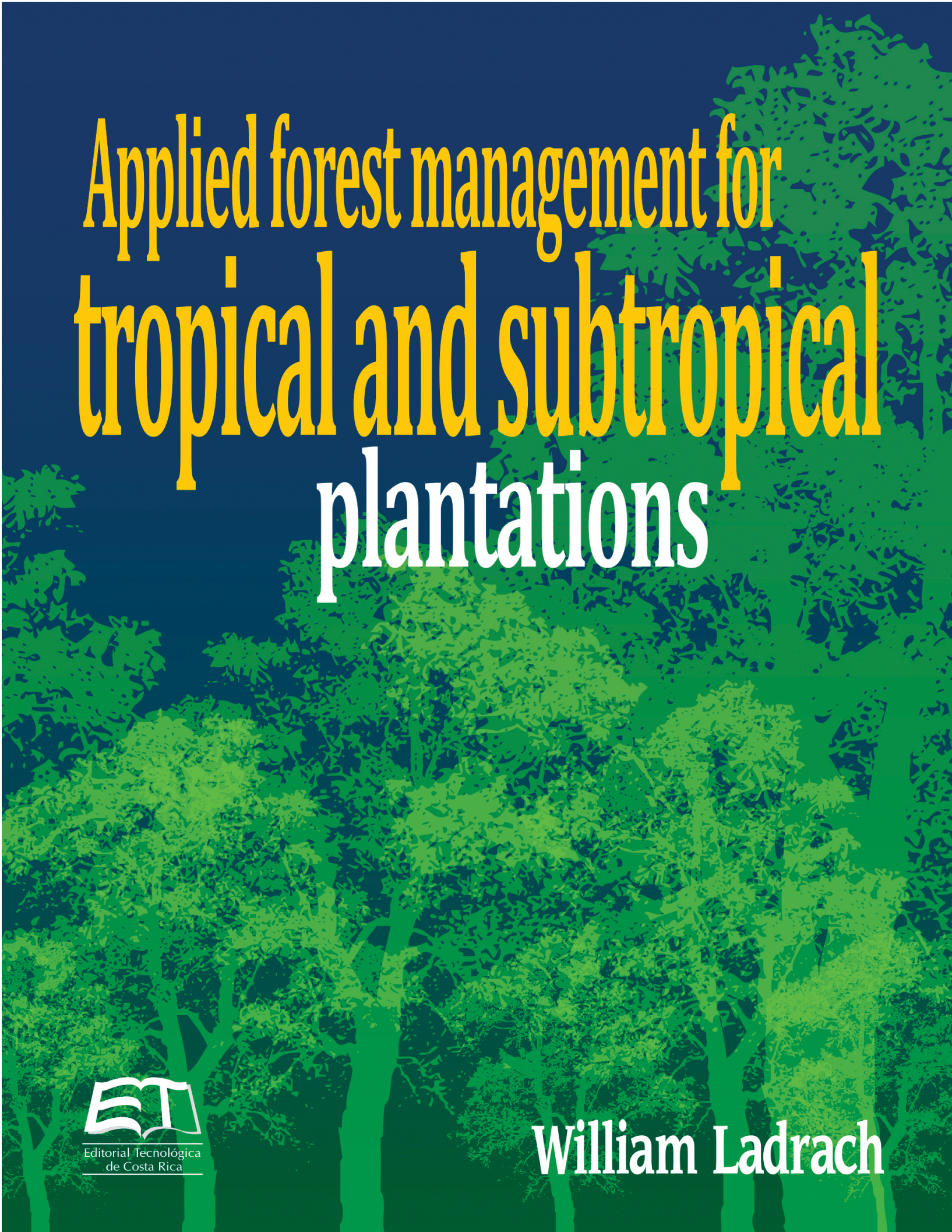
Applied forest management for tropical and subtropical plantations



William Ladrach

Editorial Tecnológica de Costa Rica

Manejo práctico de plantaciones forestales en el trópico y subtrópico

William Ladrach

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Dedication

Millán Gutiérrez V.,
1930–1997,
Pioneer in Tree Improvement in Colombia



Millán Gutiérrez teaching a group of students how to make a graft on a cypress tree.

In 1957, Millán Gutiérrez was one of the first graduates of the Forestry School of the National University of Colombia, at the Medellin campus. He continued his post-graduate studies at Michigan State University with the help of the Point Four Program of USAID. He returned to Colombia in 1959 and was contracted by Celulosa y Papel de Colombia, S.A., where he began work harvesting wood in the humid tropical rainforest along the Pacific Coastal Plain. In 1968, he participated in the beginning of a reforestation project in the Andean Region with Cartón de Colombia, S.A. In 1973, seeing the importance of forest genetics, Cartón de Colombia, S.A. invited Dr. Bruce Zobel, geneticist and professor of North Carolina State University, to be an advisor in this field and to participate in what was to become a collaboration that lasted many years and helped to promote forest research, particularly tree improvement of forest plantations.

Gutiérrez continued working in the field of genetics and forest research during the rest of his career. He was recognized among Colombian professionals as an authority in tree improvement. He gave numerous presentations on this subject to technicians, students and to the general public. He was a person liked by all who came to know him due to his cheerful personality, his ample knowledge and his desire to educate all who requested his help. For me, it was a pleasure to have had the opportunity to

work with this gentleman, colleague and friend. I will always remember him with respect and admiration.

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I wish to thank the following persons for their valuable help, collaboration and support; many gave of their valuable time to review part or all of the draft. Les Whitmore reviewed the initial draft and made many suggestions for improving the presentation. Victor Giraldo made many valuable suggestions which completed the document. I would also like to thank many others that reviewed the text and contributed to improving its content, clarity and form: Daniel Maradei (Argentina), Edgard Campinhos (Brazil), Fernando Berrío, Harry Hutchings, Billy López and Dr. Gonzalo de las Salas (Colombia), Professors Roger Moya, Freddy Muñoz, Cynthia Salas, Gustavo Torres and Braulio Vilchez (Costa Rica), Robert Hutchings (Switzerland), Dr. William Dvorak, Dr. Luís Fernando Osorio, Juan Luís López and Astrid Delgado (United States), Gonzalo Arellano and Prof. Carlos Contreras (Venezuela). Mrs. Gladys López Ladrach was of great help in reviewing my Spanish and making necessary changes to provide for a more fluid text. I also want to recognize the valuable collaboration and support of Professor Freddy Rojas of the Costa Rican Technological Institute, who was instrumental in the publication of this book.

There are many photos, most taken by the author during consulting visits. They are used to demonstrate and emphasize the points presented in the text. I wish to thank the many companies and institutions that allowed me to take photos of their field operations. Many companies have since modified or changed their names due to mergers, have been taken over by other companies or have simply changed their operational direction over the years. Besides, many operational practices have been modified and some of the included photos show practices that have been changed since they were taken. For these reasons, I decided that it was best not to indicate the exact origin of each photo, which could represent some activity that a particular company no longer practices. However, I would like to mention several of the companies where the majority of the photos used in the book were taken: Pizano, S.A./Monterrey Forestal Ltda., Grupo Smurfit Kappa de Colombia and Venezuela, P.T. Sumalindo Lestari Jaya, Pulsar/Desarrollo Forestal S.A. de C.V., Aracruz Celulose, S. A., and CVG Proforca.

Presentation

Global demand for forest products is increasing daily. This implies an incremental pressure on tropical and subtropical forests to supply wood products. Natural forests continue to supply wood, although their capacity is decreasing steadily. We are depending more and more on forest plantations to satisfy industrial needs for solid wood as well as pulpwood.

Fortunately, the warm climates have an enormous potential to produce wood fiber when the production is based on applied science. By selecting the appropriate species for given sites and the use of the principles of silviculture and genetic improvement, tree plantations can often produce more than 50 m3/ha/year. Because of their capacity for rapid growth, the tropical and subtropical regions have a great advantage over the temperate regions.

William Ladrach has dedicated more than 40 years to the research and management of forest plantations in various parts of the world, principally in Central and South America. This book, “Applied Forest Management for Tropical and Subtropical Plantations, provides a guide to future forest production. It is a guide to applied forestry and covers subjects from viewpoints of the biological, ecological, economic and industrial sciences.

This work is of great value to foresters, students, industrial managers, researchers and others who work in equatorial countries. It will have a strong and positive impact on the establishment of tree plantations during the coming decades.

Only by practicing intensive management in forest plantations can we expect to satisfy the demand for forest products in a rational manner and without destroying natural ecosystems. We can supply wood and satisfy the human needs for forest raw materials by maintaining natural forests that are healthy and productive, along with well managed tree plantations.

J. L. WHITMORE
President
International Society of Tropical Foresters

Preface

There are many aspects to the theme of reforestation, from agroforestry in small plots to tree breeding and industrial planting for wood products, as well as non-wood forest products such as palm oil or latex, protection of the natural flora and fauna, as well as maintenance of watersheds for water resources and soil protection against erosion, among others. Due to the magnitude of this topic, the focus of the current work is limited to the specific theme of reforestation for wood production in commercial plantations. The purpose of the book is to present applied management principles to managers and administrators for forestry-based companies, to forestry students and to forest technicians working in the field. Multiple aspects of forest management are presented, from seed production to the delivery of wood in the woodyards of the buyers. The information contained in this work is, in large part, obtained from the personal experience of the author as employee, teacher, researcher and forestry consultant. The book presents simple alternatives that can be applied to facilitate the work inherent in plantation management. There are multiple diagrams of tools, instruments, equipment and machines that can be produced or made locally, with the help of local mechanics, instead of having to import them from other countries. Silviculture and management techniques are presented that have been developed through trial and experience, and which help to make for efficient management of plantations for wood production.

In 2005, there were 139 million hectares of forest plantations distributed in Asia (47%), Europe (20%), North and Central America (13%), Africa (9%), South America (8%), and Oceania (3%) (FAO, 2005). Between 2000 and 2005 there was an increase of 12.8 million hectares, equivalent to 9%. During this period, Asia had 72% of this increase, followed by Europe (8%), North and Central America (7%), South America (6%), Africa (4%) and Oceania (3%).

Within the data presented by the FAO for existing forest plantations are included plantations for non-wood products, such as latex, palm oil, coconuts, tannin, pharmaceutical products, cosmetics and others. During the past decade, there has been a marked increase in the establishment of palm oil plantations, especially in Southeast Asia. The neem tree (*Azadirachta*

indica) is used for firewood and also for the production of tannins, soaps, pharmaceutical products, cosmetics and insect repellants (CATIE, 1984; Caldwell *et al*., 2005) and it is being planted widely in arid climates, especially in India and in the Sudan.

Of the plantations established for wood production, 40% are composed of broadleaf species (eucalypts, teak, acacias and poplars, among others) (FAO, 2001). Worldwide, 48% of plantations are classified as industrial, 26% as non-industrial and 26% unspecified (FAO, 2001). Industrial plantations are primarily for the production of pulp and paper, but there are also some established for sawn wood, plywood and composite board. These last are primarily with pine from the temperate regions. In Brazil, the steel industry has established plantations for producing charcoal for iron smelting to produce pig iron. Non-industrial plantations are primarily destined for producing firewood, charcoal, watershed protection or other environmental conservation purposes.

Traditionally, solid wood products such as lumber, plywood, transmission poles, pilings, furniture, flooring, construction wood and doors have come from natural forests. Nonetheless, entering into the Twenty-first Century, the reality is that a major part of the commercial wood that has been sold in international trade has been cut over. For example, 20 years ago there were 150 wood processing industries located in the city of Samarinda, East Kalimantan (Borneo), but now there are just five active, primarily due to a lack of logs to supply the mills.[1] In South America, mahogany and Spanish cedar are extremely scarce and are being replaced by woods of other species of inferior quality or of limited availability in the wood supply depots. Even with the disappearance of tropical woods for lumber and veneer products, there have been limited investments in plantations for producing this type of product. Of the fine hardwoods, the one that is managed successfully on a large scale is teak (*Tectona grandis*). Nonetheless, there are just 3% of global plantations with this species.

In the temperate regions of the world, the main species planted are pines, spruces and other conifers due to their faster growth rates in that part of the world. Except for the poplars, there are relatively few plantations of broadleaf species in the temperate regions. However, in the tropics and subtropics, most species planted are broadleaf such as eucalypts, teak, acacias and *Gmelina*. The growth of these species is often greater than the growth of tropical pines. Nonetheless, the growth rate of tropical and

subtropical pines is greater than the growth rates of temperate pines and spruces.

There is a need to supply national and international wood markets with wood products from plantations, wood products that once were harvested from natural forests. The opportunities for wood production in the tropics and subtropics are well known. However, because of the risks associated with forestry projects, the most successful forestry programs have been in those countries where the governments have created fiscal incentives to promote reforestation and the manufacture of forest products from plantations. Even with such incentives, numerous forestry project have failed due to a lack of good initial planning, or due to a lack of available technical assistance, the lack of practical experience among professional foresters and technicians or because of a lack of understanding of the relationship of sustainable silviculture and forest management with the environments in which the species are planted.

In many cases, investors willing to initiate forestry projects lack sufficient technical and practical information regarding correct management practices for tropical and subtropical plantations. On the other hand, there are many graduates from forestry schools who received an education with limited field experience in forest management and who have not had the opportunity to work in an operating forestry company where practical field experiences can be obtained.

This book was written with the desire to provide useful and practical information to its readers as a source of reference material and support to those persons who are charged with the management of tropical and subtropical forest plantations.

Note: The nomenclature used in this text follows that used in the United States and Mexico, with the separation of decimals using periods and the separation of thousands and millions with commas.

WILLIAM LADRACH

[1] These are primarily species of meranti, keruing and kapur, of the *Dipterocarpaceae* family, woods that are found in the natural forests in parts of the Philippines, Malaysia and Indonesia.

1

History of forest plantations

The first forest plantations
Pioneers of genetic tree improvement
Silvicultural practices
Wood quality in fast-growing plantations
Forest management for short rotations
Clonal propagation and biotechnology
A short history of the eucalypts in Brazil

The first forest plantations

Since the beginning of civilization, the Earth has lost three billion hectares of natural forest, which is roughly half the forest area (Bryant *et al.*, 1997; Perlin, 1999). It is estimated that natural forests covered 34% of the land 10,000 years ago, but that just 12% of the land surface is now covered with intact forest ecosystems (Durning, 1993). Since the beginning of recorded history, wood taken from natural forests has been an integral part of the progress of civilization. The Egyptians used wood from the Nile watershed to construct ship and buildings, including the wood used to construct the pyramids. Later, due to local shortages, the Egyptians obtained imported wood of the cedars of Lebanon (*Cedrus libani*) from the Phoenicians, the merchants of the Mediterranean (Ostler, 2005). The Greeks used much wood to construct their buildings, fortifications and ships. The maritime power of the Egyptians, the Minoans, the Greeks, the Phoenicians, the Carthegians, the Romans and the Spanish, each in their turn, depended directly on the availability of wood from the Mediterranean forests for the construction of their navies, their fortifications, their cities and their civilizations. The loss of the forests around the Mediterranean is directly related to those civilizations. The authors of ancient history, including Homer the Greek, and the Romans Virgil and Horace, were conscious of the negative effects of deforestation, causing inundations and landslides in and around their cities (Westoby, 1989).

The concept of forest plantations is not new. There are records of tree nurseries and plantations in Egypt near the Nile River 2,300 years ago (Burdon & Libby, 2006). In China, there were plantations of Chinese fir (*Cunninghamia lanceolata*) in the TwelfthCentury and in Japan there are references from the Fifteenth Century to differences in growth and wood quality of Japanese cedar or sugi (*Cryptomeria japonica*) (Toda, 1970). In 1882, the Japanese established a forest experiment station at Nishigahara along with a school of dendrology (Fernow, 1911).

Teak, a species originally from South Asia, has been planted in India for centuries due to the high quality of the wood. In 1856, the British brought Dr. Deitrich Brandis, a German forester, to India to organize a silvicultural management plan for the Burmese and Indian forests, in particular the teak. The plan also included a reforestation program. Brandis originated the *taungya* system of reforestation, where local Karen farmers in Burma planted crops among teak trees and cared for both. The management method for natural teak forests was named "The Brandis Selection System", with partial cuts or thinnings every 30 years (Kahrl *et al.*, 2004) and with replanting of treeless areas. In 1864, Brandis was named head of the Department of Forests of India and in 1878 he was instrumental in establishing the first forestry school at Dehra Dun. In 1881, Brandis was sent to Burma, where he developed a similar management plan for teak (Fernow, 1911). It is believed that teak was first introduced to the Indonesian island of Sulawesi about 300 years ago and teak is now considered to be a "naturalized species" in that country (Keiding *et al.*, 1986). On the island of Java, more than one million ha of teak have been planted, and managed commercially since the middle of the Nineteenth Century (White, 1991).

Large extensions of natural forest were cut and cleared in the British Isles during the occupation of the Romans. The first wood crisis registered in Germany occurred in the Eleventh Century, but there were few efforts at reforestation (Heske, 1938). During the Twelfth and Thirteenth Centuries there were notable expansions of the human population of Europe and, as a consequence, the deforestation accelerated, especially in France and Germany, in order to open more lands for agricultural crops and to use the wood for construction, for heating and cooking as well as a source of heat for iron smelting (Westoby, 1989). Frequent wars in the Medieval Period created large demands for wood. Wars and social unrest also resulted in the

cessation of normal economic activities in the villages, with the displacement of people who fled into the forests for refuge against the violence in the towns, as well as to search for food. This also accelerated the deforestation in Europe.

Because of the loss of forests, landowners and nobles charged with taking care of the forests tried to protect them and some established plantations of oaks and beeches with the expectation of future wood production to construct ships, forts and castles. In addition, these species produced acorns and nuts that were an important food source for deer which supplied venison to the armies and to the houses of royalty. The Norman invaders and conquerors of the British Isles were known for their interest in establishing tree plantations (Westoby, 1989).

In 1309, Henry VII, Count of Luxemburg and Emperor of the West, saw the importance of wood for construction and for economic power and ordered reforestation projects in what is now Germany (Fernow, 1911). After the great fire in Nuremburg in 1368, pine and spruce plantations were established to reforest the burned area (Fernow, 1911). During the Seventeenth Century, after seeing the destruction of the forests and the seriousness of a lack of wood to national security, Jean-Baptiste Colbert, Prime Minister of King Louis XIV, predicted that France would be lost due to a lack of wood (Fernow, 1911).

Later on, through much of Western Europe, oaks, beeches and other species were widely planted, including the spruces, pines, larches and poplars. During the Medieval Era, the first foresters were mainly caretakers whose job it was to protect the forest against illegal hunting, indiscriminate cutting of trees by the peasants, and to carry out the breeding of wildlife for royal hunting. Because of this role, foresters were generally hated by the local peasants. In Central Europe and the Mediterranean, the loss of forests has been very extensive; there remain little if any of the original standing forests in those regions. The majority of the current forests in these regions are plantations or forests regenerated by coppice management. The original natural forests that still exist in Europe are primarily those located in the eastern regions, principally in the Carpathian Mountains of Poland, Belarus, Ukraine, Hungary and Rumania (Wikipedia, 2006); there are still some natural forests in Scandinavia and in Russia. In 1881, Rumania developed a national forest management system for use in the oak, walnut and beech forests that utilizes coppice methods of regeneration (Fernow, 1911).

In 1879, an oak provenance trial was established in Germany. At the beginning of the Twentieth Century systematic tests were established to quantify the effect of seed source (provenance) on the development of European plantations in Denmark and Switzerland (Kleinschmit, 1986). In 1936, cooperative international trials were established with Norway spruce (*Picea abies*) (Dietrichson & Lines, 1997). The Dane, C. Syrach Larsen, described the principles of genetic tree improvement in his book *The Genetics of Silviculture* in 1943 and in an English translation in 1956 (Zobel & Talbert, 1984). His concepts continue to be the basis for tree improvement worldwide (Burdon & Libby, 2006). In Canada, research on seed source of forest tree species was initiated during the 1930's (Ying & Morgenstern, 1987).

In South Africa, most tree species planted were introduced, being mainly pines to be used for sawtimber production (Hiley, 1959). Afterwards, eucalypts were planted to produce wood for mine props and for fiber for the manufacture of pulp and paper. At the beginning of the Twentieth Century, research tests were initiated to maximize sawlog production, utilizing wide spacings, early thinnings and rotations of less than 35 years. During this same period in Europe, plantations were being managed on rotations of more than 100 years. The initial studies established by foresters in South Africa were criticized by their European counterparts, being considered too radical. Today, the silvicultural concepts developed in South Africa are recognized as correct for tropical and subtropical plantations.

During the Nineteenth Century, there was much competition among botanists in European countries to name new species, particularly so in the tropics. As botanists from different countries were discovering new tropical species and giving them Latin names, it was inevitable that some species would be given different names by different botanists. Today, the names of many of those species are being reviewed and corrected in order to homogenize the Latin designations and use the earliest designation as the correct one. Along with the discovery of new species, there was much movement of interesting species from one country to another, to be placed in arboreta or to be planted in small trials.

Although there is little documentation available for many of the early tree, plant, and seed collections, it is evident that many plantations established with introduced species represented quite small genetic bases.

Many introduced species were sent as gifts from one noble landowner to another, either as a small plant in a pot or as a few seeds. When one landowner had an interesting species, other people collected seeds from it to plant on their own lands. In many cases, the imported seed from other countries for larger reforestation projects was obtained from very few trees. In this way, large areas were planted with a very restricted genetic base. There are numerous examples of this in the history of reforestation in tropical countries.

In the Nineteenth Century in Southern United States, large forest areas were cleared and converted to cotton production. Years later, when the soils were depleted and the sites abandoned for agricultural use, natural pine stands began to naturally reseed and cover the abandoned land. The tree seed came from the few fencerow trees that remained or from pines in adjacent areas (Zobel & Sprague, 1993). Because of this phenomenon, the genetic base of extensive native pine stands that reforested the abandoned fields in the South were actually of a limited genetic base that was much more restricted than that of the original pine forests.

The wood industry in Southern United States began to expand at the end of the Nineteenth Century, exploiting the wood from the forests that had regenerated spontaneously in the old fields that had been abandoned by agriculture. Due to the low value of the land, it was common for sawmills to obtain the land along with the standing timber at very low cost. At the beginning of the Twentieth Century, sawmills and pulp mills accumulated large extensions of forest land. By the 1950's, much of the timber in these secondary forests had been cut over several times and the forests were of relatively poor quality. Silvicultural trials were initiated to regenerate the land with healthier and more productive forests. Partial cuts were made leaving individual seed trees standing so that they would reseed the sites and produce new forests of better quality. Such methods were problematic since the best trees were left standing and many fell over after thinning due to their instability during high winds; the seed regeneration was also irregular in many cases. When returning to harvest these remaining seed trees, harvesting equipment caused damages to the natural regeneration that had been established underneath them.

In the 1950's, and into the 1960's, tests were conducted with direct seeding of pines by helicopter, by tractor or manually by broadcast sowing of seed (Derr & Mann, 1959; Ladrach, 1967, 1968; Mann & Derr, 1961,

1964). Direct seeding was not very successful do to large differences in the quality of the regeneration which left some patches with too many seedlings and others with few seedlings. At about the same time, tree nurseries were being established and seedlings were being planted commercially. This method was found to be the best way to obtain a uniform stand density and to produce trees with uniform growth rates.

Pioneers of genetic tree improvement

Initially, many foresters scoffed at the idea that the seed source or the breeding of trees could have any importance for wood production. Initially, forestry schools taught that the environment was the important element that could affect the quality of tree plantations. Early on, it was a common practice to collect seed from any tree, regardless of its form, to use for establishing plantations, and often, the shortest and branchiest trees were those that had the largest seed production that was easy to collect.[1] This practice was very prevalent in the case of imported seeds, when the main objective was to buy seeds at the lowest possible cost. The result was the establishment of plantations with poor form and poor growth in many parts of the world.

In some initial plantations with introduced tree species, the genetic base was very restricted. The case of cypress plantations in East Africa is an example of this phenomenon. According to the available information, in the Nineteenth Century a few seeds were carried from Guatemala by monks and planted in Portugal. Later, the species was identified by English botanists as *Cupressus lusitanica* based on samples obtained from those plantations, thinking that the species was originally from Portugal (Lusitania). Later, at the beginning of the Twentieth Century, some seeds were collected from the cypress trees in Portugal to establish the first plantations in Southern Africa. In South Africa, the best individuals were then selected as seed producers for successive plantations. Later still, seeds from 12 of these seed trees were taken to East Africa and used to establish the first plantations in Kenya. In Muguga, Kenya, a seed stand was created by thinning one of these first plantations and leaving just 24 seed trees standing. The seed from that seed production area was then used to establish extensive cypress plantations in Kenya, Uganda and Tanzania.[2] Although the documentation concerning the initial movement of forest tree seeds in the tropics is limited, it appears that similar occurrences also

happened in other countries and with other species. In other words, it is assumed that the genetic base of many initial plantations was quite restricted.

In Southern United States, differences were found to occur among different seed sources (Wakeley, 1944). In the Southeast, seed production in natural stands of *Pinus taeda* was greater in Piedmont trees and could be collected at a lower cost, so that seed from Piedmont sources was also used for planting in the Atlantic Coastal Plain. In a short time, the problem that was created by this practice became evident, since the growth of those Piedmont seed source trees was much slower. In other cases, seed from coastal trees was planted in the Piedmont, and these had faster growth, but, at the same time, those trees were more susceptible to ice damage and low temperatures during the winter months. Generally, foresters blamed the plantation failures on droughts, on the nurseries or on other causes, rather than on the use of the incorrect seed source.

The initial classification of slash pine, an important southern pine species, was *Pinus caribaea,* the same name given to the pines in the Caribbean and in Central America. Later, slash pine was reclassified as *Pinus elliottii* (Little & Dorman, 1954). Still later, three varieties of Caribbean pine were classified, these being *Pinus caribaea: hondurensis*, *bahamensis* and *caribaea* (Barrett & Golfari, 1962). Literature from South Africa prior to 1950 mentions *Pinus caribaea*, but such references most often refer to slash pine, the species now known as *Pinus elliottii*. In some tropical countries serious errors were committed by acquiring slash pine seed from southern United States instead of Caribbean pine seed from Central America.

Gradually, research foresters began to find differences in the development of trees according to the origin of the seed and to begin selecting the best phenotypes as seed producing trees. In Sweden during the Nineteenth Century, Őrtenblad demonstrated the existence of difference among trees of Scots pine (*Pinus sylvestris*) due to seed origin (Lindgren, 1986). In 1908, Sylvlén made self polinizations of pines and spruces in Sweden to demonstrate the disastrous effect of this phenomenon (Lindgren, 1986). In 1946, the Danish parliament established the Forest Genetics Department with Åke Gustafson as professor. The first tree seed orchard was established in 1947 by Värmland (Lindgren, 1986). The first forest

genetics institute was established in 1925 in Placerville, California, USA (Lindgren, 1986).

The collaboration provided by Scandinavian researchers was instrumental in the initiation of forest tree improvement. During the decades of 1940 and 1950, the Swedish researchers, Bertil Lindquist and Åke Gustaffson, were very influential in the development of forest genetics. Dr. Gustaffson made a presentation on tree improvement at Texas A & M University, which was attended by the Governor of Texas as well as by the President of the university. The impact of Gustaffson's conference had such an effect on these men that they initiated a tree improvement program at the university soon afterwards (Zobel & Sprague, 1993).

In 1951, Dr. Bruce Zobel was named as the first director of the Cooperative Western Gulf Tree Improvement Program at Texas A & M University. In 1953, Dr. Ray Goddard initiated a tree improvement cooperative at the University of Florida (Perry & Wu, 1955). In 1956, Zobel moved to North Carolina and began a tree improvement cooperative at North Carolina State University in cooperation with several forest industries, to work with several native pine species and later with hardwood species. In Michigan, Dr. Johnathan Wright began genetic tests of several forest tree species and proposed methods for making genetic gains for commercially important tree species (Wright, 1961, 1962). In the beginning, many foresters working for industry, along with many scientists and professors, were skeptical of this new idea. Nonetheless, researchers persisted in their work and now tree improvement is accepted as an integral part of the silviculture of all tree species planted worldwide. The geographic source of seed became important when tree species were planted in new environments. In 1952, a south-wide geographic seed source test of southern pines was initiated in the United States (Zobel & Talbert, 1984). Tests established with *Pinus taeda* in Argentina (Barrett, 1973), Brazil (Barrichelo *et al*., 1977) and Colombia (Ladrach, 1983c) have shown that seeds from the North of Florida and from Southern Louisiana grow better in those countries than seeds obtained from other locations in the United States.

Meanwhile, tree improvement efforts were being initiated in other countries, including Australia, where Dr. Garth Nikles began studies of pine hybrids, including *Pinus elliottii by Pinus caribaea* var *hondurensis* (Nikles *et al*., 1977; Nikles, 1995). Wood quality and the effect of genetic selection

on wood utilization became key factors in the process of tree improvement (Nikles, 1991). Researchers in South Africa tested other pine hybrids, crossing *Pinus patula*, *Pinus elliottii* and *Pinus taeda* (Barnes, 1977; Denison & Kietzka, 1992). Under the auspice of the tree improvement cooperatives, many graduate students were able to conduct research in conjunction with forest industries, and such studies demonstrated to the forest industry the importance of selection of desirable traits such as wood density, stem straightness, crowns with small branches and straight wood grains, without spiraling. Significant research efforts on tree improvement were also being carried out in other parts of the tropics with the technical support of the respective colonial powers, the Belgians, Dutch, English and French.

In Argentina, Drs. Lamberto Golfari and Wilfredo Barrett began trials of pine species to evaluate differences among seed sources and the adaptability of these to different climatic conditions within the country (Golfari, 1959; Barrett, 1960, 1987). Later, Dr. Golfari developed guidelines for relationships between tree species and the environmental conditions of several South American countries including Brazil (Golfari *et al*., 1978) and Venezuela (Golfari, 1993). In 1986, Dr. Barrett was named the first technical director of the CIEF Forest Research Cooperative (*Centro de Investigaciones y Experiencias Forestales*), where he expanded the provenance research on many forest tree species.

In 1968, The Forest Research Institute (*Instituto de Pesquisas e Estudos Florestais*) was established at the University of São Paulo, Brazil, with Dr. Heladio Mello named the first director of the tree improvement cooperative. Other tree improvement cooperatives were established in other Brazilian universities in this same time period.

.Cypress (*Cupressus lusitanica*) is a species originally from Central America and Mexico and has been widely planted in East Africa since 1905, as well as in the Andes Mountains of Colombia, Ecuador and Peru and in parts of Brazil. In 1966, the first cypress seed orchards were established in Kenya (Dyson, 1977; Owino, 1975) and, in 1973, a program of selection of cypress plus trees and clonal seed orchards was begun in Colombia to produce commercial seed (Gutiérrez & Ladrach, 1978). In 1952, forest research was organized in Kenya, Uganda and Tanzania as EAAFRO[3] with installations located at Muguga, Kenya, under the auspices of the East African Commonwealth (Pereira, 1959).

Pinus radiata, a species originally from California and Baja California in North America, was introduced into New Zealand, Australia, South Africa and Chile, where it has become an important industrial species in the Southern Hemisphere. Genetic selection has resulted in the production of trees with excellent form, growth and wood quality (Eldridge *et al*., 1977; Shelbourne & Thulin, 1977).

CSIRO, the Australian government research organization, has made countless seed collections of native eucalypts and acacias for distribution and research testing around the world. Research with these species has shown important differences in growth based on the provenance of the seed (Turnbull, 1977). Research in South Africa on the provenance of many forest tree species, including *Acacia mearnsii*, has also produced significant results (Nixon, 1977).

In 1980, the CAMCORE international research cooperative was founded at North Carolina State University with the purpose of collecting, testing and conserving the most important coniferous resources of Central America and Mexico.[4] The Cooperative is totally financed by its members, which include forest industries and government institutions from around the world. Currently, CAMCORE is the major world institution that is making conservation plantings on a sustainable basis for tropical tree species.[5] The initial mission has been expanded to include broadleaf species in Central America and Southeast Asia, along with the coniferous species. This scientific effort has produced valuable results concerning the genetic variation of many tree species, as well as producing local sources of genetically improved seed that can then be put to commercial use.[6]

Currently, the majority of the pines planted in Southeastern United States come from genetically improved seed and many are produced in advanced generation seed orchards. Some companies have established third and fourth generation seed orchards of *Pinus taeda*. Many eucalypt plantations in the tropics are based on seed collected from trees of the best provenance or from seed orchards. In Southern Europe and in Southern United States, as well as in Southern China, there are provenance tests of eucalypt species from the most southerly latitudes of Australia to determine their capacity to grow in cold climates with freezing temperatures during part of the year. Other eucalypts have been selected from the driest climates of Australia and Indonesia for their adaptation to arid sites in Brazil, Venezuela and other countries.

In Scandinavia and Central Europe there are important tree improvement tests of Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and larch hybrids (*Larix eurolepis*). In Canada there are studies with white and black spruce (*Picea glauca* and *Picea mariana*) as well as with jack pine (*Pinus banksiana*). In Japan, tree improvement has been focused primarily on Japanese larch (*Larix leptolepis*) and on *Pinus densiflora* and *Pinus thunbergii* (Toda, 1977).

In spite of its potential for tropical planting, there has been relatively little tree improvement research conducted on teak. Between 1970 and 1980, the Danish Forest Tree Seed Center, working under DANIDA and the FAO, has made collections of teak seed for distribution and provenance testing in many tropical countries (Keiding & Kemp, 1977). DANIDA, in cooperation with the Royal Department of Forestry of Thailand, proposed a teak tree improvement program in 1988 that was begun in Thailand (Wellendorf & Kaosa-Ard, 1988). Towards the end of the Twentieth Century, PERHUTANI, the government forestry organization of Indonesia, was placed in charge of forest plantation management in Java and made selections of plus trees and established seed orchards for its own use. Unfortunately, there has been minimal research on teak tree improvement in other parts of the world.

Silvicultural practices

Initial plantations were established under variable conditions: Interspersed within the natural forest, under the forest canopy, or in small clearings within the forest (Wadsworth, 2000). After many trials with different methods, most forest industries adopted the planting of trees in open areas with full sunlight and without competition from other forms of vegetation. Most tree plantings around the world have been established on degraded soils, marginal agricultural lands or on sites that had once been used for grazing or cultivation, but that had developed superficial erosion, had nutrient losses and that had been invaded by noxious weeds and grasses (Zobel *et al*., 1987).

Initially, there was little thought given to site preparation prior to planting. The main objective of planting in temperate countries was to establish plantations with good survival, with little or no attention to growth and initial development of trees, since it would be many years before the trees reached maturity and were ready for harvesting. As such, there was

little interest in adequate silvicultural practices. Over time, the concepts have changed, due primarily to experiences acquired with fast growing species. Control of weeds, grasses and woody vegetation is now a universally accepted practice that has been shown to be crucial to the survival and development of tree plantations. Generally, practices included the use of disking to eliminate vegetation and to increase soil porosity, subsoiling to break up compacted soil horizons and the use of bedding to improve surface drainage in low lying sites.

Previously, many foresters believed that grasses helped to protect trees from winds and inclement weather and improved their initial growth. However, it is now known that weeds, grasses and brush not only compete with planted trees for soil moisture and nutrients, but that the roots of many of them produce toxic substances[7] as a biological method of competition by slowing the growth of adjacent plants. It is now recognized that grasses and weeds can reduce the initial growth of trees and, in some cases, continue to reduce tree growth during many years (Osorio, 1988). It has been shown that the use of herbicides is a more effective method for grass and weed control than manual or mechanical methods (Ladrach, 1982, 1983b; Lambeth, 1986). Many companies have found that chemical weed control is more economical as well as more environmentally friendly than mechanical methods.

It has been shown that the quality of the nursery stock and the time of planting have a large impact on the initial growth of a plantation, as well as a significant impact on the overall wood production at the end of the rotation. When trees are provided with adequate spacing in the nursery, they are robust, have better initial field survival and growth than when nursery densities are too high, resulting in seedlings that are tall and spindly. The increased cost of producing high quality nursery stock is minimal, when considered within the overall cost of a cubic meter of wood harvested at the end of the rotation and delivered to the mill. In Southern United States, it was once considered acceptable to have pine seedlings with just a few centimeters of growth during the first year in the field. Now, with improved nursery techniques that produce hardy seedlings with good diameters, it is now possible to establish plantations that attain 80 to 100 cm height growth during the first growing season. In the case of broadleaf species in the tropics, the initial differences in tree growth due to nursery management are even more pronounced. Many tropical companies now utilize initial field

irrigation of recently planted trees in order to obtain a better coordination between the nursery and field planting, to make sure that the trees are planted precisely at the beginning of the rainy season, even though the rains are sometimes delayed (Haigh, 1993).

The old concept of many foresters was to establish plantations at high densities in order to have a “sea of green” as a means of controlling weed and grass competition. It used to be considered a good practice to “plant a few additional trees” to compensate for any mortality that might occur during the initial stages of the plantation. This philosophy resulted in stagnation and growth loss in plantations established at very high densities, with small, thin trees. Spacing trials in the tropics as well as in temperate regions have shown that the number of trees planted per hectare has little or no effect on total biomass production at harvest age[8] (Haigh, 1989; Osorio & Uribe, 1994; López & Aparicio, 1995; Coetzee, 1997). To the contrary, total wood production is a function of the soil quality, available sunlight, precipitation and other environmental factors. The current practice is to reduce the number of trees planted per hectare in order to obtain the same amount of wood but with fewer trees of greater diameter and of higher quality. This increases the value of the stumpage for sawtimber and for pulpwood by reducing the cost of plantation establishment as well as the cost of wood harvest.

Forest fertilization has been a common practice for many years (Mello, 1968). Initial fertilization didn’t take into account soil quality and thus the results obtained were sporadic. Positive research results in greenhouses did not necessarily result in increased wood production in plantations. One of the problems was the use of agricultural guidelines for forest plantations. Many pine species can grow in soils that have been depleted of many essential nutrients by grazing or by cultivation. In general, the response thresholds for fertilizer applications to trees are much lower than those for agricultural crops. Therefore, it is important to define the response thresholds of plantation trees through research in order to know when to expect growth increases from fertilizer applications.

Tropical and subtropical soils are generally deficient in phosphorus. Phosphorus is routinely applied to forest plantations at time of planting in the tropics and also in the Atlantic Coast of North America with outstanding results. In fact, without phosphorus applications many plantations would not be productive. In Argentina as well as in Uruguay,

initial fertilization of eucalypts with diammonium phosphate is a general practice. Tropical soils often show deficiencies of boron, especially those formed from volcanic ash or in deep sands that have been highly leached over time. The tree response to boron on deficient sites has been dramatic (Hunter *et al*., 1990; Ladrach, 1980, 1990; Sayagués & Méndez, 2006). Economically speaking, nitrogen is most efficiently applied to established plantations to increase the total wood production (Kane *et al*., 1992). Nitrogen applications are generally made after a thinning, when there is sufficient space for the trees to respond to the fertilization and in order to direct the fertilizer to the best standing individuals.

In general, tree response to potassium fertilization has been minimal to nil, in spite of this being an important macro-nutrient that is routinely applied in agriculture. Broadleaf and conifer tests in the temperate and tropical regions have shown little to no response to potassium applications, even on soils that have deficiencies of this element (Gonzalez, 1993). There is no good explanation for this phenomenon, except that the trees may require less potassium for their development and that they have an efficient method for recycling the element internally.

Wood quality in fast-growing plantations

Wood that forms in the center of the tree, near the pith, is different from the wood formed near the bark. That near the center is called juvenile wood and that towards the outside is called mature wood. In pines, the juvenile wood generally has a lower density and shorter fibers than does mature wood. The wood in the upper part of the pine tree and in the center of the basal portion is juvenile wood, whereas the outside wood in the basal portion is mature wood (Zobel & van Buijtenen, 1989). Thus, as a pine grows, it produces juvenile wood towards the top and mature wood towards the bottom during the same growing season. Mature wood formation in tropical pines begins normally between the 4th and the 8th years, and in temperate pines it begins to form at a later age. For example, in the case of the southern pines in the United States the production of mature wood begins in the 8th to 12th annual growth rings and for longer lived species, such as *Pinus ponderosa*, it can begin to form between the 20th and 30th annual rings. With increasingly intensive management of plantations resulting in faster tree growth, the harvest age is reduced and, as a result, there is more juvenile wood in the harvested logs.

Contrary to popular beliefs among many foresters, wood density is relatively independent of tree growth rate (Zobel & van Buijtenen, 1989). For example, it is possible to make genetic selections for increased tree growth and still select for high density wood. However, when pines are harvested at earlier ages, there will be an increased proportion of lower density juvenile wood, resulting in lower yields of pulp, or sawn boards with lower structural resistance. One of the future challenges to the wood industry is to produce pulp and sawn wood of a useful quality using predominantly juvenile wood.

Broadleaf species also produce juvenile and mature wood, but the differences in the wood quality between the two is generally less pronounced than in the conifers. In the case of tropical eucalypts, it is desirable to harvest trees for pulpwood before they reach eight years of age since older trees tend to deposit polyfenolic compounds in the heartwood, which can cause problems in the pulping processes (Zobel & van Buijtenen, 1989).

Today, it is possible to use genetic selection to increase the desirable characteristics of trees and wood for the final products. In fact, tree breeding to improve wood characteristics has become an integral part of many tree improvement programs by companies as well as industrial cooperatives. One leader in this field is Aracruz Celulose in Brazil, which has been able to increase the pulp yields per ton of dry wood and reduce the variation in wood density of the trees being harvested for pulpwood (Brandão, 1984). This has resulted in increased pulp production per ton of wood with improved pulp quality; this equates to increased profits for the company.

Forest management for short rotations

It is possible to have shorter rotations by using the best land races of trees, good site preparation, fertilization, weed control and other intensive forest management practices. In essence, short rotation forestry is an extension of agriculture, the principal difference being that agronomists measure their rotations in months and foresters measure their rotations in years.

Most plantations established around the world are for pulp and paper production. Plantations produce woods with uniform quality for pulp, whereas natural forests with mixed species do not. The eucalypts and also

the acacias have been the preferred species for short fiber pulp production. There is interest in growing broadleaf species, primarily eucalypts, in Argentina, Brazil, Chile, Paraguay and Uruguay in Latin America, as well as in Australia, Spain, Portugal, South Africa and New Zealand. Poplars (cottonwoods) are grown in the temperate regions of Argentina, South Africa and several European countries. More recently, poplars are being cultivated in the Northwest of the United States (Koncel, 1998; Wierman, 1994). In China there are also large areas planted to poplars.

In very general terms, and considering the world's demand for solid wood products made from hardwood species, it can be said that most of the wood of commercial value in the accessible natural hardwood forests has been exploited. The huge standing inventories of tropical woods such as meranti and lauan in Southeast Asia are nearly gone. Indonesia and Malaysia have maintained their exports of meranti plywood by deviating logs once destined for sawmills for local commercial use to the plywood mills to produce products for export. Within very few years, there will be a scarcity of meranti wood for all uses. During the later part of the Twentieth Century, most decorative paneling in the world markets was made of meranti, over which were often printed or embossed the decorative grain patterns of other woods for their export to North America, Europe and Asia. Now, however, it is common to find that these decorative panels are often made using MDF panels.[9]

As a result of this trend, there is growing interest in managing industrial plantations for solid wood products. In New Zealand, Chile and Australia there are large areas of radiata pine plantations managed for solid wood products. Plantations are pruned and thinned in order to produce large diameter logs that are free of knots (Maclaren, 1993). *Gmelina arborea* is being planted on a pilot scale in many tropical countries, as a potential source of wood for veneer production. Sawn wood made from eucalypts is a reality in South Africa, Brazil and Argentina. In the Delta Region of the Parana River, poplars are managed to produce sawtimber. Poplars are also being grown in other provinces in the South, including Mendoza, Neuquén and Río Negro, where they are being irrigated with water coming from the Andes Mountains. In 1997, Aracruz Celulose announced a solid wood production line with a capacity to produce 75,000 m3/year of wood products for the Brazilian markets as well as for export, using eucalypt wood from its plantations (Aracruz News, 1997). Woods of *Eucalyptus*

grandis are harvested from plantations on 21 year rotations and used for manufacturing molding, furniture parts, and framing as well as for general construction.

Rubber trees are planted in Indonesia and Malaysia for latex production and such plantations are an important source of wood for furniture manufacture in Southeast Asia. There is a large availability of rubber wood which is a sub-product of the millions of hectares of rubber plantations established for latex production.

In the Twenty-first Century it is estimated that forest plantations will provide between 40% and 50% of the world's demand for wood (Whitmore, 1998). Traditional concepts of forest management with long rotations for sawtimber production are being replaced with new concepts with sawlog production on rotations of less than 25 years, and, in some cases, less than 12 years in the tropics, by using high quality genetic stock, clonal plantations, fertilization and intensive management. The use of new technologies and high-speed industrial machinery allow for the manufacture of sawn lumber and plywood from smaller diameter logs. In the not-too-distant future, the forest industry will depend on short rotation plantations with mostly juvenile wood as the source of wood for manufacture.

Clonal propagation and biotechnology

Vegetative propagation of genetically improved trees has become a common method for the establishment of eucalypt plantations, as well as for other species in the tropics. It is also used to establish plantations of *Pinus radiata* in the Southern regions, as in Chile and New Zealand, as well as for some pine hybrids in Australia. There are promising research results with the rooting of *Pinus taeda* and *Pinus elliottii*, species once considered difficult to root (Goldfarb *et al*., 1997). In Argentina, operational plantings of *Pinus taeda* are being established using processes similar to those developed for *Pinus radiata* in New Zealand and Chile. Clonal propagation research is continuing with other broadleaf and coniferous species and in the not-too-distant future it is expected that vegetative propagation with rooted cuttings will become a common method for planting many forest tree species.

There has been considerable research carried out on the development of plantlets based on tissue culture. This allows for the production of many plants from the tissues of a single parent plant, generally by means of a

process called somatic embryogenesis, where embryonic tissue of recently germinated seeds is used (Grossnickle *et al*., 1996). There exist methods for introducing desirable traits or genes into the chromosomes of plants by gene insertion techniques, such as the inclusion of resistance to herbicides or to insect attack (Shin *et al*., 1994). Such biotechnological practices are commercial for some agricultural and horticultural plants, but they are still in the research phase for forest trees (Ahuja *et al*., 1996). One logistical problem for the forest sciences is the genetic structure of trees, which is extremely complex in comparison to annual plants and crops. There now exist genetic structural analyses of several tree species, including species of eucalypts (Brondani & Grattapaglia, 1997; Marques *et al*., 1997). Research in genetic science has demonstrated that most commercially important tree traits are controlled by gene complexes and that these sometimes influence a visible or phenotypic trait only during a part of the life of the tree (Ahuja & Libby, 1993; Klopfenstein *et al*., 1997). This is problematic for the effective use of gene insertion for a given trait since its effect may only be active during a short period when that trait is controlled by that particular gene or gene complex. Another concern is the formation of genetic mutations during the chemical stresses created by clonal propagation techniques in the laboratory (Ahuja, 1996). A logistical problem with tree selection is the particular adaptability of a given selection to adapt to local conditions of climate and soils, which is the land race concept. Thus, if gene insertion techniques are to be applicable for commercial plantations, it will be necessary to develop low-cost methods for carrying out such work.

A short history of the eucalypts in Brazil

During the Nineteenth Century, there was a significant movement of eucalypt species from Australia to many tropical and subtropical countries around the world. The first recorded references to eucalypts in Brazil included one in the Rio de Janeiro Botanical Garden in 1829, followed by another in Rio Grande do Sul in 1865 and later in São Paulo in 1868 (Sampaio, 1975). In 1904 and 1909 the São Paulo Railroad Company (Compañía Paulista de los Ferrocarriles) introduced species of eucalypts as a source of firewood to fuel the steam engines, due to a scarcity of coal in the country (Sampaio, 1975).

The first plantation trials by the railroads were established in the Rio Claro tract in São Paulo State, where many species of eucalypts and other

trees were tested for their potential to produce firewood for the steam engines. Among the species tested in Rio Claro, one that showed good promise was *Eucalyptus saligna*, a species introduced from southeastern Australia.

In 1918, Professor Maiden, an Australian taxonomist, separated *E. saligna* into two species. One species kept the name *E. saligna* and Maiden named the other species *E. grandis* (CAB International, 2000). However, in Brazil it had already become the custom to call both of these *E. saligna* without differentiating between the two and this tradition continued for several more decades. The result was confusion in the nomenclature of the two species, particularly so in other tropical American countries that obtained seeds from Brazil imported under the name of *E. saligna*.[10] Years later, and after many species and provenance tests with seeds imported directly from Australia, various researches in tropical America found that *E. grandis* grew best in most tropical locations (i.e., those nearest to the equator and at low altitudes), whereas *E. saligna* showed more promise at greater latitudes and higher altitudes.

In low altitude tropical sites with pronounced dry seasons, another species of eucalypt from Indonesia turned out to be better than either *E. grandis* or *E. saligna*, and it was called *Eucalyptus alba*. The history of this species also has its complications. It is a species that occurs naturally in Indonesia, as well as in Papua New Guinea and Australia. Generally, *E. alba* in Indonesia is a species that grows from sea level to an altitude of approximately 700 meters. On seven of the islands where *E. alba* grows, *Eucalyptus urophylla* can also be found, but growing at higher altitudes, normally above 500 meters above sea level.[11]

Part of the confusion regarding the identification of *E. alba* and *E. urophylla* is centered around a single tree planted in the Nineteenth Century on the island of Java, Indonesia, in what is now the Bogor Arboretum, adjacent to the Presidential Summer Palace. This individual tree grew very rapidly and was initially identified as *E. alba*. Because of its good growth, many seed collections were made and the seed planted in other locations. In Rio Claro, Brazil, *E. alba* grew well and, since it had a relatively high wood density, it was of much interest to the São Paulo Railroad Company.

