0.84	95
Yield Plot 5 - 13 mo. old		
Eucalyptus camaldulensis (Gibb R.)	1.44	83
Leucuena leucocephala	1.33	98
Yield Plot 6 - 13 mo. old		
Eucalyptus camaldulensis (Gibb R.)	1.24	89
Yield Plot 7 - 13 mo. old		
Eucalyptus camaldulensis (CAF)	1.07	99
Cassia siamea	0.54	93

leucocephala, *Eucalyptus camaldulensis*, *Cassia siamea* and *Azadirachta indica*. The remaining species deserve continued observation, especially the native species that may catch or surpass the exotic species by harvest time.

Promising Species

The initial growth trials and observations of yield plots and pilot plantations produced a tentative ranking of tree species in terms of preference for fuelwood plantings. The early results indicate that a "basic portfolio" of six species allows choice for planting in most of the sites of the country. The key species that offer basic surety of success are:

SPECIES	RECOMMENDED SITE CONDITIONS
Eucalyptus camaldulensis	Semi-arid to medium rainfall; basic or neutral soils; any altitude in the Dominican Republic.
Leucaena leucocephala K-8, K-28, K-132	Arid to medium rainfall; basic to neutral soils (not acid); low altitude.
Cassia siamea	Semi-arid to semi-humid rainfall; deep basic or neutral soils; low altitude.
Azadirachta indica	Arid to medium rainfall; basic or neutral soils; low altitudes.
Eucalyptus robusta	High rainfall; wet to well-drained acid soils; any altitude.
Calliandra calothyrsus	Medium to high rainfall (above 1000 m); neutral or acid soil; any altitude.

The following species show strong promise, although there is still relatively little research data on their performance under conditions in the Dominican Republic. Further observations and plantations are suggested before ISA can make specific recommendations.

SPECIES	RECOMMENDED SITE CONDITIONS
Eucalyptus citriodora	Deep soils, pH 5.8 - 7.0; very well-drained, rich soil; rainfall above 1000 mm.
Eucalyptus grandis	Medium, moist soils, slightly acid; rainfall above 1200 mm.
Eucalyptus urophylla	Rainfall above 1500 mm, deep acid soils; some tolerance of slow drainage.
Acacia mangium	Humid area, acid soils, good drainage, low altitudes.
Acacia auriculiformis	Humid, acid soil, low altitudes.
Acrocarpus fraxinifolius	Semi-humid, neutral soil, well-drained.

There are several "maybe species," their recommendation pending yield measurements or more information that should be forthcoming from these experiments. Some of these are special cases that have grown poorly on marginal soils or off-site but have done well in other locations.

SPECIES	RECOMMENDED SITE CONDITIONS
Eucalyptus torelliana	Neutral, well-drained soil; rain +1000.
Eucalyptus tereticornis	Basic-neutral, well drained soil; rain 850-1500 mm.
Gmelina arborea	This large tree with light-weight wood is very specific about its site requirements. It grows rapidly on deep, well-drained acid soils in humid areas.
Gliricidia sepium	This will be used mostly for living fence in areas with 1200+ mm of rain. Has potential for plantations, but not in Santiago, where cuttings all failed unless irrigated.
Leucaena diversifolia	Performs like *L. leucocephala*, but was tested for browsing and forage cutting. No data on wood production.
Casuarina equisetifolia	Superb firewood/charcoal; grows moderately well most places, but death in Mao raises doubts for dry areas. Inoculate roots with *Frankia* spp.
Casuarina cunninghamiana	The few trials indicate good early growth where +900 mm rain. Inoculate roots with *Frankia* spp.

In agroforestry and silvi-pastoral trials the following species can be tried: *Leucaena leucocephala*, *Leucaena diversifolia*, *Calliandra calothyrsus*, *Gliricidia sepium* and probably *Guazuma ulmifolia*. Only leucaena seems to do well on marginal or dry sites in plantations.

There are some species that are not recommended at the present time for commercial plantations because of the high risk of failure or the very limited experience and information available. Some of these are natives that can probably be managed more economically from natural regeneration.

SPECIES	COMMENTS
Eucalyptus globulus	Performed weakly on thin moutain soils.
Eucalyptus sideroxylon	May work in very dry areas; poor form.
Simarouba glauca	This popular local species grew poorly in ISA-Rio and Jacagua, apparently requiring more moisture, less competition.
Tamarindus indica	Very slow initial growth.
Prosopis juliflora	On dry sites, manage its spontaneous regeneration. Died in mountains.

Calophyllum calaba	Mara needs better soils than it had. It is tough, but slow-growing in these trials.
Guazuma ulmifolia	Untried here for plantations; study for wood and forage.
Pithecellobium saman	This tree regenerates spontaneously in old fields and grows rapidly. It failed in plantations. Ability to grow straight in forest is questionable.

Analysis of Lead Species Performance

Among the more than 40 species tried, six are recommended for commercial scale planting, based upon their performance in the experiments. With these six species, excellent growth can be expected on a variety of deep to moderately deep soils. By carefully matching species to site, they provide a choice that will produce high yields, when managed properly, on all but the most arid or shallow soils of the country. Species selection, plantation establishment and management should be done with the direct field supervision of a professional forester with training and experience in the tropics.

It is expected that the highest yields and income will be achieved on the most favorable sites. On sites inappropriate for these species, each is capable of failing. The research program provided some vivid examples of such failures, in part to demonstrate the limitations of the species. Examples are listed below, along with the diagnoses of the probable reason for failure (Table 21).

Table 21. Cases of failure among the selected species.

Species	Location	Diagnosis
Eucalyptus robusta	La Celestina	Shallow, dry soil
Eucalyptus camaldulensis	Mao-II	Planted at start of summer drought
Calliandra calothyrsus	ISA-Rio	Rocky, shallow soil, 3-4 month drought (resprouted)
Azadirachta indica	Los Montones La Celestina	Shallow soil, high altitude
Leucaena luecocephala	El Valle Los Montones La Celestina	Acid soil Altitude, shallow soil, cattle
Cassia siamea	El Valle Los Montones	Acid soil Shallow soil, few nutrients

All six of the recommended species are exotics, if the giant El Salvador cultivars of the native *Leucaena leucocephala* are included as exotics. This does not mean that native species will not grow rapidly in plantations. It simply implies that 1) their comparative performance on the usually poor sites used was less than several of the exotics and 2) there is a need to study their potential site requirements more thoroughly and to match their best genetic potential to the best sites. It should also be noted that the native species tested were not selected just for rapid growth, but also for value of the trees and their products.

Likewise, the recommendation of the six species should not be considered as a disqualification of other exotic species. Several others showed excellent promise, but had not been studied for long enough to predict their success with confidence. Other untried species should be introduced in initial growth trials throughout the country. A summary of some of the characteristics of the selected species is presented in Table 22. All of these species are multiple purpose, filling a variety of rustic and processed product needs. In a nation that imports its wood, they are finding new uses.

Table 22. Characteristics of the six recommended species for plantations.

Attribute	Species initials					
	Ai	Cc	Cs	Ec	Er	Ll
No. seeds/kg	4000	20,000	34,000	220,000	110,000	18,000
Mature height (m)	10-15	12	20	24-40	25-30	20
Mature diam. (cm)	30-80	20	30	60-100	100-120	20+
Wood Sp. gr.-g (cm^3)	0.7	0.55	0.7	0.6	0.75	0.65
Wood Kcal/kg	4780	4490	high	4800	--	4445
Other uses	Constr Posts Furn	Forage Erosion control	Posts Ties	Constr Posts Ties	Constr Pulp Posts	Posts Forage Constr
Resprouts	Yes	Yes	Yes	Yes	Yes	Yes
Recommend in DR: Soil pH	6.0-8.0	4.5-7.5	6.0-8.0	6.0-8	4.5-7	6.5-8.0
Soil depth	deep	any	med-deep	deep	wet-deep	any
Rainfall (mm)	700-1500	+1000	800-2500	700-1200	+1200	700-1200
Altitude (m)	0-500	0-2000	0-700	0-1500	0-1500	0-500

Source: CATIE (1986) except *E. robusta* and recommendations, which are based on recent experience in the Dominican Republic; future experience may alter the limits. Ai = *Azadirachta indica*, Cc = *Calliandra calothyrsus*, Cs = *Cassia siamea*, Ec = *Eucalyptus camaldulensis*, Er = *Eucalyptus robusta*, Ll = *Leucaena leucocephala*.

Azadirachta indica A. Juss

Common name: Neem, nim, neeb, nimba
Family: Meliaceae
Synonyms: *Melia azadirachta* L; *Melia indica* (A. Juss) Brandis. There has been some confusion in the literature of this species with chinaberry or violeta (*Melia azedarach*), although they are distinct.

Distribution and Characteristics

This species is native to Burma and southeast Asia and possibly in India, where it has been cultivated for centuries. Starting about 100 years ago, it was planted as an ornamental and plantation tree in large areas of Africa and in Trinidad and Tobago (Pliske, 1984).

Apparently, the Haitian Department of Highways introduced the species to the island of Hispaniola within the past few decades. The Pan American Development Foundation foresters indicate that most of the roadside and plantation trees have as their origin 6 trees planted at one of the workshops of the highway agency. Over the past 10 years, strong interest in the species for reforestation in Haiti has produced some impressive young trial plantations with seed from these trees.

This is a very attractive, dark green tree that usually exhibits a single, straight stem when grown in a plantation. In India and southeast Asia, it is often seen as a spreading shade tree. It has been a successful, attractive and resistant highway tree in Haiti, where it has also been planted on a variety of arid, even salty soils. It is still considered experimental in Haiti, since commercial plantations are just arriving at merchantable size. It was introduced to the Dominican Republic by this program for plantation use, simultaneously with introduction of a few trees by the Universidad Nacional Pedro Henriquez Ureña, on the southern coast.

The neem tree may live for more than 200 years (Ahmed et al., 1984). It begins to produce fruit in its natural habitat at 5 years of age, although in the Dominican Republic, it began to produce viable seeds in the second year. After its tenth year, 30-50 kg of fruit per tree are produced. Six kg of oil and 24 kg of nutrient rich "neem cake" can be made from 30 kg of fruits, using a simple press (Ahmed et al., 1984).

Uses

There are few tree species with as many practical uses as neem. The list below was compiled from Asian colleagues, observations, and dispersed literature sources.

1. Organic pesticide: insecticide, insect repellant, temporary and reversible sterilizer of male insects, inhibitor of insect feeding, nematicide, fungicide, bactericide.

2. Oil: light lubricant, soap ingredient, dental paste ingredient.

3. Fertilizer: cake form or direct incorporation of leaves and fruits into soil.

4. Food for livestock in India, although leaves apparently not appetizing for Dominican sheep and cattle.

5. Fuel: firewood, charcoal.

6. Posts, poles, etc.

7. Sawn or veneer wood: somewhat resembles mahogany.

8. Tannin.

9. Medicines.

The tree has received considerable recent attention, particularly from German chemists, for the production of biological pesticides and other uses. The presence of the hormone azadirachtin and three others in the leaves and fruits permit the utilization of extracts for various pesticides (Rembold et al., 1984).

Some of these biological values have been known for a long time, especially among Hindus, and neem has been used as medicines for centuries (Pliske, 1984). The dry leaves of neem are put in grain sacks by Asian and African farmers to reduce damages from insects during storage (Ahmed et al., 1984).

Environmental Requirements

Azadirachta indica does not grow vigorously when it is planted at high elevations. In the Philippines, trees planted above 1,500 feet (almost 500 m) did not grow well (Baluyut, 1984). The soil should be neutral or basic, above pH 6.2 (CATIE, 1986). In India, texture varies from sandy to clay, achieving good production in well-drained soils (Singh, 1982). The species is capable of growing in stony areas of little depth. In Haiti, it has prospered in dry, apparently salty soils where other species did not grow. The tree seems to do best on semi-arid or slightly moist sites (perhaps 800-1200 mm of rainfall) on neutral to alkaline, deep soils and at low elevations.

Silviculture and Management

The propagation and management of neem in plantations presents various possibilities and problems. The first problem in the Dominican Republic has been the lack of seeds. Rapid importation from Haiti and other countries has been necessary to allow germination within one or two weeks after seed collection. Storage of seeds results in very low or no germination. This happened in the Philippines, after importing a ton of seeds from Burma (Ahmed et al., 1984). Also, in the Dominican Republic, seeds sent from Burma via Washington, D.C. showed no viability after a one or two month trip. On the other hand, seeds collected in Haiti and taken directly to the nursery in the Dominican Republic resulted in excellent germination (50-80 percent) when the process was initiated 2-5 days after collection.

Chaney and Knudson (1988) reported that the mechanism inhibiting germination after drying appears to be the physical barrier of the endocarp. Fagoonee (1984) experimented with various methods of affecting germination. He concluded that it is not necessary to use chemicals to stimulate germination, although gibberellic acid produced results equal to a water soaking. He demonstrated that the germination rate falls when the fruit is left intact. Seeds soaked in water for 6 days gave the best results with 88% germination. Nevertheless, the removal of the endocarp accelerated germination, reducing its time to half of that of the other treatments.

Establishment

It is reported that direct seeding is possible when the land is plowed, placing seeds in small groups (Singh, 1982). The abundant regeneration that occurs under stands in Haiti and the Dominican Republic suggests that this method should be studied further. Weed control will have to be thorough during the early growth period and each seeded spot will have to be clearly marked to prevent damage to the emerging seedlings.

Growth and Yield

In Central America, CATIE (1986) reported results of seven trials, obtaining a range of survival between 53 and 98 percent. Annual increments were one meter of height per year or less in five locations within the tropical dry forest, at ages varying from 20 to 110 months. In a more humid zone, one Honduran plantation reached 4 meters in 20 months (2.4 m/yr) and a Nicaraguan arid zone plantation was 7.3 m at 28 months (3.1 m/yr), with a dbh of 7.7 cm. These results and those of the Dominican program indicate that, although the tree is beautiful and vigorous on many sites, it will not achieve miracles of productivity in all places.

The tree resprouts well and seems to naturally prune itself. However, observations in Indonesia and reports from India indicate that the tree can be heavily branched and of spreading, somewhat twisting form. Even a few of the trees in Dominican plantations manifested a propensity to multiple stems. This may become a major problem in coppiced stands. The tendency toward strong apical dominance by a central stem may be genetically variable, which suggests that tree improvement research could be cost effective.

Experience in the Dominican Republic

Seeds from Haitian trees were introduced into experimental plantations of the Wood Fuel Development Program in Santiago and Mao, starting in 1984 (Figure 25). As far as is known, these are the first sizeable plantations in the country of this species. The plantations of Haitian origin comprise almost all of the stands on ISA property. Because these trees may be of rather narrow genetic base, possibly all originating from one Asian or African tree, seeds from India, exact provenance unknown, have been planted along the avenue near the entrance to ISA in La Herradura, Santiago (ISA-Avenida). This stand was originally purely from Indian sources, but replacement trees were added from the Haitian seed source. Individual trees from Haitian seeds were also planted in the experimental nursery of the Universidad Nacional Pedro Henriquez Ureña, west of Haina, on the southern coast.

Trees planted in ISA-Rio in December 1984, and January 1985, had produced viable seeds by the summer of 1986. Abundant natural regeneration appeared beneath stands of these trees starting in late 1986. Wildlings were successfully (50%) removed from the plantations and placed in plastic bags in the nursery. They were planted out about three months later, with successful establishment of about 10,000 seedlings from Dominican-grown trees. It appears that the ISA plantings can now provide adequate seed for large plantations without the costs of international transportation and the potential delays of importing seeds through the rigorous customs procedures.

According to Dominican experience with fresh seed imported from Haiti, germination in moist newspaper was 95 percent. These germinated seedlings were then transferred to soil in small polyethylene bags and rootrainers where they developed for about 4 months before planting out. Reynoso (1987) reported 85% survival of the newspaper germinants in the nursery. Two lots of seeds imported from India had no date of harvest, but apparently one lot had spent about a month in transit and none germinated. The second lot was shipped directly to the Dominican Republic without delays and may have been only 2-4 weeks old; germination was 27 percent.

In all the experiments of the research program, the seedlings were produced in containers, either plastic bags (4 by 6 inches) or in Rootrainers with soil. They were planted out with the root and soil intact during the rainy season.

Neem has been successfully planted in the Dominican Republic in dry and semi-arid areas including Mao, Santiago (ISA-I, ISA-Rio, Barrio Lindo, ISA-Avenida, ISA-Naranjo, Jacagua), and San Pedro de Macoris. It was the only species to prosper in Mao-II, surviving relatively well through a very

Figure 25. Plantations of Azadirachta indica*:*
3.4 years at Mao (above).
3.0 years at ISA-Rio.

dry first year. It has not proven practical in the thin soils and moderate rainfall of La Celestina, La Guázuma, Los Montones, all above 500 m altitude. It is still under study in Jánico, Bani, and Puerto Plata.

Plantation experiments have shown diverse results. At the age of two years, the species showed good growth in Mao, Santiago, Muñoz in Puerto Plata and Cementos Nacionales near San Pedro de Macorís. On these sites, neem reached average heights of two to four meters. Development was less promising in Jánico, La Cejita, La Celestina, Los Montones and Manaclar in Puerto Plata. All of these sites are at 400 to 700 m in elevation with varying soil depths.

At Jacagua, near Santiago, the experiments installed were weeded only twice. The effects of weeds and horses that were admitted in the second year eliminated virtually all of the 10 species except neem, eucalypts and *Cassia siamea*. Despite severe weed and vine competition plus trampling, approximately one half of the planted neem reached 2 to 4 m in height after three years.

Within the ISA campus, at 200 m elevation, the species varies greatly in its early growth rate in response to physical soil conditions. Its worst performance is on compact, arid subsoil that was a degraded pasture, where it persisted but grew very slowly during the first two years. In the third year, trees on the less eroded or compact spots on this site began to gain rapidly in height growth. By contrast, the best development has been in ISA-Rio, with deep, sandy soil, where average heigh at the end of two years was 3.6 m and dbh was 3.86 cm.

In Mao, on deep, plowed, clay loam soils, neem was associated with *Leucaena leucocephala* and reached a height of 2.1 m and dbh of 1.2 cm by age 21 months. This site receives an average of 200 mm less rainfall than ISA-Rio. At age 4.5 (June 1988), the neem and leucaena had grown to about the same height (2-8 m depending on soil) and had begun crown closure.

Spacing

The 4-replication spacing experiment, located on sandy, deep, fairly uniform soils, showed several phases in development that may be helpful in understanding the dynamics of other neem plantations. During the first year, seedlings grew alone and fairly uniformly, regardless of spacing. In the second year, the closely spaced trees (1.5 x 1.5 m) began to achieve crown closure, gradually eliminating the competing ground vegetation. As crown closure became more evident, these trees increased more rapidly in height than the more widely spaced plots. As the 2 x 2 m plots closed, beginning at the end of the second year, they too seemed to accelerate in height growth, virtually catching up with the 1.5 x 1.5 m group. Apparently this has continued with the 2.5 x 2.5 m plots (Table 23) and may continue with the 3 x 3 m plots, in their fourth year.

Table 23. Heights of *Azadirachta indica* in 3-year-old spacing trials at ISA-Rio.

Spacing	Ave. Ht. (m)	Dbh (cm)	Survival (%)
1.5 x 1.5	6.83	6.81	83
2.0 x 2.0	6.50	7.08	90
2.5 x 2.5	6.97	8.15	92
3.0 x 3.0	5.81	7.11	69

It also will be interesting to watch the development of the volume growth in these stands. This will help determine whether neem will tend to stagnate when growing very close together or whether some of the trees will dominate and out-compete the slightly less vigorous individuals. At age 3, there was no clear pattern except perhaps in average diameter. The low survival figure for 3 x 3 m plots is somewhat misleading because half of the dead trees were concentrated in one of the four replications.

Pests and Problems

En Mao and occasionally in Santiago there were scattered attacks of the stem borer, *Apate monacha*. This also attacked stems of *Melia azedarach* planted in Santiago. The black adult beetle perforates the stem of the young trees, forming galleries that are nearly straight and ascending. The holes are about 30 cm long and 2 mm wide. The attacked plants secrete an amber colored latex that hardens with time. Depending upon the size and the physiological vigor of the tree, they may have from one to ten galleries; most observations were of single or double galleries. Some of the smaller trees become weakened and are broken off or bent over by strong winds. It seems that the insect is most active in the early months of the year, which corresponds with the greatest drought stress in most years. Reynoso (1987) observed that pruned trees may be more susceptible to attack than unpruned ones. Attempts at control have been to "cork" the entry hole with paper or candle wax and to remove any infested trees that have broken over. The effectiveness of these measures has not been tested.

The form of the root collar area has been observed to be quite variable. Some trees form a loop of the root or lower stem right at ground level. Apparently, this occurs in the nursery. One hypothesis is that it is related to the position of the seed when placing it into the container medium. The problem with this hypothesis is that the same occurs even when pre-germinated seeds, with the hypocotyl evident, are placed in the containers properly. The cause of this deserves further study, since the trees become prone to tipping over and may eventually have to form a second primary root to survive.

Cattle, goats and sheep have been in some of the ISA plantations of neem. They have nibbled at neem seedlings, particularly the new growth, but have not done extensive damage. This observation has led some to suggest that the trees are animal-proof and to hope that livestock can be allowed to run free in neem plantations. This ignores the physical damage by trampling, which has occurred even with only occasional livestock visits, and the fact that longer exposure to the trees may increase their susceptibility as favored vegetation disappears. The species is used as a forage in India. Another damage by livestock is compaction of soil, which apparently can seriously affect the productivity of a stand. Study of the technique and damage abatement related to livestock grazing in neem plantations deserves research attention but, in general, the combined use of the same land is not recommended. Disciplined herding and maintenance of stocking numbers of livestock would have to become much more common for this technique to be practical, even if the trees could stand some grazing.

Performance in the Dominican Republic has indicated that early growth of neem is slow under dry conditions or on a "difficult" soil. After 6-18 months of developing a deep root system, it begins vigorous crown growth. At close spacings, the crowns may close near the end of the second year, eliminating most of the ground vegetation. At the wider spacings, such as 3 x 3 m, there is still sunshine reaching the forest floor between the trees, allowing the growth of abundant ground vegetation, even after two or three years.

Fertilization and Irrigation

To stimulate early growth of neem plantations, a sequence of experiments with water and fertilizer was tried in Santiago, with little apparent effect. The sequence of trials was in the order presented below.

The first attempt was to add water at strategic dry times to eliminate or reduce the effects of dry soil. Cipión (1985) applied water at low- rainfall dry periods in the fall and winter months, twelve times during six months after a September planting of neem in ISA-1. The soil was deep, well- drained, with a pH of 7.3. None of the trees grew much in height during this period, but roots penetrated to depths of 0.65 to 1.00 m. The crowns averaged 0.37 m in height at the end of the trial and there was no difference between treatment and control.

Following this experiment, the same plantation was fertilized with NPK (15-15-15), four ounces per tree, and compared to unfertilized controls. The trees were eight months old when the fertilizer was applied. No response to the fertilizer was apparent; fertilized plots and control plots developed at the same rates through the next two years.

These two trials left the possibilities that fertilizer applied earlier and in greater abundance might be effective and that water applied in greater quantities might stimulate early growth. A new plantation in ISA-Barrio Lindo was installed by Morrobel and Lantigua (1987) to determine whether different nutrients applied at the start would stimulate early growth. This trial in droughty, slightly basic soils was planted and fertilized in April 1986. No significant difference in heights after six months was found. There was more variation within each treatment than among the different treatments. The four replications, although apparently on the same soil and very compact in arrangement, showed different rankings of average heights among treatments. The trees were measured again at age 19 months (Table 24).

Table 24. Response of *Azadirachta indica* to fertilization after 19 months.

Treatment	Height (m)
Control (no fertilizer)	3.31
Triple super phosphate (8 oz)	3.21
Ammonium sulphate (8 oz)	3.59
P + N (8 oz)	3.68

Source: Morrobel and Lantigua, 1987.

Although these averages suggest some benefit from nitrogen, the magnitude of the benefit is so small that it is probably not worth the cost of adding fertilizer. This experiment was located within a larger plantation of neem, much of which succumbed to weed competition in the first few months. The experimental plots were kept clean of weeds and survival was over 95 percent. The surrounding area had about 10 percent survival and was replanted with *Leucaena leucocephala*, which has prospered with better weed control.

The next trial also tested whether large doses of fertilizer would trigger a height growth response, on the supposition that much of the phosphorus could have been tied up by the slightly basic soils. In summary, despite two applications of 8 ounces per tree, there was no significant effect of the fertilizer. Likewise, when fertilizer was combined with watering, there was no stimulation of growth. Before this trial, located at the entrance to the ISA campus (ISA-Avenida), the soil was leveled out with a grader. The three replications of the experiment were on three adjacent but different soil conditions. The first set of four treatments was on undisturbed, rather brown surface soil, a flat, very deep alluvial outwash. This was not considered a productive agricultural soil, being quite low in nitrogen and phosphorus with a tendency toward droughtiness in the dry seasons. For convenience, in this experiment, this is considered as the "good" soil. The adjacent "medium" soil was similar, except that its surface was yellow and slightly compacted, having received some fill material. The "poor" soil was yellow subsoil, the top 20-50 cm having been removed in the leveling process. Weed growth after the planting was directly related to the quality of the site. On the poor site, few weeds had grown in two years, while on the good site, two cleanings had to be made and a good stand of tall weeds existed in the spaces between the trees.

All trees within each four-treatment block were treated with 8 ounces of commercial fertilizer (15-15-15), mixed into the surface soil at planting time. One year later, after relatively little growth, two plots in each replication were fertilized with 8 oz more of NPK. One fertilized and one unfertilized plot in each replication also were watered daily during two months of dry weather, in an effort to keep the root zone well supplied with moisture at all times. The other two plots were left unwatered. Heights were measured on February 27, 1987, when trees were one year old and the NPK-water treatments were started; on April 27, 1987, when watering was ceased; and finally on January 27, 1988 (Table 25). The total heights and the growth differences showed no appreciable difference among treatments.

Table 25. Heights (m) at different ages of neem with fertilization and irrigation (ISA-Avenida).

Treatment*	Age of seedlings (months) 12	14	23	Growth 12-23 mo
Control	.71	1.12	2.22	1.51
Water	.68	.90	2.33	1.65
Fertilizer	.71	1.08	2.47	1.76
Water + Fertilizer	.74	1.14	2.40	1.66

*Water and second fertilizer treatments were started 12 months after planting.

However, the three replications did show major differences as related to the undisturbed and disturbed soils. Clearly, neem responds positively to differing soils, growing more than twice as much in the first year on the "good" soil as the trees planted on poor soils. The trees maintained their growth, adding 2.3 m in the second year, while on the poor soil, the trees added less than half this growth (Table 26).

Table 26. Neem height (m) as related to different soils (ISA-Avenida).

Soil quality	Age of seedlings (months) 12	14	23	Growth 12-23 mo
Poor	.45	.68	1.48	1.03
Medium	.62	.96	2.23	1.61
Good	1.05	1.55	3.35	2.30

It is recognized that the application of one pound of fertilizer per tree and daily applications of water are not normally practical measures for commercial plantations. This experiment used these relatively extreme measures to clearly establish the fact that this species in these soils does not appear to respond to even very heavy treatments of chemicals and water or that they are not factors limiting the growth of the species. It appears, rather, that the physical characteristics or organic matter in the soil may have more influence on early growth; these should be studied further with neem.

At this stage of experimentation, the interim conclusion is that neem appears to be sensitive to physical qualities of the soil, but it does not respond in the first or second year in a significant way to fertilizer or spot irrigation, at least in conditions similar to those in Santiago.

Recommendations

1. Prompt germination of recently picked seed is the most reliable and economical method. Present information does not allow for long-term storage of large quantities of neem seed.

2. Plant this species in neutral or alkaline soils (pH 6.0 - 8.5). Avoid soils that are poorly drained or with high water tables, compacted or acid.

3. If the site has been heavily pastured, plow it before planting.

4. Plant at altitudes below 500 m, until Dominican research can indicate otherwise.

5. When planting in dry sites (less than 1,000 mm/yr), be prepared to apply water in critical periods, especially during the first year, to assure good survival and early development. Do not expect early supplemental irrigation to produce rapid growth in the first year, however.