In 1972, Dr. Lindsay Pryor, an Australian forest taxonomist, visited the Bogor Arboretum and changed the identification of that tree to *Eucalyptus urophylla*. Since then, that famous tree of Bogor has been known as *E.*

urophylla, rather than *E. alba*. On the Indonesian island where both species occur together (normally between 500 and 700 meters above sea level) many hybrids form spontaneously. Because of the difficulty of climbing the steep cliffs of those islands, the first seed collections identified as *E. urophylla* were often made in this zone of hybridization. Thus, it is common to find trees of *E. urophylla* in Brazil that exhibit traits of both species, in other words, they are natural hybrids from many generations past in the original locations in Indonesia. Even though *E. alba* is not a promising species for industrial reforestation, the natural hybrid with *E. urophylla* is widely used for reforestation on those sites where there is a highly defined dry season. The natural hybrid is easily distinguished due to the form of the leaves as well as the bark, which are quite different from pure *E. urophylla*. Those hybrids have been widely used with good results, especially at latitudes nearer to the equator, as in the states of Pará and Maranhão in northern Brazil.

In 1964, Dr. Bruce Zobel was invited to Brazil to dictate a series of conferences concerning the organization of the tree improvement cooperative at North Carolina State University a decade earlier, which involved forestry companies and state forestry organizations in Southeastern United States. Shortly after his visit, similar cooperatives were initiated by Brazilian universities at Piracicaba (São Paulo), Curitiba (Paraná) and Viçosa (Minas Gerais), which continue to the present and which have resulted in the establishment of genetically superior tree plantations throughout Brazil.

In 1966, the Brazilian Government initiated a very optimistic program of fiscal incentives which lasted one decade and was designed to promote reforestation, cattle ranching and fishing. As a result, there was a renewed interest in reforestation starting in 1967. In order to meet the needs of the tree nurseries, several of the Rio Claro plantations were converted into seed production areas, particularly those of *E. alba*.

At that time, it was not known that many of the eucalypt species planted in adjacent lots in the Rio Claro trials hybridized readily and that seed from those trees called *E. alba* was often a hybrid mix of many species, including *E. saligna*, *E. camaldulensis* and others. That seed, called *E. alba* (remember that Dr. Pryor still had not identified the tree in Bogor as *E. urophylla*) was widely planted in Brazil and also exported to many other countries in tropical America. These hybrids are from the “f2”, generation,

that is, a second generation hybrid, but without any control of the parentage by genetic research testing. Those plantations of "*E. alba"* began to show certain non-desirable traits, including large growth variations among trees, forking and poor form. The result was the establishment of plantations covering huge regions in Brazil with trees that had growth rates inferior to the growth of the original trees in the Rio Claro test plantings. After planting thousands of hectares with this material, Brazilian foresters realized that there existed a problem in the genetic composition of seeds produced from those seed production areas. The seed from the Rio Claro trees became known by the derogatory nickname of "Eucalyptus sal-alba".

One way to use hybrids without seed is by vegetative propagation, where the propagules are genetically identical to the parent or donor tree. By this method, the favorable characteristics of the hybrid plants or trees are passed on to the cloned plants. An important technique for clonal propagation of eucalypts was developed in the Congo by Dr. Henri Chaperon, a French researcher with AFOCEL (Chaperon & Quillet, 1977; Chaperon, 1984, 1987). Brazilian foresters visited the Congo and observed the clonal reproduction techniques developed by Dr. Chaperon using rooted cuttings. Then, those techniques were duplicated in Brazil to propagate the best individuals selected in the plantations established using seed of *E. alba* from Rio Claro. The process was a total success and the cloned plantations attained growth rates more than double those of the plantations established with material from seed.

It was recognized that there was a need to obtain seed of pure material that was correctly identified by location of origin if a tree improvement program was to be successful. In 1970, Dr. Lamberto Golfari clarified the importance of using seeds from origins with similar climatic conditions to those in Brazil where the trees were to be planted. He proposed that plantations along the coastal regions of the State of Espíritu Santo should use seeds from the northern part of Queensland, instead of seed from further south (Golfari, 1970). After several dry seasons, the seed that was obtained from the region of Coffs Harbor, Australia, began to show signs of eucalyptus canker. Because of the seriousness of this problem, in 1973, Aracruz Celulose decided to send Golfari and Edgard Campinhos to Australia to make seed collections from the locations with the best potential for plantations in Brazil. Later, during a second expedition, seeds were collected from individual parent trees that were selected due to their good

form and growth. That seed was then used to establish progeny tests in Brazil. In 1984, four employees of Aracruz were given the prestigious Marcus Wallenberg Award in Sweden because of their efforts with the research and development of clonal reforestation on an industrial scale. The award was presented in Sweden by King Gustav Adolf. Gains made by this research work by Aracruz are summarized in Table 1-1.

In the mid-1970's, there was a very serious attack of thousands of hectares of eucalypt plantations by a canker-causing fungus. Researchers identified the fungus as one that is associated with cloves which originate in the Moluccas Islands of Indonesia. As clove bushes were planted in many tropical countries, the fungus was also distributed unknowingly. Since the eucalypts are in the same family, *Myrtaceae*, the fungus also attacked the eucalypt plantations. Although the fungus is, at best, a chronic problem for cloves, its effect on some of the eucalypts was devastating, causing cankers and gummosis on the stems of trees and even causing some trees to die. The fungi caused so much damage that, at one point, the Brazilian forest industry considered abandoning the planting of eucalypts altogether.

Because of this problem, research studies were begun centered at the Federal University of Viçosa. Dr. Charles Hodges, forest pathologist on loan from the U. S. Forest Service, worked for several years with a group of scientists at Viçosa. Through that research, Hodges determined the origin of the fungus and its relationship with cloves. It was also found that there was a relationship between the susceptibility of the eucalypts and the latitude of origin in Australia (Golfari, 1975). The Viçosa scientists determined that the more northerly eucalypt species, which are closest to the Moluccas Islands, had the greatest resistance to the fungus, in particular, *Eucalyptus urophylla* and *E. alba* from Indonesia. The more southerly species, such as *E. saligna* and *E. grandis* from Australia, were the most susceptible to the fungal attack (Hodges *et al.*, 1976). Meanwhile, the name of the fungus was changed from *Diaporthe cubensis* to *Cryphonectria cubensis (*Hodges, 1986) and later it was again changed to *Chrysoporthe cubensis* (Gryzenhout, 2004).*[12]* Through genetic selection and the cooperation among companies and the universities, it was possible to find resistant strains of trees among the various commercial eucalypt species and, currently, these are being used successfully for commercial reforestation by most of the forest companies.

Based on a series of genetic tests, Brazilian researchers have developed hybrids between *E. urophylla* and *E. grandis*. The hybrids, called "uro-grandis", have proven to be better for plantations in many locations than the pure species. The uro-grandis hybrid is widely planted in the central and northern states of Brazil and *E. urophylla* is planted much less. In the South, *E. grandis* continues to be the preferred eucalypt. Almost all industrial plantations are clonal. Seeds are utilized for research tests in order to develop new strains that, afterwards, are used commercially as clonal material. Today, Brazil is the leader in forest research on eucalypts and on the use of clonal propagation with rooted cuttings for industrial reforestation. During the 30 years between 1975 and 2006, forestry companies in Brazil planted more than one million hectares with clonal eucalypts.

Table 1-1
Genetic gains with eucalypts by Aracruz Celulose, S. A

Parameter	Units	Total Plantation 7 years	Improved Plantation 7 years	Gain %
Growth	m^3/ha/year*	33	70	112
Wood basic density	kg/m^3 wood*	460	575	25
Pulp	%	48	51	6
Rotation wood to pulp	m^3 wood*/ton pulp	4,2	3,4	-19
Forest productivity	ton pulp/ha/year	7,9	18,5	135

*/wood without bark

Fuente: (Marcus Wallenberg Foundation, 1984).

There are several important points that can be summarized from the history of the eucalypts in Brazil:

- The concept of the classification of a "species" can be modified over time and this has happened numerous times with commercial forest species. When reading past reports, botanical names may be different from those used at present. Currently, there is a movement among Australian taxonomists to divide the genus *Eucalyptus* into three separate ones, although the international scientific community still has not totally accepted this proposal.

- Susceptibility of trees to fungal attack can vary for different reasons, such as historical contact between the two in the original habitats. Through genetic selection, it is possible to develop resistance to some diseases.
- It is important to understand the reproductive cycle of trees when designing seed stands and seed orchards. In the case of the eucalypts, which are primarily pollinated by insects, it is important to maintain adequate isolation between species to minimize contamination with foreign pollen.
- Seeds that result from species hybrids, known as f2 hybrids, may have highly variable traits, some good, others bad: the lack of uniformity is common in such cases. The use of such seeds, without first making progeny tests, can result in long-term economic failures. On the other hand, the use of vegetative propagation of such hybrid material will provide planting stock that is genetically identical to the parent or donor trees.
- When a government initiates fiscal incentives for reforestation, it is important to consider how planting material is to be obtained, either by seed or cuttings, as an integral part of the incentives package.
- Reforestation with introduced or exotic species necessarily requires support by forest research to avoid disasters and to improve the productivity of commercial plantations. History demonstrates that well conceived forest research is an excellent investment and is a guarantee to keep commercial plantations pest-free, to increase growth of select trees and to improve the quality of the products that are manufactured from wood.
- Collaboration among public and private entities is critical to the success of forest plantations on a national level. Tree improvement cooperatives, such as those in Brazil and Chile, as well as in the United States, have shown the advantages and benefits of cooperation among all participants, allowing for appreciable gains through joint efforts that are greater than those that could be attained by individual companies or research personnel working in secret.
- International cooperation among forest research organizations is important in order to maintain up-to-date information on research developments and happenings. Those companies that allow their research personnel to write technical reports and present them at

national and international meetings are those that obtain valuable information in exchange. Those that don't do not have good contacts and good professional interchange with other organizations.

[1] This is known as dysgenic selection.

[2] Personnel communication, Dr. Jeff Burley, Oxford University, England.

[3] EAAFRO is the acronym for the East African Agriculture and Forestry Research Organization.

[4] Camcore is the acronym for the International Tree Conservation and Domestication Program. The Cooperative has 32 members, classified as active, associate and honorary members in 18 countries in Central America, South America, Africa, Southeast Asia, the Pacific and the United States (Camcore, 2006).

[5]This is called *ex situ* gene conservation. The Cooperative is working to conserve species and specific provenances that are at risk for loss or extinction (Dvorak, 1996).

[6]Improved seed sources that have been adapted to local conditions are known as land races or geographic strains.

[7]These are defined as allelopathic substances. Allelopathy is the capacity of one plant to restrict the germination of seeds or reduce the growth of other competing plants. Commercial grasses, including many species in the genera *Brachiaria*, *Imperata*, *Melinis*, *Panicum* and *Pennisetum*, are known to be highly allelopathic.

[8]Some studies report wood volumes overbark and, of course, the total volume with bark is greater when there are many small trees, compared with a few large trees. However, when net wood volume without bark (underbark) is calculated, research shows that total wood volume is independent of the number of trees/ha at the end of the rotation.

[9]MDF (medium density fiberboard) is a product made of mechanical wood pulp which is commonly manufactured into decorative interior panels and low-cost furniture.

[10]One difference between the two is that *E. saligna* forms lignotubers at the base of the seedlings, whereas *E. grandis* does not. The seed capsules of *E. grandis* also tend to be slightly squared, whereas those of *E. saligna* tend to be rounder.

[11]*E. urophylla* occurs naturally on the Indonesian islands of Flores, Adonara, Lomblen, Pantar, Alor, Timor and Wetar (Camcore, 2004). On Wetar, *E. urophylla* is found at lower altitudes, growing down to 70 meters above sea level.

[12]The species name, *cubensis*, resulted from the initial identification of the fungus in Cuba. Through DNA testing, taxonomists have modified the taxonomy of living organisms to provide the best possible information. Thus, there have been numerous changes in the scientific names of organisms, especially among the fungi and insects. It is probable that there will be further changes in the future. In the specific case of the eucalypt canker, the DNA analyses have shown variations among populations of the pathogen in different parts of the world and the original relationships developed by Hodges appear to be even more complex than once thought.

2

Plantations to supply wood to the forest industry

Site selection for plantation establishment
Unification of forest properties into economically manageable units
Definition of a plantation management lot
How to calculate a forest land base for a wood processing facility
Forest productivity concepts
Selection of species and the development of land races

Site selection for plantation establishment

Before initiating an industrial forestry project, it is necessary to determine the net area in plantations that will be needed to supply wood to the proposed industry. Selection of the region for establishing plantations is the first step. It should include lands that are suitable for the species of trees that are to be planted and to be used as the wood supply for the desired industrial products. Existing small plantations or trees planted in fence rows or small groups can provide some idea of the potential growth of a species in the locality. It is also important to evaluate the environmental factors for the site and make comparisons with the environments where plantations of the same species already exist within the same country or in other parts of the world. The determining factors for the forestry potential of a given site include the following:

- Latitude and altitude above sea level,
- Climate (precipitation, number of dry months, temperature means and extremes),
- Soil quality (drainage, texture, depth, acidity, fertility, hydrology),
- Topography,
- Sizes of available properties that could be acquired for reforestation,
- The potential to acquire adjacent properties to create land nuclei that are of a size that is economically and administratively manageable,
- Availability of roads, availability of rock or other materials for road construction and maintenance,

- Distances between the lands to be planted and the location(s), existing or anticipated, of the industries that will utilize the wood.

The species to plant and their adaptation to a given environment can be affected by latitude and by altitude. As a general rule, the closer to the equator, the higher in altitude a plantation needs to be to occupy a similar growing environment. *Eucalyptus urophylla* generally grows between 500 m and 1200 m altitude on the islands of Flores, Timor and Wetar in Indonesia at latitude 10° S, but the same species does not prosper in plantations in East Kalimantan at 0° latitude and 50 m altitude. *Eucalyptus globulus*, a species originally from the South of Australia, grows well at 50 m altitude in the Pampa of Argentina, but does not do well at altitudes below 2000 m in Ecuador at 0° to 2° South latitude. Nonetheless, there are exceptions to this rule of thumb. For example, *Pinus patula* occurs naturally in the Eastern Sierra Madre range of Mexico between 1500 and 3100 m at latitudes between 17° and 24° N (Perry, 1991), but it grows well in plantations in Colombia at similar altitudes, between 1700 and 3200 m at latitudes between 2° and 4° North.

Normally, 1200 mm/year is considered to be a minimum annual precipitation necessary for industrial plantations, although this can vary according to altitude and latitude. On those sites nearest to the equator and at low altitudes, there is a greater rate of evapotranspiration. On sites with a monsoon climate, having a pronounced dry season, the duration of this season is a critical factor to consider, along with the annual precipitation. Where there are more than three months of dry season, this becomes a determining factor in the growth and health of trees as well as in forest productivity. A dry month is considered to be one where the precipitation is less than 40 mm (Evans & Turnbull, 2004). The species that best adapt to monsoon climates are those that drop their foliage during the dry season. Defoliation is a means for protecting the tree against loss of moisture during the dry season.

On the other extreme, it is not desirable to establish plantations on sites where the rainfall is excessive. When the precipitation is greater than 2500 mm/year, there can be problems with excessive soil moisture, greater risks of phytosanitary problems in plantations and serious logistical problems for operations, especially the harvesting of wood and road maintenance.

Soil analysis is an important part of the evaluation of a given environment for plantations. Normally, the soils most suitable for agricultural crops are already in crop production and are not available for tree plantations, since such soils are generally too expensive and/or government regulations do not allow for their use for forestry purposes. The soil texture and acidity are the most important factors to evaluate initially, since they are not economically modifiable. Even though it is possible to modify soil pH for agriculture by adding lime, this practice is not economical and it seldom produces significant benefits for forest plantations. It is possible to modify soil fertility by adding nutrients in the form of fertilizers. Thus the initial fertility of the soil is less important for site selection than are the texture and pH. A soil scientist can sample the soil horizons in the field using a soil auger in order to determine the soil texture by tact.[1]

Soil acidity is important for the selection of the species to plant, or for the selection of sites for species already chosen. Soil pH can be checked in the field using portable equipment (Figures 2-1, 2-2 and 2-3).



Figure 2-1. Soil analysis is an important part of the initial evaluation of the forestry potential of a property.

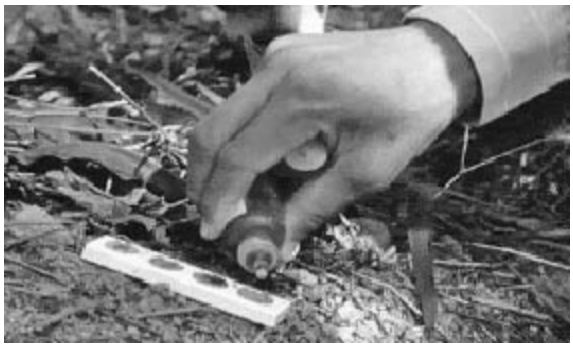


Figure 2-2. Soil acidity (pH) can be quickly checked in the field using a color test.

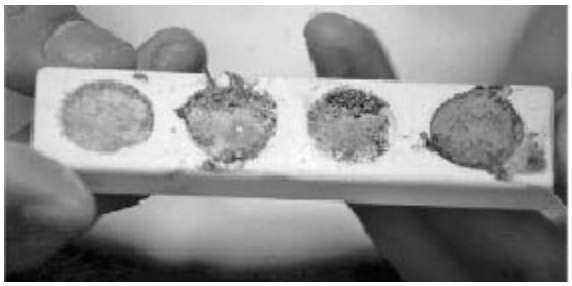
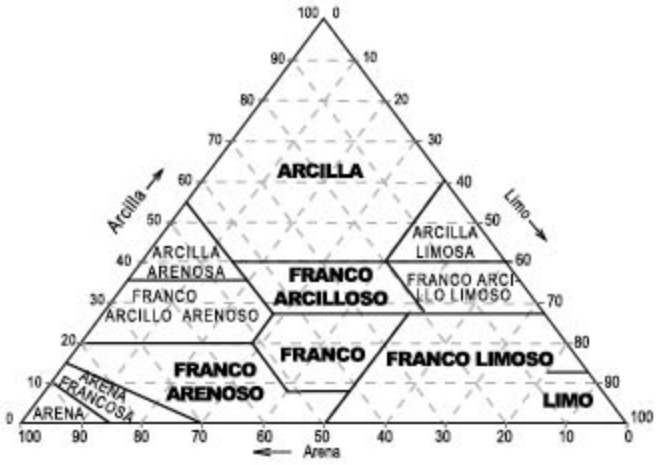


Figure 2-3. In this example, it can be seen that the surface soil (left) is acid (pH 4.0) by the yellow color, whereas at greater depths (left to right) the soil becomes more alkaline (pH 8.0), as indicated by the purple. This sample variation was found in an alluvial soil on a river terrace in Venezuela.

Soil texture is defined by the proportion of different size particles in a sample. The following sample sizes are recognized in soil science (Coile, 1964):

Name	diameter of the particles mm
clay	less than 0.002
silt	0.002 to 0.05
very fine sand	0.05 to 0.10
fine sand	0.10 to 0.25
sand	0.25 to 1.0
coarse sand	1.0 to 2.0

Figure 2-4 shows the classification of soil texture graphically. Agricultural soils tend to be those with loam textures and with soil pH values near neutral (pH 7.0). Soils optimum for reforestation depend on the tree species to be planted. In general, pines and eucalypts do best on sandy loam to clay soils with pH values between 4.5 and 6.5.[2] Species such as teak and *Gmelina* grow best on silt loam to loam soils with pH values between 6.0 and 8.0. Some tropical acacias (*Acacia mangium*, *Acacia crassicarpa*) adapt well to very acid clay loam to clay soils with pH values between 5.5 and 3.5.



Topography is important with regards to the logistics of wood harvesting. The use of harvesting machinery increases productivity when compared with manual harvesting methods. On very broken and hilly sites, the use of machinery is limited and the overall cost of all operations will be higher. In broken and mountainous lands, the cost of road construction and maintenance is greater than on level lands. It is common to use articulated tractors for harvesting operations and these sometimes work two or even three shifts per day when lights are mounted on top of the operator's cabin to illuminate the work area, but this practice is only feasible where land is level or slightly rolling.

Mechanization of soil preparation is often needed to stimulate good initial tree growth. Subsoiling is a common practice for plantation establishment in the tropics. This can be done on level lands or working along the contour where the slopes are minimal, but is not operational on steep lands.

Soil Tactile Texture Classification

The following descriptions are useful for making field determinations of soil texture. If the soil is dry, add just a few drops of water to the sample in the hand to make it moist, but not wet.

Clay: Soil can be pressed into a ribbon between the thumb and forefinger and extended to more than 4 cm length. A thin soil rope (+ 5 mm diameter) can be formed more than 10 cm long between the palms of the hands and then formed into a circle or wheel rim without breaking or cracking.

Clay loam: Soil can be pressed into a ribbon between the thumb and forefinger, but it will break before being extended to 4 cm length. A thin soil rope can be formed more than 10 cm long, but it will break when trying to make it into a circle or wheel rim.

Loam: Cannot be pressed into a thin ribbon between the fingers. A long, thin rope cannot be formed without breaking. Some grit may be felt when rubbing the soil between the fingers. A ball of soil can be formed with the hands and bounced in the hand several times before breaking apart.

Sandy clay: Similar tactile description as clay loam, except that grit can always be felt when rubbing the soil between the fingers.

Sandy clay loam: Grit can be felt when rubbing the soil between the fingers. A thin rope can be formed between the hands, but this will break before elongating to 10 cm length. A ball can be formed between the hands and it will remain intact when bounced several times in the hand.

Sandy loam. Grit can be felt when rubbing the soil between the fingers. Cannot form a thin rope of soil between the hands, but a ball of soil can be formed and bounced a couple of times before breaking.

Loamy sand: Grit can be felt when rubbing the soil between the fingers. A ball of soil can be formed between the hands, but it will break after being bounced two or three times in the hand.

Sand. Grit can be felt when rubbing the soil between the fingers. A ball of moist soil can barely be formed, but it will break apart if bounced once in the hand.

Silt: Feels greasy between the fingers. Cannot form a thin rope between the hands; soil is sticky. No grit is felt when soil is rubbed between the fingers.

Silt loam: Tactile similar to loam, except that soil feels greasy when rubbed between the fingers.

Silty clay: Tactile similar to clay, except that soil feels greasy when rubbed between the fingers. A ribbon can be formed between the fingers, but this breaks before being extended to 4 cm length.

Silty clay loam: Tactile similar to clay loam, except the soil feels greasy when rubbed between the fingers.

Unification of forest properties into economically manageable units

The cost of maintenance and administration of forest properties depends in large part on the distance between tracts of land. Ideally, forest properties should be contiguous to minimize the cost of peripheral fence maintenance, the risk of fires entering from outside properties, the cost of

internal road infrastructure, the cost of technical personal in the field and the movement of machinery. In Brazil, it is common to consider a minimum area for pulpwood or for industrial charcoal production for steel smelting to be approximately 3000 ha for purposes of efficient administration. For a sawmill or other industry of a smaller scale, it is common to have minimum forestry units of between 500 and 1000 ha for efficient management.

Harvesting and wood transport are invariably the largest plantation costs. Mechanization of harvesting can minimize the cost of placing wood at roadside. The closer the plantations are to the wood-using industry, the lower the cost of wood transport. In the case of Costa Rica, a transport radius is considered to be no more than 200 km for an economical wood haul cost. The types of roads are important, as well as the cost of their construction and maintenance. In unified land bases that are relatively level, internal road costs can be minimal. In mountainous land and with disperse forest properties, the cost of forest roads increases proportionally. In hilly and steep land it may be necessary to use smaller trucks for wood hauling, which increases the unit cost of wood delivered to the mill woodyard.

Another factor to consider is the availability of rock or aggregate for road surfacing. Hard rock can be scarce in many parts of the tropics (Sessions & Heinrich, 1993). Before acquiring land, it is important to determine the availability of rock or aggregate at a reasonable truck transport distance, so that it can be used to surface the roads that will be constructed. There have been cases where forestry projects have been rejected based on the lack of rock for road construction and maintenance.

Initial planning of plantations is important prior to beginning the planting operations. Roads need to be constructed and located so as to minimize the movement of wood from the stump to roadside as well as to minimize truck hauling costs within the forest properties. Plantation design is based on harvesting plans, connecting the planted forests with a minimum of road construction and road maintenance. Ideally, a forestry lot has a road through its center with non-forestry areas such as streams, natural forest reserves, steep slopes or other non-plantable areas along the flanks. The size of a plantation lot is designed according to the harvesting plan, making units of a size that justifies the movement of harvesting equipment into the plantations.

Definition of a plantation management lot

In agriculture, it is normal to maintain permanent separations between fields and pastures. In many places, it is a common practice to name lots so that farm workers can easily identify each lot. A pasture has a fence, access for cattle, and a water source (stream, lagoon, well or water trough) within the lot. The border of the pasture or field is a road that passes by one side, while a stream may be on the other edge of the lot, this being an ideal way to manage pasture animals.

A forestry lot has a distinct orientation (Figure 2-5). It is easier to prepare the soil mechanically, plant the site and harvest the trees when the lot is on both sides with a road through the middle. This provides for the most efficient use of the road investment, rather than having the lot on one side of a road. It is not desirable to have a creek, wet area or other obstacle to machine movement within a lot. For these reasons, when an agricultural farm or ranch is acquired for planting trees, the original lot configuration is seldom useful for designing the tree planting plan.

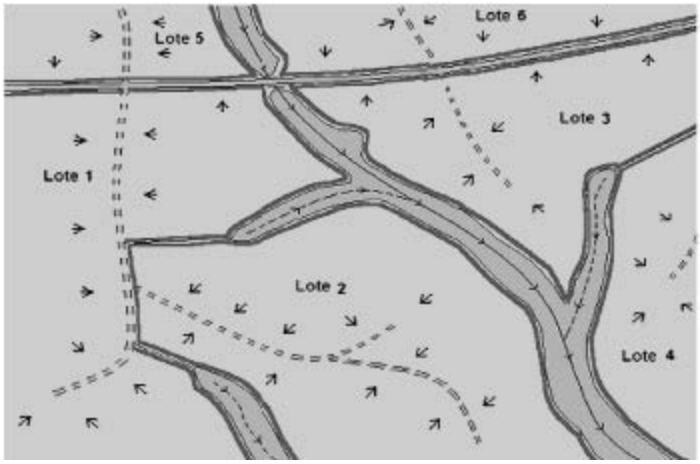


Figure 2-5. Forestry lots are defined according to the scheduling of wood harvesting operations. A lot is define d prior to planting in order to minimize the cost of wood extraction as well road maintenance.

A forestry lot is a management unit that has an integral border, has been planted with one species, has received the same soil treatment, has trees of the same age and has uniform growth throughout the lot.

The objective of the design of a lot should be:

1. To minimize the overall movement of wood from the stump to roadside,

2. To maximize the use of internal roads during harvesting in order to minimize wood harvesting costs. In this way, the cost of road maintenance can be minimized during the harvesting process.

For mechanized or semi-mechanized harvesting, a minimum lot size is considered to be around 20 ha with an optimum lot size of 50 to 100 ha. Obviously, lot size must also take into account the topography and the harvesting plan.

How to calculate a forest land base for a wood processing facility

When a forestry project is initiated to supply wood to a pulp mill, the forest manager must guarantee a minimum wood supply to meet the raw material demands of the mill. This is not an average potential forest productivity; rather it is the amount of wood that can be supplied routinely and reliably given a worst case scenario for the forestry situation. Such a concept is based on the fact that the capital investment in a pulp mill is usually on the order to ten times the capital investment in commercial forest plantations. Therefore, it is more profitable to guarantee sufficient wood supply to the mill, discounting any calculated wood losses while operating within a framework of acceptable risks.

Unanticipated risks can include:

- Losses during dry years when growth is reduced and/or there is high mortality,
- Major losses due to large or extensive fires that may occur infrequently,
- Losses due to disease or insect damage to plantations,
- Losses due to social unrest or social problems.

For such reasons, it is important to anticipate incidental losses when making calculations as to the required forest area to assure the continued wood supply to the wood processing facility. Table 2-1 provides an example of how to calculate the forestry base for a pulp mill. On the line “plantation losses”, a 20% loss may appear high, but in reality it is quite common to find such losses in forestry projects, particularly during the first rotations. In forestry companies with many years of experience and several rotations of

management, losses of 15% during the life of the plantations are still common.

It is important to remember that the total biomass does not change by modifying the stand density nor by making thinnings. Biomass production depends on the soil/site capacity. However, planting too many trees or not enough trees can result in less commercial (useable) biomass than when having the optimum stand density for a given site.

In the case of a pulp mill, all commercial wood is used for pulp manufacture and rotations are relatively short; for example, six or seven years in the case of eucalypt or acacia plantations. On the other hand, a sawmill does not use all the wood for lumber production and requires an additional market for residues: Small trees removed in thinnings, tops of trees, trees with poor form that do not produce sawlogs, as well as slabs, sawdust and shavings in the sawmill. The rotations for sawtimber production are longer since the objective is to produce larger diameter logs for lumber. Table 2-2 provides calculations of the forest plantation base required for a sawmill. In the example, it can be seen that there will be a significant production of chips as well as sawn lumber. For a sawmill to be more profitable, it will be necessary to have markets for the chip wood as well as the sawn lumber.[3]

Table 2-1

How to calculate a forestry base for a pulp mill

Land Calculations	Comments/Calculations	Amount	
Pulp mill design capacity, bleached kraft pulp		300,000	AD tons/year
Average operating rate, %		95	%
Pulp mill production, bleached kraft pulp			
air dry basis	10 % moisture	285,000	AD tons/year
bone dry basis	0.0% moisture	256,500	BD tons/year
Woodyard wood-to-pulp conversion factor	6.4 m^3sub/BD ton		
Woodyard losses	5 %		
Wood delivered to mill woodyard		1,728,000	m^3 sub wood/year
Harvesting losses	5 %		
Plantation losses	20 %		
Annual plantation stumpage required		2,273,684	m^3 sub wood/year
Average site carrying capacity	150 m^3sub/ha		
Rotation length	8 years		
Mean annual increment	25 m^3/ha/year		
Net plantation area required		90,947	ha
Annual planting required		15,158	ha
Average harvest to replant interval	8 months		
Area in process of site preparation for planting		15,158	ha
Total area needed in plantation management		98,626	ha
Non-plantation land in timber estate	25 %		
Total land requirement		131,368	ha
Harvesting Information			
Annual area to harvest		12,126	ha
Average harvested volume		150	m^3sub/ha
Planting density		1,100	trees/ha
Tree mortality during rotation		25	%
Commercial trees at harvest		825	trees/ha
Average tree volume at harvest		0.18	m^3sub/tree
Average total tree height at harvest		23	m
Average tree diameter at harvest		16	cm

Table 2-2

How to calculate a forestry base for a sawmill

Land Calculations	Comments/Calculations	Amount
Sawmill design capacity,		25,000 m^3sub/year
Sawmill design capacity,	1 mbf = 4.53 m3 lumber	5,519 mbf/year
Average operating rate, %	95 %	
Annual lumber production		23,750 m^3sub/year
Annual lumber production		5,243 mbf/year
Log conversion efficiency	55 %	
slabs	31 %	
sawdust	14 %	
Annual chip production from slabs		13,494 m^3sub/year
Annual sawdust production		5,838 m^3sub/year
Annual sawlog consumption		43,182 m^3sub/year
Woodyard losses	5 %	
Annual sawlog requirement		45,456 m^3sub/year
Estimated sawlog production in plantations	25 % of total volume	
Harvesting losses	5 %	
Plantation losses	20 %	
Annual plantation production required		79,745 m^3sub/year
Average site carrying capacity	250 m^3sub/year	
Rotation length	20 years	
Mean annual increment	12.5 m^3sub/year	
Net plantation area required		6,380 ha
Annual planting required		319 ha
Average harvest to replant interval	6 months	
Total area needed in plantation management		6,539 ha
Non-plantation land in timber estate	25 %	
Total land requirement		8,719 ha
Harvesting Information		
Annual area to harvest		255 ha
Average harvested volume		250 m3/ha
Planting density		1,100 trees/ha
Tree mortality during rotation		25 %
Commercial trees at harvest		825 trees/ha
Average tree volume at harvest		0.30 m^3sub/tree
Average total tree height at harvest		25 m
Average tree diameter at harvest		20 cm
Sawlog volume		63 m^3sub/ha
Roundwood volume for chips		188 m^3sub/ha
Roundwood volume for chips		47,947 m^3sub/year
Total chip production from roundwood + slabs		61,341 m^3sub/year

*/ mbf = thousand board feet

sub = solid underbark Hay que hacer las notas de pie de cuadro a un tamaño similar a lo del cuadro

Forest productivity concepts

The site capacity is the maximum potential biomass production of a species on a given site, according to soil quality, precipitation and available sunlight. In agriculture there also exists a maximum crop production for a given site and the agronomist or farmer learns to know this capacity after planting several crops on the site. Similarly, there is a maximum wood volume or weight capacity for a species on a given site. The goal of

plantation management is to approach this maximum value in the shortest possible time utilizing optimum silvicultural techniques (Figure 2-6).

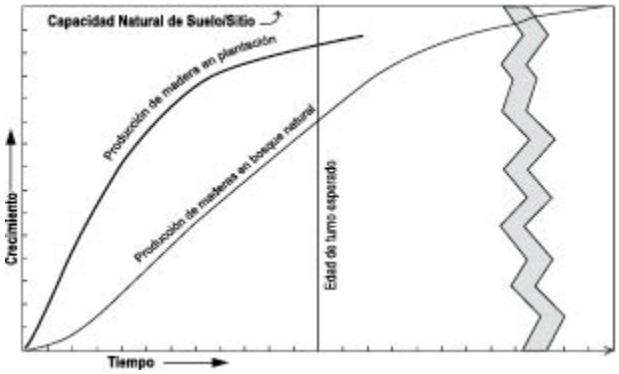


Figure 2-6. The soil site capacity is defined as the maximum productivity for a given site.

The objective of the agronomist is to sow the optimum seed density to obtain the maximum harvest. It is not worth planting more seeds than necessary; that only increases the crop density and reduces crop yields due to plant stagnation. Similarly, if a cattle rancher puts too many head of cattle on a lot, it does not increase meat production, rather the animals eat all of the available forage and, afterwards, suffer hunger and produce less meat than if the optimum number of animal units are maintained. In forest plantations there also exist optimum stand densities, according to the species and the desired product(s) (Figure 2-7). When too many trees are planted, the trees have smaller diameters and a larger percent of bark per cubic meter of wood produced. There is also the risk of stagnation, which reduces the overall wood production and can also result in premature mortality. When tree densities are too high, trees suffer stress from competition among themselves and run the risk of greater potential for disease or insect attack of weakened individuals. If the stand density is too low, it will take more time to reach the optimum site productivity. In summary, the silviculturist, as with the agronomist, must learn to manage a tree crop to maximize wood production on the forest properties.[4]

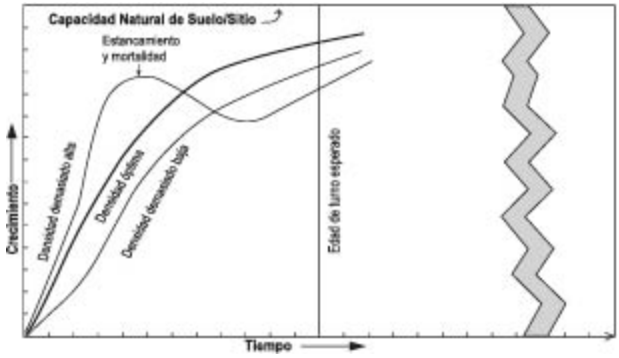


Figure 2-7. Optimum plantation spacing will result in maximum commercial wood production in the shortest possible rotation.

It is possible to increase the soil/site capacity through genetic selection and breeding for greater growth as well as by silvicultural practices such as soil preparation, fertilization and good control of grass and weed competition (Figure 2-8). In each case, it is a question of the investment cost for tree breeding, fertilization and weed control, etc., versus the additional gain that can be obtained. The best way to determine the growth benefits that can be attained is through forest research.

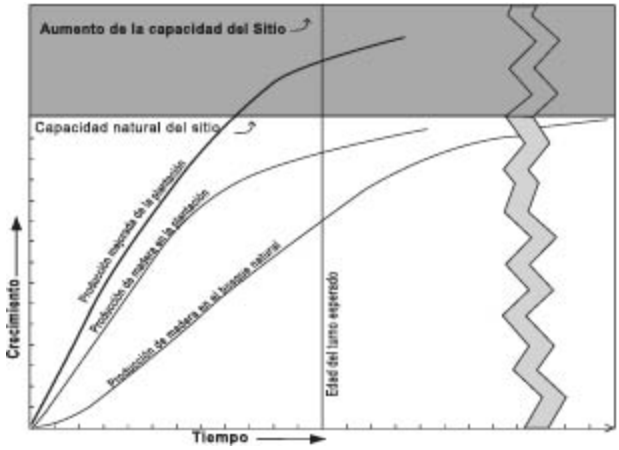


Figure 2-8. Certain silvicultural practices can increase the site capacity.

Forest growth is defined as the total commercial volume at the anticipated harvest age in m3/ha. The *Mean Annual Increment* (MAI) is the total volume (or weight) divided by the number of years of growth and is expressed as m3/ha/year (or tons/ha/year) (Figure 2-9). The MAI is not an absolute value; it varies based on the rotation length. The *Current Annual Increment* (CAI) is the growth during a particular period, for example, between year 3 and year 4. The point where the CAI curve crosses the MAI

curve is the point of maximum biological growth of the plantation. Nevertheless, this is not necessarily the best time to harvest the trees from an economic point of view. A plantation cost analysis needs to be made based on growth rates, harvest costs and transport costs in order to determine the optimum cost per cubic meter of wood delivered to the mill woodyard. The point where there is the greatest wood production at the least cost per cubic meter or ton is normally considered to be the optimum harvest age.

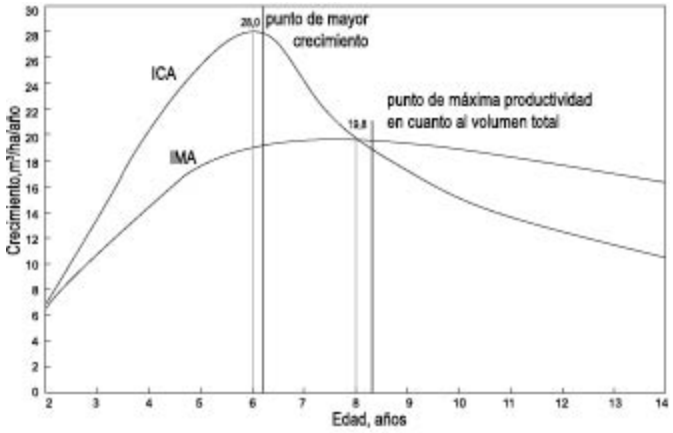


Figure 2-9. Relationship between current annual increment and mean annual increment.

Selection of species and the development of land races

Table 2-3 provides a list of tree species commonly used in plantations in the tropics and subtropics as well as in the temperate region of the Southern Hemisphere. Wood density data are also provided along with species growth rates. This is generalized information to provide the reader with an overview of the species most commonly planted. The values may vary for specific sites, based on latitude, longitude, soils, precipitation and other environmental factors.

Table 2-3

Common species used for industrial plantations in the tropics, subtropics and in the Southern Cone of South America

Botanical name	Family	Common name	Origin	density	pulpwood	sawlogs
Species primarily used for fiber and pulp production					years	years
Acacia crassicarpa	Mimosaceae	acacia	Australia	0,45	6 to 8	

Botanical name	Family	Common name	Origin	density	pulpwood	sawlogs
Acacia mangium	Mimosaceae	tropical acacia	Australia & New Guinea	0,44	6 to 8	
Acacia mearnsii	Mimosaceae	black acacia	Australia	0,55	6 to 8	
Eucalyptus dunnii	Myrtaceae	white gum	Australia	0,50	7 to 12	
Eucalyptus globulus	Myrtaceae	blue gum	Australia	0,65	6 to 8	10 to 15
Eucalyptus grandis	Myrtaceae	red gum	Australia	0,46	6 to 8	10 to 15
Eucalyptus nitens	Myrtaceae	shining gum	Australia	0,55	10 to 15	
Eucalyptus uro-grandis	Myrtaceae	eucalypt	hybrid	0,52	6 to 8	
Eucalyptus urophylla	Myrtaceae	Timor white gum	Indonesia	0,54	6 to 8	
Pinus caribaea var hondurensis	Pinaceae	Caribbean pine	Cental America	0,42	12 to 15	15 to 20
Pinus oocarpa	Pinaceae	ocote pine	Mexico & Central America	0,46	12 to 15	15 to 20
Pinus patula	Pinaceae	weeping pine	Mexico	0,44	12 to 15	15 to 20
Pinus radiata	Pinaceae	Monterrey pine	California & Baja California	0,44	12 to 15	15 to 20
Pinus taeda	Pinaceae	loblolly pine	Southern USA	0,45	12 to 15	15 to 20
Pinus tecunumanii	Pinaceae	pine	Guatemala	0,45	12 to 15	15 to 20
Species primarily used for solid wood products						
Acacia melanoxylon	Mimosaceae	blackwood	Australia	0,57		12 to 15
Araucaria angustifolia	Araucariaceae	Parana pine	Brazil	0,45		30 to 50
Cupressus lusitanica	Cupressaceae	cypress	Central America	0,42	12 to 15	15 to 25
Gmelina arborea	Verbenaceae	melina	South Asia	0,41		10 to 15
Pachira (Bombacopsis) quinata	Bombacaceae	red ceiba	Central & South America	0,32		15 to 25
Paraserianthes (Albizia) falcataria	Mimosaceae	albizzia	Indonesia	0,26		8 to 12
Populus sp (also hybrids)	Salicaceae	poplar, cottonwood	North America, Europe	0,30		10 to 15
Swietenia macrophylla	Meliaceae	bigleaf mahogany	Central & South America	0,44		20 to 25
Tectona grandis	Verbenaceae	teak	South of Asia	0,55		15 to 25
Toona ciliata	Meliaceae	toon	South of Asia	0,42		20 to 25
Hevea brasilensis	Moraceae	rubber	Brazil	0,50		25 to 35

Oven dry wood density = specific gravity, i.e., the oven dry weight divided by the green volume

Hevea (rubber) is planted for latex; the wood is a subproduct when overage plantations are eliminated

Pachira quinata has several common names: pochote (Costa Rica), saqui-saqui (Venezuela), cedro espino (Panama), ceiba tolua (Colombia)

Species selection is a function of the desired wood products, taking into consideration the environmental conditions were the trees are to be planted. If there are other plantations in the region, they can be very useful as indicators of species adaptation to the sites of interest. If there is no local information regarding which species to plant, the first step would be the establishment of a species trial, in the form of a *technical arboretum*, planting various species on those sites that are most representative. In an arboretum, the species of interest are planted along with other potential species and some locally existing species which serve as observational checks. A design that is simple but effective is to plant plots with 7 x 7 trees, or 49 trees per species, with a wide spacing (for example, 3.5 m x 3.0 m) to allow for good development. It is also a good idea to leave alleys between rows of plots to allow for the passage of people and vehicles.

The species are placed randomly within the arboretum (for example, don’t plant all of the eucalypt species beside each other). Optimum management practices are used in order to assure good survival and optimum growth. Figure 2-10 provides an example of an arboretum design. Species are selected which are most suitable to the particular environmental conditions, those of greatest interest in the region or those that are available in local nurseries. What is important is to plant all of the species in the arboretum (or a section of it) at the same time (at least within the same month) and to treat all species similarly, with the same spacing, the same weedings, the same fertilization, etc. In this way it is possible to see how each performs under uniform growing conditions and this also allows for visitors to evaluate differences with their own eyes, without the need for interpretations or explanations. Thus, the arboretum is a good device for public relations as well as being of scientific use.



Figure 2-10. Example of a technical arboretum design.

As has already been mentioned, besides its technical value, the arboretum is an excellent site for explaining reforestation concepts to visitors. A kiosk can be placed within the arboretum as a focal point where forestry personnel can explain details of the forestry program.

Signs are placed at the corners of plots with the botanical name of each species, the family, the common name, the origin and the planting date (Figure 2-11). The signs should be constructed of materials that will not deteriorate over the years.



Figure 2-11. A sign in an arboretum.

Species selection also depends on the planned use for the wood. This requires knowledge of the wood characteristics of the species proposed for planting.

When a large scale planting program is begun without sufficient information about species behavior, there are many unknown risks,

especially in the long term. Ideally, a pilot project is initiated first in order to gain experience on species behavior as well as allowing technical forestry personnel and labor to learn to work with the species correctly in forestry operations. This *learning curve* is fundamental to avoiding financial losses in new forestry projects. There exist numerous examples of companies and governments that began new reforestation programs without sufficient knowledge of species adaptation to the local environment and without trained technical personnel or labor; many of these ended in disaster. The popular belief that plantation species are more susceptible to disease and insects comes, in large part, from disasters resulting from projects begun without sufficient technical information and that were poorly implemented, rather than that the trees were more susceptible to pests (Zobel *et al.*, 1987).

Once it has been decided which species to plant, it is important to check the provenances or seed sources to determine the optimum genetic material to plant. This is done using a series of provenance tests (Figure 2-12). Once the tests are established and growing, selections are then made of the best individuals to be used as mother trees or seed trees for local seed production or as a source of cuttings, according to the propagation scheme planned. Such local selections of well adapted provenances or sources to the local environment are termed land races. Forest research has proven that the development of land races can greatly improve the productivity of tree species with reduced risks of losses due to damages, such as disease and insects, drought, high winds or others. Even though it may appear to be a contradiction to forest managers who want to start operational large scale planting immediately, it has been shown many times that by waiting for a few years to develop good seed sources and land races the overall productivity of the initial plantations will increase and losses will be avoided that have often occurred when a full scale operational planting program is initiated without first developing the necessary field experience and management techniques.



Figure 2-12. Marked differences in forking tendencies between two sources of *Acacia ariculiformis* (left and right) in a provenance test in Sabah, Malaysia.

Example: In the 1990's, a company in Southeast Asia initiated plantations of *Acacia mangium* using low-cost seed that was collected from local trees, but of a provenance originally from Australia. After planting more than 100,000 ha with the local seed, researchers discovered through provenance tests that the sources of *Acacia mangium* originally from Papua New Guinea had superior growth rates to the local seed. Unfortunately, the available land area had already been planted with the mediocre stock and it was not possible to use the information developed by the research personnel until the initial plantations were harvested at rotation age and land was again available to use the better material from Papua New Guinea.

[1]After a field analysis, it is advisable to take samples to a soils laboratory for a complete analysis.

[2]/ The pH level is an indicator of soil acidity. A pH value of 7.0 is neutral. Soils with values higher than 7.0 are alkaline and those with values less than 7.0 are acid.

[3]A sawmill cannot just sell lumber and throw away the chips, the same as a dairy cattleman cannot sell the cream and throw away the milk. This has been a chronic problem for many small sawmills that have not found markets for the sale of chips or other types of subproducts from the waste wood.

[4] Plantation density can affect wood quality, from the point of view of physical/mechanical properties, such as the proportion of sapwood to heartwood, the modulus of rupture (MOR) and the modulus of elasticity (MOE). With more trees/ha, longer rotations are required to produce trees of a desired diameter for sawlogs and, for this reason, there will be a greater proportion of heartwood and more growth rings in the logs.

3

Plant production and forest nurseries

Seed production
Clonal production
Forest tree nurseries
Systems for producing seedlings
Substrates
Application of mycorrhizal fungi in the nursery
Application of *Rhizobium* spores to acacias in the nursery
Plant production in the nursery

Seed production

When a new forestry project is initiated, it is usually necessary to buy seed. Later, seed can be produced locally. Forest research is important in this phase by making provenance tests and evaluating the development of trees from different seed sources when planted in the local environment.

A simple method for seed production is to select some of the best existing local plantations and convert these into seed production areas (SPA). The area is thinned heavily, leaving only the best trees standing and eliminating the rest, while reducing the stand density to 100 trees per hectare or less, depending on the age of the plantation (Figure 3-1). The site is fertilized to stimulate greater seed production. Seed from the seed stand is a local landrace, adapted to the local environment, but it really cannot be considered genetically improved. If the stand was originally planted with 1000 trees/ha and the thinning reduced the density to 100 trees/ha, the selection intensity is just 1 in 10, which is not an intensive selection, simply a local seed source.



Figure 3-1. A seed production area of *Pinus oocarpa* in Colombia.

When researchers establish open pollinated progeny tests, they can evaluate individual families of seed collected by individual mother tree or by provenance. Such tests can produce useful information as to the growth and development of the seed sources and such tests can later be converted to seed production areas. This can be done by leaving just a few trees standing of the best sources or provenance, thereby converting the research trial into a SPA. Seed from the SPA is considered to have more genetic selection than seed produced in a plantation converted to a seed stand.



Figure 3-2. A seed production area of 4-year-old *Eucalyptus grandis* in Colombia, created in a provenance test where only the best trees of the best provenances were left standing.

Eventually, when many local trees have been selected in progeny tests, these can be placed together in a seed orchard, where they are allowed to cross among themselves, producing seed that is of a better genetic quality (Figure 3-3). After evaluating crosses made among these mother trees by controlled pollination, further tests can be established with seed where both parents or donors are known. Such control pollinated progeny tests can produce useful information that can be used to make thinnings or roguings of the seed orchards, leaving only those trees that have been proven

superior through progeny testing. This is another step along the process of tree breeding and genetic improvement.



Figure 3-3. A grafted (clonal) teak seed orchard in Java, Indonesia.

Tree improvement can continue during several generations of tree selection, controlled crossing and progeny testing. To carry out this work, it is necessary to have personnel trained in tree improvement as a part of the forest research team. When this is done correctly, research can be very profitable in the long run. Once local land races of improved seed have been developed, these are permanent improvements that can be used in all future plantations within the same geographic region.

The collection of fruits and seeds varies according to the physiology of the reproductive process of each species. Many pine species require two years for the pine cones to mature. Some pines, such as *Pinus taeda* and *P. kesiya* release the seeds as soon as the cones mature and it is necessary to collect the cones just before they open on the trees. Other pines, such as *Pinus patula* and *P. oocarpa*, have serotinous cones which remain closed on the tree and allow for a longer window when the cones can be collected with the seeds inside. In each case, the cones are clipped from the tree branches manually (Figures 3-4, 3-5). Care must be used when removing the cones so that the branches are not damaged, since the immature conlets that will ripen a year later are also growing on the extremities of the same branches. When cones are collected in a seed orchard, they are kept separate by mother tree (Figure 3-6).



Figure 3-4. Cones being collected from pines in a seed orchard in South Africa. A sigmoid hook is used to free the cones from the branch without damaging the immature conlets.



Figure 3-5. A sigmoid hook used for removing cones has two sharp edges.



Figure 3-6. Cones that are cut off in the tree are collected by mother tree and placed in separate bags for processing.

In the case of the eucalypts, branches with seed capsules are cut off and the capsules then removed from the branches that fall to the ground. *Gmelina* has drupes that are collected after these fall to the ground. The flesh or pulp is removed from the stone inside using a coffee depulper or similar machine. Capsules of species in the *Bombacaceae* family, such as those in the genera *Bombacopsis*, *Pachira* or *Ceiba*, are cut from the trees when they are mature and turn brown and the seeds are separated from the wool (kapok) by hand. In the case of legume pods, such as those of the acacias, these are picked and then allowed to dry and open in the nursery in order to remove the seeds (Figure 3-7).



Figure 3-7. *Acacia mangium* pods are curley and each contains several seeds.

In the nursery or seed processing center, the fruits, cones or capsules are opened and the seeds removed. For many tree species, trays are used for drying and seed removal (Figure 3-8). An efficient system is to make one meter square trays that can be stacked on a base that has wheels to facilitate the easy movement of the units outside in the daytime and inside at night or when there is a threat of rain. When the seeds are large, a fine screen is fastened in place on the bottom of the trays to allow for air movement (Figure 3-9), but for very small seeds, as with many eucalypts, a metal sheet is used as the tray base.



Figure 3-8. Trays in Honduras for drying pine cones prior to seed extraction.

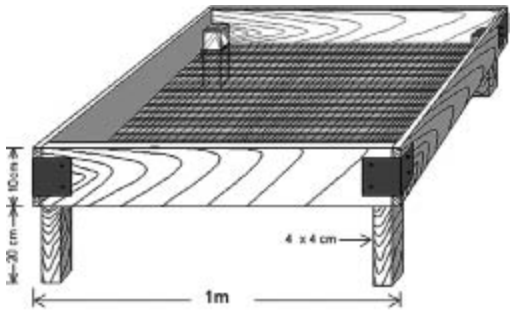


Figure 3-9. Details of the drying tray construction.

Once the seed is extracted and dried for storage, the collection data is written on a tag that is attached to the outside of the storage jar, along with a second tag that is placed inside of the container (Figure 3-10). A registry of all existing seed in storage is kept, including locally processed seed as well as purchased seed, using a format where all seed entries and removals can be noted. A recommended source for further information about processing and handling of forest tree seeds by small producers is *The Forest Tree Seed Manual* (Ladrach, 2006a).

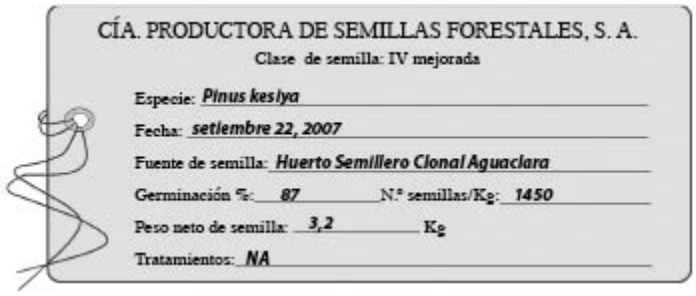


Figure 3-10. An identification tag for seed sales.



Figure 3-11. Comparative sizes of seeds of several tree species.

Clonal production

Clonal propagation is an asexual reproduction method for plants. All plants in a clone are genetically identical and each of these is called a *ramet* of the clone. This method has been commonly used for the production of flowers and fruit trees for a long time. Most roses and oranges are produced by asexual propagation. In many cases the clones of flowers and ornamental trees are patented and have commercial names; the owners of the patents have exclusive rights to their use and receive royalties for their reproduction by others.

In the 1970's, large-scale commercial production of clonal eucalypts was developed by the French researchers Drs. Henrí Chaperon and Deni

Destremau, of AFOCEL (*Association Forêt-Cellulose*, Francia) (Chaperon, 1984). These men worked in the Congo, where they were able to produce some hybrid eucalypts that adapted well to the sandy savannahs and, later, the clonal propagation was used to establish tree plantations with those hybrids.

There are several advantages to clonal propagation of plants, including forest trees:

- All material is identical and uniform. It is possible to capture the exact color of a rose, the exact taste of an orange, or the exact wood quality of a tree and all ramets of the same clone will have these identical characteristics. In genetic terminology, clonal propagation captures the "additive genetic traits" as well as the "non-additive genetic traits" of an organism, whereas sexual reproduction (by seed) only captures the additive traits.
- When selections are made of "plus" or superior trees through progeny testing, the genetic gains can be maximized by establishing clonal plantations with greater gains than can plantations established using seed obtained from the same trees. Thus, clonal forest propagation allows for a quicker recovery of the research investment in the form of improved forest productivity.
- Some important non-additive traits such as resistance to specific diseases, drought resistance or resistance to freezing temperatures can be captured by clonal reproduction, which may not be possible using seed.
- In some cases, one tree species or another may not be optimum for planting in a particular environment, but crosses between those species can produce hybrids that are then evaluated in clonal progeny tests. By evaluating the progeny tests, selections can be made of the best hybrid individuals and these then used for commercial planting through clonal propagation. The seeds produced by such hybrids will have an abundance of variation including some individuals that appear to be similar to one species and others that appear to be more like the other, but such seed origin material would not necessarily have the good growth and adaptability desired for the intermediate environmental conditions. In such cases, clonal propagation is a method for utilizing the selected hybrids in operational plantings.

Propagation using cuttings is a process that is quite similar for all tree species, although there are some specific adaptations for one species or another. Poplars (cottonwoods) and willows can be propagated simply by planting cuttings into moist soil. Willows and poplars are grown in the nursery and the long stems are cut into lengths of approximately 50 cm and these are then placed in the soil in the plantation. From there, the willows and poplars develop normally and become trees. This is a common reforestation practice for willows and poplars in Argentina, in the South of Brazil and also in South Africa. In the case of the eucalypts, *Gmelina*, the acacias and teak, succulent stems are collected from plants in a clonal garden and cut into pieces or cuttings and rooted in a shade house. Once those cuttings have formed roots, the plants are transferred to the nursery and cared for the same as plants of seed origin until they have grown to the proper size for transplanting to the field. In the case of pine, clonal propagation by branch cuttings is effective only for a few species. Clonal propagation of shoots is used for *Pinus radiata* in Chile and in New Zealand. In Chile, the shoots are cut from trees in a clonal garden and placed in nursery beds where they root and develop as plants (Figures 3-12 & 3-13). Forestry companies in Misiones and Corrientes provinces in northern Argentina plant several million trees of *Pinus taeda* each year using cuttings obtained from clonal hedges that were started by planting seed from genetically superior trees. Those pines root, but require the use of just the tip shoots of the hedge plants, whereas with many of the broadleaf species multiple cuttings can be produced from a shoot or stem, even without the terminal shoot.[1]



Figure 3-12. In Chile, shoots from a clonal garden are placed directly in nursery beds where they root to produce material for operational planting.



Figure 3-13. A shoot of a cutting of *Pinus radiata* that has rooted.

A clonal garden is a site where clonal stock of desirable trees is planted to generate vegetative material for reforestation. In the case of the eucalypts, cuttings are harvested from the stock plants in the clonal garden and these are placed in a rooting medium in a shade house where relative humidity and temperature are controlled. To promote rooting of the cuttings, the leaves are kept moist by using misting water nozzles that keep the inside environment as close to 100% relative humidity as possible.

There are several classes of clonal gardens. The type to use depends on factors of climate, the cost of production and the amount of planting stock required. The four most commonly used clonal gardens for forest tree propagation are the following:

The macro-clonal garden is a method used where operational planting is done during the rainy season, but not during the dry season. Spacing among the planted stock can be 1 m x 2 m up to 2 m x 3 m and the stock is allowed to grow normally during most of the year. The site is fertilized, but not irrigated if it is at a long distance from a nursery or a source of water. When cuttings are to be harvested, the clonal stock is first pruned to eliminate large, woody stems (Figure 3-14). When new, succulent material has sprouted, this is collected for rooting. The collection of sprouts continues every two or three weeks until there is sufficient material to supply the nursery requirements. Afterwards, the clonal stock is allowed to rest and grow until the next year’s season for cutting production.



Figure 3-14. A macro clonal garden of *Gmelina arborea* in Venezuela where the stock has just been pruned to stimulate sprout formation for cutting production.

The traditional clonal garden is common in many parts of the tropics and is used for teak, acacias, *Gmelina* and for the eucalypts (Figures 3-15, 3-16). This method is also used for radiata pine in Chile and New Zealand. The clonal garden is located adjacent to the nursery, where the cuttings will be rooted. Normally, the clonal stock is planted in clonal (family) blocks at a spacing of 1 m x 1 m or 0.5 m x 1 m, according to the species, while leaving wider aisles or passageways between blocks to allow for people and carts to travel when collecting the cuttings. The clonal gardens are watered and fertilized to stimulate shoot growth. For some species, hormones are used to improve rooting of the cuttings. A common growth hormone used is IBA (indol-buteric acid). With experience, hormone use is often reduced or eliminated altogether. In climates where it is possible to plant year ‘round, the shoots are harvested every two or three weeks when they are just beginning to lignify, while leaving one lateral branch on the clonal stock to sustain its growth.



Figure 3-15. A traditional clonal garden of *Gmelina arborea.*



Figure 3-16. A teak clonal garden where the clonal stock is bent over to produce a larger number of terminal shoots for rooting.

A mini-clonal garden is one established in trays or boxes beside the nursery or in a shade house, depending on the local site conditions (Figure 3-17). The planting stock is placed in a substrate with well drained sand underneath and using drip irrigation between rows of plants. The stock is planted at 10 cm x 10 cm or up to 20 cm x 20 cm, depending on the species and local conditions. The succulent shoots are harvested approximately every two weeks, and for many species, the succulent shoots can be rooted without hormones. This is currently the most common method of production of eucalypt cuttings in Brazil.



Figure 3-17. Collecting shoots for rooting in the nursery. This is a mini clonal garden of the hybrid "uro-grandis" in Brazil.

A micro-clonal garden is established in tubettes in a greenhouse with misting irrigation and where the shoots are harvested just when they begin to break out of the buds. The material is very soft and is rooted in the nursery without hormones. This method is effective to produce a lot of material in very little space, but is labor-intensive and is seldom used for operational tree production.

Forest tree nurseries

Industrial plantations are established using trees produced in nurseries. [2] The forest tree nursery is a strategic element in the success of the reforestation program. The quality of the trees produced has a long-term effect on the behavior and growth of the trees that are transplanted to the field.

It is important to select a good site for the construction of a new tree nursery. One of the principal requirements is to have a source of water of acceptable quality for plant production and that there is sufficient water available to supply projected needs at maximum nursery capacity. Water can come from a lake, a stream or a well, but it is important to be certain that there is the abundance and quality needed during the periods of maximum water consumption, or during the worst droughts anticipated in the locality. Water samples need to be analyzed chemically to be certain that there are no undesirable or toxic elements for tree growth. Ideally, irrigation water should have a residual sodium carbonate level below 1.25 ppm and a pH of about 5.5 (Davey, 1984). At this pH, there is good absorption of nutrients, especially phosphorus. When water is very acid (pH lower than 5.0) there can be problems of nutrient absorption due to excesses of iron and/or aluminum, potential bacteria problems and slower initial tree growth. When the water is alkaline, with pH values above 7.0, there can be problems with nutrient absorption due to an excess of calcium, problems with fungi in the leaves and soft tissues of the trees and a lower growth rate than with the optimum pH.

It is possible to modify the water pH, but it can be costly and requires the proper equipment (Figure 3-18). When the water pH is too high, it can be lowered by mixing acids with the water, the most economical being sulfuric acid. When the water pH is too low, it can be raised by adding lime to the substrate, but this also requires care so as to not cause other nursery problems by chemical imbalances within the substrate.

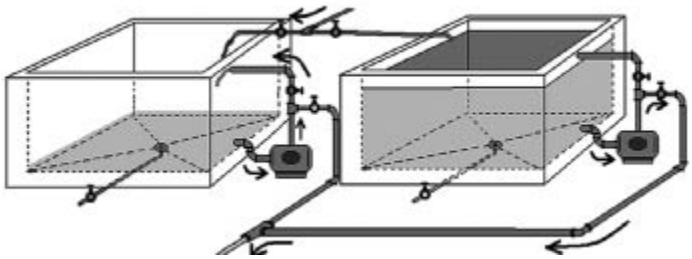


Figure 3-18. When water is alkaline, the pH can be reduced by adding sulfuric acid to the tanks. While water is being used from one tank, the incoming water is acidified in the other tank.

A tree nursery requires labor and it is important to construct the nursery where it is possible to hire workers from neighboring localities.

The nursery site needs to have sufficient space for all the necessary elements as well as for any future expansion. All too often, nurseries are located without considering the possibility of future expansion and later it becomes more expensive to relocate the nursery to a new site rather than to have built the nursery on a site with possibilities for expansion. Soil quality is not a critical factor for nursery location when the trees are to be grown in containers, but ideally the site should have good internal soil drainage, such as where there are soils with textures of sandy loam to sand (Davey, 1984). The nursery site should have a slope of between 1% and 2% across the nursery beds for drainage, and between 0.1% and 0.2% slope parallel to the beds (Davey, 1984). It is common to first level the nursery site using land shaping equipment so as to have a level site with the desired optimum slopes. In locations where there are hills without level areas, some companies have actually leveled the tops of hills for nursery construction. Nurseries can be built along the terraces of slopes at a lower initial cost, but it is more difficult to move materials up and down slopes to the terraces and this can be more expensive in the long term. The best alternative is to invest the necessary capital to acquire an appropriate nursery site in the beginning in order to minimize operating costs over time.

A tree nursery requires a source of electrical power, mainly for pumping water to the growing beds. Ideally the nursery should have access to a regional or national electrical system. The alternative is to generate electricity locally, using diesel generators.

Other electrical needs in the nursery include the following: Outdoor and office lighting, security lights around the periphery of the nursery, air conditioning in the offices, activation of solenoid valves for automatic water applications, timers for misting shade houses and power to a cold

room for storage of tree seeds. Long term seed storage does not have to be located at the nursery and, if the electrical source is not reliable it is best to locate the cold storage in another place where there is reliable electricity available.

Backup systems are needed for electricity and water pressure. If the nursery is connected to an electrical grid, it is important to maintain emergency electrical generators in case of a failure in the electrical grid. A backup diesel motor for the water pump is also needed whether water is supplied using an electric or a diesel pump. Redundancy for electricity and water systems is the means to avoiding losses of nursery stock.

Water pressure to move water through the nursery pipes can be generated by pumps or by elevated water tanks. The ideal solution is to mount an elevated tank to produce the needed water pressure for rooting shade houses as well as for irrigation in the nursery. A pressure of 40 psi (2.8 kg/cm2) can be attained with a tank that is 30 m above the nursery growing area. Most irrigating systems and misting systems in the market are designed to work at this pressure. When the water pressure is lower, it is possible that the irrigating or misting elements will not work to capacity. In large nurseries, it is a common practice to build a 50,000 liter elevated tank along with a 200,000 to 500,000 liter ground tank to supply the elevated tank (Figure 3-19).



Figura 3-19. A 50,000 liter water tank at 30 m height in a forest tree nursery.

It is always a good idea to locate the nursery as close to the forest properties as possible, but this is less important than having access to water and labor. When necessary, the nursery trees can be transported quite long distances to the field planting sites with proper protection and care.

The following are key elements for nursery construction: (Figures 3-20 to 3-25)

- Area for plant production
- Area for seed germination and/or vegetative propagation of cuttings
- Area for a clonal garden for clonal cutting production
- Area for the water well, or a water intake from a stream as well as for water storage tanks.
- Water pipes for bringing water to the nursery and for distribution within the nursery.
- Office
- Changing room for workers, including lockers and bathroom facilities and septic tank.
- A lunch and rest area for workers under roof.
- Separate storage building for chemicals (fertilizers, herbicides, insecticides).
- Fuel tanks to store fuel for diesel motors.
- A store room for parts and tools, including parts for pumps, tubing, valves and hand tools.
- A storage area for plastic tubettes, trays and other nursery production materials.
- Area for storing substrate materials (peat, sand, decomposed tree bark, rice hulls, sawdust, etc.).
- A shed for preparing the growing medium, for filling tubettes and/or for producing rooted cuttings, as well as a work area to prepare chemicals that are used in the nursery.
- Area for washing tubettes for reuse.
- Internal access roads and paths.
- Space for future nursery expansion.
- Loading dock where trees can be loaded on trucks for dispatch to the field.
- Area for the temporary storing residual or waste materials from the nursery (plastics, rejected planting stock, other waste materials.)

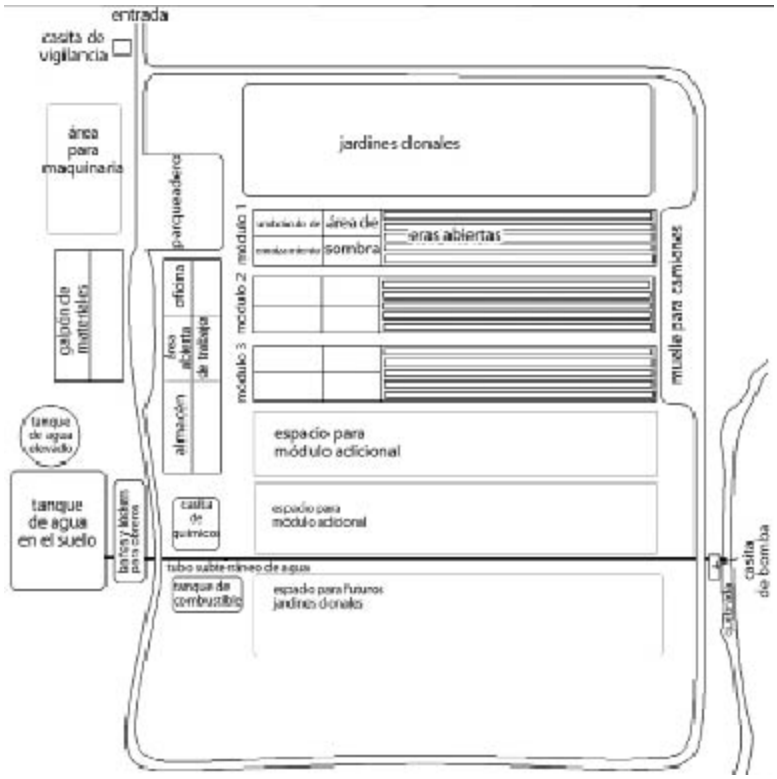


Figure 3-20. Layout of a forest tree nursery showing the distribution of key elements.

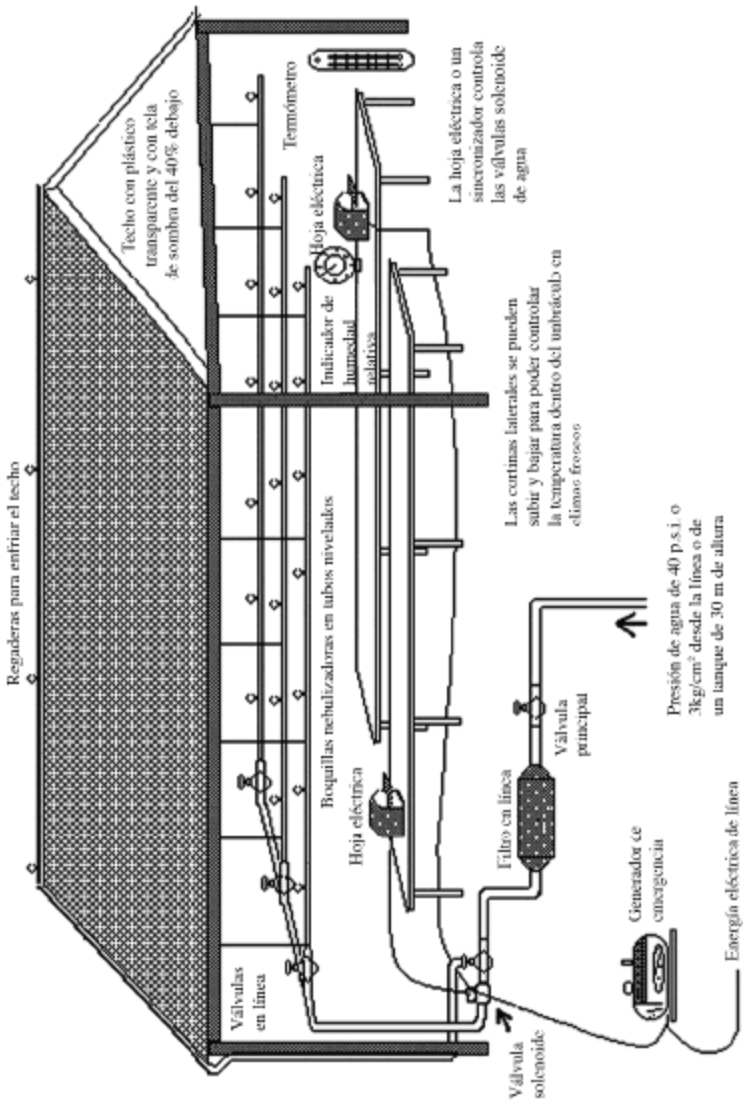


Figure 3-21. Layout of a misting shadehouse for the production of rooted cuttings.

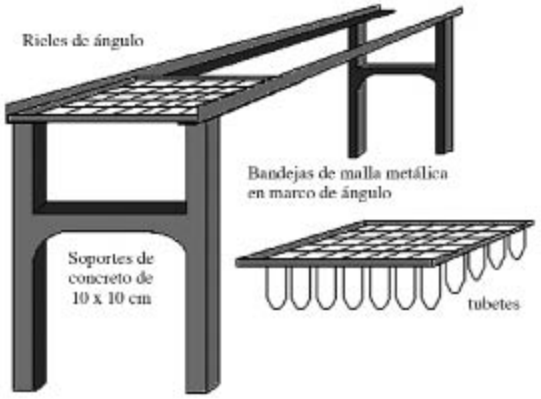


Figure 3-22. A metal screen to support tubettes in the nursery support frames.



Figure 3-23. Production of eucalypts in tubettes placed in metal screen frames.



Figure 3-24. A misting shadehouse for rooting eucalypt cuttings in Brazil. The misters are activated for a few seconds every few minutes with a timer to maintain a high relative humidity within the shadehouse.



Figure 3-25. Once rooted, the plants are moved outside to c ontinue their development. The overhead cart runs on lateral rails and it can be used for various purposes during the tree growing process in the nursery.

Systems for producing seedlings

Plastic bags

Many forest tree nurseries in the Twentieth Century initially used plastic bags for containerized seedlings, following procedures developed for raising vegetables, coffee plants and flowers. However, this method has had many problems and currently is not considered an acceptable method for producing tree seedlings on an industrial scale.

Plastic tubettes

The method most utilized for growing tropical trees in nurseries on a commercial scale is the use of plastic tubettes. The tubette produces a root plug or root mass with well formed roots and is an easy unit to handle during transport and planning. Tubettes can be round or square, but they all have common features: all are conical with the smallest diameter at the base and with a bottom hole for water drainage and for root emergence. Tubettes can be of different sizes and they normally have a useful life of five or more years.

Tubettes volume is normally between 60 ml and 100 ml. The 60 ml units work well on sites where there is good coordination between the nursery and field planning. The 100 ml tubette provides for greater substrate volume and more moisture and works well on those sites where the trees are delivered to distant sites, such as in the mountains where the trees are first left in a temporary holding area where they may be kept for several days and then, afterwards, carried to the field on animals or by tractor.

Tubettes are individual units; this allows the nurseryman to control spacing of tubettes in the nursery. The interior of the tubettes has vertical plastic ribs that run the length of the tube and which are designed to train lateral roots to grow down the inside in order to avoid problems of root spiraling within the root mass (Figures 3-26, 3-27).

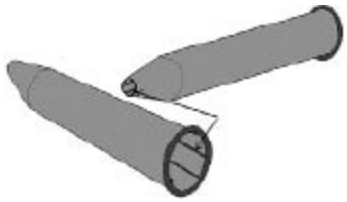


Figure 3-26. Tubettes have internal ribs that train later roots downwards.



Figure 3-27. A rooted teak cutting in a nursery in Indonesia.

An appropriate substrate should be used for growing seedlings so that the root plug can be easily removed from the tubettes when the trees are ready to go to the field. Tubettes are placed in trays or in screen frames during the nursery production phase, with these held in frames at a comfortable height for easy access for workers doing routine tending and maintenance. The roots grow out of the bottom of the tubettes and are self pruned in the air. This method allows for good drainage to avoid water puddling within the containers.

Stump seedlings

The stump or *pseudoestaca* is another method for producing trees in the nursery (Figures 3-28 to 3-32). With this method, the cuttings or seeds are placed in nursery beds and allowed to grow to a good height, sometimes over a meter tall, so as to obtain a thick stem and a well formed pivot root. Then, they are lifted and pruned, both top and bottom, leaving a stump for planting bare root. This method works well with some broadleaf species that produce thick stems, such as *Gmelina*, teak, guayacan (*Tabebuia* sp.) and red ceiba (*Pachira quinata*). This method is not used for species with delicate or thin stems, such as the eucalypts or acacias.

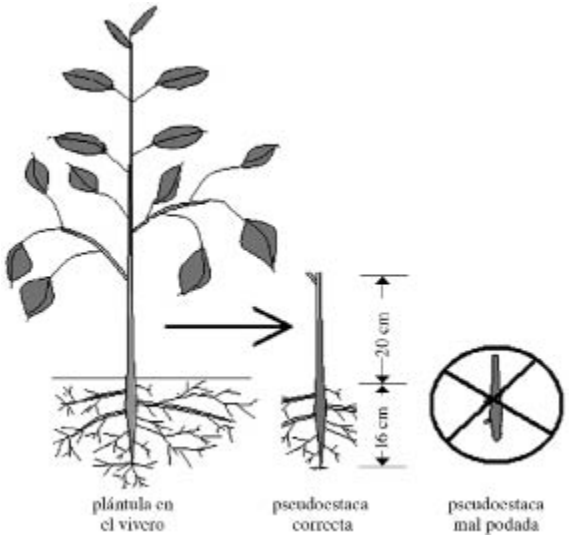


Figure 3-28. Stumps are formed by pruning the top and roots of a seedling. The primary roots and part of the stem are left intact.



Figure 3-29. Production of *Bombacopsis quinata* (pochote) with seeds in nursery beds in Costa Rica. The seedlings can be planted bare root or as stumps.



Figure 3-30. *Gmelina* stumps with the tops and roots correctly pruned. The roots are dipped in a clay slurry to protect them from drying during transportation to the field.



Figure 3-31. *Gmelina* stumps placed in plastic boxes and covered with moist burlap cloth to protect them from drying during transportation to the field.



Figure 3-32. *Gmelina* stumps incorrectly pruned, eliminating all the tops and all the roots. This results in a high rate of mortality and slow initial growth after planting in the field.

Bare root seedlings

Bare root planting has been successful for some species in the tropics and is commonly used for conifers in temperate regions. Seeds are sown in nursery beds and left to grow, the same as for stump seedlings, but they are not grown as large. Later, the seedlings are lifted with all of their roots, carefully removing the substrate and transporting the trees to the field in covered containers to protect them against wind and drying. After lifting the seedlings it is important to transplant them as soon as possible to minimize drying effects. This method of reforestation has been used successfully with cypress (*Cupressus lusitanica*) as well as with several tropical pines in the Andes region of Colombia. It has also been used with *Pinus caribaea* var *hondurensis* in the Eastern Prairies of Venezuela, where up to 30,000 ha have been planted per year by this method (Figures 3-33, 3-34). Today, the

method is seldom used due to the need for the close coordination between the nursery and the field operations and the high risk of losses when rainfall is unreliable. In Costa Rica, pochote is planted bare root.



Figure 3-33. Caribbean pine grown bare root in Venezuela. When lifting the seedlings, they are covered with a clay slurry to protect the roots against drying.



Figure 3-34. Caribbean pine seedlings are carried to the field in trucks completely covered to protect the trees against heat and wind during the trip.

Substrates

A common substrate used with containerized seedlings is decomposed tree bark. In Brazil, there are industries that produce the nursery substrate commercially based on tree bark, where the bark is ground, nutrients are added to promote decomposition, and the material is kept in piles until fully decomposed to an ideal texture for nursery use (Figures 3-35, 3-36). Then, the material is bagged for sale.

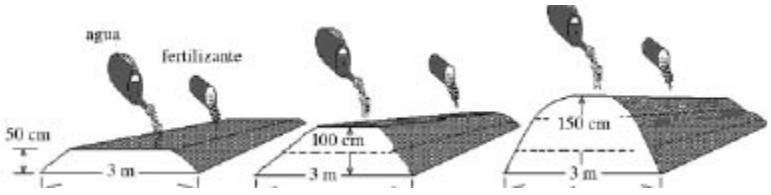


Figure 3-35. Ground bark is piled in beds 50 cm high where water and fertilizer is applied. Another layer of ground bark is applied over this and the process is repeated until the piles are 1.5 m tall. The

beds are kept moist, but not too wet. Every 10 to 14 days the beds are thoroughly mixed. The bark decomposes within three to six months, depending on the local environmental conditions.



Figure 3-36. A rooting substrate made of decomposed pine bark.

Vermiculite is an expanded mineral and it is used in mixes with organic material since it has a high water absorption capacity. Other substrates used in forest tree nurseries include locally available materials such as burned rice hulls, sawdust, ground peat, sand and organic soils.

Good compaction of the substrate in containers is important so that the root plug maintains its form and rigidity when removed from the container. The substrate should be porous in order to retain water and allow for easy root movement, but it must be sufficiently compacted to maintain the root plug intact so that roots are not damaged during the transplanting operation in the field. There are two standard methods for compacting substrate, one by positive pressure and the other by vibration.

To fill the tubettes, trays with holes are used to hold the tubettes. The tubettes can be filled with manual or mechanized systems. After filling the tubes with substrate, it is compacted using a form with fingers for each tubette (Figures 3-37 to 3-39). This process requires at least two compactions to obtain a uniformly compacted substrate in the tubettes (Figure 3-40).

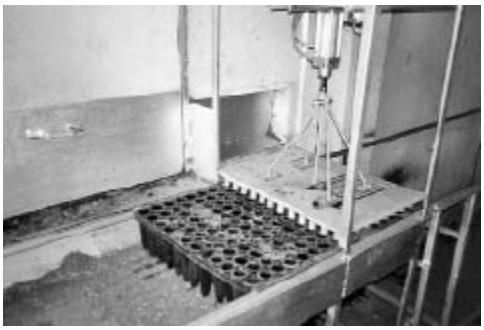


Figure 3-37. When filling tubettes with substrate in a nursery in Mexico, this device is used to compact the substrate in the tubes.



Figure 3-38. Detail of the substrate compaction fingers.

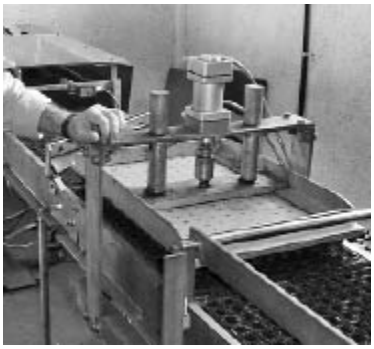


Figure 3-39. A substrate compactor working in a nursery in Indonesia.

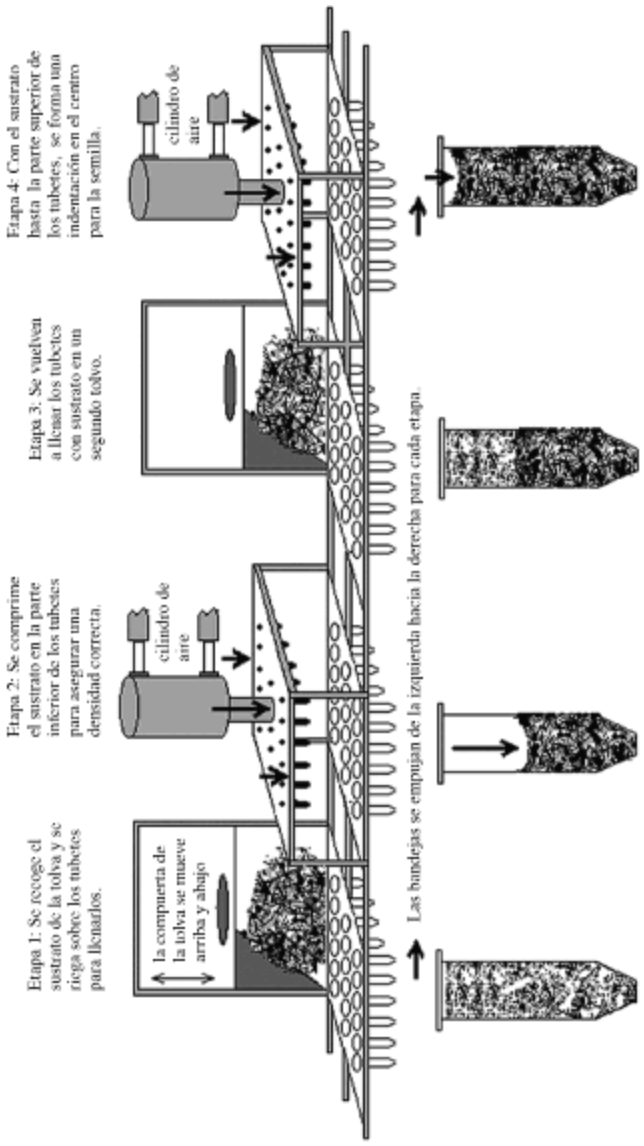


Figure 3-40. This filling station assures a uniform substrate compaction density in the tubettes.

The other method is to mount a vibrating table beneath the frame where the trays of tubettes are filled. The tubettes are first filled by hand; the vibrator is then turned on for a few seconds and then turned off. Afterwards, the tubes are topped off again with substrate and the vibrator is activated again. This produces a uniform compaction of the substrate. The vibrator works using an eccentric wheel connected to an electric motor and the vibrating table is connected to the wheel. The vibration is rapid, but the movement of the eccentric wheel is minimal (Figure 3-41).



Figure 3-41. A vibrating table is activated with an electric motor connected to an excentric wheel that makes the table vibrate rapidly to compact the substrate in the tubettes to a uniform density.

When the root plug is not sufficiently compacted in the tubettes, the seedling roots separate from the substrate when removed from the tubettes. This results in a reject seedling, not acceptable for field planting (Figure 3-42). Even when the root plug is slightly bent it is no good because it makes the job of planting the seedling correctly much more difficult for the laborer. If the roots are bent during planting, the tree will have abnormally poor growth compared with trees planted correctly.



Figure 3-42. When the substrate is loose and not properly compacted at the nursery, the root plug of the seedlings is easily damaged when removed from the tubettes.

Application of mycorrhizal fungi in the nursery

Higher plants, including trees, develop symbiotic relationships between their roots and some species of fungi. Such relationships are known as

mycorrhizae and are of mutual benefit to the plants and the fungi. Mycorrhizal fungi help the tree absorb water and nutrients from the soil and, in exchange, the tree provides food to the fungi. In some cases, mycorrhizal fungi protect the plants and trees from attack by other fungi or other pathogenic soil agents.

Ectomycorrhizae is the symbiotic relation between plants and fungi, where the fungal hyphae form sheathes around the feeder root surfaces but do not penetrate the plant root cells. Most of these fungi are ascomycots or basidiomycots. Fruiting bodies, i.e., the mushrooms, form above the soil surface (Figure 3-43). Some of these fungi are poisonous to animals, such as some species in the genus *Amanita*, which are mycorrhizal (Figure 3-44). The fungus *Pisolithus tinctorius* is one that is well known for its ability to adapt to pines and eucalypts and to increase productivity in soils that are very acid and nutrient deficient (Figure 3-45) (Cordell & Webb, 1980; Marx, 1991). *Pisolithus* is common in many parts of the tropics and is easily distinguished by the formation of separate cells within the fruiting body, something not found in other types of mycorrhizal fungi. *Thelephora* is another common genus associated with mycorrhizae in trees (Figure 3-46). Among tree families that form ectomycorrhizal symbioses are *Pinaceae* (pines, fir and spruce), *Fagaceae* (oaks, beeches), *Betulaceae* (birches), *Salicaceae* (willows and poplars), *Juglandaceae* (walnut), *Myrtaceae* (eucalypts, guava) and *Ericaceae* (rhododendron) *(*Mukerji & Sharma, 1996). The *Dipterocarpaceae* family (meranti, kapur, keruing) is also ectomycorrhizal. Pines and oaks are obligate mycorrhizal; they cannot grow and prosper without the fungal association (Figures 3-47, 3-48). Many other tree families can utilize ectomycorrhizae or endomycorrhizae, including the eucalypts, *Gmelina* and the acacias. When planting mycorrhizal tree species on a site for the first time, it is often necessary to make certain that the tree roots are infected with the necessary ectomycorrhizal fungi. This is a standard practice in tree nurseries.



Figure 3-43. Fruiting bodies of ectomycorrhizal fungi under a pine plantation in Colombia.



Figure 3-44. A fruiting body of an ectomycorrhizal fungus in the genus *Amanita*. These mushrooms are known to be poisonous to animals, but are beneficial for trees.



Figure 3-45. A fruiting body of the ectomycorrhizal fungus *Pisolithus tinctorius* under a plantation of euclaypts in Brazil.



Figure 3-46. Fruiting bodies of the ectomycorrhizal fungus *Thelephora* (small purple dots) under a one-year-old *Acacia mangium* in Indonesia.



Figure 3-47. These roots of *Pinus caribaea* are infected with ectomycorrhizal fungi which make them grow more fibrous and healthy in the nursery.



Figure 3-48. Mycorrhizal roots of *Pinus patula* are covered with white sheaths formed by the hyphae of fungi. The forking of root hairs is an indication of good seedling health and a good infection by mycorrhizal fungi.

There are several ways to infect tree seedlings in the nursery. Fungal fruiting bodies can be collected in natural forests under species of *Fagaceae*, such as oak (*Quercus* sp.), beech (*Fagus* sp.), or *Nothofagus* in Chile, including *roble*, *raulí*, *coigüe* and *lenga*. Mycorrhizal fungi can also be collected under natural forests or plantations of pines or dipterocarps. The mushrooms are dried and the spores shaken out over water which is then used to irrigate the soil or substrate where the tree seeds have been sown in beds or containers. In this way, the spores germinate and attach themselves to the roots of the germinating seedlings in the nursery. It is also possible to collect decomposed leaf litter and surface organic matter (humus) under these same species and incorporate it into the nursery substrate. Another alternative is to mix the decomposed leaf litter and humus with water and then apply it over top of the recently germinated trees in the nursery. Mycorrhizal soil or substrate can be kept in the nursery by placing it in compost piles and planting some pines overtop of the pile to keep the fungi active. When taking substrate from the pile, additional material is added and mixed with the existing substrate. The compost pile is kept moist to promote the growth of the hyphae of the fungi.

Endomycorrhizae are relations where the hyphae of the fungi attach themselves to the outside of the root hair cells and also penetrate into the cells of the roots. The fruiting bodies of endomycorrhizae fungi are often found growing within the soil, such as the truffles prized by cooks for their special flavors. Most angiosperms (broadleaf species) are endomycorrhizal. Some conifers are also endomycorrhizal. Most endomycorrhizal fungi are in the genera of the glomales and the zigomicotes (Mukerji & Sharma, 1996).

Endomycorrhizal fungi are found widely dispersed throughout most tropical soils and they attach themselves to tree roots unaided.

Application of Rhizobium spores to acacias in the nursery

The acacias are species that have the ability to fix nitrogen in their roots. *Acacia mangium* prospers by means of a symbiosis with bacteria of the genus *Rhizobium* and with mycorrhizal fungi of the genus *Thelephora* (Weber *et al.*, 2005). For optimum growth of the acacias, it is necessary to apply spores of *Rhizobium* which are specific for the species of acacia and for the environmental conditions where the trees are to be planted (Crowder, 1987). *Rhizobium* spores can be obtained through commercial

distributors and from CSIRO in Australia.[3] The *Rhizobium* bacterium is applied directly onto the acacia seeds before they are sown in the nursery. The way to determine if the spores have infected the acacias correctly is to inspect the roots to see if they have formed globules on the roots (Ivory & Speight, 1993). When the *Rhizobium* is active and alive, these structures have a rose color, since *Rhizobium* bacteria produce hemoglobin, similar to that in animal blood. The active globules fix nitrogen (Figures 3-49 & 3-50).



Figure 3-49. *Acacia mangium* with small globules of *Rhizobium* on the roots (arrows).



Figure 3-50. Detail of a globule of *Rhizobium* on the roots of *Acacia mangium.* The pink color indicates that the bacterium is actively fixing nitrogen.

Plant production in the nursery

Good nursery spacing of seedlings is important for their development (Figure 3-51). It has been shown that trees with larger root collar diameters produced at wider nursery spacings have better field survival and a greater potential to grow because they have larger root systems and a better ratio of dry weight of roots to dry weight of the total tree (South, 2000). In trials with *Pinus taeda* in the United States, normal seedlings with root collar diameters of 4.5 to 5.2 mm were compared with seedlings with root collar diameters of 8.2 to 9.2 mm. These were planted in the field and, after 12 years of plantation growth, the growth rate of the normal nursery stock was 10.2 m3/ha/year, whereas the growth rate of larger stock was 16 m3/ha/year (South *et al.*, 2006).

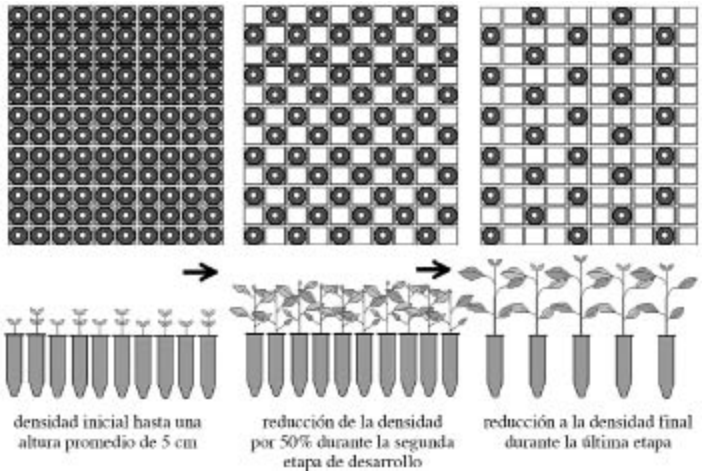


Figure 3-51. It is important to increase spacing in nursery trays as the trees develop and grow.

Nursery trees require optimum spacing for the development of foliage and the formation of a rustic and woody stem. Initially, seeds are sown or cuttings placed in tubettes that are closely spaced in the nursery trays. This initial spacing is often 400 to 450 trees/m2. After germination and when the seedlings are 5 cm tall, the spacing is expanded so that they can continue their development. For the eucalypts, this spacing should be about 250 to 280 plants/m2. Finally, one month before the end of the nursery process, the spacing is opened to between 180 and 200 plants/m2 in order to allow for the final development of the trees prior to going to the field.

However, optimum tree spacing will vary among nurseries. In very dry climates, the trees develop differently than in humid climates. It is easier to produce high quality seedlings in a dry climate because there is a greater control over the moisture available to the trees through irrigation. It is more

difficult to harden off seedlings in humid climates due to the frequent rains during the growing season.

The hardening off of plants is important and nursery spacing plays a significant role in this process. When seedlings are grown very close together and in mild climates, they produce *shade leaves* which are relatively thin, have very little wax on the upper surface and have many stomates on their undersides. These leaves are not desirable in the nursery because, when they are transplanted to full sun in the field, the leaves become sunburned, die and fall off. Afterwards, the seedling must expend more energy to grow new leaves, energy that is very scarce in a small tree. Thus, growth is delayed until a new set of leaves has been developed. When the nursery spacing is widened, the seedlings tend to produce so-called *sun leaves* which are thicker, have a heavier layer of superficial wax and have less stomates on the underside. Sun leaves can withstand the sun's heat when planted in the field and the seedling can initiate growth utilizing the sugars produced by its leaves through photosynthesis.

Similarly, plants grown in mild climates and at high nursery densities tend to have taller, thinner, more succulent stems. When such trees are outplanted, they tend to lose internal moisture quickly due to insufficient bark formation, they can wilt and the top leader often dies back due to a lack of woody tissue in the stem. To the contrary, seedlings grown in dry climates and with greater nursery spacings tend to be shorter, but greater in diameter, the tissues become woody and the thicker bark protects the tree from drying in the field.

Nursery spacing is important for the production of rooted cuttings, the same as for the production of seedlings. In the initial phase in the misting shade house, the cuttings can be placed in tubettes close together to economize spacing and to reduce costs. Later, when the cuttings are moved to a second stage shade house with more light, the spacing is widened. Finally, when the trees are moved to areas with open sunlight, the final spacing for optimum tree development is used.

Prior to moving trees to the field, it is important to make a final root pruning at the nursery (Figures 3-52 & 3-53). When trees are grown in tubettes in raised trays, the roots self prune in the air, but some root tips will come out of the bottom of the tubettes and these need to be pruned. The reasoning for this is as follows: If trees are outplanted in the field with the lower roots bent, the tree will not develop as well as one which is planted

with the roots straight. Pruning in the nursery is important to minimize the risk of poor field planting. It is also important to loosen the root plug in the nursery to make it easier to remove the seedlings from the tubettes in the field without causing damage to the tree.

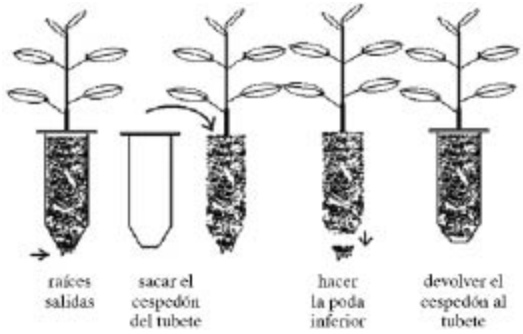


Figure 3-52. The bottom pruning of the root plug in the tubette avoids bent roots during transplanting in the field.



Figure 3-53. Pruning the bottom roots of *Gmelina arborea* in tubettes in a nursery in Indonesia. After pruning, the plugs are replaced in the tubettes for transport to the field.

The time required to produce an optimum quality tree in the nursery will vary by trees species and by the climatic conditions of a particular nursery. It is important to determine the optimum nursery management for each species by trying different times and spacing for each phase of nursery development and with different nursery treatments. In other words, to *fine tune* a tree nursery requires several crops in order to develop an optimum management scheme. During the development period, the nursery personnel are also learning how to produce optimum quality trees. This period of development and training is called the *learning curve*. It is important to begin nursery production at a smaller scale and increase production over several years until reaching the optimum nursery capacity.

When seedlings have soft bark, as in the case of *Gmelina*, it is important to first separate the root plug from the tubettes in the nursery, as opposed to doing it in the field (Figure 3-54). If the seedling is pulled out with the fingers, without first having loosened the root plug, the bark can be d amaged at the base. Such wounds are points of infection by fungi or can even cause death. It is always best to loosen the tubettes correctly in the nursery by inverting them and tapping the edge of the tubettes against the box or another surface to loosen it without causing a trauma to the seedling.

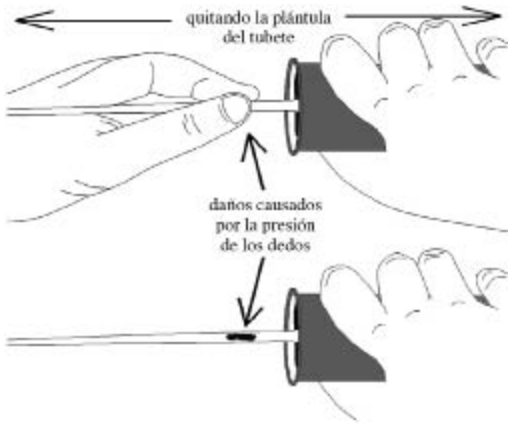


Figure 3-54. Typical damage that can occur to *Gmelina* seedlings if they are incorrectly removed from the tubette.

Seedling quality can be graded by root collar diameter (Figure 3-55). Seedlings with greater root collar diameters are more vigorous and have greater growth rates (Wakeley, 1969). In the case of *Gmelina*, the seedling should develop a basal swelling when healthy, with a minimum root collar diameter of 7 mm (Figure 3-56). This is the most important parameter for the success of field planting. There often exists a false belief among some nursery managers and foresters that the tallest nursery stock is the best. To the contrary, when seedlings are grown at wider spacings in the nursery, the plants are usually shorter, but they are hardier and of better quality for field transplanting. In the case of rooted cuttings, root collar diameter depends on the diameter of the original cutting as well as its nursery development, and root collar diameter is not as reliable a method for grading. With rooted cuttings, it is best to observe the condition of the stem, which should have a brown color, not green, and be flexible, but not succulent. Even with rooted cuttings, there should be a minimum acceptable root collar diameter. In the

case of cuttings of *Eucalyptus urophylla* or the uro-grandis hybrids, a minimum acceptable root collar diameter for cuttings is 3 mm.

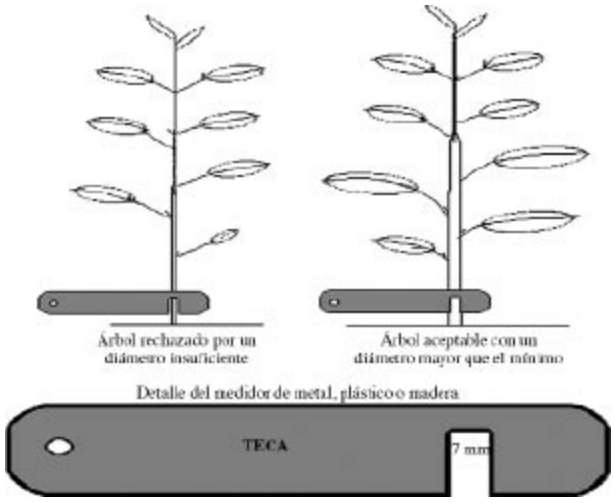


Figure 3-55. A grading tool can be made for measuring the diameter of the seedlings, using a small piece of wood, plastic or aluminum.