6. Keep weeds under control.

7. Use spacing of 2 x 2 or 2.5 x 2.5 m.

8. Do not use fertilization to stimulate early growth unless further research indicates the conditions under which it will become financially beneficial.

Calliandra calothyrsus Meissn.

Common name: Red calliandra, xalip (Guatemala)
Family: Leguminosae (Mimosoideae)

Distribution

This shrubby species is native to Central America and southern Mexico, extending into northern South America. It was introduced into Indonesia from Guatemala where it is used for forage, fuelwood and erosion control (CATIE, 1986).

It is a medium sized tree that sprouts very well. It can be cut frequently (even annually) and will continue to sprout for at least 15-20 years (National Research Council, 1983). It branches into several stems; when the height is 5-6 meters and the basal diameter is 4-7 cm, harvesting is practical (CATIE, 1986). Left to grow, the tree normally reaches about 12 m in height and 20 cm in diameter.

Although the species adapts to a variety of sites, it does best on loose, light textured, slightly acid and well drained soils. It grows in areas with rainfall higher than 1,200 mm per year and at altitudes between 400 and 1,600 m (CATIE, 1986). The roots nodulate freely, allowing the tree to fix atmospheric nitrogen.

Source: Melissa Marshall from National Research Council, 1983.

Uses

The tree is used in community and small farm forestry for its variety of values. It is a good firewood, although it produces relatively small stems. It can be used to make charcoal, but this is apparently less commonly done than is the use as firewood. Calliandra roots are good for holding soil, preventing erosion, and improving the organic and nutrient content of the soil. The leaves are good supplemental feed, containing up to 22 percent crude protein and no toxic substances. There is a 1-3 percent tannin content in the leaves (National Research Council, 1983).

Performance in the Dominican Republic

In the program's experiments, calliandra has performed well in semi-humid to humid sites with acid to neutral soils (Figure 26). Its vigorous growth on a deep sand soil in Santiago (ISA-Rio) is apparently related to sub-surface water supply at the base of a small hill. It has not performed well in Santiago on drier sites. Therefore, it is recommended that rainfall should be more than 1000 mm or that water supply be available for occasional irrigation.

Good growth was achieved at the following sites, with their altitude, rainfall and pH indicated, respectively.

Muñoz, Puerto Plata	25 m; 1,760 mm; pH 7.0
San Pedro de Macorís	40 m; 1,400 mm; pH 7.5
Guázuma/Los Montones	680 m; 1,200 mm; pH 6.4
Esc.Nac.For., Jarabacoa	540 m; 1,500 mm; pH 5.4

There was also relatively good growth at La Celestina, where this species was the most vigorous of all the 18 species tried. Apparently, in the shallow, eroded soils that exist throughout the mountainous Plan Sierra territory, this is the most fast-growing and reliable species for local firewood. Since it is used for feeding confined livestock, it can be valuable in agroforestry programs, as it has been in the mountains of Indonesia.

Figure 26. Calliandra calothyrsus. *Farmers at Zambrana peel off lateral leaves to feed pigs, leaving several terminals to continue growth in length and height.*

The most outstanding performance of *Calliandra calothyrsus* in the Dominican Republic has been in agroforestry operations on small properties of members of the Asociación Campesina de Zambrana. This area, south of Cotuí, has high rainfall and deep, acid soils. The closely planted single or double rows of calliandra reached 4 meters in two years, but has been harvested for small fuelwood sticks after only 1.5 years. The leaves are used for feeding pigs and goats, while the bushy plants hold and enrich the soil.

Recommendations

1. *Calliandra calothyrsus* is recommended for agroforestry and home fuelwood consumption, where large logs are not necessarily desirable.

2. Plant or direct seed where rainfall is over 1000 mm and soils are neutral or acid. Altitude is not a limiting factor.

3. Protect from livestock at all times. The leaves can be stripped by hand (leaving terminal leaves) and fed to livestock, but trees are fatally sensitive to direct browsing.

Cassia siamea Lam.

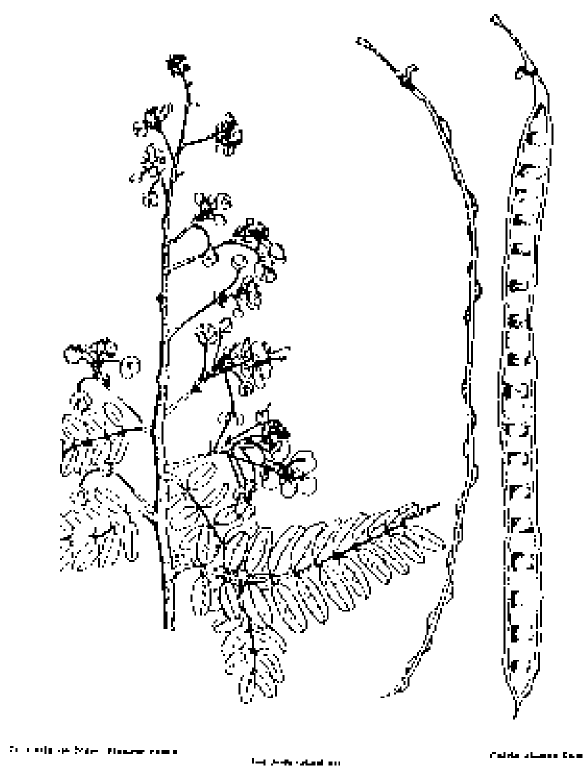
Common name: "Acacia" amarilla
Family: Leguminosae (Caesalpinioideae)

Distribution

This species is native of southeastern Asia. It has been introduced throughout most of the tropics, both as an ornamental and for fuelwood or posts. Its dark, evergreen foilage, attractive small yellow flowers, resistance to drought, and unattractiveness to livestock make it the principal street tree in semi-arid and arid zones of the Dominican Republic. It was considered as a promising plantation species in Africa at the beginning of the twentieth century, but larger trees such as eucalypts supplanted it in popularity.

Important Characteristics

Cassia siamea is a medium-sized tree, reaching up to 20 m in height and 30 cm in diameter. It is single to triple stemmed, with a heavy crown that quickly provides shade. It grows rapidly, producing up to 15 m^3/ha/year (National Academy of Sciences, 1984). Rotations for fuelwood of 5 to 10 years have been projected (CATIE, 1986). The species is so popular and has been planted for so long that there is little recent literature on its silviculture, except as related to diseases and insects in India.



Source: Little and Wadsworth, 1964.

Environmental Requirements

Normally, the tree is planted at fairly low elevations, although it is grown successfully as an ornamental at 700 m elevation in the Dominican Republic. Soil requirements are quite flexible. In Asia, it grows well on a wide variety of soils, with the exception of sandy or low fertility soils (Le Tourneux, 1957). Its usually deep root system prefers friable deep soils with good drainage and relatively high fertility. It will not do well in sterile sands, heavy clays, or inundated lands (CATIE, 1986).

Cassia siamea is capable of prospering under a wide range of rainfall regimes. It grows in most parts of the Dominican Republic, where rainfall varies from about 450 mm to 2200 mm. Since most of the plantings are ornamentals, it is assumed that water is added in the driest locations to assure survival. In the trials of this program, plantings were in areas with 750 to 2000 mm of rain per year. The most limiting factors seemed to be soils in the wet areas and long periods of drought in the dry areas. CATIE (1986) reported good results from plantations in areas with precipitation from 500 to 1800 mm. In the semi-arid areas, however, the tree may require supplemental irrigation during unusually prolonged droughts.

Uses

The wood is fairly hard, with a specific gravity of 0.6-0.8, and excellent as fuel or charcoal, although a reference to smokiness (National Academy of Sciences, 1984) has led some to question its desirability.

The tree is often used for a windbreak, living fence, ornamental, shade for coffee and cocoa, and erosion control. The wood is relatively durable, making excellent fence posts, poles, mine props and roundwood construction. Sawn wood from large trees can be useful for construction, carpentry and turnery (CATIE, 1986).

The foilage is apparently not attractive to livestock and is not used for forage in the Dominican Republic.

Silviculture and Management

The seeds are flat, with a thin but fairly durable seed coat. It is said that freshly collected seeds need no treatment to achieve rapid germination (CATIE, 1986). A trial with seeds that had been stored for some time at ISA was conducted by Ozoria (1987). Using three repetitions of 50 seeds, he tried three lengths of time for soaking in sulphuric acid, and three in unheated water plus a control with no treatment (Table 27). The control produced a 42 percent germination rate, spread over 44 days. A 10 minute soaking in sulphuric acid increased the total germination significantly and accelerated it, while a 6 hour soaking in cool water resulted in an intermediate rate and total germination. The other treatments produced lower levels than the control.

Table 27. Duration and percentage of germination of *Cassia siamea* seed after seven treatments.

Treatment	Days to germinate	Percentage of germination
Control	13-44	42.0
H_2SO_4 10 minutes	6-18	67.3
H_2SO_4 20 minutes	10-40	30.0
H_2SO_4 30 minutes	10-38	18.0
H_2O 20°C 6 hours	4-35	53.3
H_2O 20°C 12 hours	11-40	16.7
H_2O 20°C 24 hours	15-43	15.33

Source: Ozoria, 1987.

Irregular germination of untreated seeds is a problem that can tie up a germinating bed for many months or result in a loss of seedlings, not to mention the unpredictibility of numbers to be available for planting. Observations of a seedbed in Mao indicated that germination can continue for six to eight months.

Presumably, the seeds can be sown directly in the field in semi-humid areas, if constant weed control is done. However, Ozoria (1987) did not recommend this method; only nine percent of his seeds germinated in the field and all the seedlings soon died under the hot sun. Likewise, propagating by cuttings in the nursery produced high bud sprouting (about 95 percent) but no survival when these sprouted cuttings were planted out (Ozoria, 1987). Transplanting seedlings produced in the nursery is recommended.

Moquete and Abréu (1987) found *Cassia siamea* to be durable enough to transplant bare rooted during the rainy season, achieving 60 percent survival after 90 days in the field, compared to 75 percent survival for container-produced seedlings in the same plot. Ozoria (1987) achieved an average of 92 percent survival of container-produced seedlings after 90 days.

Weed control is necessary during the first two years or until there is crown closure, if this comes first. This tree develops a broad, dense crown when young and relatively quickly shades out much of the competing ground cover.

Reynoso (1987) indicates the need for protection of young trees from browsing, although the tree is not highly palatable for most livestock. The seeds, pods and leaves are toxic to pigs (CATIE, 1986) and perhaps to other nonruminants.

The tree is often bifurcated, developing two or more major stems. This characteristic may be genetically controlled, indicating that selection of seeds from single stemmed parent trees may produce more single-stemmed young trees. This characteristic may deserve more research effort by tree improvement specialists.

Growth in the Field Trials

This legume was planted in virtually all the sites used for experiments. It has demonstrated limitations in very acid soils and very dry soils, but appears to be doing well in most other locations. In few of the experiments is it the fastest growing nor the best formed tree, however.

Cassia siamea demonstrated its best growth in Mao, Santiago, Puerto Plata, Monte Plata, Sucro and San Pedro de Macorís, reaching an average of 3.9 m in height, ranging from 2.3 to 5.0 m on these sites at age 22-26 months (Table 28). The worst performance in these initial growth trials was on the low fertility, acid soils of El Valle. This contrasted with the outstanding growth on deeper, less acidic soils on the same farm, where a plot on a hillside reached an average height of 10 meters in three years (Figure 27). Here, the rainfall of about 2000 mm per year apparently had no negative effect on this species which is usually recommended for semi-arid sites.

On the sites with poor growth, shallow, infertile and/or compacted soils seem to be the common limiting factor. This is confounded with altitudes of over 500 m at La Guázuma and Los Montones. However, at a similar altitude (550 m) in La Celestina, individual trees have done well when planted on loose soil. This suggests that altitude is probably less limiting than the physical depth and perhaps chemical properties of the soil.

Table 28. Heights (m) of *Cassia siamea* in 15 sites of the Dominican Republic.

Sites	Age (months)			
	8-9	12-14	16-18	22-26
Mao (2)			(3.50+)	5.52
Mao (1)	1.11		4.12	5.00
Mao (3)	1.03	2.44		
Cementos Nac., SPM	2.90			5.00
Playa Grande, R San Juan	1.58			4.50
Muñoz, Puerto Plata	1.49	2.40	3.63	
Monte Plata	.63	1.80	2.40	3.80
ISA-1, Santiago	.88		1.59	2.98
ISA-Rio, Santiago	.98	1.82	(lost to fire)	
Suero, Higuey				2.55
Jacagua, Santiago	.62	1.08	(lost to grazing)	
Guázuma, SJM	.30	.33	.46	.51
Los Montones, SJM	.32	.32	.45	.44
El Valle, Hato Mayor	.21	.31	.38	.44

In dry zones, small experimental plantings failed in San José de Ocoa (R. Fajardo trial) and partially failed in the driest sites at Mao. The Mao problem was directly related to a severe summer drought that affected trees one year old and younger. Many trees lost their leaves during the drought and about fifty percent of these failed to sprout back. Adjacent *Cassia siamea* trees on slightly less droughty soils regained good growth and renewed vigor after the drought. This 1986 drought fatally affected 90 percent of the recently planted trees in Mao-II and about 10 percent of the one year old trees in Compartment 2 of the Mao experimental forest.

Likewise, in yield plots in Mao, there are sharp differences among tree heights of different plots, related to the organic matter content of nearly adjacent soils. Based upon these observations,it is hypothesized that future studies of productivity of this species can best focus on performance under different soil depth and tilth conditions.

Recommendations

1. Plantations of *Cassia siamea* prosper best in loose, deep soils with pH between 6.0 and 8.4. The site should probably be below 500 m elevation with average rainfall of over 800 mm.

2. Keep plantations free of weeds during the first two years.

3. Although the species resists droughts of 4 to 5 months, in arid zones recently planted trees may need occasional irrigation during prolonged droughts.

4. The substrate to use in germination beds can be a combination of 3/4 sand and 1/4 manure or topsoil.

5. Although further testing is desirable, seedlings handled with care can be planted bare-rooted after about 4 months in the nursery. At present, the recommended practice is to use seedlings with roots in a plastic bag or other container.

Figure 27. Cassia siamea *at 3 years averaged 10 m tall on fertile soil in El Valle; four-year old fertilized trees on nearby savanna soils were less than one meter tall.*

Eucalyptus camaldulensis Dehnh.

Family: Myrtaceae
Common name: eucalipto, red river gum
Synonyms: *E. rostrata*

Distribution and Characteristics

One of the most widely planted trees in the world, *Eucalyptus camaldulensis* is a fast-growing, genetically diverse tree of large size and fairly heavy wood. Its native distribution in Australia covers about 23 degrees of latitude. Selection of provenances to match latitudes of intended plantation sites is recommended (Jacobs, 1979).

The species is normally distributed along river banks in Australia (Turnbull and Pryor, 1984) where it can withstand the seasonal inundations and alternating droughts. In plantations throughout the tropical and subtropical world, including some sites as far north as Portugal and Spain, the tree has performed well on a variety of sites and soils. It has been used up to 1,800 m in altitude (Parry, 1957).

The species is generally considered to produce trees of twisted form. Indeed, many of the trees previously planted in the Dominican Republic exhibit a semi-spiraling form and seed collected from these trees produced seedlings that were twisted and easily bent by prevailing winds.

Source: Kelly, 1983.

Environmental Requirements

The natural rainfall range of *Eucalyptus camaldulensis* is 200-1,250 mm. However, for commercial plantations, a minimum of 400 mm is more advisable (National Academy of Sciences, 1984). The species appears to do best in soils with pH that is neutral to alkaline but without excessive free calcium (Jacobs, 1979). It will tolerate periodic inundations, so it can be planted on flood plains but its normally deep root system will also develop and exploit drier sites, once established.

<u>Silviculture and Management</u>

The seeds are tiny, one kilogram containing 374,000 plus chaff (Parry, 1957). They are produced abundantly on trees of 3 or more years of age. The seeds need no pregermination treatment and they can be stored in a cool dry place for several, often many, years. Because of the small size of the seed, the general practice is to germinate in a seedbed, then transplant the small seedlings into plastic bags or other containers. After 3 to 4 months, the 20-25 cm tall trees can be planted in the field.

This species is quite tender when young. Seedlings are often damaged in transit or have their roots disturbed when being removed from the nursery or in removing the container on the planting site. Mortality of young seedlings in the field is common, especially during the first few months. There are several causes in addition to those mentioned above. Poor planting practices may leave air spaces around the roots or may cause the roots to be bent or twisted in the hole. Insufficient rainfall may cause the root system to dry out before it can develop. Competition with weeds also may weaken the tree more easily than in the case of other species.

Although livestock do not seek out this species as forage, it suffers severely from direct trampling and compaction of the soil. Although this is a very aggressive and productive tree, it requires considerable care during the first 6-12 months of its life. In the Dominican initial growth trials, where all species were treated more or less equally, the eucalypts tended to show the greatest mortality of the well-adapted species, even though they eventually outgrew the other trees.

Yields of the species are variable, as might be expected from its wide adaptability to different sites. In Argentina, growth rates averaging 20 to 25 m^3/ha/yr are reported (Cozzo, 1976). In Israel, up to 30 m^3/ha/yr has been recorded. On poor and dry sites, the annual yield may diminish to between 2 and 22 m^3/ha/yr with a 14-year cutting cycle (National Academy of Sciences, 1984).

<u>Growth in the Dominican Field Trials</u>

This species has been planted as an ornamental for many years. It grows relatively well along highways and country roads, under difficult conditions. It is seldom seen in plantations, but rather in rows or as isolated trees. Although no formal data were taken, this is undoubtedly the eucalypt that is the most widely and frequently planted in the country as an ornamental. It seems to prosper under diverse conditions, with trees growing at elevations from 800 m elevation to near sea level, in rather arid conditions to semi-humid or humid areas, and in a wide variety of soil conditions.

Perhaps the small 81-tree plots planted by this research program are not the first "plantations" in the country, but they provide good opportunity for systematic measurement of development and potential plantation success. Since the first of these was planted in 1984, no data on the growth rates from the Dominican Republic are meaningful at this stage. But in small plots, the very rapid growth presages future average rates that should be well above the 25 m^3/ha/yr that was used as a norm for calculating potential profitability in the Dominican Republic. However, on low-productivity sites, the growth rate can be expected to be lower. On the sites where *Eucalyptus camaldulensis* was planted, it was the first or second species in growth potential among those tried, with only one or two exceptions, where it was still very close to the top. The best growth of this species in the trials was in Santiago at ISA-Rio (Figure 28), where environmental conditions are quite similar to those described for its native habitat in Australia; deep sands near a river and in a semi-arid climate. When measured in January 1988, about 3.5 years after planting, the trees in yield plots averaged 12.6 m in height, with some individual trees reaching more than 15 meters, and an average of 12 cm in diameter (Table 29). This compared favorably with *Leucaena leucocephala* and *Azadirachta indica*. The early survival problem is dramatized by the fact that only three of the four experimental parcels had measurable trees growing, all but three border trees in the fourth plot having succumbed to competition in early stages of life. Including this empty plot, the survival was 44 percent; it was 59 percent in the three living plots.

Figure 28. Eucalyptus camaldulensis *in ISA-Rio at 3.5 years of age.*

Table 29. Behavior of four tree species in yield plots in ISA-Rio after 3.5 years.*

Species	Height (m)	Diameter (cm)	Survival (%)
Eucalyptus camaldulensis	12.65	11.8	44
Leucaena leucocephala	10.18	8.8	95
Azadirachta indica	6.48	7.1	92
Melia azedarach	4.89	4.8	39

*Azadirachta indica was planted 6 months after the other species so were 3.0 years old when measured.

The species was planted at 12 other locations. It showed promise on all of these, although in Jacagua, Barrio Lindo and Muñoz there were damages by livestock or weeds. Drought also eliminated one young plantation in Mao. On the better sites, the average height at age two was between 3 and 5 m. Some trees in ISA reached 8 to 9 m in that period. By 3.5 years, the best trees were 15-17 m in height in ISA-Rio. In Jánico and La Celestina, on poor, shallow mountain soils, the growth was good compared to most other species, averaging 1.4 m at age 2.

Provenance is very important to the performance of this species. In Mao and ISA-1 are tests of five seed sources that indicate very good early performance and form by seedlings from Gibb River and Petford, Australia, plus seeds from a selected tree in the Companhia Agro-Forestal Santa Barbara, Minas Gerais, Brazil. Early form was poor from seeds collected from adult ornamental trees at ISA and in San José de las Matas. Although the local seed sources may eventually produce straight, fast-growing trees, so far they are quite crooked and of smaller stature than the others.

Eucalyptus robusta Sm.

Family: Myrtaceae
Common name: eucalipto, swamp mahogany
Synonym: *E. multiflora*

Distribution and Characteristics

This Australian species grows naturally along a narrow coastal strip in New South Wales and southern Queensland. It grows only in valleys and swampy lowlands and does not compete well with other Australian species in its home range (Jacobs, 1979). The tree is well-known as a plantation species outside Australia. It grows from the Mediterranean to South Africa, in the South Pacific islands and South America. It is one of the few trees able to survive well on heavy clay soils, even in areas with drainage problems. It also does well on a variety of less difficult soils.

The trees normally reach 25-30 m in height and 1-1.2 m in diameter. It has a straight trunk, clean of branches, although open-grown trees can form dense and extensive crowns. The branch tips may break off in the wind and the young trees may be deformed by persistent high winds.

E. robusta is resistant to fire, resprouting even from small branches in the crown (Jacobs, 1979). It has the capacity to produce aerial roots from several meters up the trunk.

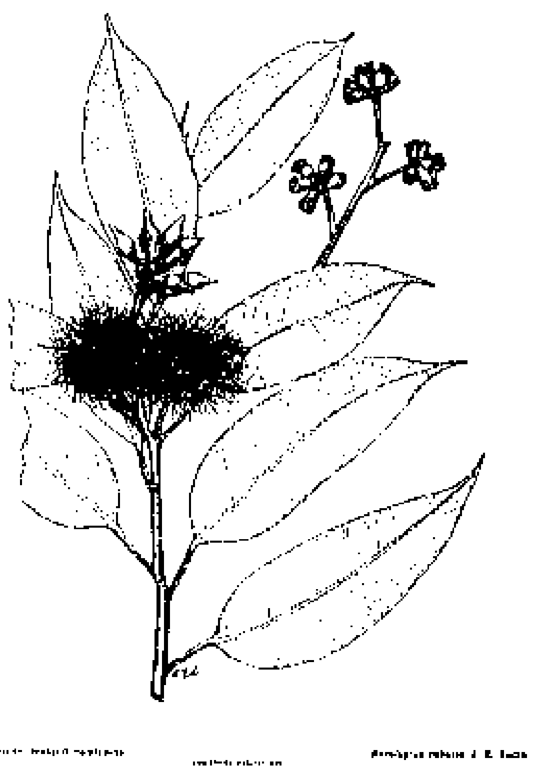
Uses

The wood is good quality for sawing, as well as for fuel and charcoal. The trees are good posts and poles, can be chipped for pulp or particle boards, and may be used for plywood. The gums contain about 30 percent tannins (National Academy of Sciences, 1984). The wood is hard and dense, with a specific gravity of 0.77 (Jacobs, 1979). It is light red to reddish brown, strong and durable but difficult to dry.

Environmental Requirements

Eucalyptus robusta can be grown on a wide variety of sites. It is tolerant to mild frost, yet can grow in subtropical climates. Because the tree is capable of growing on adverse soils, it is most frequently planted on marginal sites. This may mask its full potential. It appears to prefer acid or neutral soils which can be deep and well-drained to shallow or poorly-drained.

In Hawaii, it grows in rainfall regimes that range from 750 to 7500 mm of precipitation per year. It does well with 900 mm or more of rain per year at that latitude and will stand a dry season of up to four months (Jacobs, 1979). Based upon its altitudinal range in other countries, it appears to have no practical elevation limits in the Dominican Republic, except perhaps very high mountains.



Source: Little and Wadsworth, 1964.

Silviculture and Management

The seeds are very small, with about 110,000 seeds plus chaff per kilogram (Parry, 1957). They can be stored for long periods of time under dry conditions and have fairly high germination rates. Because of their small size, it is usual to germinate them in beds and transplant seedlings with 2-3 leaves into containers. Some nurseries put several seeds directly into containers and then thin out the weakest seedlings. Containerized seedlings can be planted out in three to four months after germination.

The tree develops fairly rapidly in the first two or three years, producing large leaves and an ample crown that helps the tree dominate the site. However, weeding is vital during the first year or two, especially to keep down vines.

Yields throughout the tropics are quite variable, perhaps partly due to the marginal sites on which many plantations are located. Average annual productivity reported by National Academy of Sciences (1984) range from 10 to 35 m^3/ha. The tree can be expected to resprout after cutting, at least for its first 25 years.

Growth in the Field Trials

This species responded superbly to a single application of fertilizer on the infertile soils of El Valle (Figure 29). Four ounces of 15-15-15 NPK just after planting stimulated a growth rate that was 3 to 3.5 times as great as the unfertilized plots, even through the fourth year. Although yields on this site may not exceed 20 m^3/ha/yr at age 10, the site was considered unproductive savanna for many years. *E. robusta* has outperformed any of the other tree species tried there and is approached only by *Casuarina equisetifolia* that was fertilized and inoculated. African palms planted nearby are performing well only after extremely heavy doses of fertilizer. On more productive sites, *E. robusta* should perform better.

Figure 29. Eucalyptus robusta *at age 4 years in El Valle savanna soils. Unfertilized (front), fertilized (back).*

In addition to the trials at El Valle, *Eucalyptus robusta* has been planted on shallow mountain soils of La Celestina and Los Montones Arriba, as well as in lowland soils of Monte Plata and San Pedro de Macorís. It has also been tried in Jarabacoa, with positive results, but it did not grow well in the semi-arid calcareous soil of Guazumal, near Santiago.

Seeds of this species produced in Florida plus crosses of it with *Eucalyptus grandis* were planted in trials at Falconbridge Dominicana, near Bonao. Although data are not available from these trials, visual inspection shows that they have produced spectacular young trees with obviously high potential yields at age seven. The most impressive stand is on a deep cove soil about 10 m above the river. Here, three-year-old trees in 1983 averaged 10-15 m tall. Another trial of these trees in Jarabacoa was measured in March 1988, at age 5 years. The average diameter of all the living trees was 13.1 cm and the height was 17.2 m. The differences among parent trees were average heights varying from 12.7 to 20.[illegible] m and diameters ranging from 8.0 to 16.4 cm. A private plantation near La Vega was established in November 1987 and February 1988. By June 1988, the survival was over 95 percent. The older trees averaged about 90 cm in height (30-200) and the younger trees were about 40 cm (20-100). The heavy grass cover was cleaned regularly.

The trees in the shallow mountain soils have not performed particularly well, but they compare favorably with other species. In Monte Plata and San Pedro de Macorís, the growth is excellent. Trees at Monte Plata averaged 6 to 7 m before the third year was complete. At Cementos Nacionales, San Pedro de Macorís, the trees averaged 2.1 m at one year of age (Reynoso, 1986).

Eucalyptus robusta may be less productive on some low altitude sites than other species that were not tested extensively by the program. Plantations established by "Los Arbolitos" on light, seasonally wet, arid, savanna soils near Bayaguana have indicated that *Eucalyptus urophylla* and *E. grandis* are growing faster than *E. robusta* (personal communications with Kevin Darrow). The *E. urophylla* is probably preferable to the *E. grandis* for fuelwood and poles because of its greater density and strength.

<u>Recommendations</u>

1. Use *Eucalyptus robusta* for high-rainfall areas with acid to neutral soils, even soils with heavy clay texture and impeded drainage.