Figure 3-56. A quality seedling of *Gmelina arborea* has a basal swelling, indicating good health and vigor.

Before reusing tubettes, it is necessary to wash and sterilize them to avoid transferring malicious fungal spores or diseases from the previous crop to the next crop of trees. One method for doing this is to wash the tubes in water to remove any residual substrate that may still be inside (Figures 3-57 & 3-58). The tubes are immersed in hot water at 80° C for a minute (Figure 3-59). Another method is to wash the tubes manually and then dip them in a bath of 10% bleach.



Figure 3-57. Hand washing of tubettes with detergent and a bottle brush.

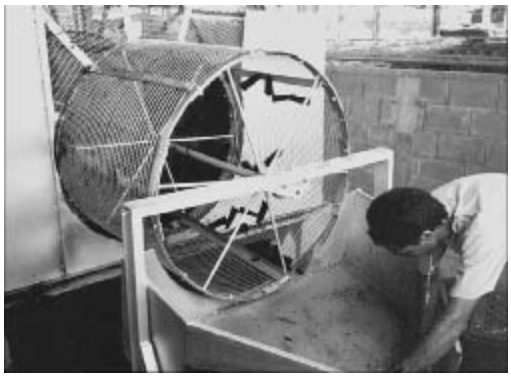


Figure 3-58. This tube washer in Venezuela is a rotating basket with high pressure jets spraying water to remove residual substrate inside the tubettes.



Figure 3-59. After washing the tubettes in this Brazilian nursery, they are placed in trays and dipped in hot water at 80° C for a minute to sterilize them.

[1]Clonal propagation of spruces (*Picea* sp.) has been successfully developed in Europe and North America, but it is only used commercially in some companies in Canada.

[2]Direct placement of tree seed in the field has not been successful for large-scale industrial forestry, even though has been used for some agroforestry programs, such as the taungya system used for planting teak on the island of Java in Indonesia.

[3]CSIRO is the scientific research center of the Australian government.

4

Plantation establishment

Drainage in low, wet areas
Site preparation
Elimination of vegetation on the site
Soil tillage
Transporting seedlings to the field
Transplanting methods
Initial irrigation of recently planted trees
Inspection and replanting
Quality control of the planting operation

Drainage in low, wet areas

When the soil has imperfect and/or slow drainage, trees do not grow well, even those species that can survive in swampy sites. The species most utilized in plantations for wood production require well drained sites for good growth and development. Even though the trees may be able to survive periodic inundations, they will not grow if the soil surface is covered with water or if the water table is high (Figure 4-1). Tree roots require oxygen for development, but when the soil is saturated or covered with water, there is little or no oxygen entering the soil and the tree roots die. The effect of too much water is similar to the effect of prolonged droughts in the sense that both reduce the root mass of trees and, as such, reduce tree growth.

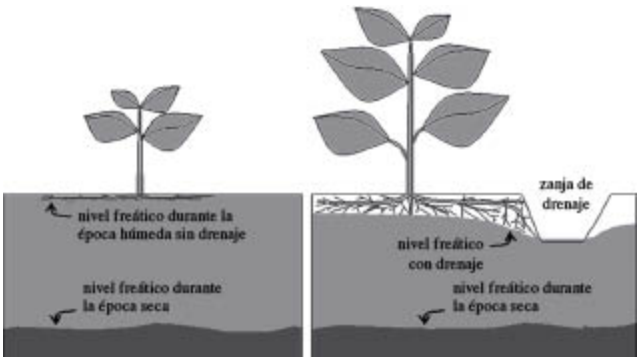


Figure 4-1. Drainage allows for rapid surface runoff after a heavy rain event.

On sites where there are serious problems with standing water, such as on river or creek terraces, or in low, level areas, one consideration is the construction of drainage ditches prior to initiating site preparation for planting (Figure 4-2). Even though the initial cost of drainage work may be high, its effect is to increase tree growth and may well be justified for planting fast-growing tree species (Figures 4-3 to 4-6). For example, on sites that were previously in rice or sugarcane cultivation, it may be necessary to construct drainages before planting trees. In Southeastern United States, there are extensive areas that once were swamps and that have been drained to become highly productive forest plantations. The large pulp and paper mills along the Atlantic Coast of the United States depend in large part on wood supplied from pine plantations established on sites that have extensive drainage networks.

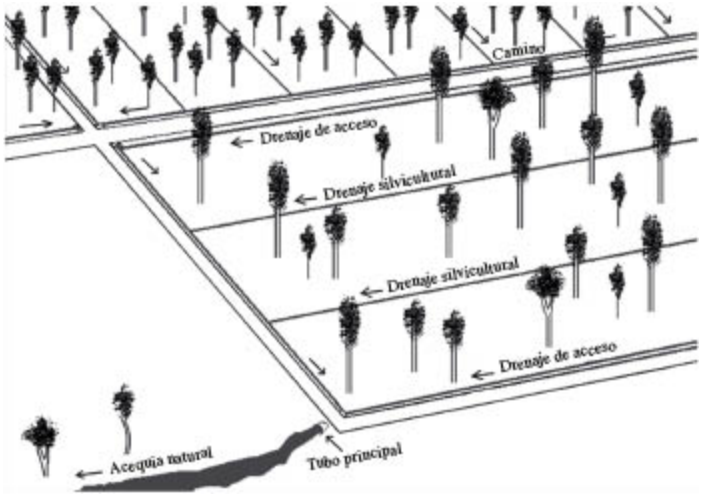


Figure 4-2. Design of a drainage system with primary and secondary drainage ditches.



Figure 4-3. A 3-month-old plantation of *Pinus taeda* in a forest property in Corrientes Province,

Argentina. The forest road is formed over the soil excavated during the construction of the drainage canal.



Figure 4-4. A drainage canal formed with a backhoe in Venezuela for a eucalypt plantation.



Figure 4-5. A drainage canal formed with a backhoe in East Kalimantan, Indonesia.



Figure 4-6. A secondary canal being excavated manually in Tabasco, Mexico; the site will be planted with eucalypts.

In Venezuela, some properties planted with eucalypts and *Gmelina* have been drained and bedded. In the North Coast of Colombia there are *Gmelina* and red ceiba plantations established on low lands that have been drained. Extensive drainage has been done for planting *Acacia mangium* and *Acacia crassicarpa* in Sumatra and Kalimantan, Indonesia, as well as along the Caribbean Coast of Mexico. Drainage is also common for pine reforestation in parts of northern Argentina.

Site preparation

Proper site preparation is needed to obtain good plantation growth. This includes the elimination of competing vegetation as well as tillage to improve soil structure.

Elimination of vegetation on the site

When a site for reforestation is covered with weeds, bushes or debris from a previous harvest, the first job is to clean the site so that it can be planted. In many countries there are laws that restrict the conversion of natural areas to tree plantations. Before starting any clearing it is important to have a clear understanding of any legal restrictions and to have any required permissions for land conversion.

Woody material needs to be removed in order to adequately prepare the soil for planting. When using a tractor to clear off woody vegetation, it is best to use a root rake rather than a dozer blade[1] (Figures 4-7 & 4-8). Bulldozer blades have negative impacts when clearing because they tend to scrape off the surface soil, and push it into piles along with the debris, thereby reducing the soil quality and, consequently, the growth of the tree plantation. Woody material piled with a tractor and root rake can be burned or left to rot, according to the particular situation and taking into consideration any legal restrictions that may exist to control burning.



Figure 4-7. A root rake mounted on a crawler tractor in Indonesia.



Figue 4-8. A root rake mounted on a crawler tractor clearing land in Venezuela.

When the woody material is not too large in diameter, it can be pushed down with a rolling chopper to be burned afterwards (Figures 4-9 to 4-12). This is an effective system for eliminating brush and debris during the dry season, when fire can effectively consume the wood material.



Figure 4-9. A rolling chopper constructed in Venezuela. The drum is filled half way with water to increase weight and improve the chopping action.



Figure 4-10. A 7-ton rolling chopper pulled by a crawler tractor in the United States.



Figure 4-11. A 3-ton rolling chopper pulled by a wheel tractor in Brazil.



Figure 4-12. A one-ton rolling chopper works well in areas with very little material, such as after harvesting a plantation of eucalypts.

Soil tillage

Normally, soil tillage is needed when establishing tree plantations. There are few sites where tree plantations can be established without some form of soil tillage. Soil tillage increase the number and size of soil macropores which allows for greater availability of soil oxygen to roots, a greater capacity for rainwater retention and a looser soil that allows for greater ease of root penetration and growth.

As has already been mentioned, tree roots require oxygen for their survival and development. If a soil is very compact and has few macropores, there may not be sufficient soil oxygen, and tree growth will be inhibited. Similarly, if there are heavy rains or inundations, causing water to remain on or near the soil surface, the tree roots will not be able to obtain sufficient oxygen and many will die back, regardless of the depth of the water table during the dry season.

The objective of using a turn plow or heavy disk plow is to cut deep into the soil, turn it over to expose weed roots and to bury weed and grass seed underneath the soil clods. Once the soil has been turned with a plow, the ideal situation is to leave any weeds or grass to resprout and then go over the site a second time with a disk plow to kill the germinated and sprouted vegetation. Due to the relative high cost of mechanical soil tillage, plowing is not being used as commonly as it was in years past. Weed and

grass control can be quite effective with herbicides and there are other alternatives for soil tillage.

Subsoiling is a common practice for establishing pine and eucalypt plantations on arable lands in Brazil. The subsoil blade penetrates 40 cm to 70 cm depending on the preference of the reforestation company, but a subsoiling depth to 50 cm is common. Subsoiling works best when done during the dry season so that the soil structure is shattered, creating multiple lateral cracks to increase the number of macropores, as opposed to subsoiling when the soil is moist and simply making a central slit in the soil. There are many different types of subsoil blades and some also serve to apply fertilizer in the bottom of the slit. In this way, the fertilizer can be made available to the deep tree roots, but not to the superficial roots of weeds and grass. After subsoiling, trees are planted over the slit so that the pivot roots can grow downwards rapidly and anchor the tree deep for good development. Subsoiling has a very positive effect on tree growth, particularly in clay soils (Figures 4-13 to 4-21).

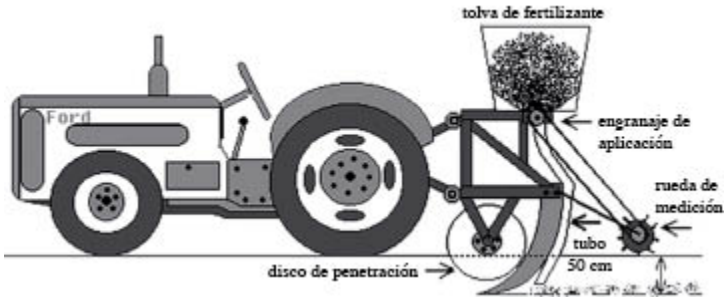


Figure 4-13. Drawing of a subsoiler with a fertilizer hopper mounted on a wheel tractor. The fertilizer is measured and released from the hopper by a wheel behind the subsoil blade and it is applied in the bottom of the slit.



Figure 4-14. A subsoiler with a Coulter disk in front and with a rear wheel to activate the fertililizer

hopper.



Figure 4-15. Rear view of the subsoiler; in this case, the fertilizer falls on top of the subsoil slit which is closed by the rear wheel.

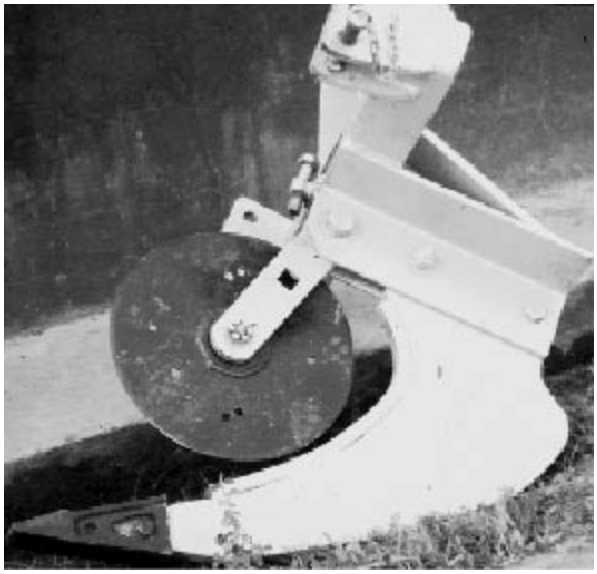


Figure 4-16. A curved subsoil blade with a Coulter disk in front is very effective for forestry use.



Figure 4-17. The straight subsoil blade requires more tractor horsepower and it tends to pull open a ditch and leave clods of soil on the surface.



Figure 4-18. In Hawaii, USA, a subsoiler with rear disks is used to prepare soil for planting eucalypts



Figure 4-19. A subsoiler made in Brazil with a curved blade, a Coulter disk and two fertilzier hoppers that are activated hydraucally to spread the fertilizer over the surface of the soil



Figure 4-20. A subsoilder built in Mexico with a fertilzer hopper activated using the PTO from the tractor, dropping the fertilizer into the bottom of the slit. A rear wheel closes the subsoil slit.



Figure 4-21. A subsoiler with two blades 3 meters apart, mounted on a tool bar behind a crawler tractor in Colombia.

On those sites where water stands on the soil surface after rains, it is advisable to bed the site and plant the trees on top of the beds (Figures 4-22 & 4-23). A forest bed is considerably larger than an agricultural formation. A good forest bed is 2.5 m wide and 50 cm tall (Figure 4-24). Commercial bedding harrows for forestry are available in the United States and Brazil. For small areas or trials, beds can be formed by making several passes with an agricultural plow pulling up soil from both sides until the bed is of sufficient size. On low sites that can flood, the beds are oriented with the natural drainage of the land to facilitate surface water removal from the site. If the beds are to be made on slight slopes, they are oriented along the contour to avoid accelerating soil erosion.



Figure 4-22. A forestry bedder with a rear packing wheel, being used with sandy soils in Minas Gerais, Brazil.



Figure 4-23. Rear view showing the effect of the packing wheel.

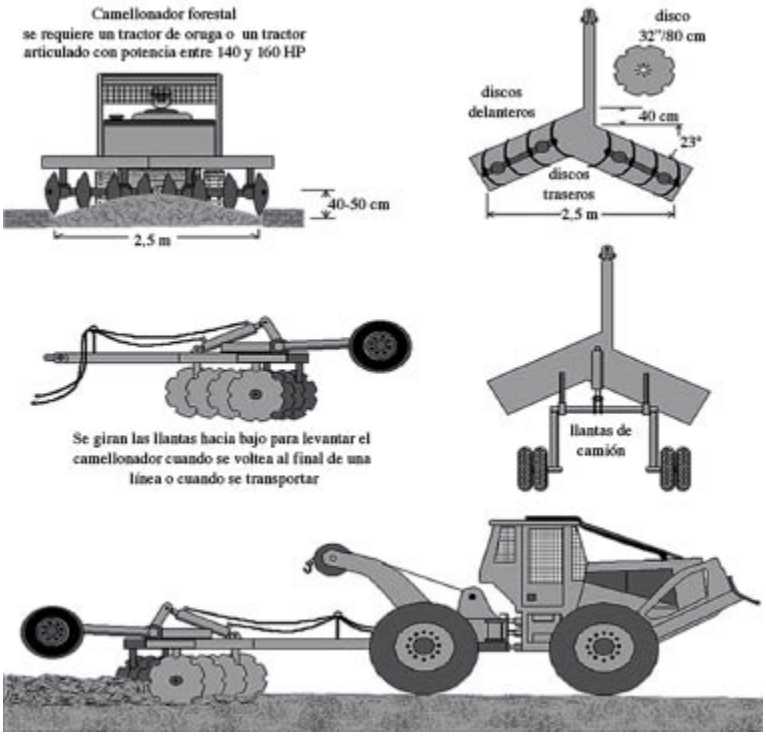


Figure 4-24. Detail of a forestry bedding plow.

On level land, trees planted on beds have an initial growth advantage over non-bedded trees (Figures 4-25 to 4-28).



Figure 4-25. One month growth of *Eucalyptus grandis* on a site that was plowed and disced in Venezuela.



Figure 4-26. *Eucalyptus grandis* at one month on an adjacent site that was plowed and bedded.



Figure 4-27. Growth of *Gmelina arborea* at 7 months in a plot that was plowed and disced on the Atlantic Coast of Colombia.



Figure 4-28. Growth of *Gmelina arborea* at 7 months on an adjacen plot that was plowed and bedded.

On slopes or sites where it is not possible to use mechanical soil preparation, manual preparation can improve tree growth. As always, the existing brush and vegetation must first be removed with machetes and/or hoes prior to soil preparation. Once the competing vegetation begins to resprout, particularly the grasses, these are best killed or removed in a circle 1.5 m in diameter where each seedling is to be planted. The soil in the center of the cleared spot is loosened with a hoe or other tool. A good rule is to loosen the soil in a 20 cm x 20 cm x 20 cm cube for the same reasons that the soil is tilled mechanically with plows, subsoilers or bedders. The goal is to control the weed and grass competition with the planted tree roots in order to allow the tree to grow rapidly during the first few months in the field (Figures 4-29 & 4-30). Without good control of grass and weeds with herbicides, or if the planting hole is too small, the trees will grow more slowly while the grass and weeds take over the site. That will result in a greater cost for manual or chemical control of competition as well as less tree growth and wood production at harvest age.



Figure 4-29. The photo shows the 2-year-old growth of a plot of *Pinus oocarpa* in the Andes Mountains of Colombia, where the trees had been planted in a cleared spot 60 cm in diamter, and with the seedlings planted in holes 20 x 20 x 20 cm made with an iron wedge planting tool.



Figure 4-30. In an adjacent plot, 2-year-old *Pinus oocarpa* were initially planted where the grass had been cleared in a 1 x 1 m square and the soil loosened in the entire square to a 20 cm depth prior to planting. The result is a plantation with nearly double the height and significantly greater survival than in the plot shown in Figure 4-29.

Transporting seedlings to the field

Handling of seedlings between the nursery and the location where they are to be planted is critical to the success of the plantation. It is during this phase that many trees are seriously damaged when there is inadequate supervision and a lack of strict control of handling procedures.

First of all, the nursery must protect the processed trees that are ready to go to the field. The root plugs need to be moistened thoroughly just before leaving the nursery. There are several ways to transport seedlings: in plastic boxes, in plastic bags or in other types of containers. The transport containers need to be tall enough to accommodate the trees without bending them over when placed in the transport vehicle. If the trees are placed in closed bags or boxes and then left in the sun, the heat generated inside the container can damage the trees. It is always necessary to keep the prepared trees fresh and in the shade during transport.

Trucks or trailers used for transporting trees need to have strong shelves that will hold the container boxes securely. Transport vehicles need to be covered in front, on the sides and also at the rear to insure that the trees are not subjected to wind during transport (Figures 4-31, 4-32). When the travel distance is long, and if the truck stops for any reason, the driver should find a place where water can be applied to the trees during the trip.



Figure 4-31. A canvas covering over the wagon protects the seedlings during transport.



Figure 4-32. A clear plastic cover over a metal frame is acceptable for transporting seedlings in a cool climate, but not in a hot climate.

Lack of proper attention and protection during transport are errors that can result in severe damages to nursery stock during transport to the field. It is very important to have proper supervision during the delivery of the trees to the field, to make certain that they are placed in shade and given adequate water. The field supervisor needs to certify that the trees are received from the nursery in good condition and to return the empty tubettes from the previous day's planting (Figures 4-33 & 4-34).



Figure 4-33. Inadequate transport allows wind to dry out the seedlings during transport from the nursery to the field.



Figure 4-34. When trees are transported in poor quality and with inproper containers, there will be increased mortality in the plantation.

The trees need to be watered when they are offloaded from the transport vehicle in the field (Figure 4-35). The truck can carry a barrel of water for this purpose, or water can be used from a local stream near the planting site. The offloaded trees need to be protected from direct sunlight and kept in shade. If there is no shade available, a temporary shade can be made to protect the trees (Figure 4-36). When offloading the seedlings in the field, care is needed to be sure that they are not placed near an ant colony or where other pests may damage them. If the trees are infested with ants or other pests at the offload site, these pests will later be distributed throughout the plantation.



Figure 4-35. These *Gmelina arborea* seedlings were left in full sun, without irrigation and they dried up and died. Without supervision, the laborers continued to plant the dead trees.

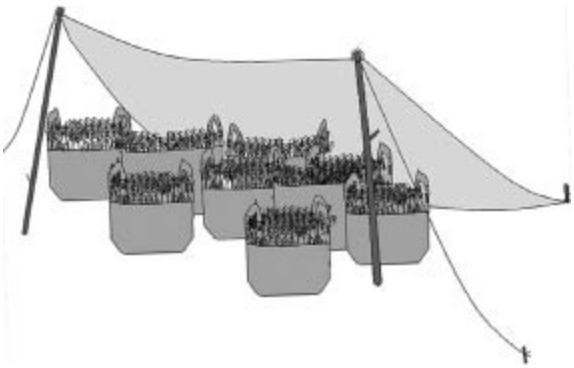


Figure 4-36. When there are no shade trees nearby, a plastic tarp can be used as a temporary shade for offloaded trees until they are ready to be planted.

Transplanting methods

Most tropical plantations are made by hand (Figures 4-37 & 4-38). There are several reasons for hand planting: it generates employment among local people, which is an important social aspect of reforestation; manual planting is more practical in hilly country as well as in smaller plots; manual planting tools can be obtained locally whereas planting machines must be imported in many countries.



Figure 4-37. Manual planting of containerized pines using small planting tools in the Andes of Colombia.



Figure 4-38. Manual planting of eucalypts grown in tubettes in Brazil.

Small agricultural tools can be adapted to tree planting, such as small hoes or iron wedge tools (Figures 4-39 to 4-42). Such tools work well in loose soils, such as in sandy lands or in clay soils that have been previously prepared with heavier tools.

Plastic boxes, such as those made for carrying soft drink bottles, are often used to carry the trees to the field. In some cases, the plastic boxes are modified, adding handles or a bag for depositing empty containers. Plastic bags are sometimes used to transport seedlings to the field. In most cases, the tubettes are taken to the field and removed at the time of planting.[2]



Figure 4-39. A plastic box is used to carry the seedlings to the field. The net on the side is used for depositing empty tubettes.



Figure 4-40. Stumps of *Gmelina* are planted using a small hoe or “hoedad”. In the nursery, a clay

slurry was applied to the roots The roots are kept moist by appling a clay slurry.



Figure 4-41. Teak in tubettes is planted with the help of a small hoe. The trees are carried in a bucket. The woman planting uses gloves to protect her hands.



Figure 4-42. A pointed tool is used to punch a hole in sandy soils for planting the root plug of the same diameter.

Some specialized tools are also used for planting trees in tubettes (Figures 4-43 & 4-44).



Figure 4.43 Transplanting eucalypts in tubettes in Mexico. The tool punches a hole in the ground, the

bottom fingers are opened and a tree is placed in the top of the tube which falls into the hole that has been formed.



Figure 4-44. Pines are planted in Brazil with a planting tool. The worker carrys the trees in a cut-off plastic oil jug fastened with a belt. The back pack contains a gel that is squirted into the hole as the tree is planted.

In some cases, a gel is applied simultaneously with tree planting. The gel is a highly absorbent material, similar to that used in disposable baby diapers. The gel maintains a greater moisture concentration near the seedling. Gel is used primarily when post-planting irrigation is planned since it holds moisture and allows for longer periods between irrigations. Tree planters can carry the gel in a backpack and it is injected into the planting hole when the tree is planted (Figure 4-44). In other operations, a trailer tank is filled with the gel and hoses carry the gel to the hand planters. Figure 4-45 shows a semi-mechanized planting operation (Figure 4-45).



Figure 4-45. A semi-mechanized planting of eucalypts in tubettes in Brazil with the simultaneous application of gel.



Figure 4-46. Bare root planting of Caribbean pine with planting machines in the eastern prairies of Venezuela. The tractor pulls three planting machines at once.

Planting machines were originally designed to plant bare root trees, a common planting method in Southern United States. These same planting machines have also been used successfully for planting bare root Caribbean pine in the eastern prairies of Venezuela, where large areas of flat land require mechanized planting (Figure 4-46). Planting machines have also been developed that can effectively plant seedlings grown in tubettes (Figures 4-47 & 4-48).



Figure 4-47. A planting machine used to plant eucalypts grown in tubettes in the Cauca Valley, Colombia.



Figure 4-48. A planting machine in Mato Grosso do Sul, Brazil, works well with eucalypts grown in tubettes and simultaneously applies gel at the planting spot. The machine can plant about 8000 trees/shift on prepared sites.

Initial irrigation of recently planted trees

In climates that have distinct and prolonged dry seasons, it is best to start planting at the beginning of the rainy season in order to give the trees the opportunity to become well established before the next dry season begins. Besides having better first year survival, trees planted at the beginning of the rainy season have been shown to have much greater first year height growth than trees planted two or three months after the rains begin. Some companies have even adopted a policy of beginning the planting up to a month before the rains begin by using initial irrigation as a means to increase first year growth.

Initial rains are seldom reliable and they may start weeks earlier or weeks later than the expected average initiation date. This creates problems of coordination of the nursery production and the field transplanting, especially for fast-growing species that can grow too large if left in the nursery for a couple of additional weeks. One way to make sure that the trees are planted at the planned date is to use initial field irrigation. This makes it possible to plan the field operations regardless of when the rains start. The irrigation process is continued until the rains begin.

Field irrigation is generally accomplished using water tanks mounted on trailers. The water is applied by gravity feed through hoses connected to the back of the water tank (Figures 4-49 to 4-51). Up to four hoses are connected to the rear of the tank to allow for irrigating four rows at one time. The tractor pulling the tank moves at a slow velocity to allow workers to walk behind and to apply the correct amount of water. Field water tanks usually have a capacity of between 2000 and 3000 liters. Tanker trucks are used to fill the field water tanks (Figure 4-52). Water can be obtained from a local stream or brought from more distant sources, as the local situation requires.



Figure 4-49. Irrigation of a eucalypt plantation in Minas Gerais, Brazil.



Figure 4-50. Irrigation of a eucalypt plantation in Espíritu Santo, Brazil.



Figure 4-51 Irrigation of a *Gmelina* plantation in Colombia.



Figure 4-52 The water tank is filled from a tanker truck.



Figure 4-53. The objective of irrigation is to moisten the soil around and below the plant (left). If there is insufficient water applied (right) it does not help the seedlings' roots to become established and grow. Checks of the effectiveness of irrigation can be made by a supervisor by excavating beside some of the trees after they have been irrigated, using a shovel or hoe.

The objective is to apply sufficient water to the soil around the planting site so that it moistens the soil below the tree roots and allows the roots to grow down as well as laterally (Figure 4-53). Frequency of irrigation depends on the soil texture and the local climatic conditions, but in most cases the irrigation is done each week until the rains begin.

Inspection and replanting

After a lot has been planted, the field technician needs to walk around the planted area and make an inspection of the quality of the planting operation. Immediately after planting, the technician should lightly tug or pull on the tops of some seedlings to see if they are tight or loose. If the seedlings are loose, the roots will have air pockets near them and can die. If the trees are loosely planted, the field supervisor must correct the planting technique of the laborers to make sure that the root plug is snug in the soil so that the tree roots can penetrate the surrounding soil and grow. The field supervisor should occasionally make an excavation beside recently planted trees to check visually that the roots are properly placed in the soil and are not bent or deformed (Figures 4-54 & 4-55). If bent roots are found, the

planting procedures need to be corrected among the workers as quickly as possible.



Figure 4-54. During the root inspection, a hole is excavated beside a recently planted tree, without damaging the roots, to see if the roots are planted vertically.

A week after planting, the field technician returns to inspect the plantation. If there are problems, such as trees wilting, leaning, turning yellow or losing foliage, the technician needs to review the situation with the labor supervisor to define the cause(s) of what has occurred and to look for immediate solutions to avoid similar problems in the next plantings.



Figure 4-55. Field supervisors need to make routine checks of the roots of recently planted seedlings. This is an important procedure for planting quality control.

If initial mortality is found in plantations for any reason, an immediate replanting can be made, assigning laborers to replace dead or dying trees (Figures 4-56 & 4-57). In such cases, the dying tree is pulled up and replaced with a healthy tree. Don’t ever leave two trees in the same planting hole. However, replanting is only effective when done within the same

season and shortly after the initial planting. The maximum time between planting and replanting varies by species. In the case of fast-growing species such as eucalypts, acacias or *Gmelina*, the maximum interval between planting and replanting is one month. For species such as pines, teak or pochote, the maximum interval is three months.



Figure 4-56. A recently planted eucalypt has wilted due to a lack of care during transport to the field and/or due to mishandling prior to planting.



Figure 4-57. This recently planted eucalypt has a spindly stem and has dropped its leaves afer just one week in the field, an indication of a lack of quality control.

Experience and several studies have shown that replanting after the indicated times results in suppressed trees that do not produce commercial wood volumes at harvest age. Late replanting is a waste of time and money. Unfortunately, late replanting is a common practice, with foresters attempting to correct initial nursery and establishment errors due to a lack of quality control and/or field supervision of planting activities. When a

high incidence of initial mortality is observed, there needs to be a general review of all processes, including nursery quality control, transport methods to the field, site preparation practices, and the quality of the planting effort itself, in order to determine where the problems exist in the system.

At the end of the planting season, or at the end of a year, a general check of the quality of the planting is needed, making a count of free-to-grow trees per hectare.[3] The check can be made with temporary plots of 1/50 ha (radius of 8.0 m) where the number and condition of the trees is recorded. Where there are well-trained field technicians, the registration can be done by means of a general overview inspection, without the need to record each tree on a paper form. Abnormalities such as forking, leaning trees, insect or fungal attacks, etc. should be recorded, however. Later, the forester in charge can review the field information with the field technician.

The goal of well established plantations should be to obtain an initial survival greater than 95% at the end of the first year. If the plan is to plant 1100 trees/ha, there should be 1045 trees/ha at one year of age. If the plan is to plant 1300 trees/ha, there should be 1235 trees/ha after the first year, etc.

In a lot where there has been a high incidence of mortality, a decision needs to be made to: (1) leave the plantation as is or (2) eliminate it and replant the next year. As a general rule, if there are more than 500 trees/ha alive and healthy after one year it is best to manage the existing plantation. If there are less than 500 trees/ha that are live and healthy, the best alternative is to destroy the plantation and totally replant it during the next rainy season. It is never an option to “correct” a bad plantation by making late replantings of trees, as has already been explained; such trees will never produce commercial wood at harvest age.

Quality control of the planting operation

The importance of doing the planting correctly cannot be overemphasized, as well as the effects of this operation on the quality of the trees as they grow. The vertical placement of the seedlings roots without bending them is crucial to the good growth of trees. Planting is a simple operation, but the planting labor must understand the importance of doing the planting correctly during the training period; it is also important to have constant supervision of the planting crew by the planting supervisor to plant healthy trees properly so that they have the optimum potential to grow. As a general rule, a hand planting crew with 20 persons will require a crew boss

to supervise the planting crew. The crew boss needs to review and check the many phases of the planting operation, including the following points:

- When the trees are delivered from the nursery, these must be inspected as to their condition (size, dryness, hardiness) and the delivery is approved or rejected by signing a delivery paper that is then delivered back to the nursery.
- The seedlings that are received in the field must be placed in shade until ready to be planted.
- When the seedlings are received in the field, they must be watered. If they remain from one day to the next, additional watering will be needed.
- Workers must handle seedlings with care, handling them by the tubettes or containers, not grabbing them in a bunch by the stems.
- Planting holes must be deep enough to allow the entire root plug to be placed in the hole without bending the roots.
- Occasional measurements need to be made to verify that the personnel who prepared the planting holes used the specified spacing between trees.
- In hard soils and clay soils, the personnel preparing the planting holes must break up soil clods into small pieces so that the planters can plant the trees properly.
- When tree planters find a damaged tree (too dry, bent, broken, without a good root plug, too small, chlorotic, etc.), the worker should be taught to throw such trees away rather than to plant them.
- If the tree is properly planted, it will feel tight when tugged lightly by the planting crew boss.

There is good evidence of the importance of proper planting of trees from a study carried out with *Pinus taeda* in the State of Georgia, USA (Harrington & Gatch, 1999). In that study, trees that had been planted with planting machines in 24 different stands and that were between the ages of three and 10 years were uprooted and evaluated as to their growth and development as well as the root orientation.

When trees are improperly planted with planting machines, the roots are bent in the form of an ”L”, i.e., the pivot root is too large for the depth

of the planting slit formed by the planting machine and is bent when put into the planting slit (Figure 4-58).

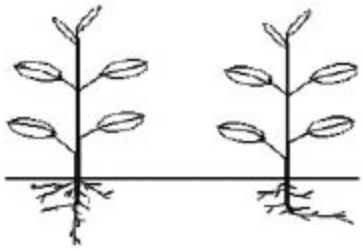


Figure 4-58. Correct planting of trees with vertical roots (left) and incorrect planting with the roots doubled in an “L” formation (right).

The following results were produced by that study:

1. Trees planted with bent roots had 9% less total height and 7% less diameter than trees planted correctly with vertical roots. That is a difference of 23% in total tree volume.
2. Where trees were planted with the pivot root bent, there was a higher incidence of crooked and twisted stems. When trees were planted correctly, there were few crooked trees.
3. The incidence of fusiform rust was double for the trees with bent roots. [4]
4. Tip moth attacks were four times more frequent on those trees with bent roots.[5]
5. Attacks by bark beetles were 60% more common in trees that had been planted with bent roots compared with trees planted correctly.

The total volume difference between trees with bent roots and straight roots is not known from the study, but it is clear that trees planted with bent roots will have significantly less growth than trees planted correctly, and many of the bent root trees will be suppressed by the healthier tree and not produce commercial wood at harvest age. In the case of trees being grown for sawtimber, it is easy to see that crooked and bent tree boles, combined with reduced volume, will greatly reduce the value of such trees for sawlogs.

This study only compared machine planted trees, but without a doubt, similar results will occur when hand planting. When trees are planted with roots bent in a “J” form, or planted with spiraled roots due to a lack of

bottom pruning in the nursery, the results will most certainly be similar (Figures 4-59 to 4-67).

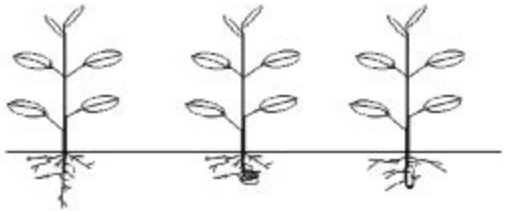


Figure 4-59. Correct manual panting with a vertical pivot root (left), spiraled roots (center) and “J” roots (right).



Figure 4-60. Incorrect machine planting of *Pinus caribaea* resulted in “L” roots as seen in these one-year-old trees.



Figure 4-61. Even after six years, improperly planted pines do not produce normal pivot roots, but continue growing horizontally, making the tree susceptible to drought due to a lack of deep roots.



Figure 4-62 A 3-year-old *Gmelina arborea* has bent roots due to a lack of initial pruning of the root plug of trees grown in tubettes in the nursery.



Figure 4-63. This leaning *Acacia mangium* was grown in a plastic bag with spiraled roots and was not root pruned prior to planting.



Figure 4-64. This 3-year-old *Acacia mangium* fell over due to root strangulation. This is due to spiraled roots of trees grown in plastic bags with no root pruning.



Figure 4-65. The bent roots of this eucalypt could be due to a lack of initial root pruning in the nursery or due to poor planting in the field, or both.

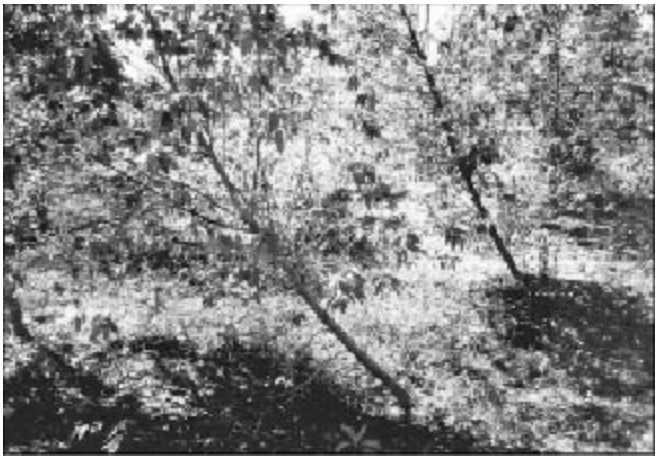


Figure 4-66. This 3-year-old *Acacia mangium* fell over due to root strangulation. This is due to spiraled roots of trees grown in plastic bags with no root pruning.



Figure 4-67. This 3-year-old *Acacia mangium* fell over due to root strangulation. This is due to spiraled roots of trees grown in plastic bags with no root pruning.

The results of this study confirm the importance of making certain that the trees are planted correctly. The magnitude of the resulting differences indicates the advantages of quality and uniform planting procedures to improve tree growth and economic returns from the plantation investment.

[1]A root rake is a series of steel fingers that remove debris without removing soil.

[2] In order for this to work, it is important that the root plug is first removed and pruned in the nursery and then returned to the tubettes. Then the tubettes are transported to the field (see the chapter on nursery management).

[3]The number of trees free-to-grow is more important than the number of trees that have died. The field count is always made of the number of live and healthy trees, not the number of dead, dying or missing trees.

[4]Fusiform rust (*Cronartium quercum*) is the disease that has had the most economic impact on southern pines. Fusiform rust can cause death as well as to deform trees that survive the attack. Trees that survive are often weakened at the point of attack and break at a later time during high winds.

[5]Tip moth (*Dioryctria* sp.) is a small Lepidopter insect that bores into the terminal shoots of southern pines causing forking of the stem and branches.

5

Silviculture

Grass and weed control in tree plantations
Fertilization
Plantation density and spacing
Thinning
Pre-commercial thinning
Commercial thinning for solid wood products
Salvage thinning: correcting situations of growth stress or stagnation
Singling
Desprouting after a clear-cut
Pruning for quality

Grass and weed control in tree plantations

Many of the commercial grasses sown in the tropics are species selected for their aggressiveness on marginal sites and many of them are allelopathic. Allelopathy is a natural mechanism that helps some plant species to compete with other plant species in the environment; many grasses and weeds are allelopathic (Zobel *et al.*, 1987). Introduced grasses in Colombia, such as *Melinis minutiflora* (yaraguá melao), *Pennisetum clandestinum* (kikuyo) and *Brachiaria* sp. tend to have allelopathic effects on young trees of *Eucalyptus grandis*, *Eucalyptus globulus* and *Cupressus lusitanica* (cypress). In Mexico and Brazil, grasses in the genus *Brachiaria* are known as being allelopathic. Without complete control of these grasses prior to tree planting, they can cause significant reductions in the growth of eucalypt plantations. In Brazil, the toxic effect of the grass *Panicum maximum* has been shown to have a negative impact on the initial growth and development of *Eucalyptus grandis* (Dinardo *et al.* 2003). In Indonesia, Malaysia and other nations in Southeast Asia and the Pacific, the alang-alang grass (*Imperata cylindrica*) is so allelopathic that without adequate control, tree plantations established within these grasses often do not close crown over them. Many commercial forage grasses form large lateral roots or rhizomes that sprout additional sprigs of grass. The roots of such grasses are strong competitors with the thin, weak roots of recently planted trees (Figure 5-1). Just cutting the grass foliage with machetes or rotary mowers or cleaning off the soil surface vegetation with hoes does not kill the deep roots of these grasses, which continue to grow with little or no negative effects from such actions.

The best procedure for grass control is the use of glyphosate, a systemic herbicide (Figures 5-2 to 5-9. If the herbicide is to be applied to rank, mature grass, it is often necessary to make a preliminary treatment of the grass, such as burning it, mashing it down with a rolling chopper or plow or cutting it down with machetes. Afterwards, once the grass resprouts, the herbicide can be applied effectively to the succulent new growth.

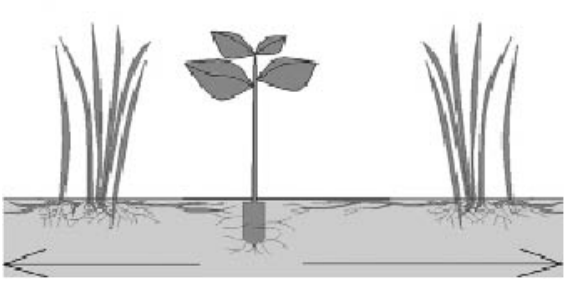


Figure 5-1. It is important to kill the roots of grasses and weeds within a 1.5 m diameter planting circle to allow for the initial growth of the roots of recently planted trees. Alang-alang grass (*Imperata cylindrica*) has large, allelopathic roots that compete with tree roots if they are not killed with herbicides.



Figure 5-2. Many commercial grasses are highly allelopathic and simply hoeing or cutting the tops off of the grass is not an effective means for controlling them, unless the roots are killed.



Figure 5-3. Grass control in planting strips using glyphosate is needed prior to tree planting.



Figure 5-4. After the trees are planted, grass control within the planting circle can be accomplished using a sprayer with a protective cover over the spray nozzle.

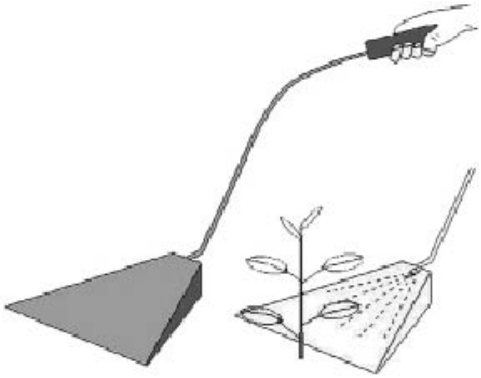


Figure 5-5. Detail of an aluminum cover over the spray nozzle to allow for spraying near small trees without causing them damage.



Figure 5-6. Another style of cover over the spray nozzle for applications close to young trees.



Figure 5-7. Application of herbicide under a small *Gmelina* tree using a plastic nozzle cover.

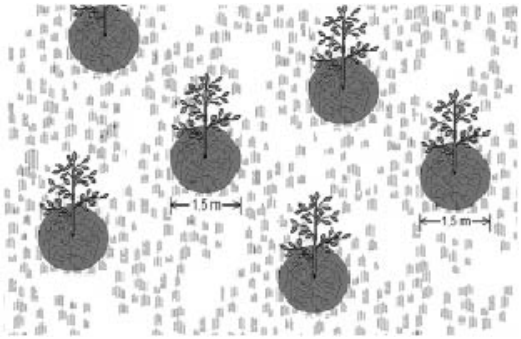


Figure 5-8. Herbicide application in the planting circle 1.5 m in diameter is sufficient to allow the trees to grow and become established in grass and weed cover.



Figure 5-9. Grass control with herbicide in a 1.5 m circle in a young seed orchard of *Pinus radiata* in Chile.

Careless application of herbicides, without using a cover over the spray nozzle, causes damage to small trees and can kill them (Figure 5-10). When stems are succulent the herbicide can enter the plant and kill it. The best time for herbicide application is when there is little or no wind, such as in the early morning or in the late afternoon. Use of the sprayer cover makes it possible to apply herbicide during more hours of the day by directing the herbicide down to the young grass sprout, but keeping it away from the tree.



Figure 5-10. It may look like a fungal attack on this young *Acacia mangium* tree, but it is actually damage from a careless herbicide application made without a protective cover over the spray nozzle. Symptoms of herbicide damage include curled foliage and chlorotic spots.

Experience has shown that the most important grass and weed control is in the tree planting circle. If herbicide is applied in a circle 1.5 m in diameter, it has the same effect as applying it over the entire area and is much more economical. In many cases it is sufficient to make an initial application prior to planting and a second application at two or three months after planting to allow the trees to grow and overtop the remaining grass (Figures 5-11 to 5-14) (Lambeth 1986).



Figure 5-11. Two-year-old *Eucalyptus grandis* in a research study in Colombia where there was rank *Melinis minutiflora* grass. This plot had good grass control using hoes and machetes during the first two years.



Figure 5-12. This adjacent plot had the grass controlled with two herbicide applications, one prior to planting and another three months after planting. The plots in the two photos are adjacent in the study, were planted the same day with the same seedlings and treated the same, except for the herbicide application.



Figure 5-13. A research trial in Colombia with *Eucalyptus globulus*, now two years of age. In this plot, the kikuyu grass (*Pennisetum clandestinum*) was controlled manually during the first two years using hoes and machetes.



Figure 5-14. In this plot, within the same trial, the grass was controlled with two applications of glyphosate herbicide, once prior to planting and later at three months after planting. Growth differences were statistically significant.

In Brazil, it was found that a 1.5 m wide herbicide application strip along the planting line worked better than a 1.0 wide strip to control *Brachiaria decumbens*, *Melinis minutiflora* and other known allopathic grasses (Bragion de Toledo *et al.*, 2003). Manual or mechanical methods can be used for grass and weed control within the strip between rows of planted trees.

Glyphosate is a systemic herbicide, which, when applied to the foliage, is translocated through the plant and to the roots which are killed. Glyphosate has a low toxicity level for animals and is even used in some formulations to kill aquatic vegetation without harming fish. When glyphosate touches the soil, it is instantly tied to the soil colloids, is immobilized, and does not enter into the ground water. It is quite safe for the environment, for laborers and for wildlife when used according to the recommendations by the manufacturer. Glyphosate is used with confidence in coffee plantations and other agricultural crops.

Glyphosate must be mixed with clean water. If the water is dirty or cloudy, as, for example, water from a stream after a rain event, or dirty water in tanks, the herbicide is immobilized by the dirt in the water and is made ineffective even before it is applied to the target vegetation. This has happened many times where there has not been a clear understanding of how this herbicide works and/or where there has not been adequate supervision of the mixing operation.

Glyphosate is normally applied at a rate of between 2 and 4 liters per applied hectare. A common method for mixing is to add the herbicide to 200 liters (55 gallons) of water, which is sufficient to cover one hectare (Table 5-1).

Table 5-1
Ratios of glyphosate and its equivalent per applied hectare

Chemical Concentrate liters	Water liters	Equivalent per ha %
2	200	1
3	200	1.5
4	200	2

An application in a 1.5 m diameter planting circle is as effective as a total application for many allelopathic grasses and weeds. With applications in just the planting circle, the amount of herbicide needed as well as the cost is lower than when it is applied in strips or over the total area (Table 5-2).

Table 5-2
Three methods for applying glyphosate and the amount required per hectare

Initial Spacing m	Trees per hectare	Herbicide concentration %	Application method		
			total area	strips 1.5 m	circles 1.5 m
		herbicide, liters/ha			
3 x 3	1100	1.5	3	1.5	0.6
3.5 x 2.6	1100	1.5	3	0.9	0.6
3 x 3	1100	2.0	4	2.0	0.8
3.5 X 2.6	1100	2.0	4	1.1	0,8

The weed killer, 2,4-D, is a herbicide that kills the foliage of broadleaf species but has very little effect on grasses. It is a commonly used weed killer in agriculture for grain crops. For a foliar weed killer, 2,4-D is used in the ester formulation. When used to control resprouting of tree stumps after harvest, it is used as an amine formulation.[1] It is an effective herbicide for killing stumps of *Gmelina arborea*, as well as the eucalypts. When plantations are thinned for sawtimber production, it is necessary to kill the stumps of the cut trees so that they do not resprout and compete with the residual trees. The amine formulation of 2,4-D can be applied directly to the freshly cut stump by spraying or by brushing, using the concentrated herbicide or a half concentration for easier to kill species (Ramírez *et al.*, 1994). Trials should be made to determine the most effective and economical concentration for stump applications after thinning in the particular environment. The herbicide needs to be applied to recently cut stumps; once the stumps have dried out, the herbicide has little effect.

Arsenal® is an effective weed killer for grasses and broadleaf weeds, but it is not effective on legumes or pines. This herbicide is often used to control of grass, weeds and brush in young pine plantations in the United States since it can kill difficult broadleaf species, such as those in the genera *Acer* (maples) and *Liquidambar* (sweet gum), which often compete with pines. Arsenal is a little slower acting than glyphosate or 2,4-D, but it is effective and can continue to kill woody brush competition after two or three years.

Diuron is an herbicide applied to the soil and it is then absorbed by the plant roots. There are several commercial trade names, including Karmex® by DuPont. Diuron is used to kill vegetation prior to planting since it kills all plant species. The herbicide remains effective in the soil for several weeks and, for that reason, it is best to wait three or four

weeks after application before planting trees (Cannon *et al.*, 1984). One advantage of diuron is its effectiveness in clay soils. During the first year after planting it can be used to control grass and weeds between tree rows when the tree roots have still not grown into these strips. It is an alternative where mechanical equipment cannot be used, such as in wet or soft soils. Another advantage of diuron is that it can be obtained in a granular formation that can be applied to the soil without the need to carry sprayers or backpack pumps with solutions in water.

Hexazinone (brand names Pronone® & Velpar®) works similarly to diuron, being an herbicide applied to the soil, but it is more effective in sandy soils, whereas diuron is more effective in clay soils. The granular formulation can be applied to the soil during the dry season, but it does not activate until moistened with rain or irrigation water.

Picloram (trade name Tordon®) is another systemic herbicide that kills all types of vegetation. It is not commonly used in forestry operations since there are other herbicides that are available in the market, usually at lower cost.

The herbicide oxyfluorfen (brand name Goal®) is a preemergent herbicide, i.e., it kills germinating seed, but it is not as effective as a weed killer on plant foliage that is well developed. Oxyfluorfen is applied to bare soil and it forms a chemical film over the soil which kills germinating seeds. After its application, care must be used to not walk over the area and disturb the chemical film or the herbicide will lose its potency where it has been disturbed. When making plantings after applying oxyfluorfen, workers must use care and watch where they walk to minimize damage to the herbicide film, which is invisible on the soil surface. Although oxyfluorfen is quite effective for the control of germinating grasses and weeds in new plantations, it is not commonly used in forestry operation due to its higher cost, compared with other available herbicides in the market.