2. At low elevations, compare this species with *E. urophylla* in terms of growth and wood characteristics.

3. Continue research on selection of superior parent trees from Florida.

4. Where soils are of low fertility, apply a small amount of fertilizer around the recently planted seedlings.

5. Rigorously control weed growth around the trees for the first two years; follow up with regular vine control.

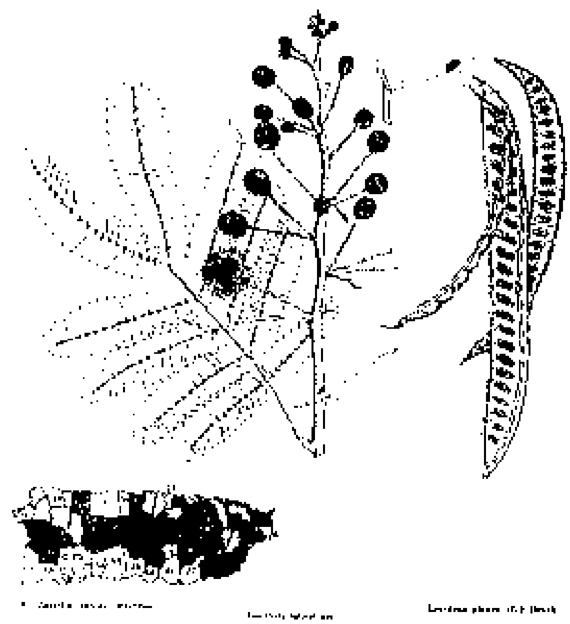
Leucaena leucocephala (Lam.) de Wit

Family: Leguminosae (Mimosoideae)
Common names: Lino gigante, leucaena, ipil-ipil
Synonyms: *Leucaena glauca* (L)Benth., *Mimosa glauca* (L), *Acacia glauca* (L)Moench., *Mimosa leucocephala* Lam., *Leucaena latisiliqua* (L)W.T. Gillis, and *L. salvadorensis* Standley.

Distribution

Leucaena leucocephala is native to the interior of Mexico, Guatemala, El Salvador, Honduras and Nicaragua (CATIE, 1986). It is a native or naturalized species in the Dominican Republic, where it is called lino; it occurs abundantly as a shrub or small tree in semi-arid or semi-humid forests at low altitudes (below 500 m). It is common in pastures on basic or neutral soils. Giant cultivars have been introduced to various countries, including the Dominican Republic, where it is used for fuelwood and forage.

There are three groups of varieties, based on size and growth habit; Salvador, Peru, and Hawaii. The Salvador (giant) has many large-growth cultivars that have been tested in Hawaii and elsewhere. There have been good results from the cultivar numbers K8, K28, K67, and K132 in the Dominican Republic.



Source: Little and Wadsworth, 1964.

Important Characteristics

According to information from the National Academy of Sciences (1984) and CATIE (1986), this species is represented by trees of 20 m or more in height or shrubs reaching no more than 5 m. Although the shrubby trees are common in the Dominican Republic, several large, straight individuals have been identified in the native dry forest in Mao for possible genetic studies and trials.

The giant cultivars, which are the only ones discussed here, are capable of very rapid growth. The National Academy of Sciences (1984) reported growth of 24-100 m^3/ha/yr as an average for 7 years.

The crown is open and with few leaves in the dry season and fairly dense in the rainy season. The tree typically possesses a straight, usually cylindrical trunk, often forked in the first two meters above the ground. Its root system is typically deep, with a tap root and several lateral roots growing at various angles to the principal axis. When there is a hard pan in the soil or a high water table, the roots are capable of adapting to a lateral, shallow form.

Leucaena has the capacity to fix atmospheric nitrogen through nodules inoculated with *Rhizobium* spp. These bacteria seem to be readily available in the natural environment in the Dominican Republic.

Uses

With a density of about 0.7 g/cm^3 and a heating value of 4445 kcal/kg at age 3-5 years, the wood is good for firewood and charcoal (CATIE, 1986). It can also be used for manufacturing chip or flake boards and particle boards or pulp. The round wood can be used as posts, and poles for rural construction. The living trees are valuable for honey production, living fence posts and an excellent source of forage supplement. The leaves have about 25% crude protein content (BOSTID, 1984). In Las Matas de Farfán, four-year old trees have been used to make turnery and chairs. The young fruits have been used as human food.

Because of the species' aggressiveness, it is feasible to use it to reforest steep slopes, marginal soils, abandoned pastures, and thus reduce erosion and establish vegetative cover that is productive (Reynoso, 1987). In Nicaragua leucaena has been used for windbreaks around cotton fields.

Habitat Requirements

Leucaena is a lowland species, growing best below 500 m altitude. It is restricted to the tropics and subtropics since it does not survive freezing temperatures.

It prefers neutral to basic soils. A pH of 5.5 or 6.0 appears to be the most acid soil in which it will thrive. To be safe, it is suggested that the soil pH should be 6.5 or more for optimal development of the plantation.

Soil textures may be variable. Because of its adaptable root system, the species can adapt to a wide range of soils, from rocky to heavy clays, but it requires adequate levels of calcium, phosphorus and sulphur. Molybdenum, zinc and boron are indispensable for good nodulation (CATIE, 1986). Absorption with the aid of symbiotic root microorganisms allows the species to thrive where some of these nutrients (e.g. P) are low.

Silviculture

The tree propagates by abundant seed produced after the first year. Direct seeding or the planting of nursery seedlings may be used to establish stands.

Direct seeding or the planting of nursery seedlings may be used to establish stands. Two private commercial plantations were established in the humid environment of Puerto Plata by direct seeding with good success, accompanied by vigorous weed control during the first six months. Direct seeding trials in Mao's drier climate proved unsuccessful, even during the rainy season, suggesting the need for use of nursery-produced seedlings for plantation establishment in arid and semi-arid lands.

Germination of untreated seeds was highly variable, from 8 to 85 percent (Finke, 1985). The hard, impermeable seed coat reduces and retards germination, making scarification highly desirable (Oakes, 1968). Methods of scarification that have been recommended include hot water, acid, mechanical and passing seeds through cattle or goats. Estimates of success are variable, but any scarification seems to produce high germination rates. Finke (1985) tested six treatments and a control lot in Santiago, using 200 seeds per treatment. He measured total germination after 21 days and a velocity index calculated by dividing the percentage of seedlings by the time required for germination. His results (Table 30) indicate that mechanical scarification and sulfuric acid treatments produced the most germinants in the shortest period of time. However, simpler hot water immersion and soaking while cooling produced acceptable levels of seedlings for this abundant seeder. Cold water soaking and no treatment produced slow germination.

Table 30. Seed germination of *Leucaena leucocephala* after treatments.

Treatment	% Germin.	Velocity Index*
Control	28	13.19
H_2O 26°C, 48 hours	19	7.99
H_2O 100°C, cool 12 hours	42	10.07
H_2O 100°C, cool 2 hours	41	10.57
H_2SO_4 2 minutes	52	29.00
H_2SO_4 15 minutes	68	44.84
Mechanical	88	96.15

Source: Finke, 1985.
*Velocity index = (% germination/number of days).

Based upon these results and practical considerations, Finke (1985) recommended that methods of mechanical scarification on a large scale be developed. He suggested mixing seeds and sand (as an abrasive) and rotating them in a drum until physical scarification is achieved. Until this method is proven and easily done, the scarification by immersion in boiling water and then letting the seeds soak as the water cools for 12 hours is suggested as adquate, of low cost, and easily done.

In general, germination of scarified seeds occurs in one to two weeks. After 8 to 16 weeks in the nursery, trees grown in containers with topsoil should be about 20 to 50 cm in height and ready to plant in the field. If root development is sufficient, some may be planted after six weeks. If the rainy season is late, seedlings may be left in the nursery a few weeks longer, then root and top pruned before planting out. Severe pruning back was used on overgrown seedlings in a Mao planting on gravelly subsoil. Early growth was slow, but survival was very good, despite the difficult conditions.

Under favorable conditions, leucaena can be transplanted bare root rather than in containers. However, this has not been widely practiced in the tropics. Trials by Finke (1985) indicated that there was considerable mortality after bare root planting on a dry site. Only 53 percent of the trees were alive after one month; by the end of six months, only 18 percent were alive and these were only two-thirds the height of the seedlings produced in bags (87 cm vs 126 cm, respectively). A later trial on more humid soils in Santiago (ISA-Pasto) proved that higher survival rates are possible. Moquete and Abréu (1987) achieved 64-84 percent survival after 50 days in the field. Survival varied directly with the number of days the seedlings were left in the nursery. This compared with 95 percent survival of bagged seedlings. Height growth of the bagged seedlings was good from the outset, but the bare rooted seedlings wilted and suffered top dieback, recovering after about 20 to 30 days. They grew back to their original height by age 40-60 days and progressed well from there, but markedly more slowly than the containerized seedlings.

Before planting, it is necessary to prepare the site, with manual cleaning of the area, burning of the residues and opening planting holes for bagged plants. On compacted soils, plowing may be productive.

Control of weeds during the first two years is important to survival and growth. Areas must be rigorously protected from goats and other livestock. This tree is a highly appetizing forage that can be heavily damaged by even occasional visits of domestic animals.

The species is apparently quite resistant to damage by insects and diseases, so there is seldom need for expensive pesticide treatments.

The tree resprouts very well after harvest. Few data are yet available on resprouting in the Dominican Republic, but recommendations are to cut stumps to 10-30 cm height, control weeds and vines vigorously, and manage the number of sprouts by thinning to the two or three most vigorous new stems (CATIE, 1986).

Growth in the Planting Trials

In initial growth trials (Table 31), the best results have been in Mao; Puerto Plata; Guazumal; Monte Plata; Cementos Nacionales, San Pedro de Macorís and in Sucro, La Altagracia; trees reached up to 6 m in height at two years of age. These sites range in altitude from 25 to 183 m, with average annual rainfalls between 740 and 1,900 mm. The soils are all deep, with pH that ranges from 5.9 to 8.4.

Table 31. Height (m) of *Leucaena leucocephala* in 12 trials in the Dominican Republic.

Sites	Age (months)				
	4-5	7-9	12-14	18-21	24-26
Guázuma, SJM	0.47	0.57	0.67	0.97	1.09
Jánico	0.96	--	--	--	2.23
Los Montones, SJM	0.40	0.51	0.54	--	0.55
Mao (1)	1.93	3.30	3.79	4.30	5.68
Mao (2)	--	--	3.58	--	4.81
Mao (3)	--	1.28	2.03	2.40	--
ISA-1, Santiago	--	1.05	1.37	2.52	3.17
Muñoz, Puerto Plata	0.58	2.28	3.62	5.42	--
Monte Plata	0.85	1.40	2.80	3.20	4.40
El Valle, S de la Mar	0.29	0.32	0.38	0.38	0.42
Cementos Nacionales	0.62	--	3.72	--	6.00
Sucro, Higuey	0.75	--	--	--	3.65
Guazumal, Tamboril	--	2.22	--	3.87	--

On the sites where this species showed poor growth, (El Valle, Los Montones, and La Guázuma), the factors that seemed most debilitating were acid soil (pH 4.5) in the first site and high altitude (about 700 m) coupled with very shallow soil in the last two sites.

In Mao, for every cm of diameter growth, leucaena is growing about 3.42 m in height, at age [illegible] months, according to a linear regression calculation (Reynoso, 1987).

Volume growth for this species depends much on the site, as is evident from the individual tree performance. From yield plots in Mao and Santiago (Figure 30), early results indicated a wide variety of average annual yields for 25-29 month old plots (Reynoso, 1984, 1985, 1986). These range from 1.06 to 4.8 m^3/ha/yr in Santiago. All of these stands are at 2.5 by 2.5 m spacing. These data and economic experience elsewhere suggest, the trees can be harvested with maximum economic benefit at age 5 to 8. At 7 years of age, some trees previously planted in ISA had an average diameter of 18 cm and a height of 12 m.

Figure 30. Leucaena leucocephala *at age 3.5 in ISA-Rio yield plots.*

In a private plantation in Camú, Puerto Plata (Figure 31), where there are about 1,800 mm of rain, the closely spaced (1X1m) trees have reached 27.6 m^3/ha/yr at 3.2 years of age (Reynoso, 1987). Part of this plantation was clearcut starting in April 1987 at age 3.3 years. The production was about 11 steres per tarea or 175 steres/ha (estimates by Loweski Luciano of COENER). Another plantation on the edge of the city of Puerto Plata was harvested starting in June 1987 at age 3.5 years after the direct seeding. Yields on this more neutral soil were about 15 steres/tarea or 238 steres/ha. This volume represents a growth rate of 53-68 steres/ha/yr. The figures are very high in comparison with many Brazilian growth rates. It should be recognized that the stems cut were quite small in diameter, producing a pile that contains a very high percentage of air space. However, Luciano estimated that 2.8 steres of firewood were producing one cubic meter of piled charcoal of high caloric value, a ratio that is above the norm for large eucalypts. Measurements in these two plantations at age 4.5 years (June 1988) indicated an average diameter of 5.8 cm and average height of 10.1 m. There is both general stunting and some suppression of individual trees. Sample trees varied in height from 5.1 to 14.5 m. The remainder of these stands will be cut between ages 4 and 7.5. The larger stems are to be sold for posts, poles and small dimension boards.

Figur 31. Leucaena leucocephala *at 1x1 m in Puerto Plata at age 4 years.*

Fertilization and Irrigation

To determine the response of *Leucaena leucocephala* to fertilization and strategic application of water, Rodríguez (1987) conducted an experiment on dry, compacted pasture land with a pH of 7.3. The surface soil had 3.4% organic matter, 2 ppm of assimilable phosphorus (P_2O_5), 366 ppm of assimilable potassium and 0.32% soluble salts. He used four treatments and four replications. The trees were planted at 1.5 × 1.5 m spacing.

The fertilizer was an even mixture of urea and simple superphosphate; five ounces per plant were mixed into the surface soil in a radius of 25 cm around the stem. The application was made 20 days after planting the trees. Water was applied to two of the treatments in small circles, retained by small circular dikes around each tree. This irrigation supplemented the natural rainfall. The applications started in September 1985 and terminated in March 1986. Natural rainfall during this period was 735 mm and water applied to the irrigated plots totalled another 819 mm. After March, the rainy season supplied additional moisture to all treatments equally.

There was an immediate and sustained response to the treatments. After 3 months, the treated trees averaged 30 to 50 percent taller than the controls. At 6 months, the gap had widened slightly, with a 36-60 percent advantage for the treatments. With the onset of the spring rainy season and the termination of additional irrigation, the gap began to narrow only slightly. At the completion of the year, the trees with both water and fertilizer treatments had reached just over 3 meters in height, while the control trees were at 2 m (Table 32).

Table 32. Effect of fertilizer and irrigation treatments on heights of *Leucaena leucocephala* K-8 at ISA-Pasto.

Treatment	6 mo	1 year	1 yr 10 mo
Control (no treatment)	0.97	2.04c	3.00
Fertilizer NP (5 oz)	1.32	2.56b	3.52
Water	1.33	2.82ab	3.82
Water + Fertilizer	1.56	3.02a	3.83

One-year heights followed by the same letter are not significantly different from each other, according to the Tukey test (p = .05).
Source: Rodríguez, 1987.

There were significant differences between the control and each of the treatments (Rodríguez, 1987). The practical differences, which are more meaningful for silvicultural practice, are that the rapid early growth produced a reduction in weed competition, probably eliminating the necessity of one cleaning, as well as contributing to early crown closure and taller trees. Diameter growth was correlated with height growth, with treated trees averaging 2.8 cm dbh while the control trees were 2.1 cm at 22 months of age.

Recommendations

1. Plant on soils that are basic to neutral in pH (e.g., 6.5-8.0), below 500 m in altitude and with annual precipitation between 600 and 1700 mm. In areas with less than 1000 mm of rainfall, be prepared to spot irrigate during the first few months, in event of drought or to stimulate early growth.

2. Seeds germinate best after physical scarification that allows water to penetrate the seed coat. A practical procedure to accomplish nearly the same effect is immersing seeds in hot water and letting them soak and cool for 12 hours.

3. Propagation may be by direct seeding in humid areas on uncompacted soil, with excellent weed control. Bare-rooted seedlings may be used on good soils with adequate humidity. Stump plantings, with roots and tops pruned, may also be used. Containerized seedlings grown in the nursery for 6-12 weeks are the most desirable for reliable establishment.

4. After harvest at age 5-8 years, regeneration by resprouting is possible. Recommendations suggest cutting stumps to 10-30 cm in height, good weed control, and later thinning of sprouts to 2 or 3. This needs to be tested in the Dominican Republic to determine how to maximize value.

5. Protect the plantation from the invasion of livestock. Cattle, sheep, goats, horses and mules all eat leucaena, apparently as a first preference.

6. Keep the trees free of competing vegetation during the first two years. After two years or less, crown closure shades out most competing weeds, but vines should be removed every 6-12 months.

Discussion of Other Species

Eucalyptus spp.

There are several hundred species of eucalypts, all of them native to Australia or islands just to its north and west. Recent books on the genus seem to avoid indicating any definite number of species or subspecies, probably due to the uncertainty and continuing revision of the taxonomy of the genus. Eucalypts are very diverse genetically, with species that are suitable to almost any environment in the tropics or subtropics. More than 120 species have been planted around the world for more than a century. About ten of these comprise the great mass of plantations: *Eucalyptus grandis*, *E. saligna*, *E. globulus*, *E. camaldulensis*, *E. tereticornis*, *E. urophylla*, *E. robusta*, *E. maculata*, *E. paniculata*, *E. viminalis* (Hillis and Brown, 1984). Jacobs (1979) reported that by 1975 plantations of eucalypts outside Australia were producing nine times the volume of the annual harvest of the native stands of the genus in Australia. This genus is commercially or experimentally planted in 108 nations.

There are individuals who warn against the use of this genus, using arguments and speculations about what dangers could possibly occur. However, there is relatively little technical proof of these claims (FAO, 1985, 1986). Much of the misinformation or speculation is based upon extrapolations of characteristic of one or a few species to the whole genus. Expansion of suppositions or observations from a few places to all sites also creates false impressions. A major factor in the anti-eucalypt sentiment is the opposition to conversion of diverse forests into "monocultures" of exotic species. This concern is valid, regardless of the kind of tree, crop plant or pasture grass.

The major value of the eucalypts for plantations is in covering old agricultural fields or worn-out pastures close to population centers. It is probably not practical and certainly not recommended by the authors to cut a diverse native forest and replace it with a eucalypt plantation. Rather, the planting effort should be to reforest or afforest areas that are not now forested. Eucalypts can help to put unproductive lands back into more productive condition. It will add organic matter deep into soils through its roots and leaf-fall. It can help protect denuded watersheds and erodable bare slopes. It may also be the most profitable use of many lands owned by private or public entities.

The emphasis of this research program has been to determine which species can best be used to plant deforested lands, never to supplant the existing forest. The Dominican Republic needs to urgently expand its forest area, for many reasons. The eucalypts and other species recommended here are among the most productive trees on earth for meeting this urgent need.

Table 33 succinctly summarizes the behavior of *Eucalyptus* species in Dominican trials. Before this research program was started, FORESTA had planted an unidentified mixture of eucalypts on a highly visible area north of Villa Altagracia. Its poor growth created a general opinion that the genus was not productive in this country. The experiments of the woodfuel research program indicate that some of its species are among the most productive of any of the species tried, if properly managed and matched to the site.

Acacia scleroxyla (candelón)

This endemic legume is almost unknown to science except botanically. It is a popular firewood and charcoal source from the dry forest. Because it lacks spines, has dense wood, fairly reasonable size and appears to be a light-demanding, aggressive species, it was chosen for 1984 trials in Mao, Santiago, Jánico, and a few other dry locations.

In the first years, the species made little or no progress. It died in initial growth trials in ISA. The only measurable success was in small trial plantations on deep soils, even though the tree regenerates naturally in Mao on road cuts and other exposed sites. ISA-2 and Mao Compartment 1 produced trees of nearly 3 m in height at 3.5 years, with about 66 percent survival. The average height growth was very little or none in the first year. In JSA-2, after 4 months, many of the trees could not be found or appeared to be dead. Survival was estimated to be 43 percent. At age 8 months, however, the trees began to add leaves and strengthen the small stems, elevating the survival estimate to 74 percent. Appreciable but slow height growth did not occur until 1986 (Table 34).

Table 33. General performance of *Eucalyptus* spp. in trials.

Species	Experience	Best sites	Avoid
E. robusta	good	humid	dry/semi-arid
E. urophylla	good	semi-humid/h	dry/semi-arid
E. grandis	good	humid/acid	dry/semi-arid
E. saligna	?/limited	semi-humid	dry/semi-arid
E. citriodora	good/limited	semi-humid	dry/shallow soils
E. brassiana	?/limited	semi-humid	
E. cloeziana	?/limited	humid/semi-h	dry
E. tereticornis	good	semi-arid/s-h	dry, humid
E. camaldulensis	very good	semi-arid/s-h	local seed
E. torelliana	good/limited	semi-arid	
E. globulus	poor/limited	none found	shallow soil
E. sideroxylon	poor/limited	arid/semi	humid
E. pellita	?/limited	semi-humid	
E. maculata	poor/limited	semi-humid	dry

Table 34. Height of *Acacia scleroxyla* in Santiago plantation (JSA-2).

Date	Height (m)	Survival (%)
Planted May 1984		
March 1986	0.58	74
Jan. 1987	1.75	66
Jan. 1988	2.82	71

This height is much lower than the *Leucaena leucocephala* planted at the same time on the same soil; it had an average height of 10 m by January 1988.

In Mao, the small plantation of about 100 trees on deep, well-drained soil had a similar height and survival. The foliage was a deep, vivid green with vigorous crowns. Here, the trees are growing alongside a stand of *Casuarina equisetifolia* that apparently died of drought at age 2 years.

Seeds collected in Mao were germinated and grown in the greenhouse in Indiana for 32 weeks by Borges and Chaney (1988). Mycorrhizal inoculation significantly improved the growth of the seedlings. Endomycorrhizal fungi used were *Glomus macrocarpum*, *G. fasciculatum*, *G. mosseae*, *G. etunicatum*, *G. epigaeum* and *Gigaspora margarita*. The inoculated seedlings continued to increase in height during the 32-week test period, while the nonmycorrhizal seedlings did not grow in height after the first six weeks. The same effect was observed for shoot and root dry weight as well as the diameter of the root collar. The percentage of the roots infected was closely matched to the pattern of growth response, regardless of the species of fungus. Thus, it was impossible to determine if the growth response was a function of inherent efficacy of the fungus species, to the aggressiveness of the fungi, or a combination of these factors (Borges and Chaney, 1988).

Casuarina equisetifolia

Various experimental plantations of *Casuarina equisetifolia* in Mao have suffered gradual drying and death after the first or second year of vigorous growth. In the majority of the cases, the first manifestations of the problem appeared at about 9 to 12 months of age, when the plantation was already well established. All the plantations observed were in deep, well drained soils of medium texture. The climate is dry, but during the first year or two of the plantations (1984-1986), there was more rain than the normal 750 mm per year. In 1986, after May 15, there was a drought that lasted for about 8 months. The casuarina problem appeared during the summer of 1986 and was reported as serious in late September, after only 4 months of drought. The trees also died in rocky soils at ISA-Rio. After a good start from large seedlings, one year old trees at Jacagua also died.

Other plantations in the Mao Experimental Forest also demonstrated high mortality. The initial growth trials established in May and September 1984, had no casuarina tree that could be considered as healthy after two years or less of growth, although they were planted in a random mixture with 11 other species that remained healthy. The yield plots of the same dates contained more green trees, but almost none was really healthy. Later examination in January and June 1988, indicated that very few of the trees were alive. *Casuarina cunninghamiana* planted nearby showed better than 50% survival.

Several small plantations containing carefully-inoculated nursery seedlings still had some of the trees alive after two years, but the negative condition was still present in a majority of the trees, even those that had been inoculated.

The experience in Mao and ISA was different from that in other parts of the country with this species. Falconbridge Dominicana has planted many hectares of *Casuarina equisetifolia* and other species of the same genus on mine spoil land with excellent results and high survival rates over a period of five years or more. Ornamental plantations in several places, most notably east of Santo Domingo, have good survival. An experimental plantation in very acid soils and high rainfall near El Valle, Sabana de la Mar, also has survived after fairly high mortality during the establishment period. This plantation lacked nutrients and inoculation with nitrogen-fixing bacteria; when the bacteria were introduced, discolored (but not dried) trees immediately responded with a healthier appearance and vigorous growth. A 10-year old plantation at Cacique, Moncibn, not far from Mao, also shows excellent vigor.

Various examinations of the stands in Mao have confirmed the problem but none offered a solution or identified the cause. In December 1985, pathology professor Pedro Jorge and the senior author examined the oldest plantation (May 1984). All the affected plants showed similar symptoms, starting with a darkening of the bark at the base and progressing up the tree. Some of these dark patches were spotted with a whitish color. Many of the trees had cracks in the bark, without the presence of exudations. The leaves (branchlets) gradually discolored at the tips, turning orange (this is not uncommon nor irreversible in many of the trees that suffer temporary drought or nutrient deficiency). The discoloration progressed and the orange color turned to a brown, dry appearance; eventually, the whole tree turned brown and died.

Isolation and cultivation of plant tissues in the laboratory revealed no causal agent. At this time, the 1.5-year-old stand was inventoried: 18% of the trees were dead, 33% were sick or damaged and 48% were considered as unhealthy or doubtful (slight discoloration of some needles). The mortality appeared in various parts of the small plantation, without a specific area of concentration or center of spread of the phenomenon. A second sampling of the same plantation in September 1986, indicated that 99 percent of the trees were dead or almost dead and the remainder of the trees showed signs of decline. In the damaged trees there were some physical wounds at a height of 0-50 cm on the trunk. Within these wounds, normally covered by bark, there were coleopters of 3-4 mm in length. Small ants were also present. Entomology professor José Díaz Patxot and the resident advisor hypothesized that these insects were probably not primary causes of the problem.

This symptomology occurred in trees that apparently had become well-established and were growing vigorously. In Mao, this species grew reasonably well during the first year, reaching heights of 1 to 2 m. Its growth during the second year, if not affected, was indicative of good health, a strong root system, and favorable growing conditions, many of the trees reaching 3 to 4 m in height before succumbing

A clear diagnosis has not been made. No similar symptoms were encountered in the available literature. Among the possible causes, the observations below represent the thinking of the research team:

1. Insects probably are not the primary causal agents of the damage.

2. Apparently it is not a problem of deformed roots or poor planting practice; excavations indicated that the root systems were vigorous and well distributed in the soil.

3. There was no clear evidence of nematodes, although this subject was not exhaustively studied.

4. The symptomology of the oldest trees seems to be related to fungi, bacteria or virus. The loss of bark and the tumefaction of certain parts of the tree and eventual drying of the wood suggest the effect of pathological organisms. However, two sets of laboratory cultures did not clearly manifest any causal agent.

5. It is possible that a lack of bacterial (*Frankia* spp.) nodules on the roots or of mycorrhizae has left the trees without adequate vigor or defense. In the first plantation examined, a search of several root systems produced no nodules. However, later occurrences of the malady were in plantations with nodulated trees (perhaps not adequately).

6. Drought is a possibility, although it seems strange that this species would die out when other species of similar drought tolerance are thriving under exactly the same conditions.

7. In some trees there were slight wounds probably caused by machetes or planting tools, but this is not thought to be the cause of generalized mortality. Examination of the wood indicated that there were some small infections that were compartmentalized in the wood, but no serious rotting. The possibility of planting or tending damages being the primary cause is made remote by the fact that other species planted by the same personnel are thriving all around these several casuarina trials.

The technical literature encountered does not indicate many serious problems of mortality of this species. To the contrary, it is known for its rusticity under difficult conditions. It is utilized in India and other countries to stablize dunes. It is known as a species with great adaptibility to edaphic and climatic conditions (Midgley, Turnbull and Johnston, 1983; National Research Council, 1984).

Because of these experiences in Mao, as contrasted to the generally positive performance of casuarina in other parts of the country, the Program researchers reserve their opinion about the use of *Casuarina equisetifolia* in energy plantations, especially in dry zones with neutral or basic soils. The subject deserves greater study of the literature and a continued search for the causal conditions. A suggested starting point for a solution is more careful experiments with inoculation with *Frankia* spp. and mycorrhizae.