Grass-selective herbicides exist which only kill grasses and will not damage broadleaf trees or pines. This group of herbicides is used in agricultural applications, but is seldom used in forestry operations due to the relatively higher cost. One brand of grass-selective herbicide is Fusilade®.

Paraquat (brand name Gramoxone) is a weed killer that has been used in agriculture, particularly in banana cultivation. However, it is not recommended for forestry purposes as it has a high toxicity level when in direct contact with animals or humans (Tables 5-3 & 5-4).

Table 5-3
Descriptions of common silvicultural herbicides

Generic name	Commercial brand*	Manufacturer	Class	Formulation	Application	Affected plants	Common doses	Toxicity levels	LD 50 mg/kg
2,4-D	Weedone	Union Carbide	weed killer	powder, liquid	foliage	broad leaf species	2 - 5 l/ha	II	375-600
diuron	Karmex	DuPont	systemic	granulated	foliage, soil	all classes of vegetation	4 - 8 kg/ha	III	3400
fluazifop	Fusilade	BASF	weed killer	liquid	foliage	grasses	1.0 l/ha	III	3000
glyphosate	Roundup	Monsanto american	systemic	liquid	foliage	all classes of vegetation	2 - 4 l/ha	III, IV	4320-7000

Generic name	Commercial brand*	Manufacturer	Class	Formulation	Application	Affected plants	Common doses	Toxicity levels	LD 50 mg/kg
imazapyr	Arsenal	Cyanamid	weed killer	liquid	foliage	all vegetation except legumes and pines	2 - 5 l/ha	III	500
oxyflurofen	Goal	Rohm & Haas	preemergent	liquid	soil	germinating seeds	1 a 2 l/ha	IV	5000
paraquat	Gramoxone	BASF	weed killer	liquid	foliage	all classes of vegetation	1,5 l/ha	III	1000
picloram	Tordon	Dow	weed killer	liquid	foliage, soil	all classes of vegetation	1 - 2 l/ha	IV	8200

*/ For products with expired patents there may be other manufacturers and trade names for herbicides

Table 5.4
Definition of toxicity levels based on LD50 levels[2]

Category	Toxicity	Label	Oral levels of LD50	Examples
I	Severe	Danger	< 50	Strycnine
II	Moderate	Warning	50 – 500	Caffeine
III	Slight	Caution	500 – 5000	Table salt
IV	Very Slight	caution	> 5000	Nicotine

Fertilization

Tree growth potential is defined by the *limiting factor*, i.e., growth can only be improved if restrictions caused by environmental deficiencies are alleviated (Kane *et al.*, 2000). For example, if the most limiting factor is soil moisture, tree growth can only be improved by increasing the soil moisture or by using that moisture more efficiently. If available soil phosphorus is the most limiting factor, applications of nitrogen will not have a positive effect on tree growth until the available phosphorus levels are increased (Figure 5-15). In order to improve plantation productivity it is necessary to first evaluate the state of the growth variables to determine the most restrictive factors and to search for the best management alternatives for a given environment.



Figure 5-15. Tree growth is defined by the most limiting factor.

Most arable soils with potential for agriculture or grazing are already in cultivation or pastures. As a rule, forest plantations are established on marginal sites for agriculture or on soils already degraded due to previous agricultural use. Trees can often grow acceptably on such sites because the nutrient demand of tree crops is generally lower than that of agricultural crops or grazing animals. In basic terms, one of the key objectives of agriculture and animal husbandry is to extract nutrients from the soil in the form of food for human consumption. On the other hand, commercial forestry has as its objective the production of wood which has relatively low nutrient levels, since the foliage, roots and fruits, which contain the majority of the nutrients in trees, are left on the site and are seldom used as they are in agriculture.

The so-called *pioneer* species are, by definition, species capable of developing and growing successfully on marginal soils that are nutrient deficient. The pines, as a group, are pioneer species since they can grow with minimal nutrients and because of their capacity to rapidly recycle nutrients from the tree and the soil. Trees extract nutrients from the soil, use them and, when the foliage and branches fall to the ground, these return to the soil. Upon decomposition, this organic material is converted to humus by the action of bacteria and fungi, and then the tree roots are able to absorb those nutrients from the soil again.

Tropical soils are commonly deficient in phosphorus (P), which is one of the macronutrients. Among the micronutrients, boron (B) is a nutrient often deficient in volcanic soils as well as highly weathered soils. Positive tree responses to applications of these elements have been reported in numerous research trials. There can also be deficiencies of other nutrients critical to agricultural crops and grasses, such as potassium (K), calcium (Ca), zinc (Zn), molybdenum (Mo) or copper (Cu), but in most forestry research for commercial plantations, deficiencies in these elements are uncommon. Even though potassium is a macronutrient, it is rare to find significant tree growth responses to K fertilization either in the field or in the greenhouse.

Nitrogen (N) is a special nutrient in the sense that responses to nitrogen fertilization occur only when there are sufficient amounts of other available nutrients for tree growth. Nitrogen fertilizers are commonly applied during the mid-term of a plantation rotation and is also accompanied with phosphorus. Growth responses to N and P have been reported for pines and eucalypts (Ballard, 1984; Kane *et al.*, 1992).

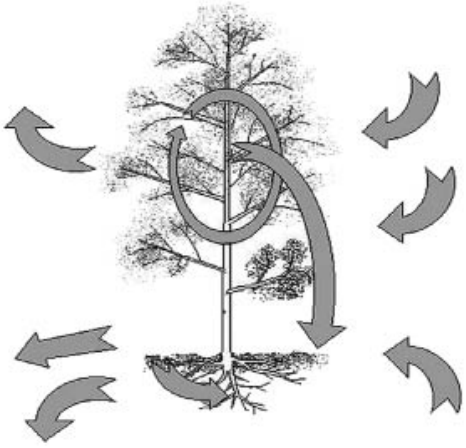


Figure 5-16. Nutrient cycling in trees.

The nutritional state of trees can vary by individual nutrients from extremely deficient to toxic (Figure 5-17). In general, when trees show acute nutrient deficiencies, certain characteristic symptoms appear that help to determine the deficient nutrient and the severity of the deficiency. Sometimes, when the deficiency is not too severe, there are no apparent deficiencies to see, but the deficiency can be detected by the slow growth of the trees. This is an intermediate nutritional level which is called *hidden hunger* and where the trees will respond positively to fertilization. When nutrient levels are above the necessary levels required by the species that is planted, adding that nutrient as a fertilizer does not produce a positive growth gain. Only on rare occasions have forest plantations been established on sites that have such high nutrient levels as to be toxic to trees.

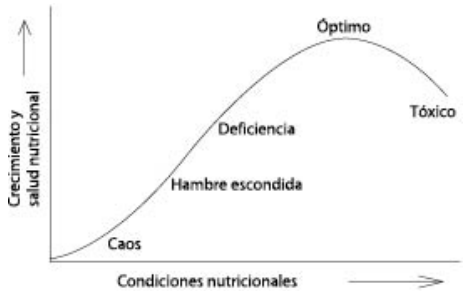


Figure 5-17. The nutritional health and the growth potential of trees under varying nutritional levels (Kane *et al.*, 2000).

Plantations of *Eucalyptus grandis* and *E. globulus* established in andisols in the Colombian highlands require fertilization with phosphorus and borax (Cannon, 1983). The application of 50 grams of diammonium phosphate and 10 grams of borax per tree at time of planting increased tree growth between 8 and 30 m3/ha/year on six year rotations. Tree volume can be increased between 10% and 20% when refertilizing eucalypt plantations after one or two years using nitrogen, phosphorus and borax (Kane *et al.*, 1992).

In South Africa, plantations of *Eucalyptus grandis* attained growth increases of between 3 and 11 m3/ha/year at harvest age, due to initial fertilization at time of planting. With rotations of 7 to 10 years, growth responses to fertilization averaged 57 m3/ha. Optimum doses vary among sites from 0 to 60 kg/ha for elemental nitrogen, 10 to 40 kg/ha for elemental phosphorus and 5 to 40 kg/ha for elemental potassium (Schönau, 1977). South African growth gains due to fertilization of pines at time of planting varied from 1 to 8 m3/ha/year. The optimum doses of elemental nitrogen varied from 0 to 100 kg/ha, for elemental phosphorus from 10 to 50 kg/ha and for elemental potassium from 0 to 60 kg/ha (Herbert & Schönau, 1989). In New Zealand, the growth of a plantation of *Pinus radiata* fertilized with phosphorus reached 200 m3/ha on a 20-year sawtimber rotation (Mead & Gadgil, 1978).

In Australia, the fertilization of *E. grandis* with 60 kg/ha of P at time of planting increased average tree volume by 60% at 5½ years of age in highly weathered and leached soils (Cromer *et al.*, 1998). The combination of N and P increased growth slightly more than that obtained with P only. Wood density increased with N and P fertilization. In that study, wood specific gravity of *E. grandis* increased in direct proportion to the fertilization

(Cromer *et al.*, 1998), which is contrary to the popular belief that wood density decreases with increases in tree growth rates.

Visible symptoms of deficiencies of some nutrients can be seen in trees. For example, in pines, a progressive dieback of the tips of branches can often be attributed to a deficiency of boron. Short needles and a purple tinge to the foliage of pines is an indication of a phosphorus deficiency, while in eucalypts phosphorus deficiency can be detected by a purple color to the foliage and abnormally wide spaces between leaf veins. Some other symptoms are not as obvious and additional information is needed to define which nutrient is causing the deficiency. There can be deficiencies of multiple nutrients that can be seen as a chlorotic color to the tree leaves. Since most symptoms of deficiency appear when the condition is severe and there is already growth loss, it is not a good idea to use deficiency symptoms as the primary method to determine if and when fertilization is needed.

Chemical analysis is a reliable means for determining deficiencies in some nutrients, but first of all there must be a calibration established between tree growth and soil nutrient availability. When soil samples are taken for laboratory analysis, they must be representative of the area under study if they are to be used to determine commercial fertilization doses. All too frequently, errors are made in fertilizer recommendations due to poor sampling procedures of the target soils

Relations need to be defined between critical nutrient levels in the soil and the species of interest that is planted on the site. Fertilization can be justified when nutrient concentrations in the soil are below the critical response levels. Soil nutrient calibration can be very valuable when determining growth responses to phosphorus and potassium, but it is not very effective for determining deficiencies of nitrogen. Minimum available nutrient levels defined by specific analyses can determine if soil levels are near to critical levels and can show the need for immediate fertilization. To interpret the results of soil analyses requires that the same procedures be used for determining critical levels as were used to initially establish those levels.

There are some important interactions between fertilization and other silvicultural practices. Weed and grass control in plantations is important so that fertilizers stimulate tree growth rather than weed growth. Where trees are being grown on sawtimber rotations, it is best to fertilize with nitrogen-based fertilizers after thinning so that only target trees receive the benefit and have the additional growing space to respond to treatment. As a rule, initial fertilization at time of planting is best concentrated near the root systems of the small trees to restrict the fertilizer availability to weed competition. Fertilizers can be applied at determined points, such as under the tree, in a circle around the trees or in thin bands near the trees (Figure 5-18).

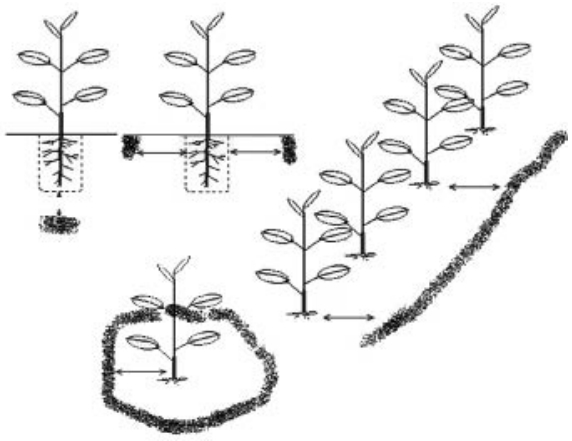


Figure 5-18. Four methods of fertilizer placement at time of planting. The best methods from an operational standpoint are those in circles or in bands.



Figure 5-19. Correct fertilizer application in a circle 20 to 30 cm from the tree stem.

\Bands or rings of fertilizers are placed 20 to 30 cm from the tree; if they are placed closer to the stem they can cause damage to the stem or the roots by toxicity and can even cause the death of the tree (Figures 5-19 to 5-22). Surface application methods are often used due to the ease of application, but subsoil application are more effective for stimulating deep root growth when the fertilizer is applied in the bottom of the subsoil slit.



Figure 5-20. Incorrect application of the fertilizer against the seedlig stem, which can cause damage or even death.



Figure 5-21. The tree should not be planted directly over a fertilizer application since this can cause root burn or death. The fertilizer is placed in a deep hole, 5 cm of soil is placed on top of the fertilizer and the tree planted on top of that.



Figure 5-22. Incorrect fertilizer application at the base of the tree causes burns on the soft bark tissue and can reduce initial tree growth.

Research trials are needed to determine the effectiveness of fertilizer application. *Chemical compounds*, not commercial mixtures, are needed for quantitative trials. In this way it is possible to define the tree response to a given chemical element that is suspected of being deficient. Examples of chemical compounds include: urea, ammonium sulfate, diammonium phosphate, triple super phosphate, potassium chloride, agricultural borax, magnesium sulfate, zinc sulfate, manganese sulfate, copper sulfate, iron sulfate and others. Commercial fertilizer mixes such as 10–30-0, 14–14-14, etc. should not be used for quantitative research to determine deficiencies in a given element. The manufacturer of the commercial mix guarantees a minimum of the stated compounds; for example, 10-30-10 contains a minimum of 10% N, 30% P2O5 and 10% K20 (or their equivalents in other compounds), but it does not say what those other elements may be nor the composition of the "fill material" used. The manufacturer can use any available material as filler which is currently cheapest in the market, such as ground rock phosphate, ground limestone, ground alum, flour, sand, or other materials. For this reason, such mixes are not useful for determining tree growth responses to individual fertilizer elements.

Once the response to given elements has been determined, along with the doses of each, pilot operational trials need to be made to show the growth response to those elements on an operational scale, using commercial fertilizer mixes that are available in the market at acceptable costs.

In a fertilizer trial on andisols in Colombia, the application of phosphorus and boron was spectacular (Figures 5-23 & 5-24). Volcanic ash soils are highly deficient in both P and B, which resulted in significant growth increases with their application. In this study, a combination of both P and B was necessary to obtain the growth response; one element without the other did not produce significant growth responses when compared with the unfertilized check trees (Ladrach, 1978a). When nitrogen was added to the phosphorus and boron there was a growth increase, but it was marginal.



Figure 5-23. In a fertilizer trial on volcanic soils in Colombia, the 3-year growth of *Eucalyptus grandis* without fertilization was poor and the trees tended to fork.



Figure 5-24. In the same trial, 3-year growth of *E.* grandis was very good with just one initial application of 50 g of triple superphosphate plus 5 g of borax at time of planting and the trees did not fork.

When designing trials it is important to remember not to try to “solve all the world’s problems” at one time. It is best to make several trials where some elements are held constant in one trial while others are varied. For example, a trial can be designed to vary the concentrations of N and P while using just one rate of other elements such as K, B or Mg. Once the optimum levels for N and P have been defined, another study is established holding those elements constant, but varying the doses of the K, B and/or Mg. For more information on study design, see the chapter on Forest Research.

The principal sources of nitrogen used as fertilizer are urea, ammonium nitrate, ammonium sulfate and diammonium phosphate. Trees absorb nitrogen in the form of ammonia (NH4+) and in the form of nitrate (NO3). Most tree species are more efficient at absorbing and using ammonia than they are with nitrates. Ideally, nitrogen fertilizers are applied when the roots are actively growing and are well distributed throughout the soil surface, with moderate temperatures and when the soils are moist and well aerated. Many

fertilizer sources of nitrogen can be equally effective under most field conditions, but in specific cases one source may be better than another. Urea has a high concentration of N (45%), but care must be used in its application: The nitrogen in urea can turn to gas and evaporate when the soil is dry, temperatures are high and there is little rainfall. Nitrogen gasification can be particularly severe when applied to alkaline or limestone soils. Urea fertilizers need to be incorporated into the soil when used under conditions when gasification can occur.

Table 5-5 shows the percentage of elemental nutrients by fertilizer type.[3] It is best to work with elemental units for phosphorus (P) rather than with phosphate (P205).

Table 5-5
Fertilizers and their elemental content

Fertilizers	Chemical Nutrient percent by chemical										
N	P	K	S	Mg	B	Zn	Ca	Fe	Cu	Mn	
Ammonium sulphate	21			24							
Urea	46										
Ammonium nitrate	33										
Diamm. phosphate	18	21									
Triple superphosphate	21							27			
Potassium chloride			52								
Potassium sulphate			45	18							
Magnesium sulphate				27	20						
Iron sulphate				21					37		
Borax						11					
Zinc sulphate				20			40				
Copper sulphate				20						40	
Manganese sulphate				21							36
Rocks											
Dolomite					13			33			
Rock phosphate		13-18						40			
Limestone (CaCO3)								40			

In Table 5-6 is a summary of commonly used fertilizers and their chemical formulas. The type of fertilizer used and its handling can affect its absorption by the trees as well as the tree growth response.

Table 5-6
Formulation of common fertilizers used in forest management.

Fertilizer	Chemical formula	Nutritional content
Ammonium nitrate	NH4NO3	33% nitrogen
Ammonium sulfate	(NH4)2SO4	21% nitrogen
Urea	CO(NH2)2	46% nitrogen
Diammonium phosphate	H4)2HPO4	21% nitrogen & 23% phosphorus
Triple superphosphate	Ca(H2PO4)2H2O	21% phosphorus
Rock phosphate	Fluorine & chlorine apatites	8 - 15% phosphorus
Potassium chloride	KCl	40 - 50% potassium

Fertilizer	Chemical formula	Nutritional content
Potassium sulfate	K2SO4	40 - 42% potassium
Borax	Na2B4O7.10H2O	11% boron
Boric acid	H3BO4	17% boron
Copper sulfate	CuSO4	25 - 40% copper
Zinc sulfate	ZnSO4	22 - 40% zinc
Manganese sulfate	MnSO4	26 - 36% manganese
Iron sulfate	FeSO4	20 - 37% iron

Foliar applications of fertilizers have not been found to be as effective as soil applications and foliar applications tend to be more expensive to apply. Another consideration is that foliar applications are seldom an alternative for small trees that have just been planted since they have very little foliar area. It is necessary to wait until there is sufficient foliage to receive a treatment. On the other hand, if there is a known deficiency, it is important to correct it at time of planting, rather than to wait some years for the tree to grow.

The common sources of phosphorus used in forest fertilization are triple superphosphate, rock phosphate and diammonium phosphate (DAP). DAP is the most soluble of the three and can be applied to the soil surface. Triple superphosphate and rock phosphate should be incorporated into the soil. The P contained in phosphoric rock is only available in acid soils and, as such, is best used in soils with pH values below 4.8. The slow liberation of P in rock phosphate can be an advantage in soils with a low capacity for P fixation as well as in soils with a high capacity to fix P. One alternative is to apply rock phosphate at time of planting on acid soils along with a complimentary application of triple superphosphate or DAP.

For good initial growth of trees it is important to add a source of soluble phosphorus at the time of planting. The selection of the phosphoric fertilizer depends on the type of soil and fertilizer costs. It is a good idea to compare prices versus total P content of fertilizers. In some markets, DAP is priced about the same as triple superphosphate and is a better alternative since it is also a good source of N. When comparing P sources for application in acidic soils, it is important to evaluate the soil capacity to fix P, the price of the fertilizer, the costs of transport and the costs of application of such fertilizers as triple superphosphate and rock phosphate. Ground rock phosphate is less expensive per ton of fertilizer, but will require more fertilizer with the accompanying increases in transport and application costs.

Potassium is applied as potassium chloride or potassium sulfate, both of which are soluble in water. Potassium sulfate is recommended where there is also a deficiency of sulfur. The common source of boron is borax. Agricultural borax contains 48% boric acid.

Most commercial fertilizers are mixes. Mixes of N, P and K are identified as to the percentage of elemental N, phosphate (P2O5), and potash (K2O). For example, the mix 12–24-12 contains 12% nitrogen, 24% phosphate and 12% potash. The content of elemental P in phosphate is 43.64% and elemental K in potash is 83.02%. Commercial mixes are often used at time of planting and are effective when the amounts and proportions of nutrients are adequate for the species being planted and for the soil where the trees are planted. When large amounts of fertilizer are required, it is sometimes possible to work with the manufacturer or distributor to obtain the precise mix needed. In other

cases, it may be more economical to buy fertilizers such as triple superphosphate or potassium chloride separately.

Nutrient absorption by trees is less than that of agricultural crops, which is why tree plantations can be successfully established on sites that are marginal for agriculture or cattle grazing. Since wood contains few nutrients compared with other plant parts such as flowers, fruits, foliage or roots, the loss of nutrients during harvest is less than for agricultural crops. Nonetheless, with repeated harvesting of fast-growing trees there will be some nutrient loss to the site. In order to maintain site productivity, it will be necessary to replenish the nutrients lost. Many companies make soil analyses prior to a timber harvest and calculate the expected losses during harvesting. Then, to maintain a minimum acceptable soil nutrient level, a fertilization is planned after harvest for the next tree crop using rates that will bring the soil nutrients up to desired levels.

Plantation density and spacing

Due to the long-term nature of spacing studies, preliminary results are often reported before the trees in the studies reach rotation age. Preliminary results often show that there is more total volume with higher plantation densities, which is quite logical. However, the preliminary results may create an incorrect and misleading impression with respect to which spacings will eventually produce the most commercial wood volume at rotation age.

The results of spacing trials carried to rotation end generally show little or no differences in the commercial underbark volumes per hectare, when the trials include a logical range of tree spacings. As was explained in the section on Soil-Site Capacity, the maximum growth that can be attained with a given species on a per hectare basis depends on the natural soil quality. Except for biological studies, there is seldom interest in knowing the total biomass production per hectare, including bark, foliage, roots, fruits, seeds and resin or other components of biomass when dealing with industrial plantations.[4] The objective of silvicultural management is to ascertain the soil-site capacity for a rotation that will produce trees of optimum size for utilization, by employing optimum spacings for that purpose.[5]

When reporting growth data, a traditional practice has been to include bark in the volume figures, although volumes without bark (underbark) are now being reported in some countries. In trials carried out in Colombia by the author, the percent bark of 15-year-old pine trees was around 22%, whereas for trees 8 years of age the percent bark could be as high as 35% of total overbark volume.[6] With greater tree diameters, the ratio between bark volume and total volume overbark decreases due to an increase in the base value utilized for calculating bark volume. In the case of commercial eucalypt species, such as *Eucalyptus grandis*, *E. urophylla* and *E. globulus*, bark volume is commonly around 13% for trees to be harvested for pulpwood, but it can increase to 20% for trees of lesser diameter. When spacing trials report volumes overbark and the bark percentage is subtracted, differences in commercial wood volumes are usually not significant.

A spacing trial of *Eucalyptus grandis* in Argentina evaluated five spacings over a period of 12 years (López & Aparicio, 1995). The spacings tested were: 2.5 m x 2.5 m (1600 trees/ha), 2.7 m x 2.7 m (1372 trees/ha), 3.0 m x 3.0 m (1111 trees/ha), 3.5 m x 3.5 m (816 trees/ha) and 4.0 m x 4.0 m (625 trees/ha). The results of the trial are shown in Figure

5-25 as total volume overbark. If the bark percentage is subtracted, which is proportionally greater with more trees of smaller diameter, the differences among spacings are very slight, even at younger ages. The effect of stand stagnation can be observed in the total heights for the study shown in Figure 5-25, and this results in shorter trees where the planting densities are highest.

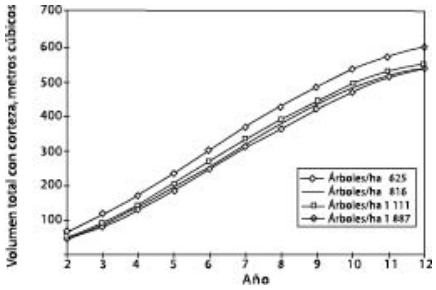


Figure 5-25. Total volume of 12-year-old *Eucalyptus grandis* in a spacing trial in Argentina (López & Aparicio, 1995).

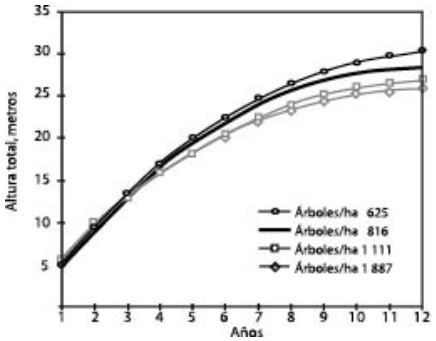


Figure 5-26. Total height of 12-year-old *Eucalyptus grandis* in a spacing trial in Argentina (López & Aparicio, 1995).

The U. S. Forest Service established pilot plantations of *Eucalyptus* species in a spacing trial in Hawaii in the 1980's for the purpose of generating information related to biomass production as a source of energy (Whitesell *et al.*, 1992). Measurements were reported in dry tons of biomass overbark for the main stem at six years of age. The results, converted to metric measure, are shown in Table 5-7. Differences in total biomass are approximately the effect of the bark weight, which increases with higher stand densities. This indicates that the actual dry weight of the wood underbark is quite similar for all plantation spacings tested.

Table 5-7
Six-year results of a spacing trial of *Eucalyptus* spp. in Hawaii

Plantation density	Average DBH	Yield	Increase over the previous spacing
Trees/ha	cm	Dry tons/ha	%
770	19.6	96	-
900	19.0	101	5
1076	18.3	105	4
1346	16.8	109	4
1793	15.0	115	5

Results of spacing trials tend to be quite similar for temperate as well as tropical climates, as well as for broadleaf species and conifers. The reason for these similarities for different species and climates is that the commercial size of logs required for producing pulpwood or for producing sawlogs is basically quite similar, independent of species and climatic conditions, and the effect of spacing is related to the size of trees that are to be harvested more so than to the plantation age or to the growth rate.

A spacing study of *Pinus patula* in Colombia provides more information concerning differences in growth rates with different spacings (Osorio & Uribe, 1994). The rotation age for pine pulpwood is considered to be about 15 years. The data reported for the study at 13 years age shows differences of just 5% in volume underbark with initial spacings of 1333 trees/ha and 1666 trees/ha, which is an indication that these spacings will most likely attain similar volumes at rotation age (Table 5-8). There was increased mortality with higher densities in this study, while average diameters increased with lower stand densities.

Table 5-8

Thirteen year results of a spacing trial of *Pinus patula* in Colombia (Osorio & Uribe, 1994)

Stand density	Total volume	Pulpwood volume	Oven dry weight	Average DBH
trees/ha	m3/ha	m3/ha	ton/ha	cm
1111	388	367	159	24
1333	420	395	160	23
1666	450	417	162	21
2000	457	418	168	20

At 13 years, differences in dry weight per hectare were less than 2% for densities of 1666, 1333 and 1111 trees/ha. This is due to the greater proportion of wood in the tops of more trees of lesser diameters when compared with the density of plantations with less but larger trees at lower stand densities. The top wood of pines is juvenile wood, which has a lower wood density than mature wood in the lower portion of the trees.

In spacing trials carried to rotation age, results generally show that when stand densities are below the optimum for a species and site, the *underbark growth decreases gradually* with decreasing stand density, but when the density is greater than the optimum, *growth deceases more rapidly* due to stagnation. Thus, from a biological point-of-view, it is better to make the error of planting fewer trees than optimum for a particular site rather than too many.

When there is crown closure, trees begin to compete among themselves for available soil moisture and nutrients as well as for sunlight, even on sites which are not considered to have noticeable environmental stresses. At the time of crown closure, when trees become more vulnerable, it is common to encounter defoliating insect attacks or the presence of diseases. If there are natural environmental stresses as well, such as extended droughts, there are increasing probabilities of attacks by diseases or insects at the time of crown closure or thereafter.

One argument often heard against wider spacings is that it requires more weed control after planting. However, the experience of many forestry companies is that reductions of

stand densities from 2000 or 1667 trees/ha to 1110 trees/ha reduce plantation establishment costs significantly but without significant increases in first year weed and grass control.[7]

A disadvantage with spacings of 3.0 m between tree rows is that tractors and other mechanical equipment cannot move between rows without damaging trees after one or two year's growth. A wheel tractor is normally more than 2.5 m wide and, when it passes through rows, it will slough off bark or cause additional tree damage. A spacing of 3.5 m between rows allows for equipment to travel between rows of trees for fire control or for other needs where a spacing of 3.0 will not allow for such movement of equipment.

During site preparation activities, such as subsoiling and bedding, as well for post-planting maintenance, the wider the spacing between rows, the lower will be the cost of site preparation and site maintenance. For example, with a spacing of 3.5 m x 2.6 m (1100 trees/ha) there are 15% fewer passes of a subsoiler or a bedding harrow than with a spacing of 3.0 m x 3.0 m (1110 trees/ha). Post-planting mechanical weed control has similar cost reductions. The result is an immediate savings in the cost of equipment for site preparation, as well as less traffic (soil compaction) on the site.

After harvesting a plantation with a 3.5 m row spacing, it is possible to subsoil between rows of stumps for replanting, which is difficult to do with a 3.0 m spacing, since the stumps will have diameters of 30 cm or more and a wheel tractor will pass over top of stumps trying to subsoil, bed or do other operations (Figure 5-27). Once a site has been planted to trees at a close spacing, it can be quite difficult to make changes for future rotations.

With a row spacing of 3.5 m, the stand density can be increased in the next rotation by increasing the distance between trees within the rows. For example, to obtain a planting density of 1000 trees/ha, the spacing becomes 3.5 m x 2.8 m.

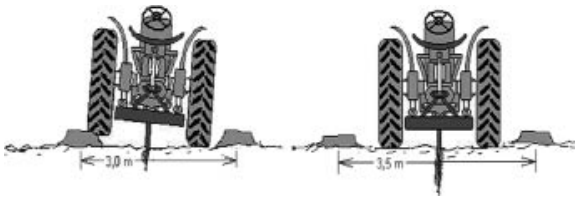


Figure 5-27. A row spacing of 3.0 m does not allow mechanical equipment to pass between rows of stumps, but with a spacing of 3.5 m a tractor can work between rows of stumps.

Some companies are using spacings of 4.0 m between rows for subsoiling or bedding in order to reduce site preparation cost even more. Row spacings of 4.0 m have been used for planting *Pinus taeda* in the north of Argentina and for *Eucalyptus urophylla* in Minas Gerais, Brazil, among others.[8]

Many spacing trials report *total volume*, but it is less frequent to read reports where commercial volumes are presented, such as in the trial cited for *Pinus patula* in Colombia, and it is not very common to consider this effect when evaluations are made of spacing variables. The greater the stand density, the greater the proportion of non-commercial trees at the time of harvest. If trees are not harvested due to their small diameters, but are left standing, this increases the cost of site preparation for the next rotation as well as the amount of combustible material and the risk of fires.

In Minas Gerais, Brazil, a study of *Eucalyptus camaldulensis* reported the harvest cost variations for nine different spacings (Contreras, 1997). In that study, spacings tested had the following numbers of trees per hectare: 123, 417, 556, 776, 833, 1111, 1667, 2222 and 3333. Table 5-9 shows the 7th year results.

Table 5-9

Seven-year pulpwood volumes with bark for *Eucalyptus camaldulensis* in the Cerrado Region of Minas Gerais State, Brazil (Contreras, 1997)

Initial trees/ha	Harvested trees/ha	Volume m3/ha
123	119	45
417	403	86
556	555	104
667	622	111
833	772	117
1111	1074	122
1667	1388	134
2222	2148	107
3333	2555	97

Observing the data presented, it can be seen that there is more volume *overbark* at an initial spacing of 1667 trees/ha (3.0 m x 2.0 m). However, the yields underbark are quite similar for the intermediate spacings in the trial because the higher density plots have more small-diameter trees with a greater proportion of bark than in the plots with lower stand densities. Mortality within the study increased notably for densities greater than 1111 trees/ha, which indicates that the trees planted at higher densities were under greater stress from tree-to-tree competition.

In the same study, a cost comparison was made for harvesting and wood forwarding to the edge of the road. Harvesting costs were based on the use of chainsaws and hand labor, since the plots were too small to permit use of heavy equipment. Based on the results, the conclusion was that the least cost of wood production per cubic meter was obtained at an initial spacing of 4.0 m x 3.0 m (833 trees/ha). Taking into account the fact that machine harvesting costs are directly related to the number of pieces of wood handled, these conclusions can also be applied to mechanized harvesting systems.

An important factor to consider when harvesting plantations with high stand densities is the cost of debarking small-diameter trees. The cost of manual or semi-mechanical debarking in the field is directly related to the number of pieces of wood handled, and, as such, with more trees of small diameters, the debarking cost per cubic meter of wood increases. If the wood is debarked at the woodyard or mill, it is quite common to observe that small-diameter top wood tends to break. When large drum debarkers are used for debarking pulpwood, the broken top wood falls out of the debarker along with the bark as waste material. Even when woodyards accept wood down to 5 or 7 cm top diameters, virtually all of the small tops break and become waste along with the bark, instead of moving to the chipper to be used for the production of wood pulp.

Thinning

The primary objective of thinning is to remove poorly formed trees at an early age in order to create more space within the stand to allow the best trees left standing to increase in diameter and thereby increase in value as sawlogs. Thinnings may produce some commercial wood, but that is seldom the primary objective of thinning.

Sawlog characteristics for lumber or veneer production are much more stringent than the characteristics of logs for pulpwood. Logs for solid wood products have larger minimum acceptable diameters and must be straight and long enough to produce the desired products. For these reasons, the amount of round wood produce for sawtimber in a plantation is invariably less that the amount of round wood that can be produced for pulpwood in a similar plantation and site.

Before beginning a planting program, forest management must clearly define the final objective of silviculture, be it for sawlogs, veneer logs, chip wood for a particle board mill, wood for a pulp mill or another use. The silvicultural thinning does not affect total wood production at rotation age, be it a thinning by rows or from below (Ladrach, 1983a). As has been explained previously, the total production of wood is defined by the *soil-site* capacity rather than by the silvicultural management method.

On the other hand, the price of wood for pulp or for chip production seldom varies due to log quality or log size. For pulpwood production, all of the round wood of commercial size is harvested at rotation age. As a rule, the minimum top diameter for pulpwood is 7 to 20 cm and log lengths can be a minimum of 1.5 m up to a tree length, depending on the type of machinery employed for the harvest. Logs to be used for pulpwood or wood for particle board can be straight or crooked since they are reduced to chips during the industrial processes.[9] As such, the most economical silvicultural method for wood production for chip wood on short rotations is to plant the optimum number trees to be managed and then make a clear-cut harvest when these have reached an acceptable size for commercial use.

In general, the cost of wood produced by thinning is between 30% and 50% greater per cubic meter than wood harvested by clear-cutting.[10] There are several reasons for this:

- Most wood harvested by thinning comes from young plantations which have smaller diameter trees. As a consequence, it requires more labor and machine time to handle a greater number of small pieces of round wood to produce a cubic meter of solid wood.
- Since thinning produces less wood per hectare, labor and harvesting machinery require more time traveling between trees during harvesting operations and, therefore, require more time to process a given volume of wood.
- When thinning, crews must be careful not to cause damages to standing trees and this requires more time. When thinning, there is the additional problem of cut trees hanging up in adjacent standing tree crowns and this results in additional delays and additional cost.
- When thinning, more plantation area must be harvested to produce a given volume of wood than during a clear-cut harvest. This increases the amount of road maintenance required for thinning.[11]

Example: If a 3-year-old acacia plantation has a mean annual increment of 25 m3/ha/year and 50% of the trees are removed with a thinning from below, we can assume that approximately 40% of the standing volume is removed. If

the same plantation is left to grow to six years of age, without thinning, the mean increment could reach 30 m3/ha/year. In each case, we assume that the wood is to be used to supply a pulp mill that requires 500,000 m3/year of wood furnish. If the mill is supplied with wood from 3-year-old thinnings, it would be necessary to thin 16,667 ha: [500,000 m3/(3 years * 25 m3/ha/year * 40%) = 16,667 ha]. If the same amount of wood is obtained by clear-cutting at six years of age, the area to harvest would be: 2,778 ha: [500,000 m3/(6 years * 30 m3/ha/year) = 2,778 ha]. Thus it would be necessary to thin five times more area to supply the mill than if the wood were supplied from clear-cuts, and would require five times the road maintenance on secondary and internal roads.

Pre-commercial thinning

Pre-commercial thinning is the elimination of young trees that have not reached sufficient size to have commercial value. A pre-commercial thinning does not mean that it is anti-economical or that it does not have commercial use; to the contrary, this type of thinning is done with the express purpose of increasing the commercial value of plantation wood. A pre-commercial thinning reduces the initial stand density at an early age in order to grow larger diameter residual trees for sawtimber production (Figures 5-28 & 5-29). There are several reasons for making a pre-commercial thinning of a stand:



Figure 5-28. A pre-commercial thinning of *Gmelina arborea* at 1.5 years of age, reducing stand density to 550 trees/ha.



Figure 5-29. During the pre-commercial thinning, the poorly formed, forked and leaning trees are eliminated.

- Plantations destined for sawlog production are often established with densities similar to those destined to pulpwood or chip wood production, so that the stand closes crown at an early age.
- Some trees will grow crooked or leaning due to the use of unimproved seed, due to poor planting practices where there are curled roots, or due to the inadequate weed and grass control in young plantations. Such crooked trees need to be eliminated at an early age in order to allow the better formed trees sufficient space to increase in diameter (and value) more quickly. Therefore, it is important to plant enough trees to

be able to make selections of good residual trees to keep and to eliminate the poorly formed trees in plantations destined to sawtimber production.

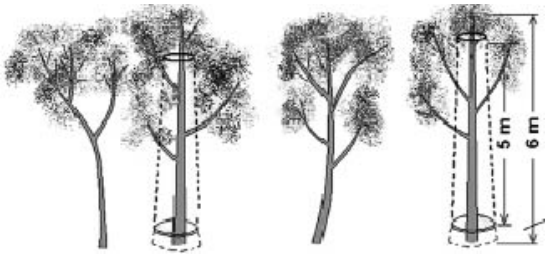


Figure 5-30. When trees reach 6 m height, it is possible to make an initial selection of trees with straight stems in the first 5 m log and eliminate those trees that are of poor form and small diameters.

- As a rule, the basal 5 m (16 foot) log in a tree contains approximately 70% of the value of the tree as a sawlog, since it has the largest diameter. Once a tree has reached a height of 6 m, it is possible to visualize the form of the basal 5 m log, whether it is straight or crooked, and to eliminate the poorly formed trees by making a pre-commercial thinning so as to grow wood only on the well-formed trees (Figure 5-30).
- In the case of fast-growing species, the youngest trees have the fastest growth rates. Thus, pre-commercial thinning opens up additional space for the selected trees to maximize their growth and their value.

A simple and effective method for marking a plantation for a first thinning is shown in the following example:

Let's assume that we want to eliminate 50% of the trees with a thinning from below. [12] The forest technician stands between two rows of trees at the edge of the lot and counts six trees on the left and six on the right (including the spaces where trees have already died).[13] Of the six on each side, three are marked for cutting, these being the smallest or those with the poorest form. However, it is not a good idea to leave more than two trees adjacent in a row, because the purpose of the thinning is to create sufficient space for the remaining trees to grow after thinning. Because of this, it may be necessary to occasionally eliminate a good tree during the marking process.

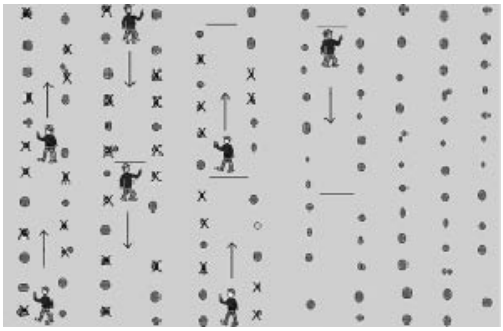


Figure 5-31. The initial selection evaluates 12 trees, six on either side of the technician, with half of these to be marked for removal during the first thinning.

After reviewing and marking six of these 12 trees, the technician proceeds between the same two rows to the next 12 trees and repeats the process until all the plantation has been marked. The result is the removal of the poorest trees, but at the same time leaving a good distribution among the trees in the stand. The forest technician can apply other thinning intensities, by varying the number of trees in the initial count and the number of trees to eliminate (Figure 5-31).

Commercial thinning for solid wood products

The first thinning removes the trees of the poorest form and allows the remaining trees to maximize their diameter growth during the succeeding years of growth. The decision to make a first thinning pre-commercial or commercial is based on the method that will produce the best financial return to the company. The first thinning can be commercial when there exists a market for small diameter round wood and when the costs of thinning and wood removal are not high.

In most cases, it is not feasible to make just one thinning for sawlog production; normally two thinnings are required (Ladrach, 2004). If too many trees are eliminated during one thinning, the stand density is decreased drastically and total wood production will be inferior to the potential of the site. Early and heavy thinnings can also result in invasions of grass, weeds or bushes which compete with the trees for soil nutrients moisture and reduce the plantation productivity. When the thinning is excessive, some trees may lean, bend or even uproot.

The second thinning is carried out with an eye to leaving the best trees for sawlog production at time of the final harvest (Figures 5-32 to 5-34). Marking procedures vary by species, by the market for sawlogs, as well as local growing conditions in the plantations. The forest technician in charge of forest inventory is the best person to mark the trees for a second thinning, since this job is very important and determines the eventual profitability of the plantation. For tropical species which have relatively uniform diameters, a second thinning can be based on the number of trees per hectare. For older plantations held on very long rotations and with significant variability in tree diameters, it may be necessary to plan the thinning based on basal area (m2/ha), but this requires much more time and more calculations during the marking process.



Figure 5-32. A plantation of *Gmelina arborea* seven years old in Indonesia, after a commercial thinning at four years of age.



Figure 5-33. The first thinning at six years of age in a plantation of *Pinus taeda* in the South of Brazil.



Figure 5-34. A first thinning of a plantation of Pachira quinata at six years of age in Colombia.

More than two thinnings are not needed for fast-growing species such as tropical pines, *Gmelina arborea* or teak, when rotations are less than 25 years. Thinnings made in older plantations run the risk of soil compaction by harvesting equipment and/or trucks. Thinnings made when trees are older also run a greater risk of causing damage to residual trees by scraping off bark or causing other damages such as breaking off large branches which can allow the entry of heart rot fungi into the trees left standing. It is also important to consider that as the growth rate slows in older plantations there is a lesser response to the increased growing space made available by thinning and it will take more years to recover the thinning investment than when thinnings are made at early ages when the trees are near their maximum growth rates. A good rule of thumb is to make the final thinning at half rotation age for plantations managed on rotations of less than 25 years. With fast-growing tropical plantations, there is absolutely no advantage to making thinnings within a few years prior to final harvest, since the residual trees will not have sufficient time to increase in diameter and value.

Modern sawmills are designed to process large numbers of small diameter logs quickly. A sawmill may be designed to accept logs less with than a 40 cm bottom end diameter, such as a *skragmill* with parallel head saws, or a *chip-n-saw*,[14] which has chipper heads instead of saws. Rotary plywood is also being produced from small logs using spindleless lathes.[15] The capital cost of a sawmill increases disproportionately with the increase in log diameter. For example, the capital cost of a skragmill that can handle 60 cm butt-end diameter logs can be double the cost of a skragmill that has a maximum capacity to handle 40 cm diameter logs.

Access rows. Thinning to improve the log quality for sawtimber implies the use of the technique of thinning from below. Row thinning, also called mechanical thinning, does not improve the quality nor the value of the residual stand (Ladrach, 1983a) and is not used to produce sawlogs. However, when making a thinning from below, access is needed to remove the felled trees, and it is often necessary to cut access rows for this purpose, so that the wood can be skidded or transported to roadside.

In level land and where wood can be transported by tractor, access rows are placed perpendicular to roads. In hilly terrain it is often necessary to make access trails along the contour lines. In steep terrain, where wood is removed by cables, the access rows are cut along the vertical slopes so that the logs can be hauled upwards by cable.

When the planting rows are in the desired direction for log removal, a row can be removed to allow for wood forwarding to roadside. If the planting rows are not aligned in the desired direction, the extraction rows will need to be opened across rows. The number of access rows required depends on the stand density, the method to be used for log removal and the topography.

When the wood is cut to lengths of 1.5 to 2.4 m for hand processing, it is common to have extraction rows every 9 to 11 rows (approximately every 30 m) (Figures 5-35 & 5-36). When the wood is cut to long lengths and the logs are lifted mechanically, the access trails are often made every 5 to 7 rows (approximately every 15 to 20 m). After cutting out the extraction trails, the rest of the trees are thinned from below within the remainder of the plantation.



Figure 5-35. A thinning of a 3-year-old plantation of *Gmelina arborea* during the dry season. An access trail is opened every ninth row for truck access.



Figure 5-36. After thinning a species that sprouts, such as *Gmelina*, it is necessary to kill the stumps so that they do not produce sprouts that compete with the residual standing trees. The herbicide, 2,4-D amine, is effective for killing stumps when it is applied as a concentrate while the stumps are fresh.

Salvage thinning: correcting situations of growth stress or stagnation

If a plantation is established at a very high planting density and tree growth stagnates, it may be necessary to make a salvage thinning to eliminate some of the trees in order to allow the remaining trees to grow normally.

In East Kalimantan, Indonesia, a plantation of *Eucalyptus deglupta* was established with an initial spacing of 1400 trees/ha, while in an adjacent lot there was a progeny test planted with 816 trees/ha. The two plantings were three years old, they had the same fertilization as well as the same weed control. However, the trees in the progeny test were 4 meters taller than those in the operational planting, which is an exceptional difference. Part of this disparity could be due to differences in seed sources, but it was also obvious that the high density plantation had stagnated and was not growing to the potential of the site, evidenced by the stagnated trees having very small, flat crowns and long, thin stems. In this type of a situation it is justified to make a salvage thinning in the stagnated plantation.

When spacings are too close, it is common to find that trees are stressed during droughts and are more vulnerable to attacks by pests and diseases. When the water table is high and the soil becomes saturated, the trees on very wet sites also suffer a similar type of stress. It is common to find that there are insect attacks or diseases immediately after the age of crown closure, when the competition among trees becomes severe. In such cases, a pre-commercial or commercial thinning can be used to eliminate the cause of the stress and to improve the overall plantation health.

Singling

Singling is an operation that eliminates forks in young trees. The objective of singling is to leave just one stem per tree. It is an operation that is generally carried out as part of the initial plantation management for pulpwood plantations as well as for sawtimber plantations. Some tree species are more prone to initial forking than others. Also, some seed sources have a greater tendency to fork than do others. It is important to evaluate seed sources in research provenance tests, not just for growth, but also for the tendency to fork.

Species such as *Gmelina*, teak, and the acacias tend to fork, but in genetic research trials it has been possible to select for trees that do not fork and to improve the overall form of the tree in just one generation. Some species of pines also have a tendency to fork more than others, notable among these being *Pinus kesiya* and *Pinus oocarpa* which, depending on the seed provenance, have large variations in forking.

Formation pruning or singling is done with a pruning saw or it can be done with a machete, eliminating the additional stems and leaving only one central stem (Figure 5-37). A first cut is made above the fork in order to eliminate the weight of the forked stem and the final pruning cut is made 30 to 40 cm above the fork itself. When using a machete, the final cut is not made close to the base of the tree in order to avoid causing damage to the other remaining stem.

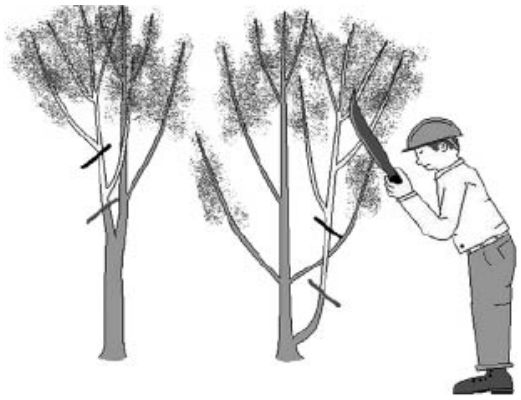


Figure 5-37. Formation pruning or singling.

Singling is only done in order to leave one stem per tree. Lateral branches which are not an obvious competition to the main stem are not pruned. Young trees need all of their available foliage in order to produce sugars through photosynthesis and to grow and be healthy.

Desprouting after a clear-cut

After clear-cutting some tree species, it may be possible to manage the sprouts as a coppice stand. Notable among these are many species of eucalypts. When the trees are harvested, they should be cut as low as possible so that the stump sprouts are more vigorous and firm to the stump.

If the stump sprouts are not thinned out, the coppice wood production will be very low and the stems will have small diameters. Experience has shown that the optimum method of desprouting is to leave just one sprout or stem per stump for coppice management.

When the stumps sprout and the sprouts reach between 4 and 6 m height, the initial desprouting takes place, leaving one or two sprouts per stump. The sprouts are cut as low as possible while being careful not to cause any damage to the selected stem(s). For desprouting, a curved pruning saw can be used or a tool with a sharpened hook that allows for making the cut from within the sprout clump cutting away from the other sprout stems (Figure 5-38). The hook is sharpened only on the inside edge (Figure 5-39).



Figure 5-38. Desprouting eucalypts with a pruning saw.



Figure 5-39. A desprouting hook.

During the initial desprouting operation, two sprouts can be left on the stump, in case one breaks off afterwards due to winds. After an additional six months, when the sprouts have had a chance to grow and become well set with the additional space, a second operation is done to remove the secondary stem (Figures 5-40 to 5-42).



Figure 5-40. A second desprouting, eliminating one of the two stems left after the first desprouting operation. When the stems are of this size, the removal is best done with a pruning saw.



Figure 5-41. A 6-year-old coppice stand of Eucalyptus grandis in Argentina. This plot had an initial desprouting operation leaving one stem per stump.



Figure 5-42. An adjacent plot in the same 6-year-old plantation of Eucalyptus grandis where there was no initial desprouting operation.