Melia azedarach - violeta or chinaberry

This species is not considered a good charcoal or fuelwood tree, but it is a vigorous escaped exotic that has shown variable growth and form. Its seeds are readily available. The tree was planted mostly in Santiago on a variety of soils in ISA-1, ISA-Rio and Barrio Lindo.

The best early growth was in a pilot plantation in Barrio Lindo. The soil was droughty, compacted from grazing, very deep with a sandy layer below the first meter. Plowing with oxen was used for site preparation; on areas where there was no plowing, the trees died. The plantation was 2.5 x 2.5 m, with alternate rows of *Eucalyptus camaldulensis* and *Melia azedarach*. The trees were planted in January 1986, enjoying a brief rainy period followed by three months of drought. The initial idea was to have the violeta serve as a nurse or spacing crop for the eucalypts, removing it as the trees got larger to give more space to the eucalypts. However, almost all of the eucalypts died, while most of the violeta survived on the plowed area. In January 1988 the trees averaged 4.37 m tall. Two-thirds of the stems had one stem, 26 percent had two and 8 percent had three stems. Form was variable. Survival was 88 percent.

In ISA-1, the species performed well in the initial growth trial, despite several visits by goats which destroyed other species. In a pilot plantation in ISA-1, the tree performed erratically, some growing very well, others dying back and resprouting and still others dying out.

In yield plots on sandy soils of ISA-Rio, the tree started very well, but became less attractive with time. At age 3.5, violeta reached 4.9 m in height, 4.8 cm in diameter but with only 39 percent survival.

Nursery Practice

Both practical experience and experiments provide the bases for the observations and suggestions about nursery practice. At the two program nurseries, in ISA and at Mao, a conservative approach was used, following nursery practices that were well understood and that used locally available materials. This assured a margin of error and produced the seedlings needed for experimental plantations. As the program developed and the research staff examined nurseries in the U.S., Haiti, and Brazil, various trials and comparisons of alternative techniques were introduced.

There are no definite recommendations offered for all cases; nursery practice is flexible and a matter of preference according to local needs and conditions. For example, in Haiti, very compact seedlings in light-weight rooting medium are preferred so that farmers can carry large numbers of trees with ease. Rather costly nursery systems are used in the interest of getting many seedlings to the field. Survival is low, close to 50 percent. On the other hand, in Brazilian industrial operations, high survival is desired and efficient transportation systems are used, so heavier plastic bags filled with soil are used in many operations. Some firms use different container systems that reduce handling costs.

Containers used in ISA and Mao were mostly 4 x 6 inch black plastic bags filled with soil (Figure 9). This method has been used for years by nurserymen in the goverment and Plan Sierra nurseries. The bags are relatively inexpensive, manufactured in the country and can be used to make a nursery virtually anywhere there is water and sun. The major disadvantage is that each bag is handled separately or in small groups of 5-7 when loading trucks and carrying to the planting site, unless special boxes are built.

Other containers tried were Rootrainers (Figure 32), made in Canada, and several types of plastic blocks and tubes, all imported. Each functions well. The commercial nursery "Los Arbolitos" uses several of these with success. The smaller the container, the more critical is the timing of planting. Trees cannot be left in the nursery for very long periods of time past their target planting date or they will suffer.

Figure 32. Rootrainers in nursery at Mao.

A common problem with many containers, notably the plastic bags, is that the roots spiral around in the bottom of the bag until they find a hole; then they grow into the ground. The Rootrainers and several other systems are elevated above the soil, with small holes in the bottom of the container. Thus, the roots encounter air and do not continue to elongate. This is an important principle that could well be incorporated into any large nursery system.

Cost is a consideration with any nursery system. Plastic bags are used once and discarded; if not picked up after planting, they create an unsightly plantation. The more rigid plastic containers are carried to the field, emptied and returned for reuse in the nursery. There is normally some damage to the semi-flexible "books" in the Rootrainer system, amounting to perhaps ten percent replacement. Because these are imported, their cost may be high by the time they reach the nursery.

Nursery "soil" or substrate currently in use in the Dominican Republic ranges from imported peat moss and vermiculite to topsoil plus manure. The former requires regular application of fertilizers. The latter carries the potential problem of damping-off diseases. Seedbed sterilization procedures range from theoretically ineffective flooding with hot water to use of chemical soil sterilants. In many cases, there is no treatment. There is a need for much more complete study and development of practices and their net costs.

Reynoso and Abréu (1984) reported on a study of substrates in Mao The most productive in the seedbed depended upon the species of tree used. Three legumes with fairly large seeds were tried: *Cassia siamea*, *Prosopis juliflora* and *Acacia scleroxyla*. Of the ten mixes of sand, soil, rice hulls and cured manure that were used, one produced large seedlings in all cases; 3/4 sand and 1/4 black soil. This applied only to the germination bed and the authors recommended further studies of the mix for containers. In practice, mixtures of top soil and sand were usually used in the plastic bags and rootrainers.

In an unpublished study at ISA, Rosado compared substrates of black soil mixed with vermiculite or sand. A commercial NPK fertilizer was added to the plastic tube containers at 3 g/seedling. Seedlings of *Eucalyptus camaldulensis* grew the largest in unfertilized soil plus vermiculite after three months in the nursery, reaching 19.5 cm in height. Seedlings grown in the fertilized substrates were shorter and showed 20 percent mortality (Table 35).

Table 35. Heights of *Eucalyptus camaldulensis* seedlings in different nursery substrates after 3 months.

Substrate	Height (cm)
Soil + vermiculite	19.5a
Soil + sand	16.2b
Soil (fertilized)	14.6b
Soil + vermiculite (fertilized)	13.2b
Soil	13.2b

Average heights followed by the same letter are not statistically different (p = 0.05).

Hernández and Bonilla (1985) tested bag containers and Rootrainers using six substrates with *Casuarina equisetifolia*. They measured height and total biomass every month for five months.

Survival in Rootrainers was lower than in the bags. The seedlings produced in the bags were taller and heavier than seedlings produced in Rootrainers (Table 36). However, the roots were better distributed and formed in the Rootrainers and the authors recommended their use, despite the significant differences between average heights and weights in the two containers. They found that the roots weighed between 34 and 51 percent of the tops in the bags and 23-49 percent of the tops grown in Rootrainers.

Table 36. Performance of *Casuarina equisetifolia* seedlings in two types of containers and six substrates.

Substrate	Plastic bags			Rootrainers		
	Survival (%)	Height (cm)	Top biomass (g)	Survival (%)	Height (cm)	Top biomass (g)
Bagasse + manure	100	32.3b	1.042a	96	28.7a	0.382a
Soil + manure	88	38.3ab	0.879ab	58	25.6ab	0.199b
Soil + rice hulls	88	40.6a	1.000a	75	21.7b	0.173b
Soil	92	34.6ab	0.941a	96	21.5bc	0.125bc
Soil + bagasse	96	23.2c	0.320c	79	16.9c	0.080c
Bagasse + rice hulls	88	41.2a	0.798b	67	16.6c	0.084c
Average		35.3			21.8	

Figures in a column followed by the same letter are not significantly different according to Duncan's multiple range test (p = .05).
Source: Hernández and Bonilla, 1985.

Another study of substrates showed marked differences among five mixtures in affecting the development of two native species, brucón (*Cassia emarginata*) and candelón (*Acacia scleroxyla*). They were direct seeded in plastic bag containers. González (1987) used six criteria to determine that brucón performed best in a mixture of sand + manure or sand + manure + rice hulls. On the other hand, candelón did best in black soil + sand. Both species produced the tallest seedlings with the sand and manure mixes (Table 37).

Table 37. Average top and root lengths at 60 days after seeding for *Cassia emarginata* and *Acacia scleroxyla* in various nursery media.

Substrate	Brucón		Candelón	
	Top	Root	Top	Root
	cm	cm	cm	cm
Sand + manure + rice hulls	19.0	25.2	20.3	23.0
Sand + manure	17.2	29.0	24.8	20.3
Black soil	8.5	25.0	18.0	21.5
Soil + sand	6.3	32.0	17.2	27.2
Sand	5.2	32.7	11.8	28.5

Source: Adapted from González, 1987.

Adjustments for overgrown seedlings are necessary. It is almost inevitable that, even in the best-managed nursery, some seedlings will outgrow their containers. Delays in planting due to weather, transport or operational problems may keep seedlings in the nursery too long. Some species can be root pruned and correspondingly top pruned before planting out. For other species, the only solution is anticipatory. Before they reach planting size, applications of water and fertilizer can be slowed and the trees will reduce the vigor of their growth and perhaps "wait" in their growth for later planting time. The final effects of these treatments on the success of the planted trees should be studied more carefully than was possible during this program.

Spacing

Spacing between trees in a plantation is a function of several variables; the site, the final products of the plantation, the local costs of establishment and tending, and the market for small wood products. Likewise, the characteristics of the species, including growth rates and tendency to stagnate are of particular concern.

After many decades of trials and discussions of spacing in plantations in Brazil, Germany, and the southern United States, there is no one clear answer. Although results of volume productivity at different spacings must be evaluated before final recommendations can be offered for the Dominican Republic, the reasoning, preliminary evidence and recommendations are presented as an interim guide.

Spacing experiments were established with seven species and three approaches. None of these experiments is yet ready for evaluation of the outcome, since the returns from differentially-spaced plots are important to compare the relative costs.

Species and Trials

Five species were used in establishing traditional rectangular plots at discrete spacings. Four of these were located at El Valle, Sabana de la Mar, on relatively infertile soils. They were invalidated by high levels of mortality in *Cassia siamea* and *Eucalyptus citriodora*. Mortality and slow growth have at least partially damaged the trials in this location with *Eucalyptus robusta* and *Casuarina equisetifolia*. However, the application of fertilizers to the one-year-old trees has produced fairly rapid growth in these two species. Although the results will be, at best, only suggestive, they may give some eventual indications of the relative value of closer or wider spacing on this type of "difficult" soil.

The fifth experiment of this type is located in Santiago on sandy soils at ISA-Rio with *Azadirachta indica*. This design is demonstrated in Figure 23 and is representative of the technique. It uses a compromise between a fixed area per spacing unit and a fixed number of trees per treatment, neither of which is very workable alone. This design allows the comparison of four rather disparate spacings to be replicated four times on a relatively compact and uniform site. There are enough trees in each spacing to allow statistical analysis of volume produced, while confining the experimental design to one topographic configuration.

Another series of square plots with *Azadirachta indica* was set up at ISA-Naranjo for later economic studies. Spacings of 1 x 1, 2 x 2, and 3 x 3 in plots 25 x 25 m (one tarea = 629 m^2) were repeated four times. As operations proceed, they are to be recorded for costs; the eventual volume yield also will be recorded at harvest.

The third set of plots are the Nelder wheels located at ISA and Mao for various species (Figure 22). They were established according to computer-generated designs supplied by Heather Palmer from CATIE. In ISA-1, wheels were established for *Eucalyptus camaldulensis*, *Leucaena leucocephala* and *Azadirachta indica*; the first two species suffered damage from livestock but replacements may make them viable by age 5 or 6. In Mao, Nelder wheels were established for *Azadirachta indica*, *Eucalyptus camaldulensis*, *Leucaena leucocephala* and *Cassia siamea*. Mortality of a few of these trees may affect some of the repetitions of these wheels.

Importance of Spacing

Brewbaker and other have recommended planting at 1 x 1 m spacing with *Leucaena leucocephala* for firewood. This produces quick site coverage and reduces the number of weedings necessary. During the first or second year, it achieves early "full utilization" of the site. This recommendation must be considered in light of costs, net benefits, and the need for a rotation-long "full utilization" concept.

For close spacings, the cost of seedlings and planting are very high per hectare. At 1 x 1 m spacing, 10,000 seedlings are used for each hectare, while only 1,111 are used at 3 x 3 spacing. Thus, the costs of buying, transporting, and planting are nine times higher for the close spacing. These costs amount to at least 50% of the establishment costs of the first two years.

At close spacing, it may be necessary to thin out 3/4 of the dense stand after 1 or 2 years or lose many of the trees to competition. Thus, a cash market for foliage or very small sticks (1-3 cm diameter) would be required to justify close planting.

In the absence of such markets, wide spacing, such as 2 x 2, 2.5 x 2.5 or 3 x 3 m is recommended if the cost of seedlings, transport and planting exceeds the savings in weeding costs. Wider spacing concentrates the harvestable volume on fewer stem and the total will probably be equal or greater than a hectare of closely planted trees. This fact is related to the concept of full site utilization during the rotation. On a 7 year cutting cycle, it is not vital and may be undesirable that the site be fully occupied during the first two years by the trees. As trees advance in age, they grow in size and root volume, thus requiring space and soil volume on a gradually increasing basis through the years. By fully occupying the site during the first year or two, the trees may be interrupted or stagnated in their growth. Only by quick removal of competing trees will the remaining trees be able to continue rapid growth. There is a natural economic tendency to thin young stands by removing the largest trees, which are the most merchantable. This may leave a stand of young trees that is inferior in growth potential, form and vigor. Although foresters can theoretically discuss thinning from below, that is, removing the smallest and the poorly formed trees, the tendency in a young plantation will be to achieve an income to write off the costs of the plantation as early as possible.

Two commercial plantations of *Leucaena leucocephala* K-8 in Puerto Plata were direct seeded at 1 x 1 m spacing. By age two years, the canopy was closed. By age 4.5 years, many of them showed the effects of competition. All the trees in the interior of the plantation had small diameters relative to their height. Compared to a plantation spaced at 3 x 3 m in drier conditions in Santiago, the diameters are much smaller in relation to their heights (Table 38). Although these sites are not directly comparable, the point is clear that more open spacing will produce trees with larger diameter without sacrificing height growth. Three fairly open grown trees at Camú gave some indication of the potential. They had an average diameter of 16.1 cm and height of 11.9 m.

Survival was excellent in plantations so closely spaced, with 85% of the trees still alive in Los Dominguez. The Camú survival was estimated at 70%. The presence of suppressed trees, those with dying tops and those that were very slender and overtopped, was clear at the January and June 1988 inspections. Trees on the borders of the plantation were noticably larger than those in the center.

Table 38. Diameter and heights of sampled *Leucaena leucocephala* trees at various spacings.

Location	Age (yrs)	Spacing (m)	Diameter (cm)	Height (m)	D/H
Camú, Puerto Plata	4.5	1 x 1	5.7	10.4	.56
Los Dominguez, P.P.	4.5	1 x 1	5.9	9.9	.59
ISA-2, Santiago	4.0	3 x 3	10.2	11.5	.89

There is still a question whether these closely spaced trees will stagnate in their growth or whether suppression will produce a takeover by dominant trees. Both factors seem to be operating. The small average diameters and lack of any large trees suggest stagnation. That some differentiation is occurring is evident from a few suppressed trees showing dieback of the tops. At present, the judgement is that close spacing severely inhibits the diameter growth of all of the trees and that dominance and suppression will develop more slowly. The lack of marked differentiation is probably related to the genetic uniformity of the one-cultivar stands. Wider spacing would probably produce larger, more valuable trees in the same time.

Wider spacing reduces the most important cost factors, the seedling and planting cost and the harvesting/hauling costs of the final product. The latter are high, especially when handling a large number of small stems instead of a few larger stems. A summary comparison between a close spacing and a wide spacing is made below:

Close spacing (1 x 1 m):	Wide spacing (3 x 3 m):
10,00 seedling/ha	1,111 seedlings/ha
Weeding-2 times in first year	Weed 4-6 times in two years
Thinning possible at age 2 or 4 years--income or cost.	Harvest fewer, larger trees, at lower cost/m^3
Harvest many, smaller trees at higher cost/m^3	

Weed Control

The second most likely source of failure of plantations (after livestock) is from inadequate weed control. The vigor of weed growth was variable among the program's different experimental sites. In a few, the soils were so poor that no control was done during the first year; tree growth was extremely slow on these poor sites, seldom reaching 1 m in the first year. In better soils, where fuelwood plantations have a chance to be economically profitable in a short (5-10 year) rotation, it is necessary to control weeds several times in the first two years.

The effects of weeds are several, as observed by Burgos and Diloné (1986) and the research team:

1. Climbers and vines wind around the trunks and crowns, deforming them (Figure 33) and sometimes breaking them. Vine removal is critical even into the third and fourth year.

Figure 33. Vines affect growth and form of very young are larger trees alike.

2. Grasses and forbs compete with young tree roots for water and nutrients, reducing growth rates dramatically in the first year or two.

3. In some cases, weeds can shade out young trees, reducing growth potential. This visually obvious effect is probably much less important than the root competition, since most of these trees receive sufficient sunlight even if slightly overtopped by grasses.

Methods of weed control include "mowing" with a long, narrow machete; weeding with a hoe or broad digging machete; and application of herbicides.

The "mowing" (chapeo) treatment is mostly useful to remove vines, shrubs and very large weeds. It is useful as a step in site preparation. Its effect on root competition is probably negligible. Its effect is limited since it merely removed part of the tops of the weeds, leaving the living roots and sprouts to continue competing with the tree roots. The mowing does improve the appearance of the plantation.

Hoeing removes some or all of the roots of the weeds. It was normally used in the trials to maintain clear circles around each tree. This is recommended as the safest, most practical, effective and efficient method under current Dominican conditions. Care must be taken not to cut tree roots by deep hoeing near the tree.

Herbicides have the advantage of quick application with relatively low manpower. It keeps dead roots in place, thus reducing erosion potential. The effectiveness varies with time and skill in application, as well as with weather conditions and the herbicide selected (Holt and Finke, 1985). The application of the chemicals near small seedlings resulted in mortality to about 10-20 percent of the trees, due to accidents in application, despite proper equipment and instructions.

The results of studies of weed control in this project are preliminary. Cost data were collected from several of the weed control operations and appear in the section on cost analysis.

In a study at Mao-II with *Azadirachta indica*, five treatments for weed control included:

1) No treatment
2) Hoeing a circle around each tree
3) Hoeing a circle and mowing (machete) the rest of the area
4) Application of a contact herbicide (Paraquat)
5) Application of a systemic herbicide (Roundup)

Twenty-five trees per treatment parcel and four replications were used in randomized complete blocks of 3-month old trees. Variables measured were 1) percent ground cover around each tree, estimated by three observers and averaged, at 2.5 and 10 months after weed control and 2) height of one-year old trees, nearly 10 months after weed control. The weed controls were effective two months after application, but had virtually disappeared by the 10-month measurement. There was no readily apparent advantage to the chemical treatments over the mechanical methods (Table 39). Height growth was not appreciably affected, which may be partly related to neem's normally slow height growth in the first year.

In the various other trials with herbicides, the types used were Gramason (paraquat), Roundup (glyphosate), and Arsenal. There were also sample trials of Poast, Fusilade, XRM4570, Esteron BK, and Surflan. The paraquat "burns" the tops of plants contacted but does not kill the roots. Roundup and Arsenal are systemic, killing the whole plant. These four must be applied with great care in young plantations, since they can kill or retard the trees if the herbicide is allowed to contact them. Poast, XRM4570 and Fusilade are expensive gramacides that have little effect on broadleaf plants; they can be sprayed over the trees with relative impunity.

Table 39. Relation of weed control methods to ground cover and height at 2.5 and 10 months after treatments in *Azadirachta indica* plantation in Mao.

	Ground cover (%)		Height (m)
	2.5 mo.	10 mo.	10 mo.
No treatment	56	64	1.16
Roundup	22	62	1.14
Hoe and Mow	21	61	1.23
Hoe	15	51	1.08
Paraquat	26	50	1.24

Herbicide comparisons were made by observation in ISA-Rio. Roundup (1%) had a 2-3 month effect similar to hoeing. Paraquat (2%) had the 3-month effect of knocking back and slowing growth of grasses. Arsenal (1%) kept the sprayed circle clean for seven months and there was little competition even after a year. The *Eucalyptus camaldulensis* trees (1-2 m tall), however, suffered severe retardation of growth for one year and several died.

Arsenal is not recommended for post-planting weed control at present. It was tried successfully in pre-planting with *Casuarina cunninghamiana* in sandy-rocky soil in ISA-Rio. The trees were planted 2, 4 and 6 weeks after herbicide application. Survival and height growth were equal for all and approximately the same as in an adjacent untreated plantation. Unfortunately, this experiment was lost to fire after six months; it appears, however, that a light application of Arsenal several weeks before planting may work for *Casuarina* spp. This should be tried experimentally again before wholesale use.

Timeliness of weed control was a major scheduling problem with all methods. Weed growth is most rapid during rainy periods, which is the time that laborers are occupied in planting work. Outside laborers are often involved in agricultural activities at this time, so they are hard to contract. Most herbicides are not effective unless they have several hours without rain after application; during application, there should be little or no wind. It was often difficult to find more than two to ten hours per week with favorable conditions in the rainy season at Santiago. Thus, planning is important but must be flexible in application to match the variable weather conditions.

There is a need to study alternative timing strategies, applying herbicides or hoeing just before or after the rainy season, comparing the tree growth response with the same kind of treatment during the wet period.

Recommendation: After good site preparation, hoe weeds in a circle around trees, probably twice in the first year and twice in the second. In large plantations, study the practicality of developing a herbicide application system. Applied research on effects, scheduling and cost efficiency of herbicides is recommended.

Pruning

Two pruning trials were initiated. One is in Mao, with two-year old *Azadirachta indica* and *Leucaena leucocephala* planted in January 1984. No measurements were available, but any differences were difficult to observe two years after the pruning.

Another pruning experiment was established in ISA-2 in Santiago. The site is the bottom of a former pond, with deep, well-drained soil. The pruning of *Leucaena leucocephala* K-8 at two years of age removed all but one stem below the height of 1.3 m. The result was a single-stemmed main trunk. The economic objective is to concentrate equivalent volume growth on one stem, thus reducing labor costs/unit volume in harvesting and transportation. The trees were planted in May 1984, pruned in April 1986, and measured in December 1987.

Twenty months after pruning, the trees showed no significant difference in height growth. There was an evident but not yet major stimulus in diameter growth (Table 40). The stems of the pruned trees had grown 33 percent more than the largest stem of each unpruned tree, adding 3.4 cm in 20 months vs. 2.6 cm, respectively. Future measurements of total volume and quality will determine the value of the pruning for firewood, charcoal, and other products.

Table 40. Diameter and growth in diameter (cm) of pruned and unpruned *Leucaena leucocephala* K-8 in ISA-2.

	Replication				
	I	II	III	IV	
DBH 12/87					
Pruned	10.4	10.8	9.7	9.2	10.0
Unpruned	9.3	9.7	8.6	9.2	9.2
Change in DBH in 20 months					
Pruned	3.8	3.8	3.0	3.2	3.4
Unpruned	2.5	2.7	2.6	2.4	2.6

Fertilization

Several simple fertilizer experiments showed that the addition of small amounts of mineral nutrients can make a major difference on some sites with some species.

Most tropical soils are considered to be low in nitrogen and phosphorus; that was the case with all the soils tested in this research program. Nevertheless, not all species responded noticeably to the application of nutrients.

The fertilizer trial locations, species and general response level were:

El Valle (savanna, pH 4.5)

Cassia siamea 4 oz. 15-15-15/tree. Positive but inadequate response for application at 1 month and (separate trial) 1 year.

Leucaena leucocephala, K-28, K132, 4 oz. 15-15-15/tree. Positive but inadequate response for commercial use.

Casuarina equisetifolia, 4 oz. 15-15-15/tree. Positive response and probably the difference between commercial success and failure, but only when roots are inoculated with *Frankia* spp.

Eucalyptus citriodora, 4 oz. 15-15-15/tree. Positive response but questionable biological potential here due to physical conditions of the soil.

Eucalyptus robusta, 4 oz. 15-15-15/tree. Exceptional positive response, explained earlier in the description of the species.

ISA-1 (pH 7.3)

Melia azedarach - slight response

ISA-Barrio Lindo (pH 7.7)

Melia azedarach - positive response in survival and height

Azadirachta indica - no significant response (see details under earlier species description)

ISA-Avenida (pH 7.0)

Azadirachta indica - no response (see details under the earlier species description)

A simple, small fertilizer study was done in La Guázuma, where 8 trees of each of six species (in initial growth rows) were fertilized with 4 oz/tree of 12-12-12, when the trees were more than one year old (Knudson et al., 1986). The other 16 rows of trees were left unfertilized. The response after one year was remarkable, except for *Calophyllum calaba*. In one year, the fertilized trees of the six species surpassed the once-larger control trees (Table 41).

The implications of the findings of fertilizer trials are that the application of fertilizers may make a major practical difference in the commercial success of a plantation. In some cases, however, it does little or nothing to increase the height growth of neem in the first two years, at least in climatic zones and soils similar to those of Santiago.

The major economic reasons to apply fertilizers are either 1) to assure the production of a commercial forest where there is a critical shortage of nutrients in the soil or 2) to accelerate early growth so that weed control costs can be reduced. The El Valle fertilization of *Eucalyptus robusta* is a case of the former; without fertilization, the species will probably not attain commercial forest size within a reasonable time on the savanna soils. The low cost fertilizer (RD $.05/tree including application) provided critical elements that permitted fairly rapid growth of the trees. Of course, it remains to be seen whether these trees will continue to perform well in the next few years as they approach commercial size. The tight subsoil or the need for additional nutrients may become limiting before the trees reach commercially harvestable size. So far, the recommendation is clearly that fertilizer is critical to wood production on this type of acid savanna soil in a high rainfall region. Similar conditions exist on some of the marginal sugar cane plantations on savannas north of San Pedro de Macorís.

The use of fertilizers on neem on neutral or basic soils was an attempt to accelerate early growth. The dense shade of this species inhibits the growth of most weeds; therefore, accelerating crown closure would reduce the number of weeding operations needed. The lack of response to the treatments tested suggests that they are uneconomical. It also suggests that other treatments might be tried. Perhaps foliar fertilizers would be more available to the plant; perhaps deeper or more frequent irrigation would pay off. On the other hand, the trees may be genetically governed to remain small until a large root system is established and able to support the fast growth that occurs in the second or third year, as is indicated in the literature from India. It would be worth testing the species under different weed control schedules. Possibly, the weed competition has little effect during the first year or two, except for physical damage from climbing vines.

Table 41. Effect on height (cm) of fertilizing 13-month-old trees at La Guázuma, before fertilizing and one year later.

Species	Fertilized		Control		Fertilized/Control Ratio	
	Before Feb 85	After Feb 86	Before Feb 85	After Feb 86	Before Feb 85	After Feb 86
Inga vera	24	91	38	46	63%	198%
Casuarina equisetifolia	48	141	62	72	77	196
Leucaena leucocephala	48	203	62	109	73	186
Eucalyptus spp.	79	210	110	148	72	142
Cassia siamea	15	72	33	51	46	141
Calliandra calothyrsus	108	373	182	290	59	129
Calophyllum calaba	48	64	54	69	89	93

Source: Knudson et al., 1986.

Water Conservation

In arid and semi-arid parts of the country, seedling establishment and early growth are critical in the life of a plantation. Irregular and scant rainfall in some years may keep the soil from being adequately supplied with moisture to support growth of the small, young root systems. The problem is particularly acute on steep slopes and soils that have been compacted and eroded. These are the areas that are often chosen for tree planting for purposes of conservation and because nothing else will grow there.

Several such sites within the ISA campus in Santiago were found to have very little absorption and retention of water. One area in ISA-Pasto, on a nearly impervious subsoil, was planted with neem. Much of it had to be replanted twice in the first year to replace dead or dying trees. Observations of the soil after periods of heavy rain revealed that the soil was dry below the first inch or two. Thus, the neem roots had an inadequate environment in which to develop. Attempts to increase infiltration involved 1) digging small holes which filled up after one heavy rain and 2) driving broad wooden stakes into the soil. A third method was to place sheets of plastic around the seedlings to retard evaporation. None of the methods seemed to be very effective on this site, although more trees with the plastic survived than in the control plots.

Two trials to test methods for conserving water were established in ISA-1 on very well-drained, eroded slopes; one with *Azadirachta indica* and the other with *Eucalyptus camaldulensis*. Four treatments were used: control, small catch basins dug around each tree, stones around each tree, and plastic sheets 1 x 1 m around each tree with a hole in the center. Each had four replications with ten trees each, located at random. In both cases, the plastic sheets produced taller seedlings and lower mortality (Table 42).

Table 42. Heights (m) and survival (%) in water conservation treatments after 6 months.

Treatment	Azadirachta indica		Eucalyptus camaldulensis	
	Height	Survival	Height	Survival
Control	.39	60	.48	70
Stones	.36	68	.65	100
Basins	.42	60	.73	80
Plastic	.44	82	.91	100

The technique of using plastic sheets should be investigated further as to costs and long-term efficiency. The installation cost is merely one of cutting the sheets, placing them around the seedling and weighting them down with soil and rocks. This is suggested only for problem soils as a means to assure establishment and early growth.

Livestock

One of the most important non-experimental lessons of this research program was that the presence of livestock in forest plantations will not allow profitable forestry in the Dominican Republic. It is vital to protect forest investments from livestock.

Goats are a serious impediment to forest growth. In the native forest, they compact the soil and eat regeneration. Goats must be barred from plantations if there is to be any hope for profitable success from forestry investments. They eat young trees, bend them, break them, rub horns on them, peel the bark, and compact the soil, inhibiting water infiltration. The same can be said for sheep, cattle, horses, mules and burros. Livestock and forest plantations simply do not mix. Part of the cost of establishment of plantations and of the management of native dry forest is building, maintaining and patrolling a secure fence. Employment of fence menders and livestock patrols are essential in most cases.

Some foresters and virtually all livestock owners suggest that animals can be introduced into the plantation under certain conditions: 1) when trees are fairly large, 2) when tree species are unappetizing to livestock (e.g., *Azadirachta indica* and *Cassia siamea*) and 3) when grazing is carefully controlled in duration and number of animals. While this may be feasible under ideal conditions, it is not recommended, based upon recent experience and observation. Livestock management is seldom conducted in a way that would allow the "ideal conditions" to exist. There is little effective control of duration and intensity of grazing, even in expensive planted pastures and in research institutions.

Physical damage to the trees of any species and to the soil will reduce the productivity of the forest plantation, probably to a greater extent than it will benefit animal productivity. Neem trees, apparently unappealing to sheep and goats in the Dominican Republic, are used as fodder in India. Sheep that escaped into neem plantations at ISA nibbled the tops out of small trees.

When trees are large enough to resist breakage and bending by livestock, they will not allow much forage to grow beneath the stand. Even then, cattle and goats will rub or peel the bark and cambium, creating wounds that reduce growth and allow the introduction of disease.

The period of plantation formation that is most appealing to graziers is the first to third years, when trees are small and the grass has been allowed to flourish. This is the key time to keep livestock out and to control the weeds by means other than animals.

During this project, almost every experiment was damaged slightly or seriously by accidental or intentional entry of livestock. In several cases, the animals stayed long enough to completely invalidate the research results. In some, they so severely destroyed or deformed the trees that the plantations disappeared and the establishment investment was lost. Thus, even under the relatively careful procedures used in protecting research plots, it quickly became evident that strong, persistent and consistent measures were necessary to prevent the entry of livestock. Despite the centuries of destructive experience with grazing in other parts of the world, emphasis is given to this point because the public attitude toward livestock is so positive and the experience with forestry so new in the Dominican Republic. There are many small plantations in the country that have been damaged by livestock. In 1983, it was difficult to find really untouched young plantations, because livestock was given higher priority than tree growth.

The livestock factor is and will probably continue to be the most limiting to forest productivity in the Dominican Republic. The planter who seeks a profit from forestry must surely invest in protection from livestock.

In plantations at ISA which cattle, goats and sheep occasionally invaded, there were severe damages in the following species:

- *Leucaena leucocephala* K-8/K-28 are highly favored by all livestock.

  2 year old trees (ISA-2) 4 to 6 m tall; cows damaged bark on all trees by rubbing horns and peeling bark.

  1 year old trees (Naranjo) of 2 to 3 m; virtually all broken, deformed and defoliated by cattle.

  1-2 year old trees (Pasto) of 2 to 5 m tall; sheep peeled bark of all trunks to bare wood.

  New seedlings (ISA-1) all eaten back by occasional goat entries, retarding growth by at least one year.

- *Acacia scleroxyla*

  Young trees were eliminated from three initial growth trials by cattle or goats.

- *Calliandra calothyrsus* is highly favored by sheep, goats and cattle.

  1 and 2 year old trees were killed and virtually eliminated from three experiments by goats, and sheep and/or cattle in ISA-Pasto.

- *Pithecellobium saman*

  Initial growth trial trees all died, apparently due to goats.

- *Melia azedarach*

  Repeated visits by goats and burros resulted in physical damage and multiple stem sprouts.

A study of the impact of goats on the dry forest of ISA was initiated by Dutch and Dominican students. The objective was to determine the effects of three levels of browsing pressure on both goats and the forest. Identification of changes in vegetation composition related to browsing also will be made. Procedures were described in preliminary reports (Kho, van Paassen and Zambon, 1987; Smits and Seubring, 1987) but other data are still forthcoming.

Agroforestry

Virtually all of the trees mentioned can be grown successfully in association with agricultural crops. Some tree species offer many benefits for crops and livestock while producing fuelwood. On the other hand, plantation costs can be recuperated and reduced by growing crops with trees.

There are several approaches to agroforestry. ICRAF in Africa and CATIE in Latin America have outlined the various alternatives in courses and publications. For centuries, traditional farmers have been practicing some form of this array of techniques. Here, the interest is in establishing and managing plantations for wood fuel and other types of timber production. Therefore, the several methods mentioned include wood production as a major elements, except method 4.

1. Plant crops between the rows of newly planted tree seedlings. After the trees are large enough to shade out the crops, the agricultural cultivation will be shifted to another area. The plantation property can be organized so that the cropping and tree planting can cycle through the various sections of the property on a continuous basis. Thus, on a 100-tarea (or hectare) property, 10 tareas could be inter-cropped and planted to trees each year. If practical, the cropping could be continued for a second year in the young plantation, thus cropping 20 ta per year. If there were a 7 year tree rotation, the property would have 70 tareas of forest plus 30 tareas dedicated to fruit trees, permanent gardening, penned pigs and chickens, forage trees such as leucaena plus a residence. This is an excellent method to share costs of weeding during the first two years of the plantation. The income from the crops will often off-set the costs of the seedlings and planting, thus reducing carrying costs and interest charges for the plantation.

2. Another model is that of the hill-side farmer who needs to control erosion in his fields, supply feed to his pigs and confined goats, and produce firewood for family use. This idea is used in several small farms in the Dominican Republic with *Calliandra calothyrsus*. The farmers have 10-20 tareas of land (0.6-1.2 ha). They have planted dense rows of the bushy tree through their cultivated fields, leaving strips of land for cultivation of 4-10 m in width (Figure 34). The trees are planted along the contour, forming a barrier to runoff and holding some of the surface soil. Between the rows of trees, a variety of crops is grown. Plowing by hand or oxen provides the soil preparation and control of weeds. The trees help keep the soil moist, provide organic matter and tilth, and contribute nitrogen, thus reducing fertilizer needs, according to the farmers. The branches of the trees are stripped by hand for livestock feeding on a rotating basis, always leaving the terminal leaves and buds so that wood growth can continue. About once each year, the trees are cut

back for firewood, again on a rotating basis, with vigorous resprouting occurring within a few weeks. "Accidental" trials of direct browsing of these trees at ISA indicate that the trees soon die and the trunks are badly damaged if livestock is allowed to enter into the plantation area. Therefore, the system works best for feeding confined livestock.

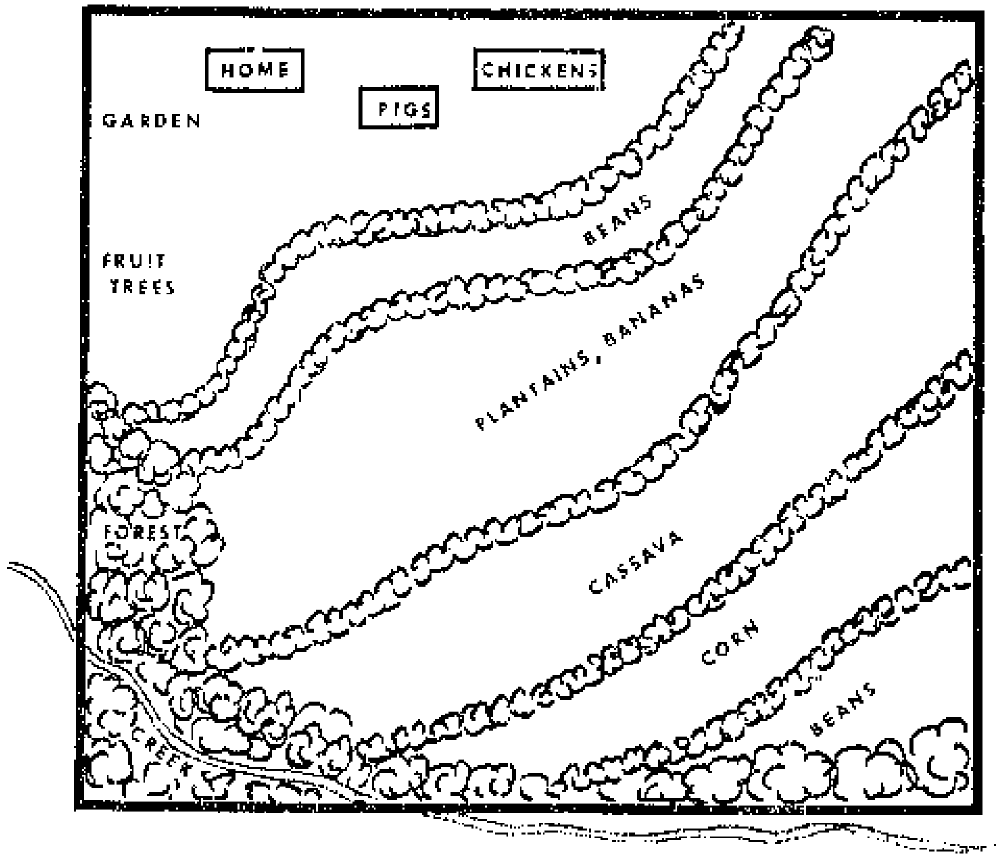


Figure 34. Agroforestry design of small hill-side farm for cultivation of animal and biennial crops with Calliandra calothyrsus.

3. Another variation is growing strips of leguminous trees that are 3-7 rows thick, leaving 10-30 m "alleys" of pasture between the trees. Grazing between the tree strips is possible while providing shade for the cattle and supplemental feed from the tree branches that are cut. However, this method will require careful husbandry of the animals, to prevent them from killing the trees. It may require the placement of electric fencing to protect the trees. It can be an excellent source of fuelwood, posts, poles and other wood products.

4. Another silvipastoral approach is based upon cut and carry methods. This was tested at ISA on an experimental basis with *Leucaena leucocephala* and *Pennisetum purpureum* (Tavárez and Vargas, 1987). The giant Merker variety of the grass is low in crude protein but high in fiber. The mixtures of the grass and the tree, cut every two to three months provided significantly more nutritious feed than the grass alone,

even when there was as little as 10 percent leucaena. The physical arrangement to plant one, three and five rows of leucaena with 2.0 to 2.5 m wide strips of grass on either side for mixes with 10, 30 and 50 percent of the area in leucaena, respectively.

Pure stands of leucaena and of the Merker grass were compared by Tavárez and Vargas (1987), from cuttings of young (60-90 day) sprouts (Table 43).

Table 43. Forage production from pure stands of *Leucaena leucocephala* and *Pennisetum purpureum*.

Characteristic	Leucaena	Pennisetum
Green matter (t/ha/yr)	73.2	157.7
Dry matter (t/ha/yr)	25.8	26.7
Crude protein (t/ha/yr)	5.4	2.2
% Crude protein of dry matter	21.0	7.0

Source: Tavárez and Vargas, 1987.

Both species produced about the same amount of dry matter but the leucaena produced much more crude protein. This is important because of the chronic shortage of protein and nitrogen in most tropical forages.

The productivity of the various combinations is summarized in terms of dry matter and crude protein in the cut feed in Table 44. The figures represent the harvests of grass and trees combined in the mixed plots. Clearly, the presence of leucaena sharply increased the nutritional value of the forage.

Table 44. Average production of dry matter and crude protein by treatment plots.

Treatments	Dry Matter (t/ha/yr)	Crude Protein (%)
100% leucaena	25.6	5.4
50% leucaena - 50% Merker	34.5	3.7
30% leucaena - 70% Merker	23.7	5.1
10% leucaena - 90% Merker	27.0	5.5
100% Merker	26.7	2.2

Source: Tavárez and Vargas, 1987.

A practical application of these and other findings was that the ISA animal production department established small "protein banks" of leucaena for dairy cattle. Some are used for light browsing every few weeks. Others are used for cut and carry supplemental feed. The operations are not experimental, so there have been no data other than the positive impressions of faculty and practical animal husbandman. This area deserves more scientific attention.

In Santo Domingo a student (Hoffiz Sanz, 1987) set up three feeding treatments for calves. The base of each was a controlled quantity (18% crude protein), a mineral concentrate "ad libitum" and African star grass pasture "ad libitum." The variable was ground leucaena as a supplement at levels 0, 15% and 30%. Twenty-one calves were used, seven per treatment. After seven months, average weight gains per animal were slightly higher when leucaena was added, although average feed consumed was about equal (Table 45). The results led the investigator to recommend the 30% supplement for calves, because of its positive effects and its ease of management and storage.

Table 45. Effects of rations with three levels of leucaena flour on young cattle.

Treatment (% leucaena)	Consumption (kg/cow/day)	Weight Gain (kg/cow/day)
0	3.64	0.304
15	3.67	0.306
30	3.65	0.326

Source: Hoffiz Sanz, 1987.

At ISA, Uit de Bosch and Sewalt (1987) studied intercropping of leucaena with grasses. Their experiment is still in progress due to difficulty in getting the grasses established. They noted the need to control weeds during the establishment of leucaena; weed growth had a big influence on the development of the young trees. The first cutting of leucaena was at 11 weeks after planting. The average crude protein content for the cut plant fractions were; leaves, 29%; edible stem, 14%; and inedible stem, 11%.

Cost Projections for Plantations

Financial Estimates

Morell and Knudson (1984) studied the growth rates and productivity of most of the pre-1983 plantations in the country. These included small 25 to 100 tree plots at FORESTA nurseries and in Plan Sierra, the Falconbridge and Gulf + Western experiences with *Eucalyptus* spp., *Casuarina* spp. and *Leucaena leucocephala*, as well as trials at schools, parks, military sites and several private plantations. From these data, they projected growth rates and yields at harvest. Although there was considerable variation among the sites and species, the average for reasonably productive forest soils (not good agricultural soils) was conservatively estimated at 175 m^3/ha/yr at 7 years (m^3 = steres). This was found to be comparable with industrial and private experience in other areas of similar latitude and climate (Sedjo, 1983; Simões et al., 1981; Gomes, 1983).

Cost analyses were based upon 1) the limited experience data in the Dominican Republic, 2) data from other locations (Sedjo, 1983; Brazilian industrial data collected during field trips; Simões et al., 1981); and 3) calculations and adjustments based upon prices of materials and labor in the Dominican Republic. Income analysis was based upon a study of bakeries, major purchasers of firewood in Santo Domingo. This does not imply that only firewood can be sold. The agile investor will evaluate several markets and sell for the highest income. An industrial investor, on the other hand, often dedicates the plantation as the raw material uniquely aimed at the factory and therefore, equates the cost of production of the trees as an internal cost.

This estimation of costs and returns, flawed in details as it surely is, suggested that, after the first seven year cutting cycle, accumulated direct costs could be RD \$3,357.50 and income would be RD \$5,250 per hectare. After two cuts and sprout regeneration, by age 19, cash expenses could be about RD \$7,000 and income over RD \$14,000. Figures are in constant value 1984 pesos. Applying real discount rates (which would normally be added on to inflation rates) of 10% yielded positive net present value figures. The internal rate of return projected for the 19 years was 20.6 percent. Real cases indicate that this very positive projection is extremely modest, probably because the only market considered was for industrial firewood.

A general re-evaluation of this study two years later suggested that establishment costs may be lower than indicated, harvesting and transportation costs would be higher and strategic marketing of the wood could bring a much greater income, as is illustrated in the investment cases with *Eucalyptus citriodara* and *Leucaena leucocephala*. Sensitivity analyses produced positive returns (1.9%) even when increasing early costs 20% plus reducing growth to 15 m^3/ha/yr plus dropping the price of firewood from RD \$30 to 20/m^3.

In a separate analysis, after several years of record-keeping on 11 small ISA experimental plantations, Serrata (1987) reported that the average cost for establishment and cleaning was RD\$2,447.55 per hectare, with a range of RD\$1,363.75 to 3,702.32/ha, or average of RD\$154/tarea. He noted that costs could be reduced by paying workers by piece work contract rather than the daily wages usually used at ISA and by planting larger areas on an industrial basis. These rates were compatible with the estimates of Morell and Knudson (1984) when inflationary effects are considered.

Based upon these observations, and more recent inflation, most plantations can be established and cleaned for RD\$2,500 - 4,500 per hectare over 1 (RD\$150 - 280 per tarea) or less over two years. Wider spacing of 2.5 x 2.5 m or more would be at the lower end of these costs, while very close spacing would probably result in the higher level. By growing crops and using "no cash" family labor, costs can be reduced considerably.

Serrata (1987) estimated that operating costs were roughly divided in three parts: one-third is the cost of seedling production or purchase delivered; one-third is the process of site preparation plus planting; one-third is the cost of cleaning, maintenance and supervision. This does not include the value of land or any new road construction. Included in some of the figures are costs of fencing and occasional hand irrigation for early survival.

Regardless of the details of the analyses, the financial potential for growing and marketing trees from plantations offers a valid option to the landowner. Whether or not to buy new land for plantations (or agriculture) would require additional analysis of the specific case. Forest plantations appear to provide strong income opportunities at this time, when the forest resource is very depleted and demand for all types of wood products is rapidly rising.

The fuelwood market now includes bakeries, sugar refineries, pizzerias, laundries, foundries, meat roasters and a small percentage of rural homes (most families collect their own firewood). Markets for charcoal include urban homes, restaurants, chimi-churri stands, and small industries. Potential markets for small to medium trees include tobacco producers (poles and rafters), rural construction, stakes, fence posts, power poles, scaffolding, furniture, matches, toothpicks, all types of lumber, chips and flakes for various types of reconstituted boards, excelsior, boxes and dozens of other products. These illustrate some of the options that are open for markets and new industry, once a resource base is developed. If the experience of other nations (Brazil, Chile) is any indication, the demands and markets will develop much more rapidly than the plantations. It is predicted that a Dominican planter of trees faces a vast, growing internal market with fuel as only one of many options.

Investment Case 1

A riverside property on the edge of Santiago was once a scrubby pasture filling in with twisted, spiny shrubs, producing no income for the estate of a local family. One family member formed an agroforestry company and put part of the land into *Eucalyptus citriodora*, with the initial goal of extracting essential oils from the leaves.

Beans were planted between the 2.5 x 2.5 m rows of trees. The cost of establishing and tending the 26,000 trees was about RD $5,000. The bean crop, cultivated simultaneously with the trees, produced a net income of RD $4,000.

The trees received two more cleanings in the first two years. The dry, deep sandy soil produced relatively slow initial growth, but as roots deepened and as the rainy season came, growth accelerated (Table 46). About 18-20 percent of the trees died during the first year. By the end of the second year, some trees were large enough to be marketable as long, slender poles, used as rafters in tobacco drying sheds. Thinning of the largest trees started in year two and continued through the third year. Prices of the tree-length (6-10 m) poles varied from RD $10-20 each.

Table 46. Average tree heights during the first 3.5 years of a plantation of *Eucalyptus citriodora* in Santiago.

Date	Average height
Planted 4-6/84	(m)
Dec. 84	2.5
July 85	4.8
Apr. 86	7.6
Sept. 86	8.9 (harvest in progress)
Jan. 88	10.6 (after partial harvest)

In January 1988, less than four years after planting, about 25 percent of the trees had been cut. If each of these 5,000 trees were sold at RD $10, the gross income was RD $50,000. Although company income statements were not requested, it appears that the enterprise may have made a net profit of RD $45,000 or more and there is still a growing stand containing about 2/3 of the trees (Figure 35). Measurements in January 1988 indicated that the remaining stand averaged 10.6 m in height and 7 cm in diameter at breast height. There are also sprouts on at least half of the stumps of the cut trees (Figure 36). Thus, a small investment of planting on land that was virtually idle and unproductive yielded a net return of perhaps 1000% in 3.5 years and the investment remains highly productive without further investment.

This case is probably unusually favorable. The owner carefully studied the species and the site before planting. Because no one else had planted trees, there was a serious shortage of tobacco shed poles and few local sources.

Figure 35. Recently harvested 3.5 year old stand of Eucalyptus citriodora *in Santiago.*

Figure 36. Sprout from 10 month old stump of Eucalyptus citriodora *cut at age 3 years.*

Investment Case 2

Two *Leucaena leucocephala* plantations in Puerto Plata have proven to be economically profitable only three to four years after establishment by direct seeding. Ing. Eddy Brugal reported that his costs of site preparation, establishment, tending and harvesting were RD$5,630 per hectare or about RD$350 per tarea. This is higher than other projections for several reasons. First, it covers three years of operations including harvesting costs. Second, the very close spacing involved four to six times as many trees as 2 x 2 or 2.5 x 2.5 m spacings. The cost of seedlings was offset by direct seeding. Third, this was an experimental plantation that involved some "learning costs" that would be reduced in continuing plantation work. Fourth, this plantation received meticulous care and intensive management that might have contributed to its high productivity.

According to Mr. Brugal, forest plantations can be profitable if managed and marketed properly. Although his original plan was to produce only charcoal, the value of other products dictated a more diversified approach for impressive profits. The first cut of 70 tareas at the end of three years of growth was organized and sold on the following basis per tarea (629 m^2).

The 629 trees established on each tarea produced 500 merchantable trees. The 100 straightest trees were selected to make 25 foot poles. Another 100 trees were sold as 200 ten-foot posts. A third 100 trees were used to make 400 6-foot fence posts. The 200 remaining trees in each tarea were used to make charcoal. Table 47 shows the values.

Table 47. Products and income from 3 year old plantation of *Leucaena leucocephala* in Puerto Plata.

Product	No Trees	Units/ta	Price/unit (RD$)	Income/tarea (RD$)
Poles 25'	100	100	12.50	1,250
Posts 10'	100	200	5.00	1,000
Fence posts 6'	100	400	3.00	1,200
Charcoal	200	14 sacks	30.00	420
			Gross income	3,870
			Costs/tarea	354
			Net income	3,516

The net income is approximately ten times the direct cost investment. In this case, the land already belonged to the investor and was not being used. These figures do not consider inflation. Translated to dollars by the approximate exchange rate for each year, the net income was about US$665.00 per tarea by the author's calculations. This figure does not include net income from agricultural crops in the first one year nor calculations of interest on the original loan. They may be assumed to be about equal.

With further development of this plantation, other product outlets are available. Small sticks are sold for tomato stakes and firewood for bakeries. Larger trees of 4 years or more can be sawn and sold for boards of various sizes for construction, furniture, handles of implements and brooms, as well as to fabricate box springs. Mr. Brugal has contracts for these high value boards, to be delivered in 1989. The other products have risen in value such that, in 1988, construction posts, poles and fence posts are selling at one peso per linear foot, double that indicated in Table 47. This demonstrates that forest products can be rather good inflation fighters in a society without a good internal wood supply.

Economic Analyses for Dendroelectric Plants

Two major consulting reports have been prepared independently for the Corporación Dominicana de Electricidad. The first was a feasibility study for a dendrothermal plant at Cumayasa, between San Pedro de Macorés and La Romana (SERCITEC and C.T. Main, 1984). Much of this report was concerned with the analysis of soils and site productivity. The benefit cost analysis of wood as compared to coal and petroleum was favorable. The study envisioned a 50 megawat electrical generator from 7,500 ha planted to *Leucaena leucocephala* (50%), *Cassia siamea* (20%), *Albizia lebbek* (15%) and *Gliricidia sepium* (15%). Another 1,250 ha would be unusable or in roads and support.

The plantation would produce 123,750 tons of wood (50% moisture content) per year (16.5/ha) at a cost of 184 RD $48.80/ton (years 1-11), which would decline to RD $36.70 after year 11.

The 30 year projection, in constant pesos was:

Total cost =	RD $ 71,447,296	Discounted cost 5% =	RD $51,497,360
Total income =	143,781,412	Discounted income =	68,045,078

The discounted benefit/cost ratio was 1.32.

Likewise, the Pedernales proposal of the Corporación Dominicana de Electricidad had a positive economic projection. This dendroelectric plant of up to 3,000 kw in the semi-arid southwest, using native forest and a 2,400 ha plantation for the wood supply. The national economic yield for the whole project, based on production of electricity, was estimated at 13.2% per year by analysts of the Organization of American States and National Planning Office (Corporación Dominicana de Electricidad, 1986).

The Prospects

The findings presented in this chapter indicate that: 1) growing trees in plantations in the Dominican Republic is biologically promising and financially profitable and 2) the ecological complexity of the nation requires careful matching of site to species and silvicultural practice. An investor or financier would do well to pay for professional forestry guidance and supervision throughout the project, as well as a financial analysis and soils analysis before starting to reforest.

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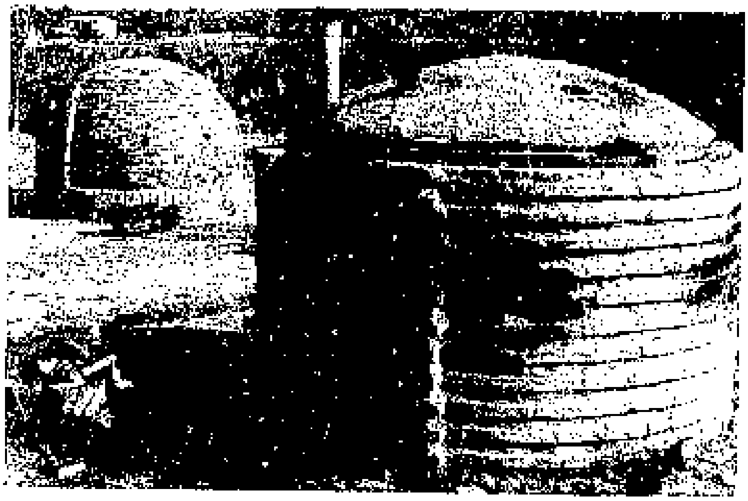
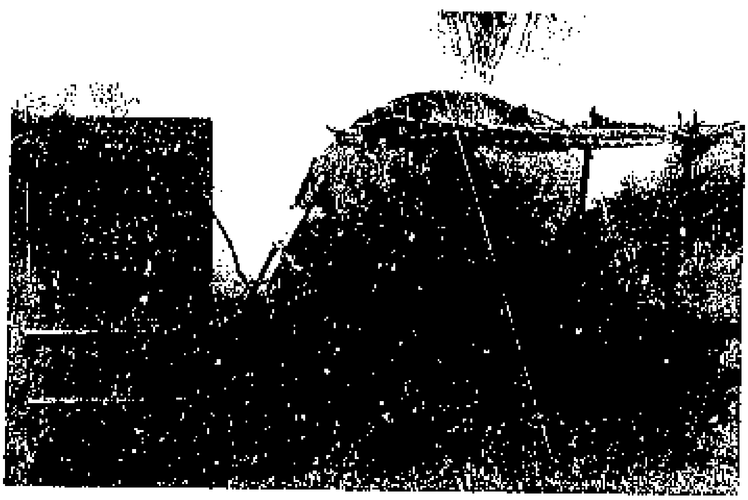
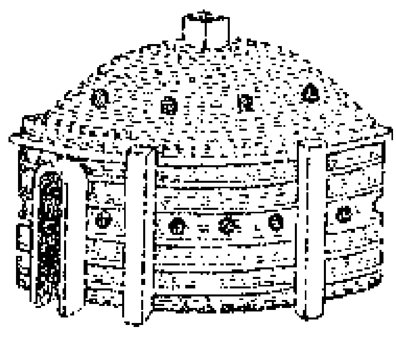




Charcoal Production



CHAPTER IV

CHARCOAL PRODUCTION

Introduction

Using trees and other biomass for domestic and industrial fuel is a traditional, economical and renewable procedure. In the Dominican Republic, bottled gas, kerosene and electricity (mostly generated from burning petroleum) now exist with charcoal and firewood as sources of energy. Of course, gasoline and diesel fuel dominate the transportation market, but wood or charcoal are used in many of the nation's homes and industries. Although bottled gas is used for cooking, approximately 65 percent of Dominican families, or more than 725,000 homes, use wood or charcoal to cook and heat (Morell, et al. 1987). Rural families commonly use firewood, as do bakeries, sugar mills, and other industries. Charcoal is used primarily by urban families for cooking (García, 1987).