Stump sprouts generally grow quite rapidly during the first year of coppice management, but total wood production at the end of the rotation is normally less than that of a new plantation. In the case of hybrids, such as those of *Eucalyptus* uro-grandis in Brazil, the first coppice stand is generally considered to have about 14% less total harvestable volume than the first harvest and the second coppice harvest will have about 17% less wood production than the first coppice. The decrease in wood production during coppice management is due to the fact that some stumps die after cutting and there is also a loss of stump vigor after each harvest. For these reasons, coppice management is best done when the original stand was established using genetically improved trees of high quality, but when the plantation was established with unimproved seed, it is best to eliminate it and replant the area.

When managing a plantation for coppice harvests, the maintenance after each clear-cut is similar to that of a new plantation, including weed and grass control and fertilization, as well as desprouting.

Pruning for quality

Plantations managed for sawtimber require some additional silvicultural treatments that are not required for pulpwood or chip wood production.

The objective of management for sawtimber is to produce logs of larger diameters and clear wood, without knots or defects. Such logs produce wider boards and wood that has a higher value in the marketplace than narrower boards or boards with knots. Tree and log diameter can be increased by thinning the plantation; clear wood production is increased by pruning branches off of the bole of the tree (Tables 5-10 & 5-11). Pruning activities are best coordinated with thinning programs in order to minimize the cost of pruning. Nonetheless, pruning for quality is best done based on tree diameters, rather than on plantation age. Thus, the age at which the plantation is pruned depends on its growth rate.

Table 5-10

Example of a silvicultural plan for tropical pines on a 15-year rotation for producing sawlogs 4 m long.[16]

Year	Silvicultural activity	Tree m	Height trees/ha	Trees left cut	Trees Comments
1	planting, maintenance	-	1100		
2	maintenance	2 - 3	1000		assumes an initial mortality of 10%
4	thinning	6 - 8	550	450	wood for treated fence posts
4	prune to 2 m		550		prune after thinning
6	prune to 4 m	8 - 10	550		
8	thinning	13 - 16	350	200	wood for chips, treated poles
8	prune to 4.5 m		350		prune after thinning
16	final harvest	25	0		sawlogs and chip wood

Table 5-11

Example of a silvicultural plant for teak with a 20-year rotation for the production of sawlogs 5 m long.[17]

Year	Silvicultural activity	Tree m	Height trees/ha	Trees left cut	Trees Comments
1	planting, maintenance	-	1100		

Year	Silvicultural activity	Tree m	Height trees/ha	Trees left cut	Trees Comments
2	maintenance	2 - 4	1000		assumes an initial mortality of 10%
4	prune to 2 m	6 - 8	1000		trees to be removed in the next thinning are not pruned
6	thinning	7 - 9	550	450	wood for fence posts, charcoal, and/or construction poles
6	prune to 4 m	8 - 10	550		trees to be removed in the next thinning are not pruned
8	thinning	12 - 14	350	200	wood for construction poles, charcoal
8	prune to 6 m		350		prune after the final thinning
21	final harvest	23	350		wood for sawtimber, charcoal, wood pellets

The objective of pruning is to keep the knotty wood within a central cylinder of wood in the center of the log and to produce clear wood free of knots on the outside of the log. As a rule, a central knotty cylinder for most species would be about 12 cm in diameter (Figure 5-43). In other words, when the trees reach 6 or 7 m of height, an initial pruning can be made to 2 m height, but the pruning is not done where the diameter of the stem is less than 12 cm. Later on, as the tree continues to grow up to 8 to 10 m height, another pruning can be made up to a height of 4 m, again pruning up to a minimum diameter of 12 cm. A final pruning is made to a pre-determined top height for the length of logs that are to be produced at time of the final harvest. For example, to produce sawlogs that are 4 m long and free of knots, the pruning would be to 4.5 m height in the tree. To produce logs 5 m long and free of knots, the pruning would be carried out to 5.5 m height in the tree. It is important to remember that a half-pruned log has little, if any, additional value over that of an unpruned log. For this reason it is very important to coordinate the pruning schedule with the length of logs that are to be harvested.

Figure 5-43. The purpose of pruning for quality is to keep the knotty wood (defect) within a central cylinder of the log and to produce clear wood on the outside of the tree.

The tools used for pruning depend on the tree height and the species in question. In Chile, it has been found that for low pruning of pines, a large garden clipper can be effective and there is little risk of damage to the tree bark (Figure 5-44).

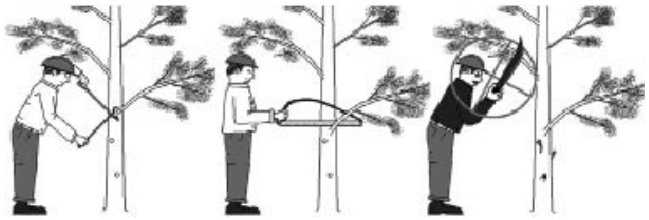


Figure 5-44. Pruning with a garden clipper (left) and with a pruning saw (center). Pruning is done flush with the base of the branch, but being careful not to damage the bark of the main stem. Machetes (right) are not used for pruning, since they tend to tear out bark and wood splinters which makes wounds that allow rot fungi to enter into the tree and cause eventual heart rot.

For pruning of those species with dense wood, such as teak, a saw is needed. Hardened steel blades can be obtained in the market that have teeth designed for pruning and that can be fastened to a curved frame. These pruning saws are relatively inexpensive, and they are

usually not filed since the steel is very hard and very thin, but the tooth angle must be reset occasionally for proper cutting. Hand held pliers for setting the angle of the teeth can also be purchased from blade suppliers (Figures 5-45 to 5-47).

Figure 5-45. A hand pruning saw made with a high tensile steel blade and an arch made from common rebar used in reinforced concrete construction.



Figure 5-46. A locally made saw mounted on a pole for high pruning.



Figure 5-47. Correct pruning of *Pachira quinata* in Colombia, flush with the stem, but without damaging the bark.

The maximum pruning height depends on the cost of pruning versus the increased value of clear wood in the pruned sawlogs. In Malawi, the cost of pruning to 6.8 m was 2.5 times the cost of pruning to 2.1 m and pruning to 11 m cost four times pruning to 2.1 m (Evans & Turnbull, 2004).

There are several alternatives for high pruning:

1. Use a hand pruning saw mounted on an extension pole (Figures 5-48 to 5-53). This is hard work, but is effective where labor costs are relatively low.
2. Use a hand pruning saw with a ladder. This requires an additional one or two persons to hold the ladder against the tree, as well as to carry it between trees, while the other person does the pruning with a hand held pruning saw. It is a simple system, but production yields are low.

3. Use a motorized pruning saw with a small chainsaw blade on the end of an extension pole to reach high branches. This method is quite rapid for high pruning and is efficient with species that have hard branch wood, such as teak.



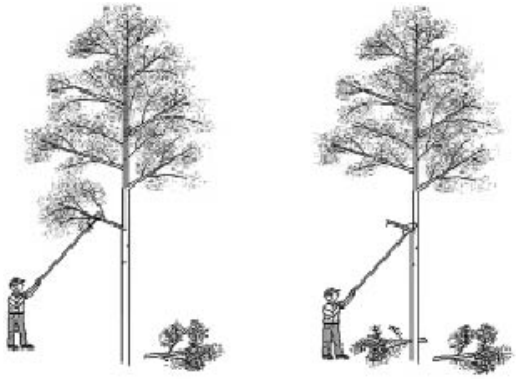
Figure 5-48. Pruning 4-year-old *Pinus taeda* in Misiones, Argentina, after an initial pre-commercial thinning.



Figure 5-49. Correct pruning of pine, flush to the stem, but without damaging the bark.



Figure 5-50. Pruning of 4-year-old teak in Indonesia with a hand saw mounted on an extension pole.



Etapa 1. Quitar el peso de la rama al cortarla 30 cm desde la base para evitar daños al fuste del árbol.
Etapa 2. Quitar el pedazo de la rama a ras con el fuste.

Figure 5-51. High pruning in two stages.



Figure 5-52. High pruning of 7-year-old teak in Indonesia using a motorized pruning saw.



Figure 5-53. High pruning of 9-year-old *Pinus taeda* in Transvaal, South Africa. On the best sites some trees are pruned to 11 m height, but the normal procedure is to prune to a maximum 7 m height in pines (Marsh, 1978).

[1] The herbicide 2,4-D is sold under many brand names. The ester formulation is petroleum-based and the amine formulation is water-based.

[2] Classification by the Environmental Protection Agency (EPA) of the USA. LD50 oral is equivalent to 50% of laboratory rats dying from an ingested dosis, expressed as mg of chemical per kilo of animal weight (Gross, 1987).

[3]These are total elemental values. The available nutrient available to trees can vary based on the solubility of the fertilizer in water, the soil pH and other factors.

[4]For tannin production in South Africa, the bark of *Acacia mearnsii* is of interest since it is an important source of tannic acid. In a seed orchard, fruit and seed production are of interest. In some cases, pines are tapped for resin production, especially in those locations where there is no available market for the sale of wood. In the case of *Hevea brasilensis*, the primary product of the trees is latex, which is collected by scoring the bark of the trees to produce latex sap. In some species, foliage is also used, such as the foliage of *Eucalyptus citriodora* from which lemon oil can be extracted, or *E. globulus* where menthol oils can be extracted.

[5]In agricultural terms, sowing more seed does not produce more corn or wheat, nor do more heads of cattle necessarily produce more meat or milk. It is the same with wood production. The key is to define the product, tree growth rates and to maximize the production of the desired product at a minimum cost at time of harvest.

[6]The species referred to are those that have thick bark, including *Pinus oocarpa*, *P. caribaea* and *P. kesiya*.

[7]This information was obtained by personal communication between the author and technical personnel of various forestry companies in Colombia, Venezuela, Brazil, Mexico and Indonesia.

[8] Personal observations by the author.

[9] However, straight trees give greater pulp yields due to differences in the physiological composition of the wood itself. It is also more economical to harvest straight trees than crooked trees. Modern, high productivity harvesting machinery requires trees of uniform size and straightness to reach maximum efficiency. Because of this, pulp and paper companies invariably include tree straightness as a component in their forest genetic research programs.

[10]The forest manager of one South American pulp company told the author that the cost of thinning in company plantations was 80% greater per cubic meter of wood produced than was the cost of clear-cut harvest.

[11] During harvesting operations, it is necessary to improve secondary and internal roads, but when there are no harvesting activities, road maintenance can be minimal. Road maintenance cost is more directly related to the size of the area to harvest than to the amount of truck traffic on a given section of road.

[12]The term *thinning from below* means eliminating the poorest trees in the stand; those that are forked, crooked, leaning, diseased or that are the smallest.

[13]It there is an area with a high mortality and with few standing trees, do not eliminate 50% of the existing trees, rather, 50% of the total trees that were initially planted. Even where tree form is generally poor, it is not a good idea to make a thinning if there are just a few tree standing. It is better to leave those trees than to remove them, which would create an area void of trees and stimulate competition by weeds, grasses or other woody plants.

[14]A skragmill has two parallel head saws that can remove slabs from two sides of a log simultaneously. A chip-n-saw is similar to a skragmill, but it has four chipper heads that produce squared cants without sawdust or slabs, just chips. The chip-n-saw is in common use in the USA and Canada, where there are markets for long fiber chips and where there are many small conifer trees to process to produce dimension stock for the building industry.

[15]Traditional, large rotary lathes have two spindles that hold the log in place while it is being turned and peeled. A spineless rotary lathe is sometimes called a “shotgun lathe”, since it can process many small logs quickly. Back pressure rolls, not spindles, keep the log in position against the lathe knife while it turns on the lathe. Modern spindleless lathes are totally automated and can process between 2000 and 3000 small logs (20 cm to 30 cm diameter) during an 8-hour shift.

[16]If the rotation is 15 years and is planted in year 1, then the final harvest is during year 16, after 15 year’s growth. To produce logs 4 m long, the trees are pruned to 4.5 m height to allow for stump height.

[17] If the rotation is 20 years and is planted in year 1, than the final harvest is during year 21, after 20 year’s growth. To produce logs 5.0 m long, the trees are pruned up to a 6 m height to allow for stump height as well as basal fluting common in teak trees.

6

Mensuration

tree measurement precision
Tree volume formulas
Developing tree volume and weight formulas
Other measurements of wood volume
Wood weight
Growth and yield projections in plantations
Mapping
GIS: Geographic Information Systems
GPS: Global Positioning Systems
Creating maps with a hand compass in the field
Classes of maps used in forest management
How to file maps
Map title and heading
Map scales
Map orientation
Conventions used on maps
Map codes for vegetation
Map codes for forest management
Formats for map codes
Forest inventory
Forest sampling
Intensity of sampling
Field inventory formats
Resolving variations between the inventory and the harvest

Tree measurement precision

It is important to understand the factors of natural variation and how they affect the precision of inventories and growth projections. The precision of tree measurement is limited by the natural variation that exists among the trees measured. The purpose of a forest inventory is to calculate the amount of standing timber (stumpage) at a level of precision that is acceptable for the marketing of wood products and which can be determined at a reasonable cost. The precision of growth projections is affected by these same factors of natural variation among trees and by variations in the environments where the plantations are located.

The diameter of standing trees is measured at breast height (DBH = 1.3 m) with a diameter tape or with calipers. Diameter measurements cannot be more precise than the natural variation that exists within the trees themselves. Although the calipers may be able to register variations to within 1/10th of one millimeter, such precision doesn't really exist in the trees themselves. If several persons measure the same tree, or one person measures a tree from different positions, the variations among readings can be greater than a millimeter. This is due to differences, however small, in the placement of the diameter tape or the calipers, that results in discrepancies among readings, since the tree bole is seldom perfectly round and the bark is rough; even the height of the measurement at DBH can vary for different people standing on different sides of a tree (Figure 6-1). When measuring large trees, it

is a good practice to take two measurements of DBH, at 90° one from the other, and then use an average value of the two to define the tree DBH.

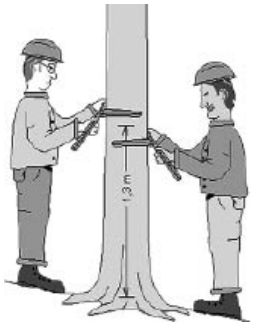


Figure 6-1. The height where DBH is measured can vary accoding to where the technician stands as well as the characteristics of the tree itself.

For purposes of a pre-harvest inventory, a precision of 2 cm is more than sufficient to provide the required information for calculating wood volume per hectare.[1] When the calipers is marked with 2 cm diameter classes, it makes taking field data easier (Figures 6-2 & 6-3). Calipers for measuring tree diameters can be made in a local carpenter's shop. What is important is to make the calipers so that the sliding jaw is exactly parallel to the fixed jaw when pressed against a tree or log.

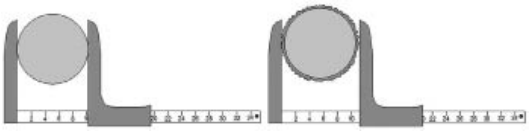


Figure 6-2. Diameter overbark includes the bark as well as the spaces within the bark.



Figure 6-3. Measurement of DBH by 2 cm classes using a wood calipers.

Tree heights are measured with a hypsometer, a clinometer, or similar instruments that function based on trigonometric principles: by knowing the length of one side and one angle of a right triangle, all other lengths and angles can be calculated by the theorem of Pythagoras (Köhl. 1993). The distance can be measured with a metric tape or with a sturdy cord marked at the exact distance desired. When measuring heights, the tree is assumed to be perfectly vertical, that is, at 90° to the ground surface, thus forming two legs of a right triangle. When the hypsometer is pointed at the top of the tree, the angle between the triangle's vertical leg and its hypotenuse is formed and the instrument reads the angle between these two, but converted directly into a reading of the length of the vertical leg. which is the tree height.

Tree height is determined as follows (Figure 6-4):

Length AB = D * tangent of the angle a1

Length BC = D * tangent of the angle a2

Length AC = D * (tan a1 + tan a2)

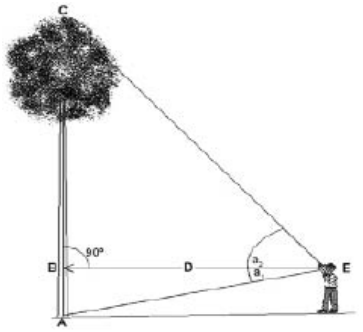


Figure 6-4. Measurement of tree height.

When the technician stands at a defined distance from the tree, normally 15 or 20 meters, the hypsometer reads the values of AB and BC directly in meters.

Although it is possible to read height variations with a forestry hypsometer to a tenth of a meter, such a level of precision does not exist in the field. It is rare indeed to find a tree that is perfectly vertical. Even when the tree is vertical, it is often difficult to define the top most branch in the crown. More commonly, the tree has some inclination, and although this may be slight, it has an important effect on the precision of the height measurement, as is shown in Figures 6-5 to 6-8.



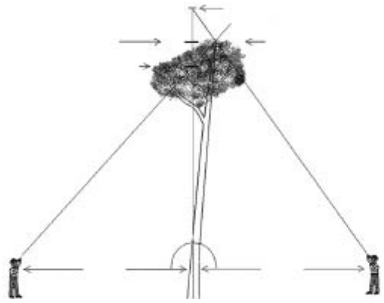
Figure 6-5 When measuring tree heights, the technician stands at a measured distance from the tree base, usually 15 or 20 meters.



Figure 6-6. Height measurements with a clinometer or other device function using the principles of trignometry.

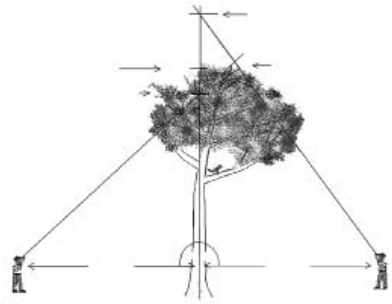
The variation in height measurements also depends on which side of a tree the person stands. with respect to any inclination. In reality, a precision of one tenth meter does not exist when determining heights of trees that are of commercial size. Experience has shown that a precision of

one meter for trees taller than 20 m is sufficient for making commercial inventories in order to determine tree volumes for timber sale.



Altura verdadera
Medición por el lado izquierdo
15 metros
90º
90º
Medición por el lado derecho
15 metros
Punta del árbol

Figure 6-7. Height measurements of leaning trees can be erroneous.



Altura verdadera
Medición por el
lado izquierdo
15 metros
90º
90º
15 metros
Medición por el lado derecho
Punta del árbol

Figure 6-8. The error of measurement is even greater when the tree is leaning towards the technician.

The significance of the results of a forest inventory depends on the precision of the field data. Measurements are adjusted to the precision of the objects being measured. The following levels of precision are considered sufficient and acceptable for purposes of forest management and for commercial inventories:

+ 0.1 ha land area

+ 1 m total height of trees for pre-harvest inventories

+ 2 cm tree diameter for forest pre-harvest inventories

+ 0.1 m3 volume/ha

There is a tendency among some forestry personnel to carry many decimals when recording field data. In some cases, it is customary to write down non-significant variables, such as two additional zeros for hundredths even when the measurements are to a round number. This increases the work required to transfer non-significant field data to a computer file in the office which is a waste of time. The standards of measurement precision need to be defined by the forestry organization and then field data recorded to those standards. For example, if diameters are measured by 2 cm classes. write “2” in the box, instead of “2.00”. There is a four-fold increase in the number of digits written as 2.00 which increases the office work of transferring to a computer file by four times, as well as increasing the chances of making errors during the transfer process. If total height is to be measured to the nearest meter, it is counter-productive to read and record values such as “11.52” from a hypsometer instead of “12” and the added digits duplicate the potential for error when transferring data, both for the person measuring and recording the field data, as well as when transferring the data to a computer in the office. Worst of all, the additional digits do not add any precision to the data.

In the field, the person making the forest inventory can (and most probably will) make some errors while recording field data. It is always important to review the field data sheets before leaving the field to be certain that all the information is correct, all numbers clearly written and all pages clearly identified (Figure 6-9). If errors are found in the data sheets, these can be corrected in a timely manner. On the other hand, if the data sheets are put in file folders and placed in a file cabinet in the office for days or weeks, it becomes extremely difficult or impossible to detect errors made while recording the data in the field. The field review of data sheets is even more important when other office personnel transfer the field data to the computer.



Figure 6-9. Review of inventory data in the field during the day.

Tree volume formulas

Tree height and diameter (DBH) are commonly used as variables in formulas. In natural forests. where the trees are mature and over mature, there are often forks in the crowns or broken tops due to wind, heart rot or other damage that limit the commercial height of the tree bole. In plantations most trees have their crowns intact and total height is easier to use for determining commercial volume to a desired level of precision. Most tree volume formulas for plantation trees utilize total height as a variable, even when the calculated volume is to a minimum commercial top that is less than total tree height.

The volume formulas are calculated by mathematical regression. In a regression, data (variables) are obtained by measuring trees in the field and then calculating a statistical formula that adjusts well to those data. A regression formula has two parts: the independent variables, that is, the data used to calculate the desired value, and the calculated value. which is called the dependent variable.

Many tree volume formulas use similar models, the differences being in the *constants*, that is, the values used to modify the formula to give the best adjustment of the formula to the field measurements used to generate the formula. A simple regression formula that can be used to calculate the volume of small trees in research tests is the following (Ladrach. 1998a):

Volume = 0.3 D2H

where: Volume is the total tree volume in cubic meters

D = DBH in meters

H = Total tree height in meters

This formula can be made to use DBH values in centimeters by modifying it as follows:[2]

Volume = 0.00003 D2H

where: Volume is the total tree volume in cubic meters

D = DBH in centimeters

H = Total tree height in meters

This is a simple regression formula that can be used for calculating the volume of small trees of most any species with a single stem, since it has only one constant, and since small trees generally have quite similar forms.

A formula commonly used to obtain volumes of commercial-sized trees has the following format:

Volume = C1 + C2 * D2H

where: C1 is the independent constant (the intercept value on an X-Y graph) and C2 is the constant associated with the factor “D2H” (which is the slope of the line on a graph).

This formula adjusts well to the volume of commercial-sized trees found in plantations. There are other formats, some based on non-linear regressions with several constants, but when comparisons are made among different formats, the one shown above adjusts well to the field data and is simple to calculate. The relationship between the independent variables (height and DBH) and the dependent variables (volume. weight, etc.) depends on the mathematical calculations that are generated utilizing data obtained from trees sampled and measured in the field. Using just the DBH and total height as independent variables, it is possible to generate multiple regressions for varying dependent variables, such as total tree volume, volume to a 10 cm top, volume to a 20 cm top, green weight, dry weight (using wood analysis in the laboratory) and other factors.[3]

The validity of a volume formula depends on several factors:

- That the trees measured in the field as a basis for calculating the volume regression are of a similar size to those in the forest inventory to which the volume formula is to be applied. A volume formula can produce erroneous information if it is based on a sampling of trees that are of a different size group to those being measured in the forest inventory. For this reason, it is always important to know the origin of the formula that is to be used for the volume calculations.
- The field sample of trees used to develop the volume formula must be sufficient to produce a representative volume formula. For commercial inventories, it is usually considered acceptable to measure between 50 and 100 trees that fairly represent the variation in heights and diameters within the sampled trees used to generate a reliable volume regression with an acceptable statistical fit.

- The formula must calculate volumes to the same specifications as are applied to the forest inventory. For example, if the objective is to calculate commercial volume underbark to a 10 cm top, the formula must have been made using these same independent and dependent variables.

A volume formula can be utilized even if it was generated in another country (or even on another continent), if and when the trees sampled for developing the formula were of a similar size as the trees in the local forest inventory, and that the same variables are used in both instances (that is: overbark, underbark, total height, commercial height, and minimum top diameter).

The formula that is most representative for tree volumes was developed by Professor Schumacher of Duke University. USA, as a non-linear regression model (Schumacher & Hall. 1933):

ln Volume = bo + b1 ln D+ b2 ln H

where: the “b” values are the constants.

ln = natural logarithm (base e)

D = DBH

H = total tree height

Schumacher’s formula is the most reliable when the formula is used to calculate the volume of very large trees, and it gives good extrapolations of volumes even when the trees are larger than the sample population used to generate the regression. Schumacher’s model is very useful for making volume inventories in natural forests where an exceptionally large tree may occasionally be found. However, it is important to remember that any extrapolation of a formula beyond the sample population dimensions is risky and may result in errors.

The formula: Volume = C1 + C2 * D2H adjusts quite well to volumes of trees in plantations and is much easier to use than the non-linear format of Schumacher. This model is quite adequate for forest inventories in plantations when it is applied to inventories where the trees are of similar sizes to those used to develop a particular formula.

Developing tree volume and weight formulas

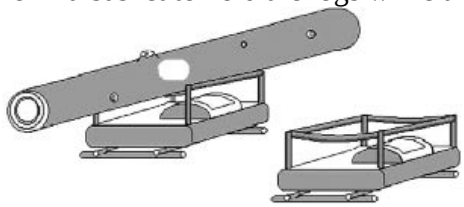
Many forestry companies generate their own volume formulas in order to guarantee a good fit to the inventory data. Some companies even generate specific formulas for the inventory of each different clone, such as in clonal eucalypt plantations. Other companies update their volume formulas annually, taking sample measurements of trees in the areas that are to be harvested the next year.

When developing tree data for a volume formula, it is best to sample trees in plantations of the same age and tree size as those where the formulas are to be applied. The best way to make good measurements during the sampling process is to cut the sample trees and measure them on the ground. Trees to be sampled are selected as representative of the plantation or plantations of interest. It is not a good idea to include forked trees or poorly formed trees when the objective is to produce formulas for typical trees in a plantation.[4] Trees are selected that represent the range of sizes within a plantation, from the smallest to the largest, sampling a similar number of trees in each size class.

If the objective is to calculate volume overbark, all that is necessary is to measure the diameters in several locations along the tree bole. If the objective is to calculate volume underbark, the tree is cut into sections of a given length and the diameters are then measured inside the bark for the stump and for the top diameter of each log.

If the objective is to generate a green weight formula, the logs are weighed in the field as well as taking diameter and log length measurements. When weighing logs, a precision of 0.5 kg is considered sufficient for producing reliable green weight tables for commercial purposes. Logs can be weighed in the field using an agricultural balance, such as those used to weight bales of cotton.

The balance can be hung from a tree or a tripod or it can be mounted on a pole on a tractor for ease of movement. Another way to measure tree weight in the field is by using a modified bathroom scale. which is sufficiently precise for commercial inventory purposes and much easier to transport. The bathroom scale is fitted with a wood or metal frame underneath so that it can be set on the ground without interfering with the scale itself, and a tubular frame can be welded overtop of the scales to form a basket to hold the logs while they are being weighed (Figure 6-10).



balanza casera modificada con soporte para trozas
troza

Figure 6-10. A bathroom scale can be modified so that it can be used for weighing pulpwood-sized logs in the field.

The sample data obtained in the field is recorded on a format (Table 6-1). In the example, logs are cut to 2.4 m (8') lengths so that they can then be used as pulpwood. The logs can be cut to other lengths, if desired. Large logs that are too heavy for the scales can also be cut in half, each half weighed separately and then the two weight values added together.

Log volumes are calculated using the geometrical formula for a truncated cone.[5] This formula provides for a good representation of log volume and is more precise than the Smalian formula for short logs:[6]

Table 6-1

Example of a field measurement sheet for recording log volumes and weights for a tree

Tree No.: 23 DBH, cm: 21.4 Total height, m: 20.5		Specie: Eucalyptus grandis Location: Finca La Vergel Personal: Juan Jiménez. Pedro Pérez					
		Base diameter	**Green weight**	**Volume**			
		ob	**ub**	**ob**	**ub**	**ob**	**ub**
log. No.	**log, lenght**	**cm**	**cm**	**kg**	**kg**	**m3**	**m3**
A	Stump 1.3	24.0	23.6	46.0	43.5	0.05267	0.04994
B	DBH 1.1	21.4	20.6	33.0	31.0	0.03478	0.03094
C	2.4	18.7	17.2	60.0	51.1	0.06211	0.04805
D	2.4	17.6	14.7	54.5	48.5	0.05418	0.04299
E	2.4	16.3	15.5	40.6	40.4	0.042279	0.03786
F	2.4	13.8	12.8	33.0	26.6	3142	0.02653
G	2.4	12.0	10.9	25.5	22.0	0.02307	0.01927
H	2.4	10.1	9.3	16.5	14.5	0.01518	0.01275
I	1.1	7.8	7.1	4.5	4.3	0.00474	0.00372
Top		7.0	6.0				
Total	17.9			313.6	281.9	0.32095	0.27205
% Bark				10.1		1.520.000	

ob = over bark, ub = under bark

Sample ? = Identify where the wedge samples are taken for laboratory analysis.

Log volume, m3 = 0.2618 * L * (d12 + d22 + d1 * d2)/10.000

where L = log length (m)

d1 = bottom end or large diameter of the log (cm)

d2 = top or small end diameter of the log (cm)

Wood volume can be measured as solid cubic meters overbark (m3sob).[7] This measurement includes the bark as well as the spaces between the bark ridges (Figure 6-2). Wood volume can also be expressed as solid cubic meters underbark (m3sub). which is the measurement of wood only. without including other elements. When describing a volume formula or volumes calculated with the formula it is very important to specify the volume as “m3sob” or “m3sub”.

Traditionally, many inventories presented tree volumes overbark, but this is changing since the forest industry requires more precise information regarding the amount of usable solid wood without the bark. A problem can occur where a report or publication does not clearly define volume data as overbark or underbark which leads to confusion among the readers of the report.

Volumes overbark and underbark vary among species and also within a species at different ages. For thin barked conifers such as *Pinus patula* or *Cupressus lusitanica*, bark volume can represent between 10% and 17% of total overbark volume for plantation trees 12 to 15 years old. For conifers with thick bark, such as *Pinus oocarpa*. *P. kesiya*. *P, caribaea*, and *P, maximinoi*, bark volume can represent between 40% and 50% of overbark volume for 8-year-old plantation trees and between 20% and 25% of overbark volume for trees 12 to 15 years of age.[8] In the case of *Eucalyptus grandis* bark volume for 6-year-old trees is about 13% of overbark volume and for *Eucalyptus urophylla* the bark volume is between 15% and 17% for the same age.

Stere meters: The volume of wood piled on the ground or on a truck is measured as stere meters and registered as SMsob (overbark) or SMsub (underbark). Piled volumes are often used as a measure for paying field labor for work such a felling, bucking and debarking logs.

Wood piled on a truck is measured as stere meters before leaving the field as a method for control of wood transport between the plantation and a woodyard (Figure 6-11). Stere meters can also be used to measure wood being moved from a landing in the field to a mill woodyard.



Figure 6-11. Truck load height is measured at several points along the side and averaged. The load height times the load length times the load width determines the piled or stere volume of wood on the truck.

A stere meter is generally considered to have a volume of between 0.67 and 0.7 solid cubic meters, but this can vary depending on the size of the logs in the pile and whether they are debarked or not. To determine the actual stere volume for a given plantation, some trees will need to be cut and the logs piled as shown in Figure 6-12. The end diameters of each log are then measured and the volume of the log is calculated using the formula for a truncated cone. When the trees have small diameters, such as those harvested from a thinning, the ratio of solid wood per stere meter will be less than for larger logs from a final harvest.

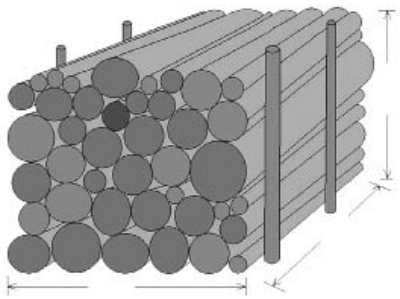


Figure 6-12. A stere meter.

Other measurements of wood volume

Although cubic meters is the most common measurement for wood volume, other measurements are utilized in some countries and it is worth mentioning some of these. In individual countries there are terms used for buying and selling wood, both round wood and sawn wood. For example, in Costa Rica wood is bought and sold in *pmt* (market inches, or *pulgadas ticas*). Costa Ricans also use their own measurements for loads of wood carried by animals. In Malaysia and other parts of South Asia, a measurement sometimes used is the *hoppus ton* which is equivalent to 50 cubic feet of volume. In Chile, pulpwood is measured as ruma meters. where a ruma meter is piled wood measuring 2.44 m3 (1 m x 1 m x 2.44 m). In the section Forestry Conversions other common measurements used in forestry are shown.

Wood weight

One complaint frequently heard by truck drivers is that the scaler who measures wood at a woodyard makes “adjustments” to the height of the measuring stick depending on whether the company wants more wood or less wood. When the company is short of wood, the scaler may add more height to the measurement of the load and pay a little more, but when the company has sufficient wood in the woodyard, the scaler “shortens” the stick measurement in order to pay a little less. Similarly, if the scaler only measures the truck from one side, there is the temptation to load the truck so that the load is higher on the scaling side in order to get a little more money for the load (Figure 6-13).



Figure 6-13. Scaling a load of logs at a woodyard.

In the woodyards of many mills the wood is weighed. The truck stops over a scale and is weighed with its load. Later, after unloading, the truck is weighed empty on the way out. The

difference between the two weights is the net weight of wood delivered on the truck and is an absolute value.

Although buying and selling wood by weight is generally accepted to be a fair method, it also has its discrepancies. Wood weight varies by species, by age and by drying time. In Colombia, green weight of wood was found to vary by species and by ages. Fresh wood of four conifers when measured just after felling, varied between 975 kg/m3 and 1200 kg/m3 (Table 6-2).

Table 6-2

Fresh green weight of conifers eight years old in Colombia (Ladrach. 1986)

Species	kg/m3
Pinus kesiya	1200
Pinus oocarpa	1100
Pinus patula	1050
Cupressus lusitanica	975

For many species of eucalypts, the fresh weight of wood is close to 1000 kg/m3 at six years of age, but this can also vary among species.

Once the trees are felled, the wood begins to lose moisture and dry out. Drying is faster when the crown foliage is attached, since the foliage acts like a felt which extracts the moisture from the tree, even after the tree has been felled. When the logs are debarked, the wood dries more quickly than when the bark is left on. Trees that die while standing continue to dry and can loose much of the moisture in the wood.

Because of these variations. when wood is sold by weight, it is to the advantage of the wood harvest contractor and truck operator to deliver the wood as fresh as possible to get maximum weight (and value) for the truckload. When the wood enters a woodyard in different stages of dryness, payment by weight has the difficulty of large differences in the amount paid for a given volume of wood. This is not to the advantage of the truck operator who has no idea of the value when partially dried wood is being delivered. Where the wood has been left in the field for several weeks (or months) before delivery to the woodyard, it is logical that truck drivers do not want to deliver dry wood that it is paid for on a weight basis.

One solution to this problem is for the company that buys the wood to offer two measurement options to the truck operator. When the wood is partially dry, the truck driver can request measurement of the load in stere meters and be paid for the volume delivered. If the company accepts dry wood, but really prefers fresh wood, it can pay a little more for wood weight than for wood volume as an incentive to have wood delivered fresh. This system with two measurement alternatives is the most equitable for the truck operators and makes for good relations between the company buying the wood and the contractors that cut and deliver the wood.

When a forest technician makes a report of wood production by weight, it is important to specify the condition of the weight of wood:

Tgr green metric tons (freshly cut wood)

Tam metric tons at ambient dryness (variable dryness of wood on a truck)

Tad air dry metric tons (after sitting several months in a woodyard)

Tbd bone dry metric tons (zero moisture content measured in a laboratory)

When a report does not specify if the wood is green or dry, there can occur large errors in wood production calculations and in the company accounting. At each phase of wood production, it may be useful to work with different levels of humidity or dryness of the wood. For example, for a pulp mill, the pulp yield is normally reported at 10% humidity, compared with an oven dry weight of wood basis.[9] In a sawmill, the wood is considered to be dry when the lumber has less than 12% to 15% humidity.

When the forestry company is part of the same company that utilizes the wood as raw material, it is sometimes convenient to leave the wood to partially dry in the field to reduce the weight (and cost) of wood transport. However. when pulp mills utilize pine and other conifers, fresh wood results in improvements in certain pulp qualities. Some companies that use wood of broadleaf species also want their wood to be as fresh as possible for the quality of the pulp product.

In the case of sawlogs, it is always best to have fresh wood and to saw the wood fresh to avoid cracks and end splits in the logs. Since pine sawtimber tends to be attacked by blue stain fungi, it is best to receive fresh sawlogs and to saw them and dry them as quickly as possible to avoid this defect of lumber appearance.

Growth and yield projections in plantations

When a forest inventory is conducted in a plantation, it provides information that can be used to calculate the volume and/or weight of wood that exists at that point in time; it can also be used to calculate the mean annual increment to that point in time. However, this does not provide any indication of the amount of wood that will be in the plantation at a future date. For example, if a pre-harvest inventory is made in a plantation of *Gmelina* that is five years old, how much wood will there be at six years of age? How can the growth be calculated between the date of the inventory and the expected date of harvest?

Growth projections are made by developing formulas and tables of growth and yield. This methodology is well known and has been used to generate many growth and yield tables for temperate tree species, particularly in natural forests of pines and spruces in North America and in Europe (Nyland. 1996). Growth and yield formulas have likewise been developed for topical species, such as teak in Trinidad (Miller. 1969). *Pinus kesiya* in Zambia (Div. Forest Research. 1972). *Gmelina* in Nigeria (Greaves. 1973) and *Pinus patula* in Colombia (Córdoba. 1985). There are two ways to generate field data to use for making these calculations:

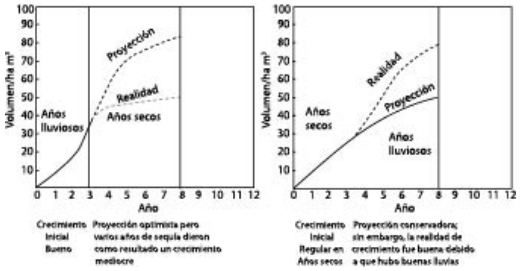
1. Measure plantations and research trials during all the years from when they were planted to their harvest age.[10] To generate information about plantations on different site classes and different stand densities, it is necessary to establish research trials on those sites with the desired variables and to continue such studies until they have grown to the desired age to provide the required information.
2. Fell trees in mature and over-mature plantations, buck them into short pieces (about one meter long), measure the diameters at each cut, and count the number of annual growth rings for each cut. When trees are felled, sectioned and measured on several different site classes, and inventory measurements are made on adjacent stands, this information can be used to generate growth and yield formulas. One problem with many tropical species is the difficulty of counting annual growth rings with a high level of reliability. Some tree species may seldom produce visible annual rings while others may produce more than one growth ring per year. In a study of *Pinus patula* in Colombia. Córdoba (1985) had to cut many trees to find some that had visible growth rings that could be counted with confidence. Another source of information to use is long-term research trials as well as commercial forest inventories. which can also be included in the data that is used to develop growth curves for a tree species.

This process of generating growth and yield tables requires knowledge of advanced mathematics related to regression analysis and sampling statistics. Such work is normally done by universities or in research institutes where there are persons who have advanced degrees in mathematics.

In the temperate regions. where rotation ages are greater than 25 years, tables can be generated that show growth and yields on a 5-year basis. Average 5-year values are used, thus eliminating annual growth variations. The result is a series of smooth and regular growth curves.

In the tropics. when rotations are much shorter, say six or seven years for eucalypts, acacias and *Gmelina*, or 12 to 15 years for pines, the annual growth curves generated have more variability than those made in the temperate regions using 5-year averages. Annual variations in rainfall patterns can also affect tree growth and make it difficult to produce reliable formulas to be used as tools for projecting plantation growth into the future. This is particularly apparent in climates which have a well-defined dry season, as occurs over large geographic areas of Central and South America. Africa. Australia. India and the island of Java in Indonesia, as well as in other sites where tree plantations are established in the tropics and subtropics.

Figure 6-14 shows examples of the problem of projecting plantation growth for fast-growing tree species in the tropics. In this example, an inventory of *Gmelina* was made in a 3-year-old plantation which has had a good pattern of rainfall. Based on the previous growth pattern, the future growth is projected to eight years of age. However, if we assume that the future years are much drier than normal, then the real growth rate is then much lower than the projected growth.



Figures 6-14. Examples of growth projections for *Gmelina* starting at year 3 where there are two different regimes of drought during the years of growth projection.

In the same figure, the second example shows just the opposite. with the growth during the initial three years being slow due to severe dry seasons, but where the growth from year 3 to year 8 is good, since the rainfall during those years turns out to be ample. This effect. which can be quite dramatic, makes it quite difficult to make very precise growth projections for tree growth in those climates where there is a wide variation in precipitation from year to year.

Under such environmental conditions, the reliability of growth and yield calculations for plantations can be quite low, and many of the projections made for young plantations to estimate the growth of older plantations may not be reliable. Simplistic projections can often be just as useful under such conditions as are formulas based on complex statistical calculations.

There is a useful alternative for making short range projections of inventory growth data for a year or two. When there are no local yield tables for making short range yield projections, one option is to select a yield table from another source that can be found in forestry publications. In this case, it is presumed that the growth pattern among trees in different locations and in the local site is similar, and that the growth curves follow a similar pattern.

This technique was developed by the author when a need arose to calculate yields of conifer plantations in Colombia and local yield tables were not available for the species of interest. Using yield tables published for *Pinus kesiya* in Zambia. Africa (Div. Forest Research. 1972), annual volume gains for pine in Zambia were projected as percentage changes in growth. Afterwards, these percentage growth gains were applied to actual inventory data for conifers in Colombia between the

inventory date and the expected harvest date. The regression model used to calculate the volume increase is as follows:

% annual volume increase = C0 + (C1/agex)

where: C0 and C1 are constants and "x" is the exponential constant of age

This formula produces a concave curve as is shown in Figure 6-15. With this method it is possible to calculate the growth increment from the date of the field inventory to the expected date of harvest. In practice, calculated growth projections using this method were within 5% of the harvested volume of pine and cypress plantations.

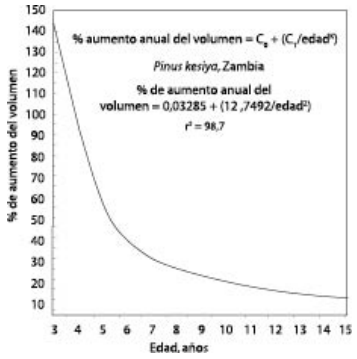


Figure 6-15. The percentage annual growth increment of plantations follows a curve that decreases with time.

This method always uses the base volume obtained from local plantation inventories, but the growth increment is calculated based on the growth pattern obtained from published yield tables for other plantations or locations. Projections of between one and two years are quite precise using this technique, but as projections are extrapolated beyond a year or two, it becomes obvious that there will be more variation. Nonetheless, this is a useful technique where there are no other growth projection alternatives.

The following formula was calculated for *Gmelina arborea* based on published data by Greaves (1973) for Site Class 1 in Nigeria:

Percent annual volume increase = 4.61174 + 4847.83/(age2.7)

C0 = 4.61174

C1 = 4847.82

x = 2.7

With this regression, it is possible to project growth of *Gmelina arborea* plantations in Indonesia using the data from the pre-harvest inventory and the expected age of harvest:

Age of the inventory (initial age): 5 years. 2 months: 5.17 years

Standing volume at the age of the inventory: 63.8 m3/ha

Expected age at time of harvest 6.5 years

Projected volume at harvest age: 117.1 m3/ha

The percent change in volume is calculated for each year, from the initial age to the projected age. Thus, this percent increase is applied to the initial volume and these increased volumes are accumulated each year or part of a year up to the projected plantation age.

Mapping

An important phase of forest management is the collection of data as to the amount of standing timber, yield projections to harvest age and the available volumes at time of harvest. There are two primary methods for the control of wood in forest plantations; these are *area control* and *volume control*. Both methods are used simultaneously and both depend on the precision of the mapping of forest properties. In fact, this is the wood accounting for a forest industry and is based on two functions:

- Mapping. where the net area in plantations is defined.
- Forest inventory. which defines the standing volume on a per hectare basis.

Mapping and forest inventory are integral functions and the responsibility for both are normally placed within the same department. This department is sometimes known as technical services, planning, biometrics or another similar name and that group is responsible for making future volume projections of wood available for harvest based on the actual field inventories.

GIS: Geographic Information Systems

Maps are now commonly generated by computer using programs designed for this purpose, and which are called Geographic Information Systems or GIS. GIS is defined as a system of data entry, data handling and analysis and the presentation of spatial or geographic data (Congalton & Green. 1992). There are two parts to GIS, the graphic part and the data base.

Graphic or visible maps

Maps generated by computer utilize commercial graphic programs such as Autocad. Such programs define lines and limits for the characters represented on the map. There are two methods for entering geographic data into a computer: the *vector system* and the *raster system* (Pancel. 1993). In a vector system, a geographic point is defined by vertical and horizontal coordinates on the map. In the raster system a location is defined by a fixed point, called a pixel. within a network. The resolution of the data is defined by the size of the network. The raster system is easier to manage and requires less computer memory capacity. The problem with a raster system is that a line is defined as a group of pixels in the computer and the scale is fixed, it cannot be changed by amplifying the precision of the map; a raster map has a fixed format based on the initial information entered into the computer memory.

A vector system is based on the formation of polygons using a series of reference points as the horizontal and vertical coordinates. It works under the mathematical concept of a line which has length but zero width. In other words, a theoretical line has no width in the program although a line can be drawn on a printed map. The vector system allows for changing the map scale and making large or small-scale maps using the same computer data base which operates as a series of points, lines and polygons.

Data base

The other part of the geographic information system is a data base that is meshed with the pixels in a raster system or with the coordinates in a vector system. This makes it possible to keep a record

of detailed information associated with the land maps. In the GIS system, both the graphics and data base are integrated into a single computer program. For example, forest inventory data obtained in the field can be assigned to the pertinent map locations. It is possible to transfer those data to the computer using several different programs, and, later, move those data to the GIS program. If inventory data are recorded in an electronic spread sheet, such as MS Excel® or Lotus®, these can later be "exported" from the spread sheet format and "imported" into the GIS program and vice-versa.

When the data base in a GIS program is kept in different layers or levels within the program's memory, maps can be printed which have different scales and types of information as needed (Figure 6-16). For example, a base map may contain just the peripheral limits of a property, that is, the legal map.

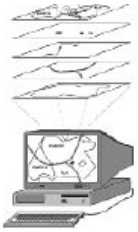


Figure 6-16. In a geographic information system, the maps can be created in layers.

GPS: Global Positioning Systems

The quality of the maps generated on a computer depends on the quality of the information that is downloaded into the computer. Most legal maps of land sales still depend on a topographical survey on the ground conducted by a certified land surveyor who is licensed to do such work. This type of map is made using topographical tools such as a professional compass, a metallic measuring tape, a transit or a theodolite.

In 1989, the United States Department of Defense initiated a new GPS system, called GPS Block II. In 1995, there were 27 GPS satellites orbiting the Earth at an altitude of approximately 20.000 km. with 24 of these being operational and three as emergency backup units (Figure 6-17) (Brain & Harris. 2000). Each satellite makes a turn around the Earth every two hours. For non-military use, the satellites were programmed to transmit data from the satellite that had a given amount of error built into the transmitted data, but starting in May. 2000, that practice was abandoned. The satellites transmit signals to the Earth on a continuous basis.[11] With the Block II system, portable satellite receivers can be utilized and placed in cars, boats and planes for instantaneous location of the unit within a precision of + 3 m.

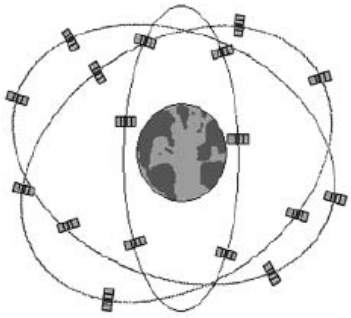


Figure 6-17. There are 27 GPS satellites orbiting the Earth.

A GPS receiver obtains signals from three or four satellites. The receiver then calculates the time delay between the transmission of the signal from the satellite and its arrival at the receptor. The system operates based on a concept where each satellite is considered to be located on an “imaginary sphere” with a radio signal equal to the distance from the receptor (in the center of the sphere) to the satellite (on the surface of the sphere). Where the imaginary spheres of the satellites intercept each other is the location of the receiver on earth. This process is called *3-D trilateration* (Brain & Harris. 2000). In order to make precise calculations, each satellite has an atomic clock which keeps exact time. The hand-held receivers have crystal clocks, but the ratio between the satellite clock readings and the hand-held unit is proportional, allowing the receiver to make the necessary calculations to locate the unit on earth. Errors in the signals can occur if they pass through an electromagnetic disturbance in the ionosphere or the troposphere, or when there is a slight change in the velocity of the signal. Errors can also occur if the signal bounces off of a large nearby object, such as a skyscraper or a stone cliff that can give the impression that the signal is traveling further.

There are many models of portable GPS units that are used by professionals as well as sport people. Since the price of the GPS receivers has come down in recent years, a GPS unit has become a tool for forest mapping around the world. Besides locating a given point on the Earth, the GPS receiver can be used for other purposes, including calculations of distances traveled by a vehicle during a trip, the velocity of the vehicle and the estimated time of arrival at a destination point. The receivers can keep a record of point locations that define a trajectory walked, run or flown. Later, that information can be transferred to a computer and used to define locations on a map. In many cases, the receivers have in their memory banks a series of integral data points that can show existing points on a base map.

Even more precise GPS data can be obtained by using a GPS differential. where signals from a portable unit are compared with signals received at a nearby base station. The base station transmits a signal to the portable unit which can then make corrections to the information received from the satellites (Figure 6-18).

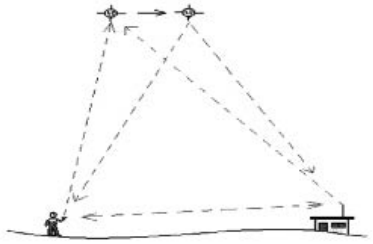


Figure 6-18. With a GPS differential, the location of a portable GPS unit can be made more precise by comparing signals with a base station.

Creating maps with a hand compass in the field

Traditional mapping methods with a compass and measuring tape (or chain) are still being used for certain types of forestry mapping. Hand-held compasses are quite useful for defining areas such as the forest area burned during a fire, or the area that has been plowed by a contractor to prepare a site for planting as a basis for making payment for work done, or for defining an area where there has been a severe insect attack and defoliation.

Some hand compasses are specially designed to be used to make field maps on paper. Such compasses have base lines for orientation as well as a built-in ruler that allows for drawing a map onto paper, and that functions as a plane table. First of all, the paper used with the compass must

have north-south lines lightly scribed on it; this can be done with a ruler and pencil. Then, for each compass reading, the distance traveled is measured and drawn with the pencil following along the rule embossed on the side of the compass. This type of mapping has a precision of one tenth hectare. which is sufficient for use in most normal forest management activities. The distances traveled along a compass line can be measured with a metal measuring tape or they can be measured by the technician by counting his paces while following a compass line (Figures 6-19 & 6-20).

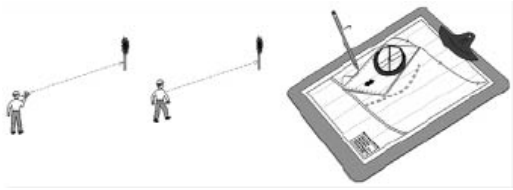


Figure 6-19. The hand-held compass can be used for mapping forest lots.

Step 1: Point the hand compass at an object in line with the desired direction of travel and adjust the arrow (bearing) on the compass to the line of sight.

Step 2: Walk towards the objective, counting the paces or measuring the distance with a measurement tape up to the desired distance.

Step 3: Place the compass on the map (or plane table); orient it N-S and mark the distance traveled with a pencil. Repeat Steps 1 -3 for the next bearing. After traveling around the entire lot, a polygon will have been drawn on the paper.



Figure 6-20. Using a hand-held compass to produce a field map in Indonesia.

The area that has been mapped can be determined by one of two methods. One method is to use a planimeter (Figure 6-21). The planimeter is precise when used on paper in its original condition, that is, a map kept flat in a map file in the office. The planimeter does not work reliably on paper that has been taken to the field, has grease from the hands, dirt, or has been damp. wet or torn.

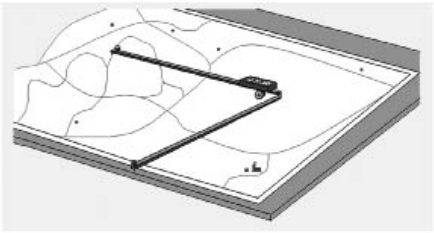


Figure 6-21. A planimeter for measuring areas on maps. As the scribe is moved around the map, the area within the polygon is recorded by a wheel attached to a mechanical recording mechanism.

To calculate the area of a field map, the best method is to use a light table and dot counts. A sheet of graph paper is placed on the light table which has squares and dots. The map is then placed over the graph paper (Figure 6-22). The graph paper is taped to the light table with masking tape and the number of squares and dots that occur within the polygon are counted on the map. For a map with a scale of 1:10.000 and with a corresponding sheet of graph paper, marked in squares 1 cm x 1 cm, each square represents one hectare and with ten points within each square, each point represents one

tenth hectare. The sum of all the squares and points within the polygon is the total area within the corresponding polygon. This method is precise for calculating the area of polygons on field maps with a scale of 1:10.000 or less.

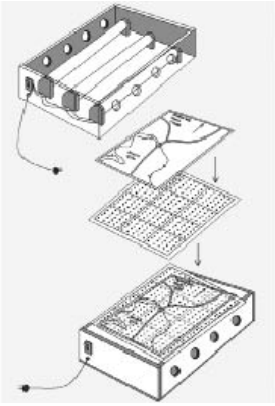


Figure 6-22. A light table can be made locally using flourescent bulbs and an etched glass surface. The graph paper is taped to the light table and the map is taped overtop of the graph paper. The squares drawn on the graph paper in this example are not to scale. However, if the squares are drawn to a scale of 1 cm x 1 cm with 10 dots placed within each square, and if the map scale is 1:1000, each square would represent 10.000 m2 or one hectare, and each dot would represent 0.1 ha. By counting the total number of complete squares and additional dots within the map poligon, the total area of the polygon can be determined.

Classes of maps used in forest management

Forest management requires multiple maps of properties, not just a single map of the perimeter polygon. With GIS it is possible to create maps by using different layers (files) of information nested in the data base. When maps are made by hand. without computers, each map must be drawn separately, using the base or matrix map of the outline of a property, and then adding the data of interest. Various maps must be drawn (or various layers of data need to be kept separately in a computer data base) in order to carry out the routine functions of management of forest properties. Each company or institution may require different types of maps according to the management need, and the mapping scale may also vary according to the planned uses of the maps.

Orientation or regional maps

Many companies use scales of 1:50.000 or 1:100.000 to show the general location of the forest properties. These maps are used for general planning and for the location of the forest holdings within a region or sector of a given country. Colors are often used to indicate different forest properties and other visual points of interest. The orientation maps are often framed and hung in the administrative offices for ease of access and to show visitors the location of the forest properties.

Orientation maps are shown within normal geographic descriptions of a land area. These maps include public highways, railroads, cities and towns, and points of interest, for example:

- Bridges on public and private roads with the maximum legal load limits (GVW) for heavy trucks. This information is important when planning wood harvesting activities by truck and also for the entry of heavy equipment into properties for forest fire control, such a tanker trucks, or trucks transporting crawler tractors for fire combat duties.
- Sites of special interest outside of cities, such as landing strips, schools, churches, cemeteries and historical landmarks.
- Rivers, streams and bodies of water.
- Points of interest to the company including fire watch towers. water sources for filling tanker trucks during the dry season for fire control, forest tree nurseries. work stations, equipment sheds and other similar locations.

Orientation maps normally have a base set of lines that show national coordinates. This allows for quickly communicating the location of a point of interest or a disturbance to the main office. This is very important in the case of emergencies such as traffic accidents or wildfires.

Basic management maps

Management maps are generally line maps in black and white, and without colors. Although non-technical personnel often prefer to look at maps with colors, a black and white map is easier to use by persons who have experience with mapping and the use of mapping codes. It is much faster to read a code placed within a lot than to have to refer to a legend where there is an explanation of the colors. [12] These maps generally have a scale of 1:10.000 for purposes of plantation management. where one centimeter on the map is equal to 100 m on the ground. Maps of this scale are used to define planting areas, forest inventories and harvest areas. This map scale also allows for a precise control of cost and yields of field activities carried out with labor and/or machinery, either by the company or by contractors.

The following are various types of maps required for forest management:

Legal tract map of the total area. When a property is purchased, this is the map that is annexed to the property title and duly recorded in the office of public documents in the local government agency in charge of property registers. These maps may be on public record and available to the general public. They are also used as a basis for determining property taxes.

These maps can have varying scales, depending on the size of the tract of land and the custom of the topographer who makes the land survey and the map. On the map, or on an additional paper, the bearings and distances are listed for all of the outside boundaries of the property. This information can be entered into a computer program or used to draw a map by hand to the desired scale for management purposes.

Matrix or base map. This is the base map (base layer in the computer file) over which all other mapping details can be drawn.[13] The legal map is used to draw the exterior polygon of the property including all permanent physical aspects of the property: Rights-of-way with legal access through the property for electric transmission lines, roads, railroads and pipelines. Also drawn on the matrix map are existing roads, bridges, drainage pipes, permanent and intermittent streams, constructions (houses, barns. watch towers and mines).

Current use map. When a property is purchased, a map of the current or existing land use is made over a matrix map. This map is utilized to plan forest activities such as clearing of vegetation, soil preparation, separation of the land into management lots, and definition of which tree species to plant.

Soils map. Not everyone makes soils maps with a precise definition of soil series. However, it is important to make a minimum definition of soil texture, soil acidity (soil pH) and an estimate of rooting depth in order to select the tree species to plant and the soil treatments to use during site preparation and fertilization. Prior to the purchase of a tract of land it is important to make a preliminary soil inspection to determine the aptitude of the site for the anticipated tree species to plant and for the objectives of the forestry project.

Potential use map. Once there is a soils map and a current use map, the reforestation plan can be made for the property. Lots are defined for planting, the area and species to plant, as well as the silvicultural treatments to be used for each species. This map and its associated data base are used to plan the tree nursery production schedule, site preparation work in the field, labor and machinery requirements, contractors and field administrative personnel.

Planting map. After the tract has been planted, a polygon of the planting area is drawn and entered into the computer along with the data base for each lot (area, species, planting date, site preparation, fertilization, etc.). With the initial acquisition of a property, the planting map will include all of the new areas planted, but afterwards. when some lots are harvested before others, the planting map for a given year will include only the lots planted during that year.

Incident maps. When there are unexpected occurrences that result in damages to a plantation, the affected areas are mapped for future reference. These include wildfires, insect defoliations or diseased areas of trees, losses due to droughts, etc. The affected areas are mapped over a copy of the matrix map and kept with the records for the forest property.

Forest inventory map. The first step in conducting a forest inventory is to review the planting maps and incident maps on file in order to define the net areas to be inventoried during the year. Afterwards, the field technician walks through the areas of interest to determine if the lot boundaries that were initially drawn on the maps are still valid. If there have been any changes to a plantation, the inventory map shows the modifications, and the current vegetation conditions at the time of the inventory. For example, if part of a lot has obviously poorer growth than another part, then the lot is divided in two for purposes of the forest inventory. This division is noted on the inventory map. In effect, the forest inventory map is an updated map of the condition of the plantations.

Harvest map. These maps define the lots that are to be harvested during a given year and are based on the results of the forest inventory map. When plantations are in mountainous regions or where there are steep slopes (over 30%) it is important to include contour lines on the maps. A 10 m spacing between lines is normally useful for management purposes such as making plans for roads for wood transport. (See the section on forest harvesting for additional information on this subject.)

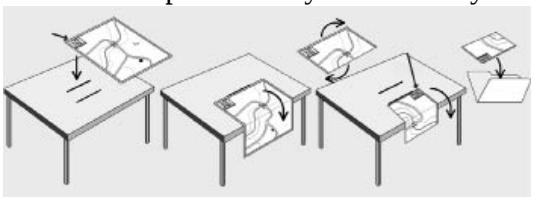
How to file maps

Originals of maps are kept flat in a map file in the office (Figure 6-23). Original maps are not folded nor are they taken to the field; they are reference maps for use in the office. Furthermore, before touching original maps, personnel need to wash their hands to avoid getting originals dirty or greasy from oils on the hands. One advantage of maps produced by GIS is that other original maps can be produced as needed.



Figure 6-23. A map file cabinet to keep original maps flat and clean.

The maps that are carried to the field should be folded to a standard size for ease of handling. If file folders are letter size, then double the field maps to letter size, always with the title and legend face up on the folded map to make them easier to find in the file folder (Figure 6-24). This process keeps maps clean and organized in a briefcase and is much superior to rolling maps up and leaving them on the floor of a vehicle where the title and legend are hidden inside of the rolled map, and where the maps can easily become dirty or damaged (Figure 6-25).



membrete del mapa
membrete del mapa

Figure 6-24. How to fold maps to a standard size: make two lines on a drawing table the match the length and width of a piece of letter-sized (or legal sized) paper, in reference to a square edge of the table. Align the map with the title and legend face up and fold the map over the edge of the table. Then turn the map 90° and fold it again using the other line on the table.

Continue this folding process the times necessary to fold the map to the desired size. Always keep the title and legend face-up to make it easy to read once the map is placed in a file folder.



Figure 6-25. When the maps are folded to a uniform size they can be placed in a file folder. In the photo, taken in a Brazilian forestry company, the maps are each placed within a plastic sleeve to keep them clean.

Map title and heading

Each map must have a title and headings that show key information. The map heading should include the following information (Figure 6-26):

Maderas Hnos. Jaramillo, S. A.		
MAPA DE PLANTACIÓN, 2006		
Predio : Finca “Aguas Dulces”		235,2 ha
Mcpo. Pilotillehue.	Estado : Nueva Esperanza	
Mapa matriz por:	Raúl Caminorreal	Abr/2005
Aprobado por:	Julio Pasatiempos	May/2006
Levantamiento por:	Juan Apurado	Julio/2006
Aprobado por:	Guillermo Lento	Julio/2006

Figure 6-26. Example of a map heading.

- Company or owner of the property
- Title (example: planting map, current use map, etc.)
- Name of the tract or property
- Location (municipality, county, state or province, national coordinates)
- Legal area, ha
- Name of the topographer who made the legal survey and the name of the person who drew the map.
- Name of the manager or administrator who approved the map and the date of approval.

The heading is placed in a corner of the map where it does not cover important information on the map. When field maps are folded with the heading face up, it make it much easier to find a particular map in a file folder.

Map scales

The scale of a map changes when copies are reduced or increased in size. In order to assure that the scale is always correct, map scales need to be in a graphic form, not written as text. The following is a graphic scale:

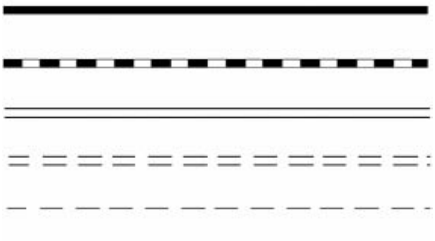
A scale that is written letters and numbers, such as: “1:10.000” will be incorrect if the map is reduced or increased in size.

Map orientation

All maps should be oriented to *geographic or true north* (the North Pole), not to magnetic north. Magnetic north fluctuates over time, but geographic north is a fixed point. When maps are drawn in the field using a compass, the current declination (variation between true north and magnetic north) is adjusted on the compass so that all bearings are read as true north.[14] When readings are taken with a GPS device, all readings are to true or geographic north. For ease of making maps of lots in the field, the base paper should have a north-south arrow that is long enough to be used to align a ruler or a compass edge along the line. A 10 cm long north arrow is good for this purpose.

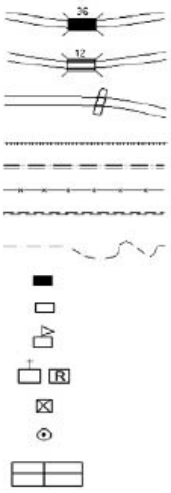
Conventions used on maps

The conventions used on maps need to be uniform and constant for all maps. Each company or institution must define the conventions to be used on their maps and for their particular needs. The following are the types of conventions and codes commonly utilized by many companies for field maps (Figures 6-27 to 6-29).



carretera no pavimentada, transitable en toda estación
camino destapado, transitable durante la estación seca
camino interno, no mejorado
senderos y rompefuegos
carretera pavimentada

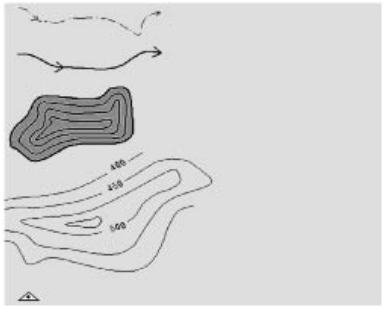
Figure 6-27. Classes of forest roads.



Puente permanente de concreto o acero (con el peso máximo legal)
Puente de madera o trozas (con el peso máximo estimado)
tubo de alcantarillado
ferrocarril
servidumbre (eléctrica, oleoducto, etc.)
cerca de alambre de púas
canal de drenaje
linderos de un predio o propiedad
casa o construcción habitada
edificaciones no habitadas

escuela
iglesia o centro religioso
torres de vigilancia
punto geodésico, mojón oficial
cementerio

Figure 6-28. Symbols commonly used on field maps.



ríos y arroyos temporales
ríos y arroyos temporales
lagos y lagunas
curvas de nivel (con altura sobre el nivel del mar)
aljibe, fuente de agua

Figure 6-29. Common conventions used for natural features.

Map codes for vegetation

Vegetation codes used on maps need to be standardized. The simplest codes are those with two letters. Examples of agronomic vegetation codes:

CL cultivated land
OR orchards, perennial crops (fruit trees, coffee, bananas, etc.)
PA Pasture, open grasslands, savannah
PB Pasture with brush, abandoned pastures, pastures with trees up to 3 m tall
PT Pasture or savannah with isolated trees, open forests

In the case of natural vegetation, use the definitions as required in a country. where the law applies to the management or conservation of natural forests. The definitions can be coded for identification on maps. Some suggestions:

BL Brush Land that is thick and has small trees 3 to 6 m tall.
NR Natural regeneration of forests with less than 20 m3/ha and that are less than 15 years old
NFD Degraded natural forest or forest land recently harvested with less than 20 m3/ha
NF1 Natural forest with 20 - 40 m3/ha
NF2 Natural forest with 40 - 75 m3/ha
NF3 Natural forest with 75 - 125 m3/ha
NF4 Natural forest with 125 + m3/ha
SW Swamp without a productive forest cover
S__ Swamp forest (use the same codes as are used for a natural forest, adding a S. Examples: SFD. SF1. SF2, etc.)

Codes are also needed for the species most commonly planted. Examples:

AM *Acacia mangium*

GA *Gmelina arborea*

TG *Tectona grandis* (teak)

EGr *Eucalyptus grandis*

EGl *Eucalyptus globulus*

EP *Eucalyptus pellita*

EU *Eucalyptus urophylla*

AF *Albizia (Paraserianthes) falcataria*

PCH *Pinus caribaea* var *hondurensis*

PCC *Pinus caribaea* var *caribaea*

PM *Pinus maximinoi*

PO *Pinus oocarpa*

PP *Pinus patula*

PR *Pinus radiata*

PT *Pinus tecunumanii*

RES Research plots

Map codes for forest management

All forest management activities should also have map codes.

Examples of site preparation codes

MC Manual brush clearing by machete

MS Manual scalping of grass, clearing planting spots with a hoe

BB Broadcast burn prior to planting

BP Burn piled debris prior to planting

DC Drum chop without burning prior to planting

DCB Drum chop and broadcast burn prior to planting

PD Plow and disk with a tractor prior to planting

PD2 Plow and double disk prior to planting

DB Disk and bed prior to planting

SD Subsoil and disk prior to planting

Examples of plantation management recommendations

When making a forest inventory, recommendations for management can be made and shown on the maps:

NT No treatment is recommended

T1 First thinning recommended

T2 Second thinning recommended

FH Final harvest recommended

DR Destroy a bad plantation and replant site

I( ) Another inventory is recommended in ( ) years prior to a future harvest

Formats for map codes

For orientation maps in the office, colors can be used to distinguish various aspects of the forest properties. However, for field operational maps. where there are many operational codes, colors can become quite confusing and standardized codes can provide much more information in an easy-to-read format. When copying maps, many different color combinations generally do not copy faithfully. whereas a black and white format will copy correctly. Figure 6-30 shows a shorthand method that allows for a maximum of five different types of codes to be placed in a compact format within a lot.

número del lote especie edad del rodal
27 AM 7
6/06* 23,5
fecha de plantación ha en el lote

*/ Codes in this lower left position vary according to the map. Examples:
In a current use map, site preparation recommendations are used.
In a plantation map, the month and year of planting are indicated.
In an inventory map, the management recommendation is indicated here

Figure 6-30. Format for a lot code.

Figure 6-31 shows an example of a map using the codes explained above.

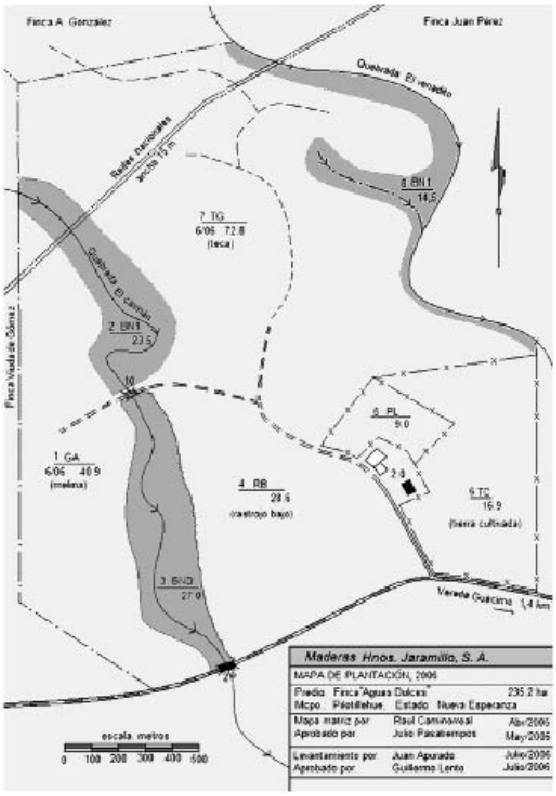


Figure 6-31. Example of a planting map.

Forest inventory

The quality of the forest inventory is of the greatest importance to the profitability of a forestry company. It is for this reason that successful companies assign their foresters with the most experience to inventory duties. The inventory should precisely reflect the amount of stumpage that is

available and also the condition of the forests. A forester trained in inventory and forest sampling is needed to direct this operation in order to make sure that the correct decisions are taken at the time of wood harvest. One of the first steps in making an inventory is to determine whether a plantation should be harvested according to the management plan or if the harvesting schedule should be modified based on the specific conditions of a particular plantation. When the objective is to produce sawtimber, the technician in charge must decide which stands are to be managed long-term for quality timber and which stands do not have the requirements for producing sawtimber.

Forest sampling

Plantation inventory is done by sampling, rather than by taking stock of the entire plantation. A well-designed sampling method produces reliable information regarding the amount of standing timber. Since trees in plantations are more uniform in their species and sizes than those of natural forests, the sampling intensity in plantations can be reduced and still produce reliable information.

During an inventory in a natural forest, the traditional method is to record the diameter and commercial height of each tree separately on a tally sheet. A common sampling method for an inventory in the natural forest is to utilize compass lines that are parallel and that are opened through the underbrush by a crew of laborers with machetes. The plots are rectangular in shape and contiguous, around a center compass line, and trees are measured side to side of that line. Plots are often 1/10 ha rectangles, being 20 m x 50 m or 10 m x 100 m, depending on the conditions in a particular forest. There are several ways to define which lines to choose for the inventory, but a common method is to select the lines randomly as is shown in Figures 6-32 and 6-33.

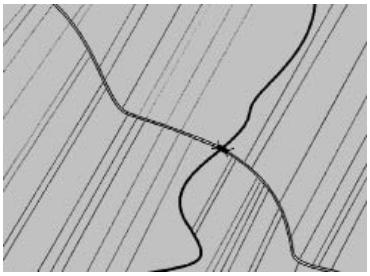


Figure 6-32. Example of the definition of compass lines in a natual forest. A random selection of sampling lines for the forest inventory is first made on a map.

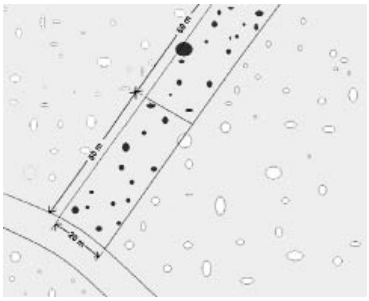


Figure 6-33. Example of a line plot made along a compass line in a natural forest. Rectangular plots usually measure 20 m x 50 m = 1/10 ha. Plots are continguous and successive in this example.

Another method of forest inventory is by point sampling. where a central position is selected as a plot center and the trees to be measured are selected using a glass prism or similar device. This method was developed in 1947 by Professor Bitterlich in Austria (Bitterlich. 1962; Köhl. 1993). The Bitterlich method is useful in a natural forest or in old plantations because it gives greater sampling intensity to larger and more valuable trees and places less emphasis on the measurement of trees of smaller diameters (Figure 6-34). However. when the Bitterlich method is applied to fast-growing

plantations where tree diameters are similar, point sampling approaches the same method as an inventory using circular plots (Grosenbaugh. 1958) (Figure 6-35). It is usually quicker to measure a circular plot than to measure a point sampling plot.

In young plantations it is seldom necessary to open compass lines, since the forest floor is usually quite open and does not have the heavy undergrowth often found in old natural forests. In plantations. where trees are in rows, there is a risk of sampling error if rectangular plots or square plots are measured along a compass line, since the width of the plot may not coincide with the mean distances between rows and that can result in an error in the calculations of plot size. When circular plots are employed there is not the problem of plot width in plantation inventories, as long as the plot diameter is large enough to cover several rows of trees.

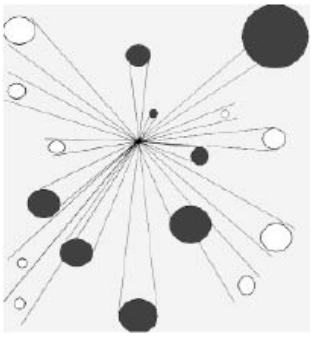


Figure 6-34. In a natural forest, point sampling gives greater emphasis to measurement of the largest diameter trees. The shaded trees that fall within the prism angle are measured.

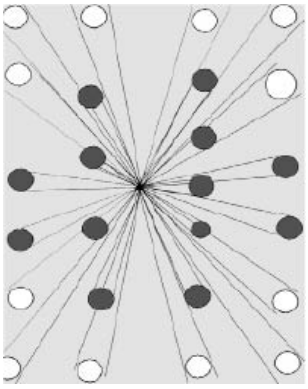


Figure 6-35. In a plantation where all the trees have similar diameters, the point sampling inventory method approaches the shape of a circular plot sample.

Circular plots have less selection error than a rectangular or linear plot (Figures 6-36 & 6-37). In the case of juvenile plantations that have not been thinned, plots of 1/50 ha. with a radius of 8.0 m work well. For plantations that have been thinned and where trees are larger, plots of 1/20 ha with a radius of 12.6 m work well.

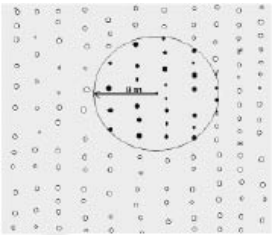
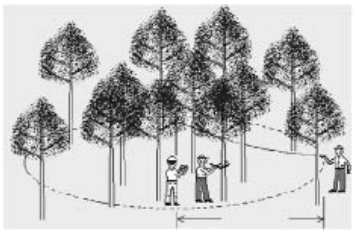


Figure 6-36. Random placement of the center of a circular plot of 1/50 ha (radius of 8.0 m) within a plantation.



8,0 m radio

Figure 6-37. The circular plot is an efficient method for sampling plantation trees during a forest inventory. A radius of 8 m represents a 1/50 ha plot (200 m2).

When plots are laid out on slopes, it may be necessary to make adjustments to compensate for the effect of the slope on the plot area (Bryan. 1956). A circular plot on a slope becomes an ellipse when projected to a horizontal plane (Figure 6-38. Table 6-3).

Data recording in the field can be simplified significantly when working in plantations by recording trees by diameter class and by determining tree height by a sub-sample. This method not only reduces the time for data recording in the field, but it also reduces the time for downloading field data to a computer in the office as well as reducing the probability of errors during the data transference.

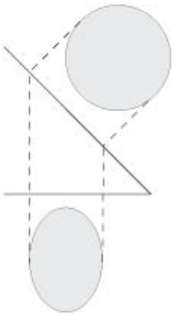


Figure 6-38. When a circle on a slope is projected to the horizontal it becomes an ellipse.

Table 6-3

Adjustments to circular plot diameters to compensate for the effect of slope

Slope %	Plot area		
0.02 ha	0.05 ha	0.10 ha	
plot radius, meters			
0	8.0	12.6	17.8
20	8.1	12.7	18.0
40	8.3	13.1	18.5
60	8.6	13.6	19.3
80	9.0	14.3	20.2
100	9.5	15.0	21.2

Tree height measurement in a dense plantation is difficult and is a job that can consume a lot of time. As has already been explained, there is a high probability of measurement error when the technician making the measurement does not have a clear view of the top of the tree in a closed stand where the tree tops are very close to each other. Under such conditions it is difficult to determine the

highest point in the crown with certainty or to see if there is a slight bend or inclination in the tree bole.

In reality, plantation tree heights are quite uniform. Thus, an option is to measure the height of some of the straightest trees in a lot for each diameter class present, and where the technician has a clear view of the tops of the trees being measured. Using a sub-sampling of tree heights and diameters, a regression can be calculated between total height and DBH that can then be used to estimate the height of the rest of the trees in a sample plot.

In field applications, this type of sub-sampling of tree heights has been found to be reliable and to provide for a precision equal or better than when all the trees in a plot are measured for height. By experience it is known that the measurement of total height and DBH of 20 trees and sampling trees of all diameter/height classes within the lot will produce a reliable regression of height by DBH. In stands where total tree heights average more than 15 m, total height can be measured to a precision of one meter. For this sub-sampling. DBH is measured to a precision of one centimeter.

A linear regression is calculated using the total height and DBH. Then, this regression formula is used to calculate the heights of all trees in the sample plots. In a Colombian company, a test was made of two measurement systems:

a) Measure DBH to the millimeter and total height to 10 cm for all trees within the measurement plots.

b) Measure DBH by 2 cm classes and total heights of 20 trees within the lot, and then calculate a linear regression of total height by DBH.

The difference in volume per plot between the two methods was 1.5% for individual plots. When all ten plots in a lot were averaged, the variation between the two methods dropped to 0.5%.

Another important aspect of recording field data is human error. Field data are uploaded to a computer for making volume calculations. When more ciphers are involved, there is a greater risk of keying in incorrect data. Let’s use an example:

1) In one case, the total height is written as, say. 10.3 m. In the other case, the total height is rounded to the nearest whole number. which in this case would be 10 m. For the first case, four keystrokes are required (1 – 0 – . – 3). whereas in the second case only two are required (1 – 0). In other words, there is double the chance of committing a data transfer error in the first case. while no significant additional information is keyed into the computer.

2) If we take the individual data for 20 trees in a plot and with 8 measurement plots per lot. while using high precision measurement instruments in the field. we have the following numbers to key into a computer:

Traditional system, recording height and DBH for each tree[15]

20 heights, recording data to 0.1 m = 20 * 4 = 80

20 diameters to 0.l cm = 20 * 4 = 80

Total data entry per plot = 160

Total data entry per lot with 8 sample plots and 8 pages of paper = 1.280

If we sample heights within the lot and record diameters by classes, the following data will be recorded:

Sub-sampling method for heights plus DBH registry by dot count[16]

20 trees/lot, sampling height and DBH = 20 * 4 = 80

5 diameter classes/plot for 8 plots = 5* (2 + 1) * 8 = 120

Total data recorded per lot with 8 plots, all data on one sheet of paper = 200

In summary, the sub-sampling and diameter class method requires less than one sixth of the keystrokes to transfer data to the computer. which implies that there is one sixth the chance of error on the part of the person transferring the data. At the same time, this method requires much less time to get the job done. In the example above, using diameter classes, all the data for a lot are recorded on one sheet of paper. whereas with the traditional system of recording all tree heights and diameters separately, eight sheets of paper are required. If the field technician does not write the pertinent information at the top of each page of the inventory sheets (date, tract, lot, species, plantation age, etc.) there is also the risk of committing measurement errors due to a mixing of measurement sheets in the field, in the office, or in the file cabinet.

Intensity of sampling

Since plantations have a more uniform structure than natural forests and are separated into lots, the sampling intensity can be less in plantations than in natural forests and still provide reliable information. In general terms, a 10% variation is normally accepted between a calculated inventory and the actual volume of wood harvested in a clear-cut for pulpwood. In such plantatio ns where there are no thinnings and where growth rates are normal, it is sufficient to make a 1% sampling using circular plots of 1/50 or 1/40 ha to obtain a variation of plus or minus 10%. Experience has shown that a precision of + 5% can be obtained with this sampling intensity.

In the case of plantations that have been thinned or where there are less than 700 trees/ha, a sampling intensity of 2% using plots of 1/20 ha (12.6 radius) provides good inventory results.

It has been shown that these sampling intensities are sufficient for making inventories in lots larger than 25 ha. For smaller lots, the sampling intensity may have to be increased. If the lot does not have uniform growth, it may also be necessary to increase the sampling intensity. For small lots, it is best to define a minimum number of measurement plots to obtain reliable results.

The objective of this type of sampling intensity is not to calculate a statistical variance, but rather to produce reliable inventory results at the lowest cost by using qualified inventory personnel. The objective of an inventory of a government concession in a natural forest is different from that of a plantation inventory in privately held properties.[17]

Example: How many measurement plots are required to make an inventory of a lot of *Pinus caribaea* seven years old and that has 62.9 ha. using a sampling intensity of 1% and circular plots of 1/50 ha (0.02 ha)?

62.9 ha * 1% = 0.63 ha in the total inventory

0.63 ha/0.02 ha/plot = 32 circular plots of 1/50 ha

Plots are selected and reviewed by the forest inventory technician and should cover the range of variation that occurs within the lot being inventoried. In this case. 20 trees are measured throughout the lot to obtain the heights and diameters for calculation the height x DBH regression. In the circular plots. only the diameters are measured and recorded by 2 cm diameter classes.

Once the inventory methodology has been tested and shown to provide acceptable results when compared with actual wood harvest information, it may be feasible to reduce the intensity of inventory sampling even further.

Example: If a company plants 3000 ha annually to produce wood for a pulp mill. how many persons are required to make the pre-harvest inventory. using a 1% sample and 1/50 ha plots?

3.000 ha/year x 1% intensity / 0.02 ha/plot = 1.500 inventory plots per year. Suppose that the inventory crew has three people (forest technician. data recorder and a laborer) plus a vehicle and that the crew can average 12 plots per day

(including the actual field work as well as travel time) and that there are 250 work days per year. Then. the crew would have the potential to measure 3.000 plots per year. Therefore. in this example. the crew would only need one half year to carry out the field inventory and the inventory technician could use the rest of the time to transfer the data to computer in the office and to calculate the inventory summary and make the required reports to management.

Field inventory formats

Table 6-4 shows a pre-harvest inventory format that can be used with a clear-cut harvest of plantations using the method of subsampling of heights and diameters and recording plot measurements by diameter classes.

Table 6-4

Inventory format for a plantation that is to be clear-cut. with a sub-sampling of DBH by height and with circular plots to record diameter classes

Predio Finca El Porvenir Bloque 3
Rodal 43 Área del rodal 28,5 ha
Especie *Gmelina* Fecha de plantación Febrero, 2001
Personal Fernando Pulgada, Rodrigo Madera Fecha del inventario Junio 2006

Muestreo del DAP x altura de árboles esparcidos por todo el rodal											
DAP, cm	21	18	11	20	13	11	22	15	15	24	
Altura total, m	18	17	8	14	12	12	18	15	13	21	
DAP, cm	15	18	19	10	20	22	26	16	13		
Altura total, m	15	17	18	11	18	20	24	15	12		

Parcelas circulares para el muestreo de diámetros												
Área de parcela	**0,05 ha**		**Radio de parcela**			**12,8**	**m**					
Clase diam. cm	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
9	5											
11	7	5		2		1	2	2				
13	5	7	6	6	6	3	6	5				
15	6	10	3	7	3	5	7	5				
17	6	6	4	5	4	5	5	8				
19	4		3	3	3	3	3	6				
21	2	2	8	5	8	6	5	5				
23		1	5	3	5	3	3	5				
25		1	6		6	5						
27			2	2	2	2	2	2				
29												
31												
33												
35												
37												
39												
Total	35	32	37	33	37	33	33	38				

Ejemplo de una clase diamétrica: clase de 15 cm = 14,0 cm a 15,9 cm

Conteo de puntos 1 = 3 = 5 = 7 = 9 = 13 = 20 =

2 = 4 = 6 = 8 = 10 = 17 =

Table 6-5

Format for an inventory with thinnings, using a DBH by total height sample and circular plots to register tree diameters by diameter class

Predio Finca El Porvenir Bloque 3
Rodal 43 Área del rodal 28,5 ha
Especie *Gmelina* Fecha de plantación Febrero, 2001

Personal Fernando Pulgada, Rodrigo Madera Fecha del inventario Junio 2006												
Muestreo del DAP x altura de árboles esparcidos por todo el rodal												
DAP, cm			21	18	11	20	13	11	22	15	15	24
Altura total, m			18	17	8	14	12	12	18	15	13	21
DAP, cm			15	18	19	10	20	22	26	16	13	
Altura total, m			15	17	18	11	18	20	24	15	12	
Parcelas circulares para el muestreo de diámetros												
Área de parcela		0,05 ha	Radio de parcela 12,8 m									
	N.º Parcela: 1		N.º Parcela: 2		N.º Parcela: 3		N.º Parcela: 4		N.º Parcela:5		N.º Parcela 6	
Clase diam. cm	Dejar	Eliminar	Dejar	Eliminar	Dejar	Eliminar	Dejar	Eliminar	Dejar	Eliminar	Dejar	Eliminar
9		2										2
11	3	4		5				2		1	1	4
13	2	3	3	4		6	1	5		3	2	3
15	4	2	6	5		3	3	4		5	4	4
17	4	2	3	3	2	2	4	1	3	2	3	3
19	4					3	2	1		3	4	1
21	2		2		4	4	4	1	2	4	5	
23		1	1			5	3			3		
25		1	1		6				5		2	
27					2		2		2			
29												
31												
33												
35												
37												
39												
Total	19	13	16	17	14	23	19	14	12	21	21	17
Ejemplo de una clase diamétrica: clase de 15 cm = 14,0 cm a 15,9 cm Conteo de puntos 1 = 3 = 5 = 7 = 9 = 13 = 20 = 2 = 4 = 6 = 8 = 10 = 17 =												

When a lot is to be thinned, the inventory must simulate the thinning. To do this, the following procedure can be used: In each circular plot, mark the trees along the plot circumference with white chalk at DBH in order to locate the plot perimeter easily.[18] Then mark the trees to be removed within the plot during a thinning with colored chalk. After marking the plot, measure the trees in the plot, recording them as being “leave trees” or “cut trees”. Table 6-5 shows a format for recording inventory data for a plot with a simulated thinning using a dot count by diameter class. Later, in the office, a tally is made of the cut and leave volumes. This process can be automated by programming an electronic spread sheet or a data base program.

Resolving variations between the inventory and the harvest

The purpose of the pre-harvest forest inventory is to have a means to predict the volume or weight of wood that will be available for a future harvest. It is important to confirm the validity of the inventory by making a comparison of the inventory results with the actual wood harvest when the wood is cut. In order to do this, it is necessary to record the lot and tract of origin of all truckloads of wood removed from a forest property. Thus, the forester responsible for plantation management must show the harvesting personnel where to cut and later, must register all trucks leaving in a harvest log book. where pertinent data are written down: stere meters on the truck, species, lot number, age, truck license number, etc. Then this information is compared to the records in the woodyard when the truck delivers the wood. If the wood is measured by weight in the woodyard, a ratio of stere meters to green tons on the truck needs to be calculated for each species and age of wood delivered.

Then. when the lot is totally harvested, a comparison is made of the variations between the inventory values and the wood delivered. This is done for each lot that is harvested. If the variation between the two is greater than is acceptable, the reasons for the variation need to be determined and the proper adjustments made. Reasons for discrepancies between the inventory values and the wood delivered to the woodyard can include the following:

- Errors in the lot area on the map.
- Errors due to inventory sampling.
- Errors due to improper data analysis in the office.
- Errors when projecting inventory data to the date of the harvest.
- Incomplete harvesting of the lot.
- Inefficient and unacceptable harvesting procedures, leaving wood lying on the ground.
- Errors when measuring the stere volume of truckloads.
- Incorrect conversion factors for stere volumes to scale weight.
- Wood losses during transport, either due to improper truck loading or due to wood being removed and/or stolen during transport.

Table 6-6
Log book for wood shipments from a forest property to the woodyard.

Empresa															
Finca															
Inspector															
Datos de campo						Medición de la carga sobre camión					Medición en el patio de maderas				Variación
Lote número	Especie	Edad años	Clase de cosecha	Tiquete número	Placa del camión	Ancho	Largo	Altura	Volumen estéreo	Volumen sólido	Peso en patio			Volumen sólido	Patio vs campo
											Bruto	Camión	Neto		
						m	m	m	m3	m3	ton	ton	ton	m3	%

Table 6-6 provides an example of a log format for wood transport. An effective method to control wood during transport is to fasten a cardboard tag to each load that has the contract number for harvesting and transporting the wood from a given lot to the woodyard. Before the truck leaves the forest property, the tag is stapled to the load and the load is measured and recorded in the log book. Upon arrival at the woodyard, the wood scaler records the same tag number when the truck is weighted (or measured for volume). In some companies, there are two parts to the tag (Figure 6-39). When entering the woodyard, half of the tag is removed at the scale shack and the other half remains with the load after it is unloaded in the woodyard to serve as an inventory control for the woodyard.



Figure 6-39. A cardboard tag with the contract number is stapled to each truckload of wood.

[1]In the United States, the level of precision used for measuring DBH for commercial forest inventories is normally 2 inches (5 cm). This is the precision used for forest inventories by the U.S. Forest Service as well as by most private companies. Measurement of diameter classes of 2 cm is more than sufficient for determining a fair price of stumpage for the buying and selling timber.

[2]Since the diameter is a squared value (d2), it can be converted from meters to centimeters by multiplying the constant by the square of 100 (100 x 100 = 10.000). Thus, four zeros are added to the constant 0.3. which becomes 0.00003, in order to enter DBH values into the formula in centimeters.

[3]In one large company, a forest manager who did not fully understand the mathematics of regression analysis, and who was anxious to show more wood volume in the plantations to his superiors, decided that the volume formula was wrong since it used DBH and total height for the tree volume calculations. To his way of thinking, the diameter measurements had to be made at the level of the stump to be correct. His conclusion. which was totally erroneous. was that there existed additional volume between the stump and DBH that was not accounted for and so he added that volume to the forest inventory results. Unfortunately. when the plantations were harvested, the supposedly additional volume never appeared, since it had already been accounted for by the regression equation.

[4]If a small lot has a significant number of forked trees, trees with broken tops or trees with other abnormalities, one alternative is to make a determination of the percent of misshapen or damaged trees and then apply a discount factor to the results obtained from normal volume equations to compensate for the existing variation. If there is a large lot (or lots) with abnormalities, it may be justifiable to make a special volume formula for that particular situation. This is called a local stand volume formula.

[5]The geometric formula for the volume of a truncated cone is: V = (π*h/12)*(d12 + d22 + d1* d2) = 0.2618 h * (d12 + d22 + d1* d2) where h = height and d1 and d2 are the top and bottom cone diameters. To convert diameter values from meters to centimeters, divide the diameter factor by 10.000, as has been explained previously.

[6]Smalian's formula is V = π (r2 +R2) length/2. which refers to a truncated parabola, a solid that is slightly convex. In the case of long logs in trees in a natural forest which may have a slightly convex form. Smalian's formula may be a better choice, but for short logs cut from plantation trees, the truncated cone formula adjusts better.

[7]Solid overbark or solid underbark are sometimes expressed as solid outside bark or solid inside bark.

[8]The bark volume percent is always greater in smaller and younger trees due to the fact that the bark thickness is relatively constant with tree size, but the base volume for calculating log volume is less in smaller trees than in larger trees.

[9]For lumber, a dry weight basis is used: moisture percent = (green weight –dry weight)/dry weight. For pulpwood a green weight base is used: % moisture content = (green weight – dry weight)/ green weight.

[10]When possible, it is best to obtain plantation growth data beyond the rotation age in order to calculate normal growth curves that extend beyond the expected age of final harvest.

[11]The Russians have a system called Glonass that is similar to the American GPS.

[12]When there are many details on a map, similar color combinations become very difficult to distinguish. Over time, colors can wash out of maps if they are used in the field and exposed to the sun. If watercolors are used in the printing, these will run if the map gets wet in the field, or if there is humidity in the map files. From an economic point-of-view, large numbers of black and white line maps are much less expensive to produce than are color maps using expensive printer inks, and black and white printing is much faster to print than are areas with solid colors.

[13]When copies are made of a matrix map, it is important to make sure that the copier produces copies that have the exact same size and orientation as the original. Printers set at 100% of the original make reliable copies. Blue line or blue print copiers (ozlid) reproduce maps faithfully to scale. Electrostatic office copiers that work with mirrors distort maps and produce copies that are slightly off scale; these cannot be used to calculate areas of lots drawn over them.

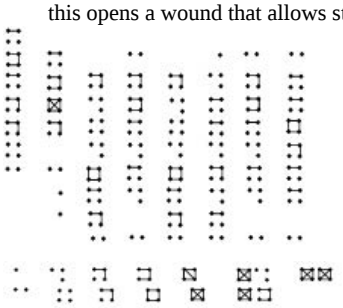
[14]Professional compasses have an adjustment for defining the magnetic declination. The local declination can be obtained from the national department of geographic information within a particular country.

[15]There are four keystrokes for height and four for diameter to upload the data to the computer.

[16]When transposing heights and diameters to create a height by DBH regression, two computer keystrokes are required for height and two for diameter. When using diameter classes for plot measurements, there are two keystrokes for each diameter class and one for the number of trees in each class. In the example it is assumed that there are 5 diameter classes involved with 20 trees to be measured.

[17]In a natural forest inventory for a forest harvesting concession. where the government or a concessionaire contracts students or other temporary personnel to make the inventory and where the forest conditions are difficult and variable (hills, slopes, swamps, vines, underbrush, etc.) a greater sampling intensity is required to obtain a statistical index for assuring that the inventory is within acceptable statistical sampling limits.

[18]Vinyl or latex paint such as is used for exterior painting on houses works well for marking trees to be thinned, but during the inventory it is best to use a chalk mark, since the inventory plots are temporary. Never mark cut trees with a machete or axe since this opens a wound that allows stain and rot fungi to enter the trees and can damage the wood.



7

Diseases and insects

Diseases in plantations
Stain fungi
Rot fungi
Brown rot of the heartwood of *Acacia mangium*
Fungi that attack foliage
Root rot of Caribbean pine in Venezuela
Disease of *Gmelina arborea* in Brazil
The pink disease of *Acacia mangium* in Asia
The *Eucalyptus* canker in Brazil
Leaf-cutting ants
Defoliating insects
Boring insects
What to do when a disease or insect pest is found in a plantation?
Publications of interest for tropical forest diseases and insect pests

Diseases in plantations

This chapter does not pretend to be an exhaustive study of the diseases that affect tropical trees; rather it is a recapitulation of some field observations that may help the reader to understand the influence of plantation pests on trees and some of the solutions that can be used to resolve pest problems. There is much literature available to help the reader to identify the most common forest pests. The reader is directed to the list of publications listed at the end of this chapter.

Apparently, diseases caused by viruses are not considered to be very important in forest plantations (Schmutzenhofer, 1988). Among the bacteria, the agrobacterium of *Eucalyptus* has caused mortality in nurseries, but, as a group, the bacteria are not considered to be important causes of diseases in forest plantations (Schmutzenhofer, 1988).

Diseases in trees are attributed primarily to fungi and can be divided into the following groups:

- Stain and rot fungi are those that attack the wood of living or dead trees. They can attack the wood structure or the material within the cells, such as sugars, starches and proteins.
- Leaf spots are caused by fungi that attack the live foliage and can cause a tree to defoliate prematurely, thus decreasing the tree's growth.
- Root rots are caused by fungi that attack the roots of trees. They can often be detected where groups of trees are moribund within a group and the foliage is turning yellow and brown. When infected roots are excavated they are found to be brown and decomposing, not a healthy white. Root rot infections can also be suspected when trees are leaning or falling over and where the exposed roots are soft, brown and decomposed and may have a fermented or vinegar-like smell.
- Leaf rusts or bark rusts seldom kill trees, but they weaken them, creating focal points where other pests can gain entrance. In general, rusts are not considered as problematic in tree species as they are in many agricultural crops.
- Cankers are diseases caused by fungi that produce lesions in the soft tissues of the bark and cambium. Cankers often do not cause mortality, but they decrease tree growth and can reduce wood quality.
- Wilts are due to systemic fungi that attack and discolor the wood xylem as the hyphae move within vessel cells and tracheids, reducing the flow of water upwards into the tree crown and thereby causing the foliage to wilt.

Some fungi attack live, healthy trees and plants and these are called *primary pathogens* or *pathogenic fungi*. Other fungi do not attack healthy trees or plants, but only those that have been weakened by stresses such as drought, insect damage. winds or other natural agents and these are called *facultative or secondary pathogenic fungi*.

Stain fungi

There are fungi that cause stain in sawn wood and in trees recently cut that are known as *bluestains* due to the color of the wood after it has been attacked. These fungi attack the sugars and starches in the interior of living cells, but do not attack the cellulose itself. Thus, they do not cause structural damage to wood; they only affect the color and appearance of the wood. Once lumber has been dried, the bluestain fungi cease to cause

additional effects. The bluestain can be a defect in wood used for ornamental purposes, such as plywood paneling and wood furniture, but otherwise it is not of economic importance.

Although broadleaf species can be affected by certain bluestain fungi, the bluestain is generally considered to be more problematic in pine lumber and plywood. When the pines are cut, spores of these fungi quickly germinate on the exposed surfaces of the fresh logs where the bark has been removed during harvesting. The hyphae of bluestain fungi growth between the cells and enter the cells through the pits of the tracheids. In a Caribbean plantation pine in Venezuela, it was found that the hyphae of bluestain fungi could reach the center of plantation logs in just a couple of weeks (Agrizonis, 1987).

When processing sawn pine wood in the tropics and during the summer months in subtropical regions, it is important to saw the logs as fresh as possible and to dry the lumber quickly to minimize the attack of bluestain. The bluestain attack can also be minimized by running freshly cut boards through an antistain bath, where the boards are submerged in a fungicide solution for a few seconds prior to being taken to dry in the open air or in a kiln dryer. This treatment kills the spores on the surface of the boards as well as the hyphae inside the cells near the surface.

When the hyphae of the stain fungi attack the wood and are alive, they are colorless. The color appears after the hyphae die and the dead material within the cells turns black. This material is then seen as a blue color on the surface of the board. When the log is sawn, it is possible that there are no visible bluestain fungi in the wood, but that the bluestain fungi are already inside the log. In this case, the affected wood will turn blue as the lumber is dried.

Although the bluestain fungi can readily attack pines, the environmental conditions for the germination of the spores is quite specific. An effective way to keep logs in a woodyard free of bluestain is to keep them wet with a sprinkler system. Although this is effective, it can be costly and is only justified when the sawn wood value is sufficient to absorb the cost of the sprinkler system installation.

Rot fungi

There are two general classes of wood rot fungi, the *white rots* and the *brown rots*. These names refer to the color of the rot hyphae in the wood.