Firewood consumption was estimated at 90-100,000 tons per year by industries in 1977 (Jennings and Ferreiras, 1979). Hartshorn, et al. (1981) estimated that 4.8 million sacks of charcoal were consumed each year, while the National Energy Policy Commission indicated consumption of 249,000 tons of charcoal in 1983, equaling 6.9 million sacks of 35 kg each (Morell, 1986). Thus, the total volume consumed in the form of fuelwood and charcoal amounts to 3,049 million cubic meters (Morell, 1986). If it is assumed that about 20 m^3 of wood are removed per hectare, this signifies the cutting of 9,588 ha (152,450 tareas) per year; this does not imply necessarily the total deforestation of these hectares, however.

In some of the more industrialized societies, the wood fuel alternative seems rather impractical on a large scale, primarily due to the costs of collection, the relatively low profit potential, and the relative inconvenience of handling (Bungay, 1981). Nevertheless, only about a century has passed since wood was the primary energy source. Conversion to coal and petroleum products has resulted in partial depletion of the non renewable reserves of these minerals so that their scarcity is now foreseeable. As prices of these fossil fuels rise, the use of wood may become more financially attractive, as was the case in the United States in the 1970's and early 1980's.

Fuelwood and Charcoal Technical Qualities

This section describes basic characteristics of firewood and charcoal as fuels. The parameters that are used to measure quality and efficiency of charcoal production are defined. Finally, results are presented of the research program studies of wood density, air drying rates of various species, and changes in the dimensions of wood as it is converted to charcoal.

Fuelwood Basics

Fire is the phenomenon produced when heat is applied to a combustible substance in the presence of air, elevating the temperature until in generates gases. The combination of gas with the oxygen of the air produces the energy necessary to allow a continuation of the process. Thus, to produce a fire, three elements are needed: fuel, heat and oxygen.

The process of combustion occurs in phases. In the first phase, the heat around the fuel raises the temperature of the fuel to something more than 100°C, which drives off water vapor. The temperature continues rising to 200°C, eliminating all the water and distilling the resins. The second phase is the combustion of the gases; the temperature is between 300 and 400°C and the components of the wood divide into flammable gases which burn with flames. The temperature continues rising to 600-1000°C. The burning gases emit heat which is more than sufficient to maintain the combustion. The color of the flames is blue. During this phase, the fire emits smoke formed by the burned gases, carbon dioxide, water vapor and particles of the fuel. The final phase is the combustion of carbon in the wood, leaving ash, which is mineral substances that will not burn (Baker, 1983).

The heat produced by the majority of woods is very similar, approximately 4700-4800 kcal/kg (8600 BTU/lb.) of dry wood. The quantity of heat derived from wood depends on the moisture content of the wood. The higher the moisture content, the greater is the heat energy needed to dry the wood and the less is the heat available for phases 2 and 3 of the combustion process. Therefore, there is an energy advantage to allow drying of recently cut wood before using it for fuel or for manufacturing charcoal.

The basic density or specific gravity of wood is the quantity of wood substance that exists in a specific volume of wood. Usually it is expressed in kilograms/cubic meter or grams/cubic centimeter. Low-density woods such as *Bursera simaruba* are usually passed by for firewood or charcoal because of the large volume needed to produce the heat equivalent to that in a smaller volume of a more dense species.

Charcoal Basics

Charcoal is produced by heating wood under conditions that carefully restrict the quantity of oxygen available for combustion. The process is often conducted in brick kilns or hermetic retorts, in chambers with varied gases or in ovens supplied with limited and controlled quantities of air. Heating to high temperatures separates the materials into gases, a mixture of tar and water, and a solid material, charcoal, that is 60-90 percent carbon. According to the U.S. Forest Service (1961), acceptable quality charcoal has 2-4% moisture content, 18-20% volatile substances, 1-4% ash, and 74-81% fixed carbon.

Traditional indicators of charcoal quality include a metallic ringing sound when it strikes a hard object and a smooth fracture of the piece as it breaks. Others include freedom from taste and odor and from undue soiling of an object that is rubbed against a fractured face (U.S. Forest Service, 1961).

The external phenomena observable during the process of charcoal production are divided into four different periods as a function of temperature and time (Trossero, 1978).

a. Drying: Water contained in the wood evaporates at temperatures between 105 and 108°C. Late in this period there may be generation of carbon dioxide.

b. Precarbonization: This is the time with temperatures between 180 and 280°C. During this period, some tar forms and several gases appear: carbon monoxide, methane, water vapor and carbon dioxide.

c. Self-carbonization: This phase begins at about 280°C and continues to 400°C. Complex chemical reactions occur in this time and there are exothermic reactions. Abundant gases form as well as most of the tar called pyroligneous acid.

d. Carbonization: Separation of the components continues in this period, with the concentration of carbon. This is a longer phase than the other periods; the time depends on the process and the qualities desired in the charcoal.

The yield of the different products and by-products is approximated for a ton of dry wood in Tables 48 and 49.

Table 48. Yield of products per ton of dry wood in charcoal manufacture.

Intermediate Products	Final Products		
100% Spirits, 5 gal.	Charcoal	600	lbs.
	"Wood" gas	5000	ft^3
Tar, no H_2O, 11 gal.	Methyl alcohol	3.0	gal.
	Methyl acetone	0.7	gal.
Acetic acid, 101 lbs.	Allyl alcohol	0.1	gal.
	Ketones	0.2	gal.
	Methyl acetate	1.0	gal.
	Soluble tar	22.0	gal.
	Pitch	66	lbs.
	Creosote oil	3.0	gal.
	Ethyl acetate	14.7	gal.
	Ethyl formate	1.3	gal.

Source: Baker, 1983.

Table 49. Composition of noncondensable "wood" gases produced in the charcoal manufacturing process.

Component	Percent of volume of dry gas
Hydrogen	2
Methane	17
Hydrocarbons	1
Carbon monoxide	23
Carbonic acid	38
Oxygen	3
Nitrogen	16

Source: Baker, 1983.

In general, wood is made up of about 50 percent carbon on a dry weight basis. Some portion of this carbon is lost during the process of converting wood to charcoal. Also, 50-84 percent of the energy of wood is lost in the conversion. For example, a hardwood tree may have 28,000 kilocalories in the wood, which converts to charcoal with 7,000 kilocalories, making a conversion efficiency of only 25 percent (Baker, 1983). Nevertheless, the lighter weight of charcoal produces transportation economies and the convenience of charcoal makes it an efficient fuel desired in many homes. It burns cleanly and produces high heat for its volume and weight, about 1.5 times more than wood. Good charcoal weighs about one-third that of wood and has about half of the volume, making it easy to transport and store. Charcoal is relatively easy to light and can burn uniformly, with little smoke and little ash. It is relatively easy for the housewife to break into the proper size for cooking. Charcoal does not rot and is not attached by insects or fungi, so may be stored for long periods.

Parameters of Production Quality The quality and efficiency of charcoal production are measured by several variables. Among them are: volume yield, weight yield, fixed carbon content and fixed carbon yield.

Although charcoal is sold on the market by volume in the Dominican Republic and the majority of other countries, volumetric yield measurements are very imprecise and should not be utilized for analytical studies. The imprecision comes from the variation in form of the sticks, the method of piling wood and charcoal, and from differences in specific gravity of different woods. For example, one stere of firewood (a pile 1 x 1 x 1 m) including sticks and air, can contain different volumes of solid wood. The measurements made in Brazil with *Eucalyptus* spp. have varied from 0.45 to 0.70 cubic meters of solid wood per stere, the first with twisted small sticks and the second with straight, large logs. The volume yield of charcoal is the ratio of the volume of wood used to the volume of charcoal produced.

Some Brazilian volumetric yields provide a basis for comparison (personal communication with Luiz Clairmont Gomes, short-term advisor to the project). Normally, the Florestal Acesita company achieves a volume yield of about two steres of piled eucalypt wood for every one cubic meter of charcoal. Experimentally, the company has produced ratios as low as 1.6:1. CETEC, a standards agency in Brazil, considers a 2:1 volume yield as feasible for plantations. From the native, twisted, small woods of the savanna, the normal volume yield is 3:1 to 4:1.

Another way to measure the productivity and efficiency of methods of converting wood to charcoal is to measure the gravimetric yield. It is expressed as a percentage and calculated by dividing the weight of merchantable charcoal that is produced by the dry weight of the wood placed in the kiln x 100.

The theoretical maximum gravimetric yield is 44.4%. Normal yields from brick kilns in Brazilian industry are 28-33 percent. In experimental conditions at the Universidade Federal de Viçosa, Minas Gerais, Brazil, the yields have been as high as 38 percent with *Eucalyptus* spp. in a small brick kiln (personal communication with Luiz Clairmont Gomes of UFV).

A key measure of quality and efficiency of yield is the percentage of fixed carbon in the final product (FC = wt. of charcoal - (volatiles + ash + water)). This is about equal for traditional earth kilns and brick kilns, unless the charcoal is poorly manufactured and contains considerable unburned wood. On the other hand, brick kilns are more efficient in gravimetric yield. They produce more charcoal for a given volume or mass of wood. Thus, the yield of fixed carbon = FC% x gravimetric yield. This is the measure of quality and efficiency that has the greatest significance.

Research Results

The charcoal production program involved research studies and practical developments related to the characteristics of native dry forest species and a few exotic species. The research included studies of the traditional and more modern methods of manufacturing charcoal. It also dealt with technical characteristics of firewood and charcoal as well as its marketing and use. Studies are described of specific gravity, air drying measurements, changes in the size of wood as it is converted to charcoal and finally, the parameters that are used to measure quality and efficiency of charcoal production.

Specific Gravity

Three studies of specific gravity were conducted in dry forest species (Betances, 1983; Almeida, Ferrer and Garib, 1984; Luciano, 1986). Variations within these species are quite common and are due to many factors including: age of the trees sampled, heredity, climatic conditions, land use or treatment and the sampling technique used. The wood density also varies more or less inversely with the height in the tree from which the sample was taken. Luciano (1986) took samples at ground level and one meter intervals up to 5 m. The average of these is reported in Table 50. The precision to three decimals is measurable, but the natural variation is so great that double decimal ranges are probably most practical (e.g., Guatapanal = 0.75-0.82, according to Almeida, Ferrer and Garib, 1984).

Table 50. Average specific gravity of wood of dry forest species.

Species	g/cm^3
Guatapanal *Caesalpinia coriaria*	0.835
Aroma *Acacia macracantha*	0.792
Quina *Exostema caribaeum*	0.792
Candelón *Acacia scleroxyla*	0.754
Cinazo *Pithecellobium circinale*	0.739
Cambrón *Prosopis juliflora*	0.576
Llvero *Coccoloba leoganensis*	0.673
Baitoa *Phyllostylon brasiliensis*	0.669
Brucón *Cassia emarginata*	0.576

Source: Adapted from Luciano, 1986.

Wood Drying

Air drying of wood used in manufacturing charcoal was recommended by Almeida (1984a). He made measurements of drying rates for five native species. Luciano and Rodríguez (1985) also studied the drying of five native species, including one in common with Almeida. Ramírez (1988) continued the study for 8-year old *Leucaena leucocephala* cut at ISA (Table 51). The wood was piled and not covered in the dry climates of Mao and Santiago. Although moisture content rose temporarily during rainy periods, there was a rapid drying to 15-20 percent within 90 days for seven of the ten species. Candelón, baitoa and guatapanal retained moisture more stubbornly, indicating that drying times should probably be in excess of three or four months. After five months drying Almeida (1984a) found that even guatapanal was below 20 percent and brucón, cinazo, guayabillo and quina were below 15 percent moisture content.

Charcoal producers normally dry the wood they cut, but without any uniform schedule. Luciano and Checo (1986) recorded a range of drying periods from 2 to 180 days. In the two cases of 120 and 180 days of drying, there were problems with the wood being infested with insects at the time of charcoal production. Most of the producers allowed wood to dry for periods from one week to two months.

Leucaena leucocephala K-8 wood dried at the rate of five percent every 15 days. Ramírez (1988) recommended a drying time of 30 to 45 days after cutting before using it for charcoal. For the native species, it appears that 90 days or more would be most efficient, as long as insects or fungi do not attack the logs.

Table 51. Air drying rates of various species of trees.

Species	Days of Drying				
	Start	30	45	60	90
	% Moisture Content				
Baitoa	51.6	43.1	39.8	37.7	33.8
Candelón	43.1	41.0	41.0	34.1	29.4
Cambrón	42.1	29.2	27.1	24.0	17.5
Aroma	41.6	34.7	29.2	26.0	19.2
Guatapanal-1	38.2	34.7	34.7	30.3	26.0
Guatapanal-2	--	32.6	--	32.6	27.4
Guayabillo*	--	42.7	--	28.7	15.0
Brucón	--	32.6	--	22.6	15.1
Cinazo	--	27.6	--	23.1	18.7
Quina	--	20.2	--	16.7	14.7
Leucaena	40.2	28.5	25.0	--	--

**Myrcianthes fragrans*

Sources: Almeida, 1984a; Luciano and Rodríguez, 1985; and Ramírez, 1988.

Dimensional Change During Conversion

Gomes (1986a,b), during a consulting visit to the program, noted that very small diameter wood was being placed in the traditional and brick kilns. One physical property of wood is its reduction in size when heated. Reduction in diameter is much greater than in length. Therefore, the concern was that very small sticks would not produce commercial charcoal but, instead, result in unusable fines.

Gomes (1986a,b) reported that in Brazil's steel industry, a small quantity of charcoal with diameters as low as 1.3 cm is accepted. The Florestal Acesita company tries to prevent fine material, using *Eucalyptus* spp. wood of 5.0 cm to 18.0 cm in diameter, the ideal being 15.0 cm. A technical research laboratory in Minas Gerais, Brasil, concluded that the ideal diameter would be 10 cm (Rezende, 1981). The program's resident advisor on charcoal research, José Mauro de Almeida, recommended that the silvicultural goal should be to produce logs (mid-tree) that averaged 10-15 cm in diameter.

After a marketing survey and muffle oven tests of dimensional changes, it was determined that the minimum commercial diameter of wood should be 2.7-3.0 cm. Maxfield (1985) selected 2.5 cm as the lowest usable diameter by asking workers in the Mao forest their opinions. He reported: "this minimum diameter is generally considered by the Dominican forestry personnel to be the smallest diameter used by the local people for firewood or for making charcoal." This reliance upon local opinion left some room for doubt and discussion, however. Therefore, observations and a survey were undertaken in Santiago charcoal markets, along with tests of the change in dimensions of the wood after conversion to charcoal.

A survey of housewives and charcoal sellers in Santiago indicated that the minimum diameter of charcoal that was generally acceptable was 2.0 cm (Ramírez, 1987b). Retailers reported that smaller materials were given away or thrown out. They tried to avoid these when buying their charcoal from the depositories.

In a laboratory test, volume changes that occurred in the wood during carbonization were recorded. The volume of dried wood of five native species was compared to the volume of charcoal produced in a muffle oven, following the schedule of 1 hour at 150°C, 2 hours at 250°C and then 2 hours at 350°C. The results indicate both radial and longitudinal shrinkage of pieces as indicated in Table 52 (Ramírez, 1987a).

Table 52. Shrinkage of native woods when manufactured into charcoal.

Species	Specific gravity (g/cm^3)	Diameter shrinkage (%)	Length shrinkage (%)	Volume shrinkage (%)
Guatapanal	0.84	22.5	14.7	48.2
Aroma	0.79	27.7	15.3	55.6
Cambrón	0.71	21.8	14.8	47.9
Baitoa	0.70	33.0	16.2	62.4
Uvero	0.65	22.1	15.8	48.8

Source: Ramírez, 1987a.

Although there were no significant differences in longitudinal shrinkage among species, baitoa and small sticks of aroma tended to shrink more than the other species. The diameter of the charcoal was 22-33 percent smaller than the wood's original dimension. This produced reductions in volume of 48-62 percent. Uvero, cambrón and guatapanal wood showed the least changes in dimension. All three of these species are highly favored by charcoal makers. There was no relationship between variations in wood density and the reduction in dimensions related to carbonization.

Based upon the consumer survey and the dimensional change study, it is recommended that the minimum commercial diameter of these native woods for charcoal should be 2.7-3.0 cm. The smaller material will end up as waste in the kiln or in the charcoal seller's sack.

Charcoal Manufacturing

A large portion of the fuelwood and charcoal currently produced in the country comes from the native Subtropical Dry Forest. Most of this area has been heavily logged and is now heavily grazed, causing deterioration in the composition and value of the vegetation. Increasingly, agricultural projects have cleared large areas of the most productive lands once covered by this spiny forest. Irrigation projects expand the potentially arable lowlands, taking them out of the diverse and complex forest ecosystem that has existed for centuries and converting them to production of monoculture crops.

Charcoal manufacturers are concentrated in the dry forests of the southwest and the northwest, with a smaller proportion in the eastern edge of the country. These forests represent the last accessible "open lands" of the nation covered by an exploitable forest resource. Although the government has recently given this area much attention, it was for many decades more or less ignored except by the poor who found here a means to produce a meager living. Charcoal manufacturers also have found several advantages in these regions. Although the trees are mostly twisted and often spiny, their wood is generally quite dense and produces very good yields of high quality charcoal. There is no competition for the wood, since the trunks are too small and crooked for sawmills and large furniture. The trees are used for a variety of foods, home medicines, teas, handcrafts and tools. Cuevas and Hernández (1987) discovered that rural residents near Mao named seven categories of different regular uses that they made of the trees of the native forest. In this area without doctors, the people used over 50 species of plants for medicinal purposes. They concluded that without the availability of these trees the already limited quality of life and ability to subsist in these zones would be seriously reduced.

In this arid climate, with little rain and long dry periods, charcoal operations are rather easy to carry out. The firewood dries rapidly, with minimal attack from insects and fungi. The main disadvantage is the relatively low yield available, averaging perhaps 2-5 m^3/ha/year.

<u>Traditional Harvesting and Manufacturing Methods</u> The "traditional" system for producing charcoal was apparently the only system used commercially in the Dominican Republic until 1987. In this system, a pile of wood is carefully laid on the ground, either with the logs placed vertically around a center pole (parado) or with the logs parallel to the ground in a neat stack (acostado). The pile is covered with green leaves, over which soil is laid deeply enough to eliminate entry of air. The research team observed this method of charcoal production throughout the country during the four years of field work. The "kilns" were operated by one to three people and were located at the most convenient sites, usually in the center of a small cut area in the forest or near places where wood residues could be gathered. The same method was used in the U.S. for several centuries.

Early in the program, a brick kiln was constructed at La Celestina, San José de las Matas, where pine residues were available from a sawmill operation. Charcoal was manufactured by traditional methods as well as in the kilns, although no yield figures were made available.

A systematic study of the traditional methods was conducted in the southwestern part of the country during two months of 1986 by Luciano and Checo (1986). This provided figures on yields, impacts on the forest, and socioeconomic phenomena. The most frequently observed temporary kilns were round with a diameter of two to three meters and a height of one to two meters, with the sticks stacked on end. A few entry points for air were left around the base and an aperture was made in the top for smoke. These openings were carefully controlled during the two to three day combustion-carbonization period. The fire was started through either the top hole or the base. During early stages, the smoke was dense and white. Eventually, the smoke turned blue; finally, it was practically transparent. At this stage, the carbonization was virtually complete and the apertures were closed. The kiln was left to cool for two or three days before opening and removing the charcoal. The total time of the operation was about one week, although variations occurred with the size of the pile and the moisture content of the wood.

Characteristics of Charcoal Operations Luciano and Checo (1986) observed that many charcoal producers in the southwest were living on the lower margin of human conditions, considering their houses and the shortage of resources to buy food. Charcoal making was often considered a last resort activity; they produced it when they had no money. For some individuals, making charcoal was their only economic option. In 27 charcoal production operations in three southwestern provinces, Luciano and Checo (1986) recorded data about the conditions (Table 53). Yields from the dry forest of firewood and charcoal were carefully measured. The firewood volume averaged 9.64 steres per tarea or 143 steres per hectare, with a range of 15 to 36 steres/ha. This was converted to charcoal at an average volume yield of 3.87 steres of wood/1 sacked cubic meter of charcoal, with a range in ratios of 2.65:1 to 6.77:1. The yield of charcoal was 2.49 m^3/tarea or 39.6 m^3/ha. This was a function of species mix, age of the stand and density of the stand. The firewood cutter typically harvested 3.29 st/day, ranging from 1.29 to 7.36 st/day. This, of course, was related to factors including skill of the cutter, density of the forest, size of the trees, abundance of thorns, and topography. Agricultural use of the cut over land was planned or in process on six (22%) of the harvest areas, half of these being on state lands.

The labor involved in producing a sack of charcoal was estimated at 0.70 man-days (Table 54). Charcoal sacks used in the southwest hold an average of 0.16 m^3, or 6.2 sacks/m^3. There is a wide range in the size of sacks, as some are home-made and others come from various agricultural operations.

Forest Conditions Luciano and Checo (1986) established 500 m^2 circular plots 50 m from the edge of the current harvest line in forests that were about to be cut. Each tree of 2.5 cm or more in dbh was measured in height, dbh, dkh (diameter knee height), species and number of trunks. Regenerating species were noted.

There was considerable variation among the sites. Some were in fairly dense forest (2000-4000 trees/ha) where few previous harvests had been made. Others were sparsely forested (120-400 trees/ha), where the current harvest was little more than scavenging the few remaining trees.

Average conditions meant little except as a general description of the forest. The average of the largest dbh of 16 sites was 13.7 cm while the average was 6.0 cm. The average height was 5.2 m, with the tallest trees at 7.6 m, ranging from 4.7-14.0 m. Average basal area was reported as 3.90 m^2/ha. This provides the picture of a sparse, short forest that in most places was already severely degraded and highly eroded. Luciano and Checo (1986) noted that the rivers were dry and some had disappeared; the flora and fauna had been drastically reduced and lowland cultivated soils were in process of salinization, according to interviews with charcoal producers and other residents.

Environmental Impacts from Traditional Methods Two studies directly evaluated the negative effects of charcoal production on the forest. These were coupled with observations of the dry forest in many stages of development and use. The impacts, beyond the simple removal of the wood, are several; some are direct and some are the consequence of the opening of the area to other uses.

Table 53. Characteristics of 27 charcoalers and charcoal operations in the southwestern provinces of Independencia, Pedernales and Bahoruca.

Characteristic or Condition	Number of Operators
Operator's economic activities	
Charcoal making	27
Agriculture	12
Other	4
Experience as charcoal producer	
0-2 years	3
3-10 years	12
11-20 years	4
Over 20 years	3
Landowner	14
Cutting site	
Private land	4
Public land	23
Distance traveled from home to charcoal operation	
0-2 km	13
3-6 km	6
7-10 km	8
Means of transport to site	
On foot	21
Burro or horse	3
Motorbike	2
Bicycle	1
Topography of cutting site	
Flat	14
Mountainous	11
Not recorded	2
Type of cut	
Clearcut	20
Selective	7

Source: Luciano and Checo, 1986.

Table 54. Labor person-days required to produce one sack and one cubic meter of charcoal using the traditional method.

Procedure	per sack	per m^3 charcoal	%
Wood cutting	0.22	1.34	31
Stacking, loading wood, moving	0.11	0.67	15
Forming "kiln"	0.06	0.35	8
Tending, covering "kiln"	0.05	0.34	8
Closing down, cooling and sacking charcoal	0.09	0.56	13
Inspecting, supervising	0.09	0.54	13
Other	0.08	0.53	12
	0.70	4.34	100

Source: Luciano and Checo, 1986.

Luciano and Checo (1986) recorded the changes in vegetation in the cut over areas. In the southwest, harvest was mostly by clearcut and only undesirable species (e.g., *Bursera simarouba*) were left.

After the cutting, the improvised earth kilns are made in the areas with the deepest soil. The round kiln locations become burned spots that are superheated and left covered with charcoal fines and ash. Erosion is a natural result, washing away the loosened, uncovered soil, especially when they are on slopes. Agriculture often accompanies and follows the charcoal manufacturing on the best soils. This contributes greatly to accelerated and sustained erosion, since the cropped areas are exposed soil most of the year. Grazing often accompanies or follows agriculture, even on the less-productive soils, resulting in compaction of soils, browsing of young trees and sprout regeneration, and increased erosion possibilities.

Any trees that manage to regrow are usually cut by a future charcoal harvest in 10-15 years. On the better sites, the public land may be "settled" by families that have no other resources at their command. They will probably move on as soon as the area is exhausted or when government officials require them to vacate the public land.

The net result, as judged by Luciano and Checo (1986) is that the forest structure of most of the southwest has been altered, with a degeneration in quality and quantity of species. The erosion and repeated cutting have caused the area to lose much of its present and future productivity. COENER personnel suggested that this area receive immediate government attention to establish forest plantations on cut over areas and to rationally and firmly manage the remaining dry forest so that the harvested areas can quickly regenerate. These suggestions are rational, possible, and of great urgency.

In Mao, the second study of former kiln sites showed serious long-term damage to soil productivity, even on flat land (Díaz and García, 1985). The natural regeneration on these circular sites is delayed for many years, although the forest surrounding them regenerates rapidly from sprouts and seeds. Since most kiln sites are used once or twice, the forest soon becomes dotted with barren circles about 6 meters in diameter.

Introduction and Comparison of Kilns One of the goals of the program was to test different alternatives to more efficient production of charcoal. By using less wood per unit of charcoal, there might be two positive effects. First, the existing forest resource could be used more conservatively. Secondly, the future volumes harvested from plantations could produce a more salable final product.

Traditional earth kilns were studied first. Vertical and horizontal piling techniques appeared to have no effect on final yields. A pit technique using the subsoil as a wall was tried at Mao. This was abandoned after three tries; the top collapsed and was very hard to tend. Workers had difficulty in removing clean charcoal from the pit.

Three types of brick kilns and two metal kilns were tried (FAO, 1983). The metal kilns became oxidized and perforated after a few carbonizations, rendering them inoperable without repair. The repair process under existing conditions required considerable time and patience in logistics, as well as in the welding and soldering.

Description of Kilns Traditional earth kilns are made of stacked wood (horizontal or vertical) covered with leaves and soil and ignited. They very in size. One horizontal kiln of 20 m length and 1.5 m height was observed. Others of 1 m in diameter are made of wood scraps for home use.

The Mark IV or Uganda or TPI metal kiln has one or two circular, braced sheet metal rings about 2.3 m in diameter and 0.75 m high plus a conical top. Wood is piled much as in the vertical (parado) earth kiln; then a second layer makes a cone. It is covered with the metal cone and ignited. Gas escapes from four chimneys. One of these kilns was built and used in Mao in 1982 trials by ISA. It developed a number of air holes. It was repaired by Plan Sierra and placed at La Celestina, where it was not possible to make it operate successfully. As the metal was heated, it developed more holes and carbonization was very irregular. The system apparently works in some areas of the world but was not considered as practical by the program personnel.

Six steel drum kilns (Figure 37) were built, tested, modified and then used by Rosado, Ramírez and Ferrer (1986) in comparison with other kilns. Probably due to design problems, there were many pieces of unburned wood residues after the carbonization. The yield of usable charcoal by weight was only about 12 percent. This would be higher if recoverable unburned wood were subtracted from the starting weight of the charge, but the process left many questions. It is unlikely that the cost and work of converting drum to backyard charcoal ovens would be accepted by campesinos if the traditional method produces a similar or better result. Therefore, the program did not recommend the steel drum burners.

Brick kilns were tried in various shapes and sizes (Rodríguez and Luciano, 1986). Brief descriptions and specifications of each follow.

> Half-orange or bee-hive type kiln (Figure 38) has no chimney. The entry of air and escape of gases is through 29 orifices, arranged in three rows, each of which can be closed with a brick. The form is hemispherical. The model used in Mao is 2.3 m in diameter and approximately 2 m in height. Its volume is 16 m^3.

Surface kiln (Figure 39) is considerably larger, with vertical cylindrical walls 1.8 m high and a domed top that adds another 1.8 m to the total height. One or more chimneys allow smoke to exhaust from the floor. The kiln used is 5.0 m in diameter. Its internal volume is 46 m^3. A small version of this was used for experimental purposes. It is the size adopted for research by the Federal University of Viçosa in Brazil.

Bank kiln (Figure 40) is dug into a slope, reducing the need for most of the side walls and therefore the costs of bricks and mortar. These were built at Mao and La Celestina as demonstrations, although the rock layers in the soil required a brick lining. On a farm near Mao, three operated successfully for at least two years. These kilns have 3 chimneys and six rear air entry holes. The body is cylindrical and the dome is semispherical. Dimensions are 4.0 m in diameter, 1.4 m high cylinder and another 1.2 m for the dome for a total height of 2.6 m. Its internal volume is 25 m^3.

A Missouri kiln was called for in the project plan. This is a large concrete kiln with metal doors and possibilities for economical recovery of by-products. This kiln was not constructed because its continuing use would have rapidly reduced the wood supply from the experimental forest at Mao. Perhaps when there are large plantations of several thousand hectares producing wood for charcoal, this type of kiln could be tested. It is completely out of scale to the present resource base.

Figure 37. Portable metal barrel kiln.

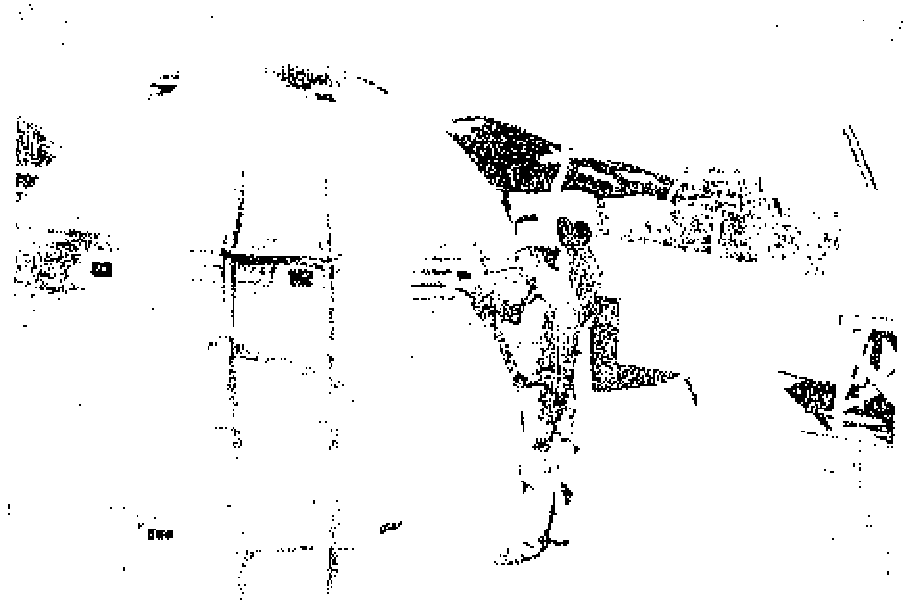


Figure 38. Half-orange or bee-hive type kiln.

Figure 39. Surface kiln.

Figure 40. Hank type brick kiln.

<u>Kiln Comparisons</u> Direct comparisons of kiln productivity were made in several studies. Almeida (1984b) reported gravimetric yields of four native species produced in both vertical (parado) and horizontal (acostado) traditional kilns in Mao (Table 55). The charcoal produced in 11 batches had an average gravimetric yield (kg charcoal/kg dry wood)of 27.8%. Cambrón had a greater yield than aroma.

Table 55. Gravimetric yield of charcoal (%) from traditional kilns in Mao for four native tree species.

	Wood Stacking Method		
Species	Vertical	Horizontal	Average
Aroma	25.4	24.2	24.6a
Guatapanal	27.7	27.8	27.8ab
Brucon	26.4	31.7	29.0ab
Cambrón	30.5	32.3	31.4b

Averages followed by the same letter are not significantly different from each other according to the Tukey test (p = .05). Source: Almeida, 1984b.

Another trial compared the two types of traditional kilns with two models of brick kilns (Rosado, Ramírez and Ferrer, 1986). Only baitoa (*Phyllostylon brasiliensis*) was used. Results indicated no differences between the two traditional kilns or between the two brick kilns (Table 56). However, the brick kilns were much more efficient than the earthen kilns. The brick kilns produced 1.57 times the charcoal (fixed carbon) as the traditional method. Thus, proper use of brick kilns could help reduce the pace of forest loss. Perhaps more relevantly, the plantation investor could get much more salable product from his wood by investing in the construction of brick kilns.

Table 56. Comparison of charcoal made with Baitoa (*Phyllostylon brasiliensis*) in four types of kilns.

Kiln type	Fixed C (%)	Gravimetric yield (%)	Fixed Carbon yield (%)
Traditional vertical	70.1a*	40.1a	28.1a
Traditional horizontal	68.6a	34.5a	23.6a
Bank/brick	72.4a	23.6b	16.8b
Half-orange	71.1a	22.4b	16.1b

*Averages in a column followed by the same letter are not significantly different at p =.05, by Duncan's multiple range test.
Source: Rosado, Ramírez and Ferrer, 1986.

Tests also were made using *Pinus occidentalis*, an unusual species for Dominican charcoal (Figure 41). These tests were in Plan Sierra, using an 11 m^3 beehive brick kiln and smaller traditional earthen kilns, all operated by experienced charcoal makers. The methodology of this study involved a) determining the moisture content of the firewood placed in the kilns from oven dried samples, b) the total and dry weight of the wood per charge, c) the weight of the charcoal produced, and d) the chemical analyses of the charcoal using technical standard ASTM D-1762/64.

Considering the averages of the trials in Table 57, Ferrer (1987) found the brick kilns to be 39 percent more efficient in weight yields than traditional kilns. The average yield in fixed carbon, the most relevant measure of efficiency, was 15.5% in earth kilns and 21.5% in the brick kiln. The quality of the charcoal, in terms of fixed carbon per unit weight was equal for both types of kilns, but the quantity of charcoal produced by the brick kiln was greater for the amount of wood used. Likewise, the amount of fixed carbon produced per stere of wood in earth kilns was only 72 percent of that in the brick kilns.

Figure 41. Loose structuring of kiln doors allows an escape valve for accumulated superheated gases which were most common when making charcoal from pine residues.

Table 57. Chemical and physical analyses of three charges of charcoal manufactured with *Pinus occidentalis* in earthen and brick kilns.

	Charge No. 1		2		3	
	Kiln Type					
Measurement	Brick	Earth	Brick	Earth	Brick	Earth
Physical Analysis						
Wood Moisture (%)	65.1	37.2	56.6	38.7	70.6	35.6
Dry wood weight (kg)	3038	1004	2810	993	2736	737
Charcoal weight (kg)	800	174	712	203	778	147
Weight yield (%)	26.3	17.3	25.3	20.4	28.4	19.9
Chemical Analysis						
Volatile materials (%)	16.3	17.4	3.9	20.6	28.8	17.9
Ash (%)	1.6	0.5	1.2	0.9	0.9	0.9
Fixed carbon (%)	82.0	82.1	89.9	78.6	70.2	81.2
Yield Fixed Carbon	21.6	14.2	22.8	16.1	20.0	16.2

Source: Ferrer, 1987.

Species Comparisons For many years there were rather rigid consumer preferences for charcoal made from certain tree species. Throughout the country, older people affirm that the best charcoal came from guayacán (*Guaiacum officinale*). But this is rather rare in commercial sizes today. Today the market accepts whatever charcoal is available, although older housewives often comment on the declining quality.

Among the preferred species for higher quality charcoal, according to interviews and opinions of charcoal makers, are cambrón (*Prosopis juliflora*), guatapanal (*Caesalpinia coriaria*), aroma (*Acacia macracantha*), candelón (*Acacia scleroxyla*) and uvero (*Coccoloba uvcifera*).

Baitoa (*Phyllostylon brasiliensis*) has traditionally been avoided for charcoal, but its abundance in the Mao forest made it one of the few single species that could be studied repeatedly in the large kilns. *Eucalyptus camaldulensis* could well become a major source of charcoal in the next ten years. Its qualities were compared with those of baitoa, guatapanal and a mixture of dry forest species (Table 58) (Rodríguez, 1987).

Table 58. Volume and gravimetric yields in manufacturing charcoal from various species in bank kilns.

Species	Dry wt. of wood	Wt. of charcoal	Gravim. yield	Vol. of wood	Bulk Vol. charcoal	Volume yield
	(kg)	(kg)	(%)	(st)	(m^3)	(st:m^3)
Baitoa (3 samples)	6091	1976	32.4	19.45	7.59	2.56:1
Guatapanal (1 sample)	7182	2116	29.5	19.27	7.50	2.56:1
Eucalyptus (2 samples)	6529	1702	26.1	21.00	7.57	2.77:1
Mixed dry forest spp (5 samples)	4751	1635	34.4	19.13	7.27	2.63:1

Source: Adapted from Rodríguez, 1987

__Costs of Charcoal Manufacture__ Cost estimates of charcoal producing operations were made by Rodríguez (1987). The estimates may be higher than an industrial operation, since they include figures from the experimental forest where measurement and development of technique were as important as productivity.

Tree cutting was done by machete and axe. Average productivity of workers in cutting and piling was 4.6 steres/man/day, with a range from 2.8-6.2. The workers observed were on a private property and on the Mao Experimental Forest. All were paid by the day.

A case study of costs was modeled after a 3-kiln operation on a private clearcutting of a dry forest parcel (Table 59). Rodríguez (1987) determined that one kiln operating at normal capacity could use 840 steres of wood per year; thus the operation's capacity is 2,520 st/yr. The yield was about 2.66 steres of firewood for each cubic meter of charcoal.

The distribution of the costs by percentage among the various operations is a good starting point for future cost-saving efforts. For example, it may be possible to save internal transport costs by trying different conveyances and systems of paying for movement of wood from cutting site to kiln. Loading and unloading the kiln may be made more efficient by developing carefully defined routines or paying by piecework.

Table 59. Annual costs of charcoal operation that has three brick kilns and uses 2,520 steres of wood/year.

Operation	Productivity person-days	Costs/year for 3 kilns RD $	% of cost
Cut and pile	0.222/stere	5,594.00	13.5
Loading (hand)	0.059/stere	1,486.80	3.6
Transport to kilns		10,164.00	24.4
Unloading	0.019/stere	478.80	1.2
Piling near kilns	0.033/stere	831.60	2.0
Loading kilns	0.200/stere	5,040.00	12.1
Unloading and sacking charcoal	$0.533/m^3$	5,047.50	12.1
Supervisor and operator		6,600.00	15.9
Sacks for charcoal ($6.2/m^3$ charcoal)		2,935.50	7.1
Tools		502.00	1.2
Kilns 3 @ RD$ 2000, deprec. 5 years		1,872.00	4.5
Storage shed		1,020.00	2.4
		41,572.20	100.0

Source: Derived from Rodriguez, 1987. Cost figures in 1986 pesos.

Wood and Charcoal Marketing

Community Consumption Studies To provide estimates of the importance of firewood and charcoal in communities around the Dominican Republic, researchers from ISA, COENER and students doing thesis work all contributed to the still incomplete knowledge of consumption patterns. These types of studies allow foresters and investors to estimate the demand for plantation products, thus guiding decisions about the size of area to be planted, the annual yields to seek and some idea of the market prices. They also provide an interesting description of the importance of wood in Dominican homes and businesses (Figure 42).

Figure 42. A popular use of fuelwood and charcoal is in roasting pigs, turkeys and chickens, as well as use in pizzerias, bakeries and street side food enterprises.

A study by COENER and other government agencies, summarized only in press releases in 1986, indicated that two-thirds of Dominican homes utilized dendroenergy for cooking, partially or completely. The proportion varies according to regions (Table 60). This percentage projects to 758,400 families. In the cities, 59 percent use charcoal or wood, while in the rural zones, 86 percent use principally the energy supplied by trees. These figures are similar to those reported earlier by Jennings and Ferreiras (1979).

Table 60. Percent of families that use fuelwood and charcoal, 1986.

Region	Percent
National District	33
Cibao (north)	74
Southeast	77
Southwest	90
TOTAL	67

In rural areas, other earlier studies had indicated the great reliance on wood as almost the only source of domestic energy. For example, Reynoso (1983) studied about 100 homes in the watershed of the Rio Cuevas, a low income rural area in the province of Azua. Wood was collected, usually at no monetary cost, from public and private lands by virtually all the rural residents. In the towns, there were some purchasers of firewood, including the bakeries and restaurants, and some users of charcoal, but many also sought their wood personally. The deforestation of the watershed was of concern to many of these people because of the increasing shortage of firewood and the necessity to walk long distances to collect it.

Similar concerns were expressed by residents of Mao, Amina, Los Quemados, Inoa, La Vega, and Neiba. The large markets in Santo Domingo and Santiago for charcoal have also faced shortages; more severe problems are to come, as the commercial operations encounter the Haitian border and the end of the natural resource.

Bueno, Checo and Reynoso (1985) studied the residents of Inoa, a mountain community that has long depended upon the adjacent mixed pine and hardwood forests for both fuel and its furniture industry. The forest resource had almost disappeared from the vicinity of this community. Its citizens walked an average of 2.2 kilometers for wood, which is still virtually the only major cooking fuel used in the community. The 16% of the residents that used gas also used charcoal or fuelwood.

By using interval sampling, this study accurately measured the use of firewood and charcoal during a given period of time. Of the families that used firewood, alone or in combination with charcoal or gas, the average consumption was 4.3 "loads" of 133 lbs. per month, or about a quarter of a ton of wood per month per family. Using a conversion of 0.67 metric tons of wood per cubic meter of firewood, the authors estimated that each of the sampled wood-using families was consuming 0.38 m^3 per month. Assuming that the sample is representative of the community of 242 families, the firewood consumption of Inoa is 81 m^3 per month or 972 m^3 per year.

Charcoal was produced by the families that consumed it, except in one case. Thirty-six percent of the families used charcoal, at a rate that utilized about 0.362 m^3 of wood per month. Projected to the community, the yearly demand for charcoal was nearly 384 m^3.

Using these consumption estimates, the community of Inoa consumes about 1356 m^3 of firewood per year just for cooking. On the generally low-productivity soils of the area, this would imply a forest plantation of slightly less than 40 ha producing 10 m^3/ha/year. However, using growth rates of the native forest, Bueno, Checo and Reynoso (1985) estimated that Inoa residents were harvesting the equivalent of the growth of more than 340 ha of forest. Families had increasing difficulty collecting firewood. A lack of wood was the main reason given for not using charcoal.

Charcoal Marketing Models Until the first commercial plantation began to produce charcoal in late 1987, charcoal marketing involved a rather complex process. It was briefly described by Jennings and Ferreiras (1979) and by Hartshorn et al. (1981). The COENER and the wood fuel research program personnel observed several of those processes leading to a detailed study in one region of the country (Luciano and Checo, 1986). They focused primarily on the manufacture of charcoal. A study of consumers and retailing was conducted in Santiago by Ramírez (1987b).

A simple model and its variations were described by Jiménez and Ceballos (1986), based upon their study of the Mao region and interviews with researchers of the southwest. In this model (Figure 43), at least five types of economic units are involved in the preparation and sale of charcoal. A sixth is ignored because there has been no economic investment or sale in the forest production. The native forest is considered as a gift, since the owner (government) has no mechanism or plan for charging for the wood that is illegally cut from public lands (Figure 44 and 45). In a plantation system, the forest owner would be expecting compensation for the timber.

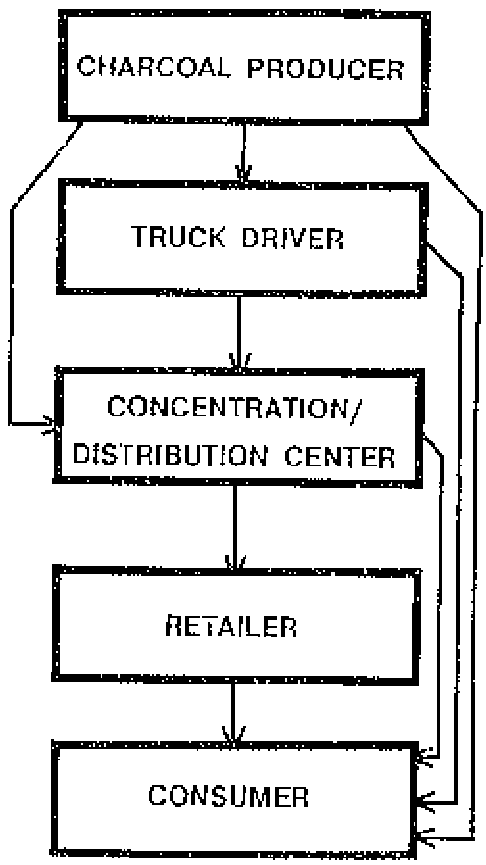


Figure 43. Charcoal marketing model. From Jiménez and Ceballos, 1986.

The normal channel for the vast majority of the charcoal produced in the southwest, northwest and eastern parts of the country follows the central path of Figure 43. The charcoal producer is an individual or small group that uses traditional earthen "kilns" in a forest that has usually been previously cut several times. They put the charcoal in sacks, set it beside the nearest road, even if it is a rough track. A charcoal truck driver runs a route seeking charcoal, buying it on the spot from the producers.

The trucker then delivers the full sacks to a concentration yard or wholesale distribution center, where he receives a payment. In some cases, the trucker may be traveling several hundred kilometers and there will be a considerable markup on the charcoal, over the price paid at the point of production. The wholesale depository typically sells bulk quantities to door-to-door vendors, many of whom travel by donkey or mule with two large fiber sacks over the saddle. These vendors then travel 1-7 km to sell on a daily or semi-daily basis to regular customers. Consumers in Santiago normally buy one or two No. 10 cans of charcoal per day.

Figure 44. Charcoal traveling from producer to retailer near El Valle, 1988.

Some consumers buy directly from the distribution center, normally in the large sacks that hold 20-40 kg (average of 62 lbs.) of charcoal. In some rural areas, the consumer may also buy directly from a truck driver friend or from the producer who is working nearby. Near Mao, some producers bring their charcoal to town on a string of burros, selling door to door to consumers or taking the product to a wholesale depository. In the case of a few small wholesale dealers, they take a pickup truck into the country to buy directly from producers. Often, these are neighborhood deposits that sell a large share of their charcoal directly to final consumers. Because their supplies may be irregular, retail sellers cannot depend upon regular availability of the fuel.

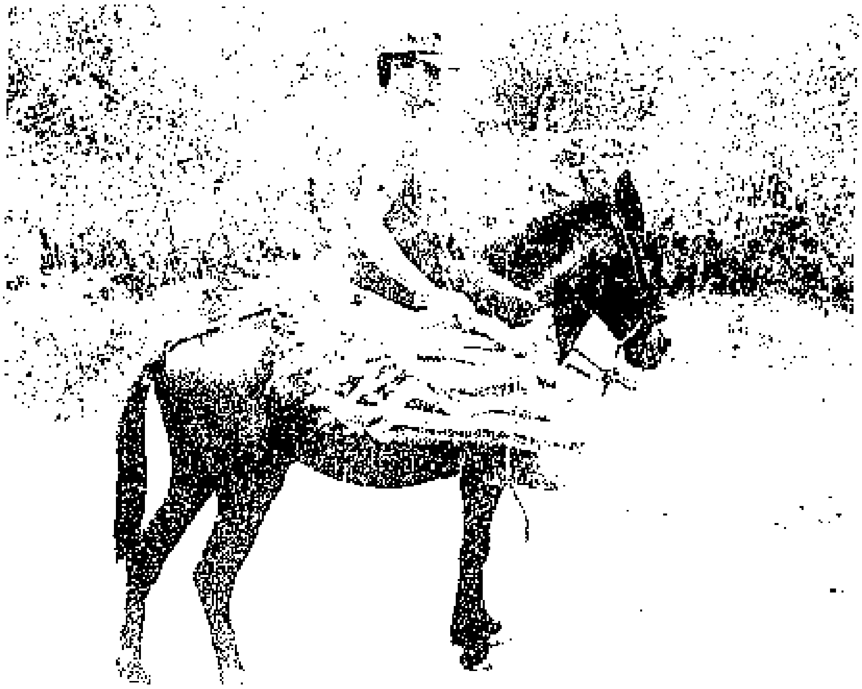


Figure 45. Family firewood collection and transportation in Mao.

Thus, the producer has three options. Most sales are to truck drivers, some are to wholesalers and some are to consumers. Truck drivers have one main option of selling to a distribution center and a minor option of selling to consumers directly. A wholesaler typically buys what is brought to his deposit. In large cities, this is nearly always by truck, often from long distances. In smaller communities such as Mao, much charcoal is delivered by the producers. These concentration centers may sell either to consumers or to retailers.

It was noted by Luciano and Checo (1986) as well as by Jiménez and Ceballos (1986) that the producer has little or no influence over the price he receives for his product. The truck driver sets the price and there is little negotiating, leaving the producer the alternative of delivering the product himself or not producing more charcoal. The fact that charcoal becomes scarce in the country during the agricultural planting and harvesting seasons suggests that, when presented with the option, many producers prefer other activities.

The ambulatory retailers of charcoal in Santiago (Ramírez, 1987b) paid RD$22-35 per sack and sold by the can at RD$31.50-40 per sack. They sold two to four sacks per day at a margin of RD$5.50-9.50 per sack. The wholesale dealers at the large deposit points reported paying RD$18-30 per sack during November-December 1986, selling at the RD$22-35 indicated above, for a gross profit of RD$4-5 per sack. They sell 75-350 sacks per day. In Santiago, there are also some small retail sales businesses that handle charcoal. Their costs and returns are about equal to those of the ambulatory sellers.

At least one plantation owner has developed a simplified marketing system for some of his charcoal. The charcoal, produced in brick kilns from Leucaena, is bagged in small plastic sacks with a brand name (Figure 46). These are sold directly to local supermarkets. The consumer pays a competitive price and takes home a convenient, clean package. The producer of the charcoal benefits from a higher gross return on the charcoal. If the plantation is located close to the market, low transportation costs contribute to a high net income for the charcoal producer. The use of a brand name reintroduces product differentiation into the market, giving the consumer some indicator of charcoal quality.

Figure 46. Prepackaged bag of charcoal at Brugal plantation, Puerto Plata.

<u>Conversion to Other Fuels</u> The possibility of conversion of the population to gas or electricity for cooking is a costly alternative that may become necessary if forests aren't planted soon. Many other countries have followed this change, almost irreversibly. Their populations apparently prefer the cleanliness and greater convenience of non-wood fuels. Nevertheless, in the Dominican Republic, two factors limit the facility of conversion. The cost and the lack of availability of alternatives.

The cost of a stove and bottle for gas is relatively expensive, inhibiting many families from the initial purchase. Electric stoves are used very little in the country, even among the wealthy. Electricity is costly. Even though charcoal may sometimes cost more than gas or the current electric charge, the prices of the apparatus make these alternatives inaccessible. The availability of gas and electricity is irregular and limited, as well. Frequently, the Dominican Petroleum Refinery finds it difficult to satisfy the existing demand of the population for LP gas. Many rural residences (more than half) do not yet have access to electricity and perhaps a third of the urban residences with electricity are connected illegally and very precariously.

The legal impediment to tree cutting and the legal complications involved with commercialization of charcoal, in effect since 1967 and reintensified in the autumn of 1986, emphasizes the need for a prompt solution to the disappearance of the basic resources that are sources of wood energy.

The solution that seems most logical and beneficial to the country is expanded forest production with the key purpose of producing fuelwood and charcoal. This strategy presents economic advantages to the country in that the fuel is produced within its borders and by its citizens, thus preventing the loss of foreign exchange that would be necessary with conversion to electricity and petroleum. Also, wood is a renewable resource with many other uses that can spur economic development.

The immediate problem is that the native forests are being exhausted rapidly, causing progressive increases in the price of wood based energy. There is urgent necessity to plant trees on a large scale on productive soils to reach adequate production levels to prevent a very costly fuel substitution process.

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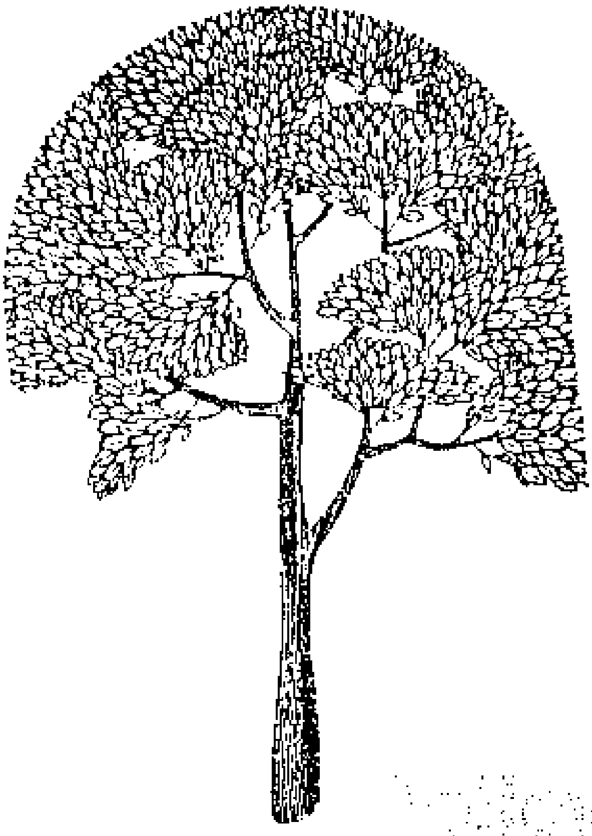

Policy Recommendations and [illegible]

CHAPTER V

POLICY

Plantations are a key to rational forestry and land use in the Dominican Republic. Wise management of the native dry forest and productive plantations for fuel, small wood materials, and sawlogs are vital to the nation's economic progress. The lack of forest plantations and rational native forest management is a major limiting factor and will continue to be a stumbling block until addressed seriously and systematically.

The majority of the Dominican Republic should be covered with forest according to land use assessments by the Organization of American States in the 1960's (Hartshorn et al., 1981). In other words, much of the nation does not have the natural capability to sustain uses other than forests over the long run. The fact that these capabilities have been violated by short-term farming, pasturing, and other uses has resulted in major deterioration of much of the nation's land. Its future productivity is in serious question, for forest production and for many other uses. The present shortage of wood and expanding demand for wood products, crops, and livestock, coupled with a lack of constructive and integrated effort to protect the land, suggests that the problems will become much worse before improvements take effect.

In noting the severe deterioration in most of the nation's watersheds, an international consulting group (Hartshorn et al., 1981), drew the following conclusions:

> Watershed degradation is a national catastrophe posing grave threats to costly development projects. Irrigation systems, hydroelectric dams, and aqueducts are rapidly losing functional capacity due to massive silitation, poor water quality and changes in stream- flow regimes.

Their prediction for the future was pessimistic in 1981 and there may be only a slight indication that there is more reason to be optimistic as the end of the decade approaches:

> Given the serious and pervasive deterioration of watersheds, the institutional conflicts and unwillingness to address the problem in an integrated effort, and the increasing human pressure for land, one can only conclude that Dominican watersheds will continue to deteriorate in the near future...converting a renewable natural resource to a non-renewable or increasingly costly resource (Hartshorn et al., 1981).

Many Dominican and foreign experts have used similarly strong words to emphasize the gravity of the Dominican forestry situation. Perhaps emphasis on the positive economic opportunities in forestry will be productive of future change. There is a strong possibility of improving the situation. It requires some rather simple actions and policies. Whether or not there is the will to implement these actions and policies is the key question, one which these writers cannot answer but can only indicate the urgency of quick action and the great benefits to the entire nation and individual landowners who have the vision and courage to plant trees.

Forestry Solutions for Economic Development

A long-term forestry program can produce rapid, positive, industry-stimulating results. Politicians can have long-term impacts on the nation, proving their vision, patriotism, and statesmanship by promoting effective forestry solutions that will live long beyond their few years on the political stage. These solutions can be achieved at very little cost to the nation and they should produce enormous, long-lasting and renewable benefits.

The development of a vigorous forestry sector in this nation is a key to sustained economic development. The process of economic growth is now paralyzed, in large part because of the lack of forest resources and partly because of the degradation of other economic resources that deforestation has produced. The insidious by-products of nearly 500 years of decimation of the forests include: erosion and sedimentation that are clogging hydroelectric and irrigation reservoirs, uneven and unregulated water supply, dependency on imported energy, dependency on imported wood products, and economic despair in deforested rural areas.

Payoffs from the development of forestry can be very high in the Dominican Republic. The Wood Fuel Development Program has shown that growth rates are very fast and that under proper management forestry investments are likely to be lucrative. A realistic, cost-effective forest resource program requires a serious commitment and will necessarily involve institutional development, sustained support of forestry research, and some patience with the concept that productive forests require follow-up after the trees are planted.

The logic of the solutions through forestry includes these basic postulates:

- The forest, rationally managed, provides a major source of energy that is renewable, easily accessible, marketable and productive of employment. Without this source of energy, which is disappearing very rapidly, the country will have to import more petroleum, thus worsening the balance of payments.

- An expanded forest resource can provide raw material for many new industries that would employ people in rural areas, provide needed wood and wood-based products that are now imported at great expense to the nation.

- The forest protects and regulates watersheds, providing a more even, abundant supply of water. Without forest cover, the expensive reservoirs are filling with the eroded soil from the watershed that supplies the artificial lakes. The water used for irrigation becomes very irregular without the steady release that occurs under forests. Thus, many rivers in the Dominican Republic have become dry during the periods when irrigation water is most needed and dangerously overflowing during the rainy seasons.

- The forest holds and enriches soils. Where the forest is stripped, the soil soon erodes, leaving poverty and little hope for recovery of soil productivity.

During the course of this project, a national reforestation plan was prepared by the ISA faculty (Morell et al., 1987). It suggested goals for gaining self-sufficiency in various sectors of the forest economy as follows:

1. Charcoal and industrial fuelwood: Plant 29,200 hectares per year for seven years. This totals nearly 205,000 ha (3,250,000 tareas).

2. "Campesino" fuelwood and agroforestry: Plant another 10,000 hectares per year for seven years, generally in small parcels. The total area in small scattered plots would be 70,000 ha (1,113,000 tareas).

3. Sawn wood: Plant about 2,500 hectares of pine and other woods each year. Eventually 37,000 ha (588,300 tareas) are needed for a sustained supply to meet current needs.

The total area required to meet these objectives is 312,000 ha (almost 5 million tareas). With these plantation programs and protection of the native forests, the country could become self-sufficient in wood. Since wood use expands on a per capita basis with economic development, the base for future consumption, new industry, and even export industries would also be present. There is no danger of an excess. In the tropics, deforestation is at least ten times the rate of reforestation and many tropical countries are still importing much of their wood needs.

Likewise, there is no danger of pre-empting agriculture or grazing. There is plenty of room for better agriculture, more productive animal produc..ion and a completely self-supplied wood industry (except for certain specialty products or trade wood). The 312,000 hectares required for plantations only amounts to six to seven percent of the national land area. Much more than this should be planted just for watershed protection.

There is an urgent need to continue to improve agricultural productivity in the Dominican Republic. Crop production and livestock production methods can be improved so that small farmers can more efficiently supply their own needs and participate more actively in the market. The efficiency of agriculture directly affects the future of forestry. They need to develop together. Good forestry requires better agriculture and sustained agriculture in this country requires good management of the watersheds.

Government Forest Policy Goals

Based upon the speeches and action of three presidents and other influential citizens as well as various studies and reports, the nation's forest policy of the Dominican Republic seems to include the following intentions (Knudson, 1987):

1. Maintain the national parks as natural preserves, allowing restoration of the ecosystem wherever it has been disturbed by agriculture.

2. Increase the forest resource base through plantations of fast growing trees which will supply energy needs, thus reducing the drain of foreign exchange for petroleum.

3. Increase plantations of sawlog species, thus providing a resource for now-idle sawmills and furniture factories.

4. Protect the key watersheds with forests to reduce siltation of reservoirs, to assure steady supplies of water for irrigation, to reduce sedimentation of rivers for better industrial and shipping use and to maintain quality and quantity flow for domestic and industrial water supplies.

5. Protect native fauna and increase its habitat.

Little has been said about managing native dry forest resources. Recent decre..s have established zones for charcoal production under national management, but the areas are so few and the management methods or enforcement so undefined that there is a need for further development of this policy to make it effective.

Prospects for Forestry Development

Achieving a major turnaround in forestry in the Dominican Republic involves social, economic and political questions. The mix of factors makes the prognosis rather complex. There are several levels of analysis and distinctly different outlooks. The technical, industrial, individual investor/farmer, and the national welfare levels are examined below.

1. Technical level. Tremendous potential and a need for technical expertise in selecting sites and tree species summarize the forestry opportunities. Results of this program indicate that there are sites where certain tree species grow well, providing large volumes of wood in short periods. On the other hand, there are some soils that need intensive care to produce a reasonable stand of trees. In terms of technical forestry, then, the country has many favorable conditions and many challenging ones for resolving its serious forestry dilemma. There are large areas of idle lands which could easily be converted to forestry, benefiting the landowners as well as society.

2. Industrial level. Frustration and uncertainty about forest policy are two words that may best describe the current attitudes of many entrepreneurs. For all practical purposes, forestry as an industry is outlawed. Although forestry laws apparently allow the harvest of plantation trees, the interpretation by authorities in the field has not been clear. Insecurity about what the government will or will not allow in 5 to 10 years makes many people reluctant to invest. There are considerable industrial opportunities on large tracts of land. The de-emphasis on sugar production has led several firms to consider plans for afforesting the poorer sugar cane lands. This seems to be a commendable policy that should be pursued with vigor. Assertiveness on the part of industries will probably produce government compliance with reasonable plans.

3. Individual investor or farmer level. Dominican landowners can be enthusiastic about forestry when they feel assured (certified or otherwise) that the government will allow them to cut and sell the trees that they manage. If this big roadblock of political uncertainty were clarified for plantations, there would probably be considerable planting. This is a pervasive problem and major consideration for most landowners.

   Many people will plant trees without government loans or incentiv..., some are already doing it. They do not want the delays, expensive trips to Santo Domingo and the paper-work that is required. These people who plant without government "help" are those who should receive the first permission to harvest what they plant. There should be no need for a person to have to seek (or pay for) a permit to cut products from a plantation.

   To halt deforestation, the market for fuelwood and charcoal must be saturated from some source other than the native forest. The only feasible and quick (7-10 years) substitute for the native forest is a massive, positive reforestation program. It seems that the only practical way to get that going is through many private landowners. Since much of the private land is owned by a small number of wealthy people, large individual efforts can be mounted.

   The triggers to get reforestation started seem to be: 1) technical information, partly supplied by this project, 2) technical assistance, supplied by newly trained forestry consultants and young professional foresters, and 3) government assurance that tree planters can freely cut the trees that they planted and receive the income they may derive from their sale.

4. National welfare level. Up to 1984, the best estimate is that the Dominican Republic had reforested 6,177 hectares in total. There are indications that between 1962 and 1980 there were 379,000 hectares deforested, despite the accumulation of legal prohibitions, published and broadcast appeals to protect the forests and the numerous authorities who publicly declared, appealed and ordered a halt to cutting (Santa Cruz, 1988).

> The forest policy of the Dominican Republic has been focused on protection as a way to conserve the natural resources. FAO investigators (Santa Cruz, 1988) identified over 400 documents going back to 1844 that attempt to control forest exploitation.
>
> Despite this, the loss of forest and degradation of mountain lands has been a long-term process, perhaps accelerating in recent years with the increase of population pressure. Warnings, prohibitions and spurts of rigid enforcement have undoubtedly had an effect in slowing the disappearance of the forest, but even the national parks are not immune to the pressing need for fuelwood and the demand for wood from clandestine industry.

The government role in these plantations may be two-fold: first to support continuing research and demonstration and second to sponsor or supervise public incentives for some kinds of plantations. The major effort of the public agencies should be in establishing large public "national forests," reforesting watersheds and other degraded areas, social forestry, management of fauna habitat and parks, and integrated watershed planning and management (Santa Cruz, 1988).

Such a program will give positive emphasis to economic development through forestry, in contrast to the past policy of trying to halt economic use. The protective function must continue in order to keep existing forests intact. The important next step is to provide for a basis for economic growth--to turn the forest from something that is prohibited or "not ours" in the minds of the campesinos into something that can offer a rational source of wood and other products to support a growing economy.

The development potential of the forestry sector is great. Because most economic activity using locally-grown wood is clandestine, there are no data on its importance. Santa Cruz (1988) pointed out that the contribution from the forestry sector to the Gross National Product probably cannot be more than 10 per cent of its potential.

A national forest policy is needed that is comprehensive. The FAO Tropical Forestry Action Plan contains five elements that are good guidelines of the areas that urgently need attention (Santa Cruz, 1988):

1. Silviculture and land use that includes the rehabilitation of mountain watersheds and semi-arid lowlands.
2. Industrial development using raw material from the forest.
3. Fuelwood and charcoal.
4. Conservation of tropical forest ecosystems.
5. Development of institutional capacity.

Positive, constructive action seems to deserve an opportunity for a trial. It is the impression of the research team, including the Dominican and foreign advisors, that the private sector is able and willing to establish plantations.

<u>Nine Recommendations for Forestry Progress</u>

1. Remove the great political impediment to private reforestation. Official sources should make it very clear that one can harvest that which is planted.

2. Continue to protect the native forests, requiring rational management and preventing the entry of cattle. It is not recommended that existing native forests be cut off in order to replace them with plantations.

3. Intensify the protection of national parks and preserved zones. Prevent agriculture, grazing and timber harvesting for any purpose within these preserves. At the same time, invest in good internal trails, protection of the resources and systems of interpreting the natural values to the public.

4. Support forestry research on a sustained basis, with continuous financing through private and public means. Such scientific investigation is vital to the success and efficiency of economic progress in the forestry sector.

5. Plant 30 to 50 per cent of the sugar lands of Monte Llano and Amistad to forest species. Evaluate the possibilities of reforesting parts of other sugar plantations to help diversify the economy, employ sugar workers, and reduce the foreign debt. Many of these plantations have an excellent, simple transportation and operational infrastructure that would be ideal for forest plantations and industry.

6. Put idle or underused rural lands into forest production. The owners should plant one-third or more in trees; if they fail to act, the government could contract to plant and cultivate trees for two years to form the plantations and then bill the landowner.

7. Officially establish and put in operation a system of national or provincial forests (not the same as national parks) on certain public lands where a major objective would be production of wood for harvest and sale. The lands can be managed to produce various other benefits as well, including watershed protection, recreation, and wildlife habitat.

8. Simplify and streamline the processes by which a landowner can get approval for reforestation projects. The simplest procedure is to permit all to establish and use plantations, without permission, just as with agricultural crops.

9. Create energy plantations as part of each agrarian reform settlement, managed rigorously by a technician and forestry consultant.

Research Development and Policy

One of this program's key aspirations was to develop institutional and individual capacity to do research in forestry at ISA. ISA and COENER personnel have demonstrated their capability for conducting and disseminating research, given adequate resources and steady technical reference advice and encouragement. However, as the project terminates, the ISA program is diminishing in the number of technical and field personnel, to the point of endangering the continuing existence of the plantations, permanent plots and kilns.

The importance of financial continuity in support of research is evident throughout the world. It is much more urgent in developing countries with few research traditions and a limited number of capable researchers. Long-term projects that have long-term objectives are certainly vital to sustained economic development.

At the present time, ISA has not developed mechanisms to financially support its new forestry research effort. Unless there is continuing funding from some source, the important future measurements of current research trials may not be made. At best, it will be difficult to get results into print. At worst, the plantations will have inadequate protection from livestock, wood-cutters and even settlers. It is recommended that ISA give increasing emphasis to the methods of developing long-range research funding. Faculty should be encouraged to seek research support from the U.S., the Dominican Republic Government, and other sources.

The growth of forest plantations and industry will necessarily be accompanied by a growing need for research, some of which must be supported by government.

It is recommended that the ISA research program be sustained by international and national funding for the next 5 years. During that time, private funding sources should be developed to partially replace the public support. Most of these private funds can come from Dominican industries and landowners, as well as ISA-generated income. After 1992, ISA could have a forestry research program that is funded 30% from public sector funds (for basic studies), 35% from specific grants, and 35% from funds generated within the private sector on a sustained basis.

One model recommended is the "Sociedad de Investigaciones Forestales" in Viçosa, Minas Gerais, Brasil, in which industries pay monthly fees to support a research office and continuing studies at the university.

Another source of support can be self-generated from consulting by an "ISA Forestry Company;" a plan prepared in 1986 for the school would provide strong incentives to faculty members to help support the institution through consulting, while increasing their own personal income.

The Mao Experimental Forest and ISA Campus Forests

The 900-1,000 hectare property in Mao was donated to ISA for forestry research and seems most appropriate for continuing this activity. The plantations and native dry forests at La Herradura ISA campus also offer excellent opportunities for productive research and demonstration on a long-term basis. It offers ISA an unusual opportunity for long-term scientific contributions to the international community, especially the tropics. The dry subtropical forest is one of the least studied and managed of the world's vegetation zones. It has suffered centuries of abuse; its decline in Africa, Haiti and Brazil is associated with considerable human suffering. This forest resource is very important to the Dominican Republic and its future potential for fuelwood production.

The two properties, well-operated and supported, can bring ISA international stature and the collaboration of scientists from many nations. It also is an outstanding natural environment that should be protected from grazing, poaching and unplanned human intervention. The management of the property will also bring its share of distress and headaches.

To minimize conflict and to maximize the properties values, it is recommended that:

1. The dominant purpose of the Mao Experimental Forest and ISA campus forest be for research in the areas of native forest management, ecology, wood utilization studies and plantations.

2. The Mao property should be zoned, as has been done under the program. At least 25% of the property should be kept as a natural reserve; not to be cut, thinned or otherwise manipulated. Studies of natural stand dynamics are vital here.

3. Throughout the properties, the native fauna should be protected rigorously at all times. The native flora and soils should be carefully protected and perpetuated in most of the property.

4. In some areas of the native forest, careful studies of thinning, vine control and different harvesting-regeneration methods should be continued.

5. Expand plantation experiments somewhat, including enrichment plantings in some areas and pure plantations on droughty soils using native species and exotics such as leucaena and neem.

6. Establish control plots of native forest to compare its productivity with plantations and silvicultural management of the forest.

7. Recognize and provide for long-term research. The dry conditions suggest that 20-25 years will be required before complete responses to today's activities will be known. This requires excellent record-keeping, constant publication of progress reports and measurements, good financing, and consistent supportive administration.

8. Encourage the visits and collaboration of scientists and students to the property. Their enthusiasm and attachment to the area may help to protect it in times of crisis and will give ISA-Forestry greater public recognition. Tour groups and bird-watchers might be charged a fee for guided tours and special use of the Mao property. These visitors will express opinions about how to best manage the area. ISA can consider and evaluate the opinions, using those that are most appropriate.

9. The idea that the experimental forests should be self- supporting is probably not realistic, although the property will surely be able to generate some income. Admission fees for tourists, production and sale of charcoal, honey, and various wood products or novelties can bring in several thousand pesos per year, especially starting in 1992. However, research work should be funded from other sources to be adequate.

10. The properties should not be converted to agriculture, grazing, baseball fields, schools, housing or club use. Their great value is as the only properties in the dry forest zone that are managed for trees and for collecting reliable data about them. There is already a multitude of lands where agriculture and grazing could be studied. Any attempts to turn part or all of it into agricultural experiments, production or housing sites, for whatever apparently strong reason, should be rigorously resisted by the ISA leaders. The investment already made in forestry research and the lack of similar alternative areas makes these experimental forests precious for ISA and for the nation. One major requirement is that the area be actively used and not allowed to just sit--a lack of activity is often the key argument in conversion to less valuable or more mercenary purposes.

A strategy is needed for focusing research on the needs of private investors. The research is applied, offering guidelines for individual landowners who will be planting trees. The private focus gives importance to the cost and return data as well as keeping the research very practical. The focus on the private sector is for various reasons:

- Private landowners control most of the productive land in the country, large areas of which are underutilized.

- Private investment is assumed to be quicker and more flexible than public investment in adopting the ideas and making investments, once the feasibility of plantations is known.

- Private enterprise is likely to quickly fund further research when their investments will be benefited, thus speeding the development of technical forestry knowledge and a high level of forest management practice at a relatively low cost to the public.

- With diversified private investment controlling the resource base, it should be easier and more efficient to establish marketing mechanisms and new forest industries.

Poor farmers on unproductive, eroded soils create social problems, increase national dependency on foreign resources, worsening the balance of payments and restricting the opportunities for economic growth. This is not in the interests of either the Dominican Republic its trading partners. This research program has shown that reforestation is one practical way to stimulate ecological improvement and economic development. Private investors in the Dominican Republic can make very good profits on forestry activities. They can help the nation supply its energy needs and cut its wood trade imbalance. Adjusted policies can remove impediments to economic development and diversification through forestry, with its many direct and indirect benefits to the Dominican land and people.

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PROJECT SUMMARY

ADMINISTRATIVE REPORT

In June 1983, the Department of Forestry and Natural Resources and International Programs in Agriculture initiated advisory work on the Wood Fuel Development Program for the Dominican Republic. The assistance part of the five year project was originally funded for a two year period. Subsequent no-cost extensions and amendments continued the collaboration to August 22, 1988.

The project was sponsored by the Government of the Dominican Republic through the Comisión Nacional de Política Energética (COENER) and USAID (AID Contract No. 517-0144-C-00-399-00). Personnel from COENER and the Instituto Superior de Agricultura (ISA) conducted the research with technical advice from faculty at Purdue University and the Federal University of Viçosa in Brazil.

The project was organized to focus on four main objectives: Basic studies, tree research, wood conversion, and training and institutional development. The project scope was expanded from a concentration on plantation establishment on arid sites to include plantation establishment on semi-humid sites as well as management of the remaining native dry forests. Specific objectives were to:

1) Develop and conduct a research program to select tree species with potential for use in fuelwood and charcoal plantations and to develop management techniques.
2) Conduct research on native forest management.
3) Conduct research on conversion of wood to charcoal.
4) Provide advisory service to Dominican scientists in forestry and wood conversion research.
5) Provide in-country technical training.
6) Provide short- and long-term technical and academic training abroad.

A large number of individuals were involved with the various aspects of the project. Franklin Reynoso, a faculty member in Forest Resources at the Instituto Superior de Agricultura in Santiago, was the Program Administrator. Victor Montero, with COENER, served much of the time as Project Coordinator. Professor Douglas M. Knudson from Purdue University was the Resident Advisor for 3.8 years from June 26, 1983, to April 30, 1987. He lived in Santiago and was provided an office at ISA. José Mauro de Almeida from the Federal University of Viçosa in Brazil also was a Resident Advisor for one year from November 1, 1983, to November 1984. He worked with charcoal production and research.

Technical coordination and backstopping for the project was maintained on the Purdue University campus during the life of the project by Professor William R. Chaney. Administrative and logistic support was provided by the Office of International Programs in Agriculture under the directorship of Dr. D. Woods Thomas. Ms. Sharon Waldo and Mrs. Katy Ibrahim served as Administrative Assistants for the project. Other administrative staff responsible for project activities were Dr. James L. Collom, Associate Director, IPIA, and Ann Oyer and Lorraine Fleetham, Foreign Student Coordinators. In-country administrative support was provided by the USAID Mission in Santo Domingo. The Project Officer for most of the life of the project was William H. Smith, assisted by Ing. Leo Pérez Minaya. The consistent support and administrative flexibility of these two gentlemen and Larry Armstrong was essential to the success of the program.

In addition to the two resident advisors, fourteen short-term advisors from Purdue University and the Federal University of Viçosa spent 13.75 person months (P/M) in the Dominican Republic to assist with various aspects of the research program. These individuals, their area of expertise and time devoted to the program are given below.

Short-term Advisors	P/M
1) William W. McFee, Forest Soils, October, 1983.	0.5
2) George R. Parker, Forest Ecology, October, 1983.	0.5
3) Phillip E. Pope, Plantations and Nurseries, February, 1984.	0.5
4) William R. Chaney, Physiology and Silviculture, February, 1984, 1985; March, 1987; January, 1988.	2.25
5) James G. Yoho, Forest Economics, March, 1984.	0.5
6) Arno Brune (Brazil), Tree Improvement, July, 1984.	1.0
7) Antonio Bartolmeu do Vale (Brazil), Native Forest Management, August-September, 1984.	1.0
8) Mason C. Carter, General Forestry, September, 1984.	0.5
9) James L. Collom, Administration and Forestry, September, 1984.	0.5
10) Harvey A. Holt, Herbicides and Weed Control, February, 1985 and July, 1985.	1.0
11) Luiz Clairmont de Lima Gomes (Brazil), April-May, 1985.	1.5
12) Carl H. Noller, Animal Production and Forage, July-August, 1985.	0.75
13) Harry G. Gibson, Timber Harvesting and Computer Systems for Forestry, July-August, 1986.	1.5
14) Douglas M. Knudson, Silviculture, January, 1988 and June, 1988.	1.75

Technical and professional research work was provided to the project by several people who are listed below. All of these individuals spent one month or more working on the project. Most spent one to four years. They were associated with COENER or ISA, the German Technical Service (DED), or the Peace Corps. The list does not include more than 100 laborers who worked diligently to install, weed and maintain the experiments in Mao, Santiago and other sites throughout the Country.

<u>COENER and ISA based personnel:</u>

Beato Abréu
Margarita Betances de Fernández
Elías Camacho
Humberto Checo
Darío Collado
M. Teresa Disla
Pedro A. Ferrer
Manuel Finke
Alfredo Garib
José Rigoberto García
Moraima Hernández
José Miguel Hernández
Pedro Jorge
Ramón Capois King
Loweski Luciano
José Mercedes U.
Víctor Montero M.
Merilio Morell
José Antonio Núñez
Franklin Ortíz
César A. Ramírez
Franklin A. Reynoso
Alberto Rodríguez L.
Víctor Rodríguez
José Rosado
Adolfo Serrata
Nicolás Thén
Mamerto Valerio
Juan Villanueva

German Technical Service (DED) collaborators:

Wolfgang Arand
Helmut Dotzauer
Hans Jochim Roesel

U.S. Peace Corps Volunteers:

Timothy Fleury
David Lowery
Robert Nelson
Mark Powell
Eric Prosnier
Robert Pryor
Mark Sorensen
Richard Trostel

A large number of students from ISA and other universities in the Dominican Republic as well as other countries conducted studies and prepared theses or special reports directly related to the program's research objectives. They were each assisted by members of the technical field staff. The students and their affiliation are listed below.

Instituto Superior de Agricultura

Rafael Abréu P.
Margarita D. Betances
Manuel Bonilla F.
Santiago W. Bueno L.
Elías R. Camacho R.
Eduardo Cipión
Carmen D. Cuevas N.
Francisco N. Diloné
Manuel Finke H.
Ruffa A. Gómez
Heidi P. González
Manlio Danilo Hernández H.
A. R. Lavandier
Mario A. Méndez P.
Julio César Morrobel
Salvador Pérez
Wilfredo Polanco R.
Ramón J. R. Rodríguez
Antonio Santana
T. M. Silverio
Luis R. Tejada D.
Jorge Vargas Fulcar
Fausto Álvarez S.
Juan M. Bonilla
R. A. Bonilla
Juan F. Burgos
Humberto Checo
Bienvenida Cuevas
José de la Cruz R.
M. Teresa Disla P.
Teresa Gil V.
Epifanio González
Moraima Hernández
Porfirio Lantigua
Francisco Matos
Antonio A. Moquete
Marcelino Nazario Ozoria
César A. Ramírez
José Rosado V.
Adolfo Serrata
José F. Tavárez M.
Daniel Uribe
Jacobo Valerio Z.
José M. Vidal M.

Universidad Católica Madre y Maestra:

Ingrid Ceballos
Rose Jiménez

Universidad Nordestana:

David Darío Díaz
Flerida Angeles García

Ohio State University:

D. Gregg Maxfield

Purdue University:

Andrew Gillespie
William Minter

Wageningen Agricultural University, Netherlands:

Herman Uit de Bosch
Ramun Kho
Marianne van Paassen
Asse Seubring
Vincent Sewalt
Michiel Smits
Ernst-Paul Zambon

The following people and organizations generously collaborated on this project by providing land, labor, and/or materials for the installation of experiments throughout the Dominican Republic. Some of the planting sites provided were very carefully managed and still remain as demonstrations of the successes and difficulties encountered in the project.

INASCA, Ramón Crouch and Luis Crouch, El Valle.
Hacienda La Mercedes, José Ramón Hernández, Monte Plata.
Cementos Nacionales, San Pedro de Macorís.
Secretaría del Estado de Agricultura, La Vega.
Escuela Agronómica Salesiana, La Vega.
Lucía Lantigua, Muñoz, Puerto Plata.
Federico Finke, Manaclar, Puerto Plata.
Eddy Brugal, Puerto Plata.
CIMPA/Assoc. para el Desarrollo, Playa Grande & Santiago.
Plan Sierra, Proyecto La Celestina, S. José de las Matas.
Carlos Andrickson/SEA, Jánico.
Valentín Castillo, Los Montones Arriba.
Escuela de Sucro, Juanillo, La Altagracia.
Instituto Agrario Dominicano, Azua.
Escuela Nacional Forestal, Jarabacoa.
Franco y Rivas, Santiago.
Sra. Ana María Antuña, Jacagua, Santiago.
Asociación de Mujeres, La Cejita, Jánico.
Sra. Antonia Rodríguez, Monción.
Sra. Margarita Guzman de Torres, Santiago.
Leónidas Estévez, Santiago.

Both short- and long-term training were important parts of the project. Short-term training included both in-country and foreign seminars, workshops, and field trips. About 20 Dominican foresters and engineers were involved in travel study to forestry operations and meetings in the United States, Brazil, Haiti, Puerto Rico, Mexico, Sweden, Denmark, and Argentina.

Long-term academic training to increase research capabilities involved three individuals who received scholarships through the project. One has completed her degree and is currently working in the Department of Forest Resources at ISA. The others are under contract to return to the faculty at ISA. The people involved and their programs of study are as follows.

Margarita Betances de Fernández, M.S. Universidad de los Andes, Mérida, Venezuela. Silviculture and Ecology.

Manuel Finke, M.S. Universidade Federal de Viçosa, Minas Gerais, Brazil. Forest Measurements.

Pedro E. Jorge, Ph.D. Purdue University, West Lafayette, Indiana. Forest Pathology.

Long-term academic training also was provided for two other students through a loan to the Dominican government from AID, administered through LASPAU. They too are expected to fill faculty positions at ISA upon completion of their degrees. These students are:

Guillermo Fulcar, M.S. Pennsylvania State University, University Park, Pennsylvania. Watershed Management.

Moraima Hernández de Martínez, M.S. Purdue University, West Lafayette, Indiana. Forest Soils.

Two other recent graduates of ISA are on other M.S. programs:

Julio Morrobel, M.S. CATIE, Costa Rica. Agroforestry.

Daniel Uribe, M.S. North Carolina State University, Raleigh, North Carolina. Tree Improvement.

Purdue University is deeply grateful to the USAID Mission in Santo Domingo, the Comisión Nacional de Política Energética, the Instituto Superior de Agricultura, and the people of the Dominican Republic for the opportunity to participate in this project. The successes and accomplishments in this program were possible because of their cooperation, support and enthusiasm.

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