White rots normally occur in dead trees and most commonly occur in the sapwood, although white rots can decompose all woody tissues. The fungi that cause white rot are more resistant to wood preservatives than are those that cause the brown rot. This type of rot has been found in eucalypt posts treated with CCA.[1] Brown rot can occur in live trees or in dead wood, preferentially in the heartwood cellulose, giving it a brown color. When trees have a rotted center hole, this is normally due to brown rot fungi. In live trees, brown rots normally enter into trees through wounds, such as those produced by wildfires that destroy bark or through open wounds at the base of the tree caused by mechanical equipment damage to the tree bole or roots. When plantations are thinned, care must be used not to cause damage to the bark or large, basal roots of standing trees while skidding logs to roadside. Fungal entry can also be caused by cuts with machetes or when there are breaks in the tops of trees during high winds or by lightening strikes.

In forest tree nurseries a common problem is *damping off*, where the stems of succulent seedlings recently germinated are infected by rot fungi that cause the death of the embryo or tiny seedlings (Schmutzenhofer, 1988). There are multiple species of fungi that can cause this nursery disease including species in the genera *Phytopthera*, *Phytium* and *Rhysoctonia*. These fungi can be controlled by fumigating or by heating the nursery substrate before utilizing it in the germination beds in the nursery. They can also be controlled by applications of fungicide by aspersion at the time when the seeds are germinating. Damping off is more frequent when the humidity is high around the seed germination boxes or around the nursery containers, but it is less of a problem when the seedlings are grown in raised beds or frames since the ambient humidity tends to be lower.

Fungal hyphae are microscopic structures that grow in the wood cells and cause their decomposition. The mushrooms or visible fungi are the fruiting bodies. In order for a fungus to develop, it requires food (wood), adequate temperature, adequate humidity in the wood and oxygen (Figure 7-1). These conditions are most commonly met when the wood is near ground line or lying on the ground. It is for this reason that posts tend to rot at the ground line, more so than below ground or in the aerial portions.

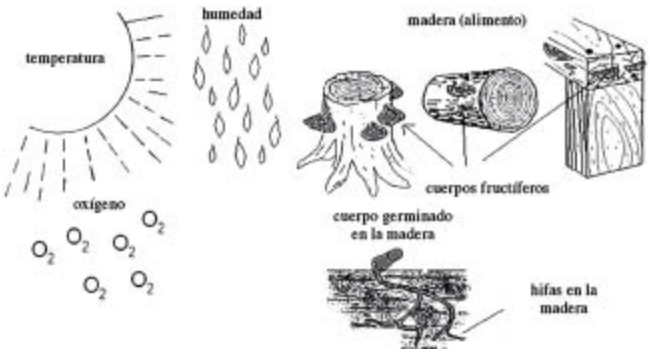


Figure 7-1. Factors that contribute to wood rot.

Fungal activity in wood can have several effects. One is the chemical decomposition of the cellulose, which results in a decrease in the structural strength of the wood. The physical effects of a fungal attack are a reduction in wood strength, reduction in wood density, shrinkage and color change.

Brown rot of the heartwood of Acacia mangium

Most fungi that cause wood rot are facultative, since they attack dead wood rather than living cells. Heart rot caused by pathogens is not common in plantation trees, even less so in very young trees. Nonetheless, there are circumstances where pathogens can cause wood rot. An important case is that of *Acacia mangium*, which has been attacked by heart rot fungi even in young trees. The heart wood of this species has a light brown color and has good density for furniture and for use as a construction timber. However, there has been a high incidence of heart rot in individual trees to the degree that the wood is not useful for making solid wood products (Figures 7-2 to 7-4).



Figure 7-2. Example of 8-year-old *Acacia mangium* in Sabah, Malaysia (Borneo). These acacias being managed on short rotations for sawtimber have been found to have a very high incidence of heart rot.

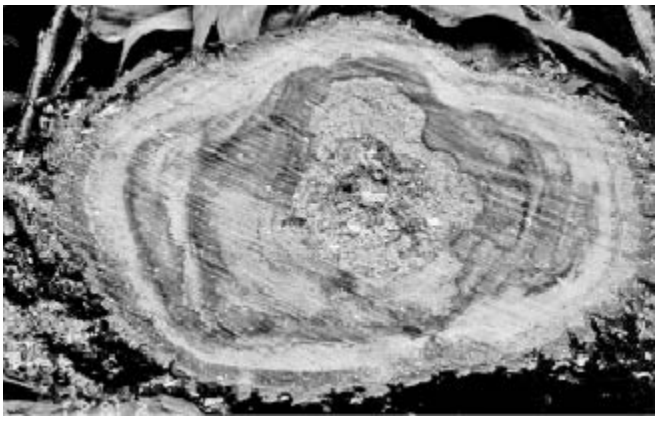


Figure 7-3. A 5-year-old tree of *Acacia* mangium with heart rot in East Kalimantan, Indonesia (Borneo).

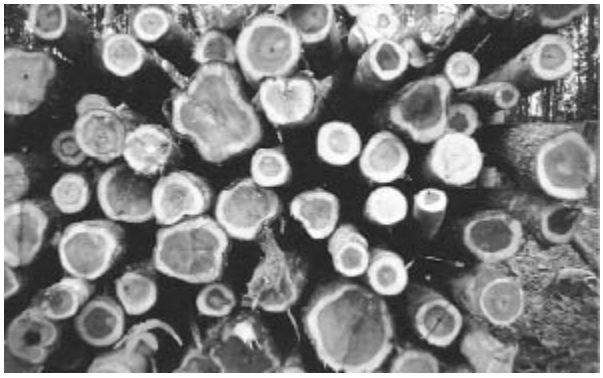


Figure 7-4. Six-year-old *Acacia mangium* in Sumatra, Indonesia, is being used as pulpwood, but even at this age stain fungi are occurring (darker brown color) in some of the trees. Others are already showing evidence of heart rot.

It has been discovered that several pathogens can cause heart rot of *Acacia mangium* in Borneo and in Peninsular Malaysia (Lee & Yahya, 1999). It appears that the pathogenic fungi gain entrance into the trees through senescing branches in the lower portions of the trees, not through normal channels such as wounds to the stem. Pathogens identified as causal agents of the acacia heart rot include *Phelinus noxius*, *Tinctoporellus epimiltinus*, and *Rigidoporus vinctus* (Lee & Yahya, 1999).

Fungi that attack foliage

Fungi that cause lesions and leaf spots on pine needles and leaves of hardwoods, such as *Cylindrocladium*, *Pestalotia* and *Fusarium* are chronic pests and normally attack the foliage during wet seasons, forming necrosis and leaf burn, but they are normally of little economic importance (Alfenas *et al.*, 1979). *Pinus radiata* is one species that is highly susceptible to the

attack of *Dothistroma pini*, which can cause serious foliar damage and economic losses in plantations.

Root rot of Caribbean pine in Venezuela

On sites were there are prolonged dry seasons, there exists the potential for facultative fungi to attack the roots of stressed trees. In Venezuela, there have been several cases of root attacks in plantations of Caribbean pine (*Pinus caribaea* var *hondurensis*) by the fungi *Sphaeropsis sapinea* (*Diplodia pinea*) and *Botryosphaeria* (*Botrydiplodia*) *dothideae*. These are normally fungi responsible for bluestain in pines, but they can become pathogenic on live tree roots when the trees are stressed by long dry seasons. During research into this phenomenon in 1988, the author identified several contributing factors that made the pines more susceptible to the fungi:

- An extended dry season.
- The root rot attack was concentrated on those sites where there were coarse, sandy, highly drained soils, i.e., where the trees suffered most from the drought.
- The attack occurred during the fourth year dry season, just when the trees were beginning to close crown and where root competition among trees for soil moisture was becoming severe. Figure 7-5 shows the “window frame effect”, where rows adjacent to the roads exhibited little mortality, due to a greater area of soil (and soil moisture) available for tree growth. In Figure 7-6 it can be seen that there was no mortality in a 5-year-old plantation adjacent to the one that was attacked, and that it had a lower stand density. The affected plantation had been planted with 1850 trees/ha, whereas the adjacent 5-year-old plantation was planted with 1350 trees/ha.

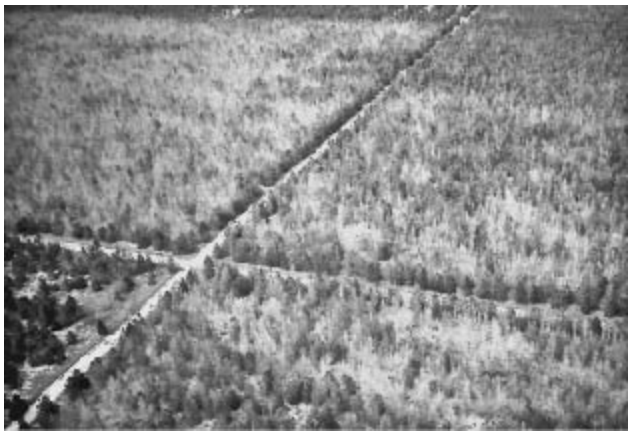


Figure 7-5. Mortality of 4-year-old *Pinus caribaea* during a severe drought in Venezuela in 1988. Trees adjacent to the roads are less affected due to greater space available for root development.



Figure 7-6. The 5-year-old plantation of *Pinus caribaea* in the foreground has a much lower stand density that the 4-year-old plantation in the background. With a lower density, there is no evidence of mortality due to root rot.

- Upon excavating several trees with a shovel, it was found that they had roots doubled into an “L” shape and grew horizontally near the soil surface. This “L” shaped root was due to poor planting practices where the planting machines which did not make a deep enough slit for the trees when they were planted. The roots of the pines continued to grow horizontally and did not put down deep roots after being planted incorrectly. Thus they did not have access to soil moisture deeper in the soil horizon.

Once the rains started again, the root rot attack to the pines ended and there was no further evidence of moribund trees. Sometimes foresters try to plant more trees on sites where they expect to have greater mortality with the intention of “compensating” for the expected losses. However,

experience has shown that the opposite is the best policy. On very droughty sites, where soils are highly drained, or where there are other risks of mortality, it is best to plant fewer trees initially to make sure that each tree has sufficient space to develop. This also delays the age of crown closure and the start of acute root competition among the trees, so that they are better able to withstand the long dry seasons.

Disease of Gmelina arborea in Brazil

In Pará State, Brazil, north of the Amazon River, there were large plantations of *Gmelina arborea* established during the decades of 1970 and 1980 in a region that had predominantly sandy soils and a well defined dry season each year. In this environment, *Gmelina* was attacked by *Ceratocystis fimbriata*, a fungus that is also known to attack rubber trees and mango trees.[2] Under those environmental conditions the fungus became pathogenic and caused damage to trees and eventually caused death.[3] Through forest research testing, several strains of *Gmelina* were developed that were resistant to the pathogen. Nonetheless, the final solution to the problem was to change species and, currently, the plantations are being made with the *Eucalyptus* uro-grandis hybrids, trees that adapt well to this environment and grow better in sandy soils than does *Gmelina*.

The pink disease of *Acacia mangium* in Asia

The pink disease (*Corticium salmonicolor*) attacks rubber trees, eucalypts, acacias and other species of tropical and subtropical trees around the world (Mordue & Gibson, 1976). This fungus has affected eucalypts in India on sites with high rates of precipitation (Seth *et al.*, 1977). It has also been observed in plantations of *Acacia mangium* on the north side of Borneo, particularly in the Northeast in the state of Sarawak, Malaysia, where the annual precipitation is between 2500 and 3500 mm. However, in Southeastern Borneo, where the precipitation is between 1600 and 2000 mm, pink disease is not common. It is thought that the high precipitation promotes conditions favorable to the development of the fungus and allows for its transmission through the air in the form of basidiospores after rains (Mordue & Gibson, 1976). The disease causes the death of the terminal ends of branches, beyond the point of attack. This reduces tree growth, but normally does not cause the death of the tree. The pink color comes from a pink, gummy sheath that forms on the infected bark surface, which gives it

its common name. In provenance tests of *Acacia mangium* in Sarawak, it was found that there is considerable variation in the susceptibility of trees to this disease (Figures 7–7 & 7-8).



Figure 7-7. A provenance test of *Acacia mangium* near Sabal, Sarawak, Malaysia, where there is a high rate of attack by pink disease, *Corticium salmonicolor.*



Figure 7-8. At five years of age, an Indonesian provenance of acacia (left) appears free of pink disease, whereas an Australian provenance (right) is visibly affected by the disease.

The *Eucalyptus* canker in Brazil

In 1976, the *Eucalyptus* canker was considered the most important eucalypt disease in Brazil (Hodges *et al.*, 1976). The disease attacks very young as well as large trees in plantations. There were thousands of hectares affected, with the greatest concentration in the state of Minas Gerais, but it was also occurring in neighboring states. The forest industry was considering a total cessation of eucalypt planting due to the disease. At that time, up to 70% of trees in pulpwood plantations were attacked with mortality reaching 30%. Initially, the cause of the disease was identified as the fungus *Diaporthe cubensis*; later its name was changed to *Cryphonectria cubensis* (Hodges, 1986) and still later to *Chrysoporthe cubensis* (Gryzenhout, 2004).[4] Several companies had eucalypt progeny tests and it was found that some strains of trees were totally resistant to this

disease. Because of these findings, Brazilian research foresters began to develop totally resistant eucalypt planting material and, today, the majority of industrial plantations in the country are free of the disease that, until a few years ago, was nearly responsible for the demise of the eucalypts in Brazil.

Leaf-cutting ants

In many parts of the tropics the leaf-cutting ants are an important pest. A strict control of the ants is needed during the first year of the life of plantations to minimize defoliation and avoid mortality in the plantations. These ants defoliate many tree species in the natural forests as well as in plantations. There are many species of leaf-cutting ants; the most important of these from an economic point of view are in the genus *Atta*.[5] The life cycle of leaf-cutting ants is complex and interesting. They are species capable of producing very large colonies where all individuals are daughters of the queen ant. There are several classes of ants that live in the colony: the queen, the drones, the workers, the soldiers, and the gardeners, each being defined by the queen when she lays an egg in the nest (Jaffé *et al.*, 1992).

During certain periods, the queen lays eggs that produce sexual individuals with wings. These are the young queens and the males or drones. As these winged ants emerge from the nest, they climb to the soil surface and begin their nuptial flights, which normally occur on nights with a full moon. It is a curious fact that nearly all of the sexual individuals of all of the nests emerge on the same night allowing for coupling among individuals from different colonies. The winged ants copulate in the air. After the nuptial flight, the queen lands in a clearing in the vegetation (including road surfaces which appear as clearings under the full moon); they cut off their wings and begin to excavate a new nest site in the soil. From this one and only copulation during her lifetime, the queen maintains enough semen within her body to fertilize all of the eggs produced during the rest of her life. (The drones die after the nuptial flight). Thenceforth, a new colony is initiated with eggs produced to form the various types of sterile female worker ants that will sustain the colony.

Ant colonies within the soil can reach depths up to five meters. The excavated soil is thrown out to form ant hills.[6] The leaf-cutter ants usually come out at night and harvest foliage from nearby vegetation. In tree plantations, some of the leaf-cutters remain in the trees, cutting foliage,

while others collect the material that is dropped to the ground and carry it off to the nest (Figure 7-9). Within the nest there are chambers where edible fungi are cultivated on the leaf pieces. The fungus serves as food for the queen and for the recently emerged juvenile individuals. The gardener ants cultivate the fungus and they are the smallest individuals within the colony. The soldier ants are the largest individuals, have large mandibles and protect the colony from invaders.



Figure 7-9. Defoliation of top branches of Caribbean pine caused by leaf-cutting ants.

During the rainy season, leaf-cutting ants have been observed to prefer the succulent foliage in the extremity of the branches (Nakano *et al.*, 1985). The ants cut off the foliage from the growing sprouts of many trees thereby reducing their overall growth. During the dry season, the ants tend to concentrate on the domination of a few individual trees, cutting and dropping old, stiff foliage, so that the trees sprout new succulent foliage, which they harvest and carry to the nest. The trees that are dominated by the ants are generally those found in the lower canopy, these being the weak and suppressed trees. It appears that such trees are easiest to dominate to produce fresh foliage. It is common to find clean trails (ant highways) from the dominated trees to the nests. If there is not adequate ant control, the excavated caverns can become so large and extensive as to cause problems for vehicles transiting on forest roads (Figure 7-10). Casual observations seem to indicate that most of the locations where defoliation attacks occur are where the trees are stressed due to very high plantation density, very poor soils or during prolonged droughts (Figures 7-11, 7-12).



Figure 7-10. A large colony of leaf-cutting ants excavated a nest under a forest road causing it to collapse when vehicules ran over it.



Figure 7-11. A spacing trial of Caribbean pine in Venezuela; the largest concentration of ant colonies was observed where stand densities were highest.



Figure 7-12. In the same trial where the spacing was the widest, no ant colonies were observed.

The key to controlling leaf-cutter nests is to kill the queen. If just workers are killed, the queen can repopulate the colony so that it survives. All ant control is based on this concept. A common control is the application of insecticide baits such as Mirex-S. The bait consists of compressed pellets of orange peelings or other fruit peelings with very low

concentrations (1.5% to 2%) of the Mirex-S insecticide. The pellets are sprayed with orange or pineapple juice to attract the ants to the bait (Nakano *et al.*, 1985). The purpose of the bait is for the field ants to begin to eat it and also to carry it underground to the workers that feed the queen. The insecticide concentration is very low so that the worker ants carry it to the queen before it becomes toxic and they begin to die. If the queen does not ingest the bait, it won't work and the colony will continue to prosper.

Another control method is fumigation using insecticide dusts or poisonous gases (Figures 7-13, 7-14). There are several chemicals used for this purpose. In large colonies, fumigation may not always be effective if it does not reach the queen. Another alternative that can be used in small, shallow nests is to excavate the queen with a shovel and kill her (Figure 7-15).



Figure 7-13. A bait dispenser in Brazil. By pushing the handle down and releasing it, 10 grams of bait are placed on the ground along the ant trail.



Figure 7-14. A fumigation device for controlling leaf-cutting ants in Colombia,. A tube is inserted into the nest and then the worker pumps the piston to force insecticide into the nest



Figure 7-15. In Tabasco, Mexico, the queen in a small nest is removed with a shovel and destroyed.

During the rainy season, baits can be placed inside very small plastic pillows or small containers so that they do not get wet and lose their potency. These are then placed along the ant trails. When the ants find the bait, they open the bag or container and carry it all to the nest within a single night (Figure 7-16).



Figure 7-16. In Argentina, the plastic bait pillow is placed inside a styrofoam cup with lateral holes to allow access for the ants. This method protects the bait from the rain until the ants open the bait pillows and carry the bait to their nest. The cups are placed beside the ant trails and all of the bait inside of a pillow is removed by the ants in a single evening.

A common species of leaf-cutting ant in tropical America, from Argentina to Mexico, is *Atta laevigata*. This species attacks pines, eucalypts, *Gmelina* as well as many other forest and savannah tree species. This is an important pest in plantations of Caribbean pine in Venezuela. It is not possible to eliminate all the nests with just one treatment of a plantation. When the ants make their nuptial flights, they drop to the ground in or around the plantations and start new colonies, especially where there are clearings or grass lands near the plantations. The leaf-cutters can defoliate

trees up to 200 m from their nests, making it important to control the nests up to this distance from the plantations. In Eastern Venezuela, it is difficult to control the ants in juvenile plantations due to the presence of natural grasses (*Trachypogon* spp.) within the region, and also because the combination of the grass and the pine branches makes it very difficult to see the ground and detect the incipient nests. However, if there is no control of the ants during the first few years of the plantations, until such time as it becomes possible for people to walk under the tree crowns (between eight and nine years) and to see the nests, the ants will have already formed extensive and populous colonies and have caused considerable damage and loss of growth in the pine plantations.

In the central and southern regions of Brazil, the leaf-cutter, *Atta sexdens*, is a pest that is more aggressive than *Atta laevigata*. Control of this pest in eucalypt plantations is a routine management operation. It is absolutely necessary to maintain a strict control of this pest using crews that continually walk through the plantations placing baits or fumigating the ant colonies. Without this continuous and complete control, *Atta sexdens* has the potential to totally defoliate entire plantations of eucalypts and cause their death.

Defoliating insects

There are many insects that defoliate trees. The majority of important defoliating insects for plantation forests are in the order of the *Lepidoptera* and they are the larvae (caterpillars) of the moths. When there are major outbreaks of defoliators it is usually associated with the absence of natural predators or parasites, or due to environmental conditions that cause the trees to be stressed. The key to preventing defoliating outbreaks is to understand the causes of these and to promote conditions that are hostile to such insect outbreaks.

Defoliator outbreaks normally occur at the time when plantation trees close crown, that is, when the trees begin to strongly compete among themselves. It is the moment when the tree roots are in competition for soil moisture and nutrients and the crowns are closing in competition for sunlight. The age of crown closure varies by species, growth rates and also because of natural environmental conditions, mostly due to soils and climate.

The lepidopter insects have a great reproductive capacity and the female typically lays large numbers of eggs, with multiple generations being produced during any given year. At the same time there are many natural controls to these insects. The most important insect controls are found in the orders of the *Hymenoptera* (example: small wasps) and the *Hemiptera* (example: stink bugs). The book "*Manual de pragas em florestas – lepidopteras defolhadores de eucalipto"* (Zanuncio, 1993) is an excellent reference to common defoliators, not only for Brazil, but for all of tropical America. Zanuncio describes several control methods for defoliating insects:

- Biological control with parasites and predators
- Control with pathogens (bacteria)
- Physical and mechanical control
- Chemical control
- Control through plant resistance

Biological control is the primary line of defense. By understanding the nature of defoliators, the forester can create natural conditions that do not promote defoliator outbreaks. These include keeping plantations healthy with adequate space for individual trees to grow, planting species well adapted to the local environment and using optimum silvicultural treatments. Parasite and predator populations can also be promoted within the local environment. The following is a brief summary of particular cases where there have been defoliator outbreaks, and successful methods of their control.

Cypress defoliation in Colombia

At the end of the 1960's, there were extensive plantations of conifers in the Andes region of Colombia, primarily Guatemalan cypress (*Cupressus lusitanica*) and weeping pine *(Pinus patula*) (Figures 7-17 to 7-20). Around the city of Medellin there were serious defoliation problems, especially in the cypress stands and later on in the pines, which were caused mostly by two lepidopter species, *Glena bisulca* and *Oxydia trychiata* (Lara, 1976, 1985; Vélez, 1974). The initial attacks were concentrated in plantations seven to nine years of age. After defoliation, the cypress dies, but the pine can resprout new foliage and survive. If the pines are defoliated several times successively, they also die. From there, the defoliations began to

appear in other regions of the country where these tree species had been planted. Some landowners applied insecticides to their plantations to kill the insects.



Figure 7-17. Total defoliation of *Pinus patula* in a 7-year-old plantation.



Figure 7-18. Defoliation of a 9-year-old plantation of *Cupressus lusitanica* in Colombia by *Glena bisulca.*



Figure 7-19. Adults and larvae of *Glena* on a cypress. The larvae stand up, looking like a small dead branch, when they are disturbed; possibly a mechanism for hiding from predatory birds.



Figure 7-20. A mechanical trap with ultraviolet lights to trap adult insects that fly at night in a cypress plantation.

It was observed that there was a lesser probability of attack by these defoliators where there were some weeds in the plantations. After inspecting multiple plantations, the following summary of conditions was developed:

- Defoliations tended to occur just after crown closure of the plantations,
- Plantations mostly affected were those with high initial planting densities, with more than 2500 trees/ha (2 m x 2 m spacings),
- Defoliation occurred in 7 and 8-year-old pine plantations that had previously been in cattle pasture and that were clean, free of grass and weeds, while in adjacent plantations of the same age where there had been brush and weeds, there was little evidence of defoliation,
- Where chemical insecticides had been applied to control outbreaks, the insect populations increased the next year with greater rates of defoliation,
- On sites where there were outbreaks of defoliators, there was little or no natural forest observed around the plantations,
- Where plantations had been thinned at eight years of age, removing half of the standing trees, there were no outbreaks of defoliators, even though the same species of defoliating insects were found to be present in those locations.

Based on these observations, a silvicultural control plan was developed to prevent future defoliator outbreaks:

- Increase the initial spacing in plantations, planting no more than 1100 to 1300 trees/ha so that the trees have more space for development and for better health,

- Keep the planting spot around seedlings free of weeds and grass but allow grass and weeds to grow inbetween the rows of the juvenile plantations,
- Where there are natural forest areas nearby, these are left intact. Promote natural forest areas near plantations where possible. Where there is no natural vegetation nearby, promote natural regeneration by protecting areas from cattle grazing or burning and/or plant native tree species in reserves. The goal is to maintain a minimum of 20% of the forest properties in natural forests and/or natural vegetation.
- Where there exist plantations with very high initial planting densities, make thinnings to reduce the competition among trees in order to keep them healthy.
- Do not use insecticides to attempt to kill the defoliating insects, since those chemicals not only kill noxious insects but they also kill important predatory and parasitic insects that help to control the populations of defoliating insects.

By applying the silvicultural procedures described, the problems with defoliators in the conifer populations were dramatically reduced. The defoliating insects are not eradicated from the natural environment, but they can be tolerated without suffering economic damages in forest plantations.

Defoliation of eucalypts in Brazil

In the state of Minas Gerais, eucalypts have been planted as a source of wood to make charcoal, which is then used for iron smelting in the steel industry at the city of Divinópolis. In this region, it was customary to plant trees at close spacings for charcoal production, between 1600 and 2000 trees per hectare. In 1988, the consulting company, Zobel Forestry Associates, recommended to a client to reduce the plantation density for *Eucalyptus urophylla* to 1100 trees/ha due to the stresses caused by a long dry season. Recommendations were also made to leave strips of natural vegetation interspersed in the eucalypt plantations, something that was not done since the natural vegetation of those savannah regions is primarily grasses, weeds and bushes, and because there are palms in the low drainages.

When the plantations reached two years of age, there were serious outbreaks of defoliating insects in the highest density plantations (1600 trees/ha), but no defoliation was visible in plantations established with a

density of 1100 trees/ha. The defoliating insects were identified as *Sarsina violascens*, *Thyriteina arnobia* and *Glena* sp., all being well known in Brazil. In nearby plantations owned by another steel company, there were no outbreaks of defoliators. Observing those plantations it was found that that company had left strips of natural vegetation 50 m wide every 1000 m of eucalypt plantations. The conclusion was that where there are frequent and severe dry seasons, the plantation density needs to be reduced so that the trees have sufficient space and root volume (soil moisture and nutrients) to grow, as well as leaving natural vegetation interspersed or nearby the plantation to promote the development of predatory and parasitic insects.

Defoliation of eucalypts in Venezuela

In the lowlands north of the Orinoco River, there are large expanses of natural prairies and deciduous forests where the dry season can be severe and extended, but where there can also be flooding during the rainy season. In the western parts of the country, the prairie soils tend to be more clayey and silty and there has been a history of fires in the region due to lightening strikes. Much of this land has been converted to cattle production but where major drainage systems have been developed, agricultural crops have also grown very well.

In this environment, some eucalypts plantations have also been established, primarily *Eucalyptus urophylla* and the *Eucalyptus* uro-grandis hybrids. In some of these plantations there have been defoliations around the second year, just after crown closure. The sites where outbreaks are most common are those with soils that are silty clays, where tree roots remain superficial due to poor internal drainage and where there exists little natural vegetation. Since the tree roots tend to be shallow, the trees suffer from a lack of soil moisture during the dry season. Then, when the rains begin, the surface flood waters cover the land and the roots suffer from a lack of soil oxygen, resulting in stress on the trees both in the dry season and during the rainy season. Under these conditions there have been multiple outbreaks of the insect *Thyriteina arnobia*, causing defoliation and death of many trees in the low sites that tend to flood.

Under such conditions, there are several alternatives available to the forest landowner.

- It is always important to preserve and promote the development of natural forests which serve as a location for the development of natural

predators and parasites of the defoliating insects.

- Drainages can be made on low sites to minimize the time that the tree roots are under water during the rainy season.
- The land can be bedded and the trees planted on top of the beds to raise them above the soil surface. Bedding increases the volume of soil available for tree root growth and it increases the amount of macropore space in the soil for root growth during the dry season as well as the amount of soil oxygen available to roots during the rainy season.
- Tree species can be selected that are deciduous for planting on the low areas and in the silty clay soils, such as *Gmelina*, teak or saqui-saqui. [7] These three species tend to adapt better to silty clay soils than do the eucalypts which grow better on sandy loam soils.
- Maintain low, flooding sites in pastures for cattle rather than converting them to tree plantations.

Defoliation of eucalypts in México

In the southeastern states of Veracruz and Tabasco the rainfall is good for tree plantations and the dry season is short. Where there are sandy soils the growth of eucalypt plantations is excellent, but even with good growing conditions there have been outbreaks of defoliating insects when the plantations are two and three years of age. The insect causing the principal defoliations has been indentified as *Sarsina violascens*, a lepidopter (Figure 7-21). Where most of the defoliations have occurred there are agricultural crops adjacent to the tree plantations, but there is a scarcity of natural forest vegetation nearby.



Figure 7-21. A three-year-old plantation of *Eucalyptus urophylla* is totally defoliated by *Sarsina violascens* in Tabasco, Mexico.

The incidence of the defoliator outbreaks in tree plantations is attributed to the use of insecticides in the neighboring fields of corn, beans and other crops. The insecticides are mostly wide-spectrum and kill all insects, including natural predators and parasites of the defoliators such as stink bugs and small wasps. Without natural vegetation nearby, there is nowhere for the predators and parasites to develop naturally. In this case, the most viable alternative has been to install a breeding program for stink bugs and to release these insects into the plantations (Figures 7-22 & 7-23).[8] Stink bugs act as parasites by laying their eggs in the egg masses of the *Sarsina* moths. The stick bug larvae emerge from their eggs before the *Sarsina* do and they eat the emerging larvae of the moths. The adult stink bugs also eat the moth larvae. This method of defoliator control has been very positive.



Figure 7-22. Stink bugs are raised by placing the foliage of eucalypts infested with the larvae of the *Sarsina* months in their cages as a source of food. The black dots in the breeding cage are the stink bugs.



Figure 7-23. The stink bugs are ready for release into the plantations to attack the defoliators.

Gmelina defoliation in Costa Rica

In Costa Rica, a company established plantations of *Gmelina arborea* in a low stream terrace where the soils were quite wet. Part of the plantation was planted flat and another part was planted on top of beds. At three years of age, the growth of the *Gmelina* was excellent due to good management

and to the abundant soil moisture. During the fourth year, there was an outbreak of the defoliator *Eacles imperalis*, a large moth which also has very large larvae (Figure 7-24). This insect totally defoliated a 70 hectare plantation in the low, flat area, but there was almost no incidence of defoliation on the adjacent plantation established on beds. The reasoning for this difference is that the trees on the low, flat area had very shallow roots due to the high water table and became stressed due to a lack of available soil oxygen for the roots. (It is important to remember that tree roots also require oxygen and do not grow well in very wet soils.) The trees planted on beds did not suffer the root stress because they had more soil volume to grow and better drainage in the raised soil in the beds.



Figure 7-24. A female adult of *Eacles imperalis* on the foliage of *Gmelina arborea.*

The affected plantation was treated with an organic insecticide which consists of the spores of the BT bacterium (*Bacillius thuringiensis*), which was applied by a light airplane. Later, as the larvae of the months ingested the spores on the surface of the *Gmelina leaves*, the bacterium developed in the stomachs of the larvae and killed them. Other non-target insects that did not eat the foliage, such as bees and other pollinators, are not affected by BT. This treatment effectively controlled the outbreak of *Eacles* and eliminated the threat.

In the long term, such defoliation outbreaks can be avoided by making drainage ditches in low, wet areas, and by planting the trees on top of beds so that they have well drained soils for good health and growth.

Boring insects

Boring insects cause damages to wood and some of them kill trees. There are boring insects in several insect orders including the Coleoptera

(beetles), Lepidoptera (moths), Diptera (flies) and Isoptera (termites) (Madrigal, 2003). Boring insects attack the cambium under the bark as well as the wood of the tree trunk. Some do not kill the trees, but they reduce the quality of the wood by making holes that allow stain fungi to enter into the tree, or they can change the form of the tree, making it branchy.

Stem boring insects in the Meliaceae family. The primary reason that mahogany and Spanish cedar are not widely planted is due to a boring insect, *Hypsipyla* spp. that is found throughout the tropics. The growth potential of the cedars and mahoganies is excellent, besides being high value woods for use in ships, furniture, molding and interior wall paneling. Some woods are resistant to termite attack and also to rot when wood is in contact with the ground. The remaining important commercial sources of these valuable woods in the primary forests are being exploited legally and illegally and are nearly exhausted. There are secondary forests that include mahoganies and cedars in the Amazon and also in Central America, but these are not the large trees with high quality wood that once existed in the original forests and they have little economic importance except for local use. In Colombia, the woods of the cedars (*Cedrela odorata* and *C. montana*) have been replaced in the lumber yards by woods of red ceiba (*Pachira quinata*), which are also sold under the commercial name of "cedar" although they are not of the same quality, and even red ceiba is also quickly being exhausted in the natural forests of the Caribbean coastal plain.

The most common American borer is *Hypsipyla grandella*, which attacks the three species of mahogany (*Swietenia macroflora*, *S. mahagoni* and *S. humilis*) as well as more than ten species in the genus *Cedrela* (Holdridge, 1976). *Hypsipyla* also attacks other genera of the Meliaceae family, primarily those in the *Swietenioideae* subfamily (Gripma, 1976). The African borer, *Hypsipyla robusta*, is an important pest of African mahogany, *Khaya ivorensis*. *Hypsipyla robusta* is also found in tropical Asia, supposedly carried from Africa with tree seeds from Africa. *H.* robusta attacks the American bigleaf mahogany (*Swietenia macrophylla*) where it is planted in Indonesia, Malaysia and other Asian countries. *Hypsipyla* attacks begin in cedar and mahogany trees as young as one year old. The female lays her eggs on the terminal buds of the trees and the emerging larvae bore into the pith of the tree stem, killing it. Eventually, the insect pupates inside of the tree stem and emerges as an adult. The result of

this life cycle is to cause the dieback of branches and terminal leaders, causing the tree to become branchy and to have a crooked stem. These attacks have been found to occur in virtually all parts of the American tropics where plantations have been attempted with cedars and mahoganies.

The Asian cedar or toon tree (*Toona ciliata*, *T. ciliata* var *australis*) is attacked by *Hypsipyla robusta* in Asia, but *Toona* has been seen to be resistant to the attack of *Hypsipyla grandella* when planted in the American tropics. In 1971, an experimental plantation of *Toona* in Costa Rica showed resistance to the borer, whereas adjacent plantations of cedar and mahogany were attacked (Sánchez *et al.*, 1976). There are plantations of *Toona* in Veracruz and Tabasco, Mexico, that are free of borer attacks by *H. grandella*, while cedar and mahogany plantations nearby are severely attacked (Figures 7-25, 7-26). Plantations of *Toona* in Brazil have also been reported to be free of attack by *H. grandella*.



Figure 7-25. The stem borer *Hypsipyla grandella* did not kill this mahogany tree in Colombia, but it did deform it and reduce its value as a commercial tree.



Figure 7-26. In this arboretum in Tabasco, Mexico, a plot of mahogany (*Swietenia humilis*) in the foreground was 100% attacked by *Hypsipyla grandella*, whereas a plot of *Toona ciliata* in the background does not show any evidence of borer attack.

In the 1970's, there were numerous studies of these boring insects (Whitmore, 1976), but there was relatively little interest in planting these tree species. Today there is still very little interest in the development of resistant strains of species of Meliaceae to *Hypsipyla.* Even though there is convincing evidence that the Asian cedar, *Toona*, has shown good resistance when planted in the American tropics, there is still very limited interest in the establishment of *Toona* in the Americas.

One possibility that is worth investigating is to create resistance to the borer by genetic modification of the trees by inserting the gene code of BT (*Bacillius thuringiensis*) into the DNA of species of Meliaceae. It is known that BT is effective for the control of lepidopters and that it has been successfully used in the genetic modification of agricultural crops such as corn. If such research were successful, species of Meliaceae could take on a very important role for reforestation in the tropics.

Wood borers in Asia. Although many of the *Lepidoptera* insects are known to be defoliators, the Cossidae family in this order also contains stem borers that cause economic damage to plantations being grown for sawtimber. These cossid borers are well known in Asia, but they do exist in other tropical regions as well.

Wood borers attack the wood of several tree species including teak, *Gmelina* and *Eucalyptus deglupta*. The teak borer (*Xyleutes ceramicus*) enters the wood as a larva and can carve out galleries up to 2 cm in diameter (Bigger, 1988) (Figure 7-27). Similar borers have been seen in *Gmelina* plantations in East Kalimantan, Indonesia, but they have not been positively identified as to the species (Figures 7-28, 7-29). Normally, the attacks are in the lower parts of the tree stem starting when the trees are three years of age. Besides causing physical damage to the woods, the borer galleries allow the entrance of stain fungi that cause stain and rot in the wood.



Figurea 7-27. Teak borers are common in logs harvested in plantations in Java, Indonesia.



Figure 7-28. The pupa of the *Gmelina* borer in Indonesia is partially extended from the hole in the tree to facilitate the emergence of the adult moth.



Figure 7-29 A cossid borer in *Gmelina* in Indonesia is 6 cm long.

The incidence of the *Gmelina* borer in Borneo increased notably after large wildfires that occurred during the extended dry season of 1997 and 1998, and which burned over thousands of hectares of natural forests as well as plantations in Sumatra and Borneo. The increase in borer attacks is thought to be due to a lack of natural predators and parasites which were eliminated in the extensive fires as well as the demise of large areas of natural remnant forests which were converted to commercial plantations. Since the larvae of the borers are well protected once inside of the tree trunk, traditional insecticides sprayed on the surface have little or no effect on them. The best hope for their control is to promote the return of the natural gallery forests around the plantations and to protect these from

future wildfires or indiscriminate cutting. Such an effort is complicated, however, since the burned areas have been invaded by alang-alang grass (*Imperata cylindrica*), a species widely distributed throughout South Asia and the Pacific islands and which is highly allelopathic. Once alang-alang is established in the environment it is quite difficult for other species of vegetation to growth through it and take over the sites. Another problem is that the alang-alang grass produces abundant combustible material which can burn easily. The moral of this story: Protection of natural areas within properties dedicated to plantation management must be an integral part of plantation management policy. It is much easier to and cheaper to maintain the original natural areas around the plantations than it is to try to bring back natural areas on sites where the natural vegetation has been eliminated.

The wood wasp borer in pines. The wood wasp (*Sirex noctilio*) is native to Europe and Asia and also to North Africa, but it has now become an important pest in pine plantations in Australia, New Zealand, South Africa, Argentina, Uruguay, Brazil and Chile. The insect arrived in Uruguay in 1980 and since then has caused the death of many pine plantations. In 1988 it was first detected in Brazil in the southern state of Rio Grande do Sul.

The female wasp injects the eggs under the bark of the tree, along with a fungus (*Amylostereum areolantum*) which is food for the larva and which also produces a mucous that plugs the vascular system of the tree (Mendes, 1992). Insect attacks are initiated in trees over 12 years of age, when the trees come under stress, such as suppressed trees or pines in plantations with very high stand densities. In New Zealand, the wood wasp has caused the death of up to 80% of the trees of *Pinus radiata* in some plantations (Haugen & Hoebeke, 2005).

In Misiones, Argentina, the first infestations were observed to occur in plantations of 17-year-old *Pinus taeda* which had not been thinned and where there were many suppressed trees in the understory. The first observations of the wood wasp in Brazil were in the southern state of Rio Grande do Sul, and these also occurred in high density plantations that had not been thinned. There is now a general consensus that the best way to prevent attacks of the wood wasp is to keep the plantations healthy and free of stress.

A biological control of the insect has been developed in Australia using nematodes (*Deladenus siricidicola*).[9] Infested trees are inoculated with

nematodes produced in the laboratory. The nematodes do not kill the insect, but they sterilize the female larvae which emerge and then cannot reproduce (Iede, 1990). Some parasites have also shown potential as a biological control for the wood wasps (Haugen & Hoebeke, 2005). The parasites lay eggs in the wood wasp egg masses or on the wood wasp larvae.

What to do when a disease or insect pest is found in a plantation?

Information is the first defense against threats to plantations. Plantations are crops, but they are not sterile. There are always insects, fungi and other environmental flora and fauna. If there is an insect present that is eating some tree leaves, or if a fungus is found that causes a deformity of some leaves, this does not mean that it is necessarily a disease or outbreak that must be eradicated, unless it is perceived to be a threat that could propagate to a larger scale and cause economic damages to the plantations.

The identification of the pest is the first priority in order to have an idea of its potential to cause economic damages. Once the species is identified, a search of the scientific literature can produce references as to its life cycle and its behavior and it if is truly a threat that requires attention or not. On the other hand, the obvious at first glance is not always the root cause of the damage to a plantation. If a particular organization or company does not have the expertise to identify a pest, it is well worth the effort to find a professional who is an expert in the field. The following are some examples of what can happen without proper identification of a disease problem. Erroneous identifications may result in incorrect actions taken to solve a supposed problem.



Figure 7-30. Effect of a mild lightening strike in a 2-year-old *Gmelina* plantation.

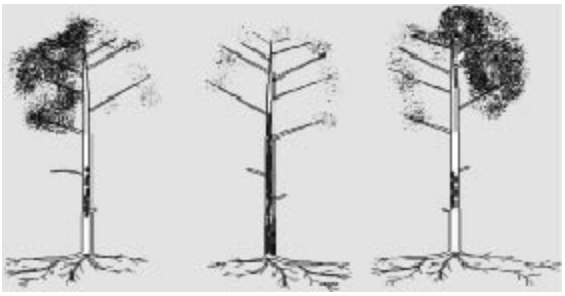


Figure 7-31. A drawing of the effects of a mild lightening strike on a *Gmelina* plantation.

Example: In a 2-year-old *Gmelina* plantation in Southeast Asia, small spots of dying and dead trees were found within the stands. The initial conclusion was that the trees were being attacked by an unidentified root fungus and the company began a treatment by excavating a ditch around the affected trees so that the “fungus” would not pass from infected roots to the healthy roots of the adjacent trees. The dead material within the affected location was cut, piled and buned. This case was similar to others that have been observed in other plantations of Gmelina, teak and eucalypts in the Americas. The “attack” presented various curious characteristics:

- Using a pocket knife, patches of bark were removed from several of the dying and dead trees and it was observed that there was dead tissue (brown colored and smelling of vinegar) around DBH and higher up along the stem, but that the tissues of the roots had a white color, were healthy and had no odor. Therefore, we knew that this was not a root fungus because the roots were healthy.

- The trees around the edges of the affected circle had dead foliage towards the center of the circle, but had green, healthy foliage away from the center of the circle (Figures 7-30, 7-31).

Because of the form of the ”attack”, and from previous experience with similar damages elsewhere, it was known that this damage was caused by a mild lightening strike. In such cases there is nothing to worry about, nor a need for any remedial treatment, since it is a normal, infrequent occurrence that hapens in some juvenile tropical forest plantations.

Example: *Gmelina* trees recently planted in the field were beginning to exhibit signs of wilting and some were dying as a result of some “disease” at the root collar (Figure 7-32). The identification made by the forestry personnel in the company was that a fungus was attacking the seedlings. After inspecting the affected trees, something curious was observed by the author: The moribund tissues occurred on two sides of the trees, and the damages were always aligned east-west, not at random. The damaged trees were those without lower foliage, but the damage was not seen in those that had fo liage down to the ground.

The symmetric orientation of the moribud tissues indicates that the damage is due to some regularly occurring factor, rather than due to a “fungus” that would attack as random

occurrences. The solution to the problem was determined in the following manner:

- The damage on the east-west sides of the seedlings was a scalding of the tissues caused by the rising and setting sun, which reached the lower seedling stem below the leaves.
- The loss of the lower leaves on the seedlings and the tenderness of the bark tissue was due to the seedlings being kept at too high densities in the nursery beds, resulting in seedlings that produced shade leaves and soft tissues that were not lignified or hardened off.
- Then, after the trees were transplanted to the field, the shade leaves were scalded by the direct sunlight and they fell off, the lowest leaves being the softest and least resistant to direct sunlight.

- As a consecuence, the basal tissues of the seedlings were exposed to the harsh sunlight, which caused the damage to the stem tissues and even the death of some of the seedlings.

The solution to the problem was to increase the nursery spacing between seedlings and allow the trees to grow stronger and hardier, producing sun leaves in the nursery.

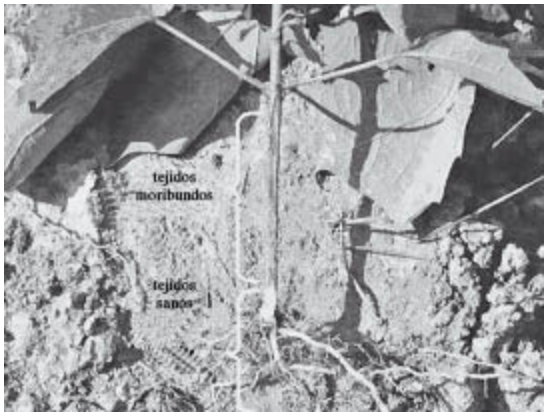


Figure 7-32. Damages at the base of seedlings of *Gmelina* due to sun scald during the morning and afternoon hours. As can be seen in the photo, the roots are healthy and white.

Example: During the thinning of a 12-year-old teak plantation, a high amount of heart rot was observed in the trees being cut, estimated to be 40% of the thinned trees. In order to determine the origin of the heart rot, several trees were cut into sections one meter long (Figures 7-33, 7-34). No heart rot was found in the basal sections of the trees inspected, i.e., the cause was not a root rot that was moving up into the tree stem. It was also noted that the rot was not continuous, but began in some of the sections near where the branches had been pruned, and ended some 40 to 100 cm above the pruning scars. The field technician explained that the pruning had been done four years earlier using machetes, not saws. In some cases, there were branch stubs remaining from the pruning; in others, the branch had been pulled out of the stem, leaving jagged edges that entered into the stem of the trees, where moisture and

fungal spores could enter the tree. The conclusion: the pruning with machetes was badly done and without training or supervision of the laborers. Additional (and unnecessary) cuts were also found in the trees which created additional points of entry of rot fungi. (The speculation was that these were places where the laborer “hung his machete” while he was taking a break, perhaps to light a cigarette!).

This case demonstrated the importance of doing a quality pruning using saws, and making the cuts flush with the tree trunk, but without damaging the bark of the tree trunk. Bad pruning does not increase log value, and in this case it resulted in a substantial devaluation of the teak plantation.



Figure 7-33. The scar is due to a machete cut where there was no branch pruned. Heart rot was found underneath the cut.



Figure 7-34. Heart rot of teak logs in a 12-year-old plantation, caused by bad pruning practices when the trees were eight years old.

Example: There was a partial defoliation of an 8-year-old plantation of *Pinus patula* in a private property in Colombia. The cause of the defoliation was correctly identified by a forest

entomologist from the local university as the insect *Glena bisulca*. The landowner, who was very interested in protecting his plantation, decided that the best solution was to immediately apply a chemical insecticide to the entire plantation and the surrounding area to eradicate the defoliator. A year later, when the plantation was nine years old, there was a complete defoliation of the plantation, much worse than the previous year. Foresters who observed the defoliated plantation noted that the insecticide had been applied at the wrong time of year, when the defoliators were pupating in the soil and were unaffected by the insecticide. On the other hand, the insecticide killed the insect predators and parasites in the locality, which allowed the defoliating insect population to explode the coming year. Also, by killing all of the insects in the vicinity, the birds left the area since their insect food source had been eliminated.

Define economic treatments

When an important plantation pest problem is found and is correctly identified, the next step is to define the treatment or treatments that are economically viable. The first alternative is to look for natural controls or silvicultural controls.

In the case of defoliating insects in the order of *Lepidoptera*, a natural treatment involves promoting strips or patches of natural forests where predators and parasites can develop naturally to control the offending defoliators. An excellent alternative is to conserve natural areas along rivers or streams. If there are agricultural crops nearby that use wide-spectrum insecticides which are applied by spray or broadcast as dusts, a good alternative is to change these for selective insecticides and to use directed applications so that the effect of the insecticide is minimal on beneficial insects in adjacent areas.

Silvicultural treatments are very effective and quite economical for controlling or preventing many types of forest insect pests. The objective is to manage the plantations so that they are kept healthy. As has already been explained, the problem often arises when trees reach levels of stress, such as planting a species outside of its natural environmental conditions (altitude, soil type, rainfall patterns), or planting the trees without adequate soil preparation (subsoiling, bedding, drainage, fertilization), planting too many trees per hectare or not making thinnings when needed as crowns close. Correct thinning practices, without causing damage to residual trees, such as sloughing off bark of the standing trees, is an important silvicultural treatment to prevent future problems in plantations under sawtimber production regimes. In some cases, the silvicultural solution to controlling a

pest or eliminating the problem is to change species and plant another tree species that shows better resistance to the problem.

The use of insecticides can appear to be a viable short-term solution, but it is extremely important to use the correct methodology in order to obtain the desired positive result, and not to increase the scope of the problem. The use of selective insecticides, such as those that contain BT, is an alternative for controlling defoliating insects instead of using a chemical insecticide. Nonetheless, it is important to make a financial analysis of the investment cost of applying insecticides in plantations to determine whether their use is justified or not. As a general rule, the use of insecticides or other pesticides is not an economic alternative in forest tree plantations; their use is mostly justified in high value sites, such as in a tree nursery, in a seed orchard or a clone bank.

The development of genetic resistance to certain diseases and insect pests can be a long-term alternative, if and when the scale of planting is of sufficient size to justify the cost of their development. Normally, the development of tolerance or resistance to plantation pests is something that is done by government research institutes, by universities or by tree improvement cooperatives, not by individual companies because of the need to hire highly trained and specialized technical personnel to carry out the work. In the case of the Brazilian eucalypt canker, the development of genetic resistance was very successful. That work was carried out by genetic cooperatives, universities and the Government. That investment was justified due to the fact that Brazil plants millions of hectares and that the eucalypts are a key source of wood furnish to the pulp mills and for producing charcoal for iron smelting.

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[1]CCA is the generic name of a vacuum-pressure chemical treatment that utilizes a mixture of salts of copper, chrome and arsenic.

[2]This fungus is known to cause bluestain in wood in the temperate regions of North America (Muchovej *et al*., 1978).

[3]Problems with this fungus have not been reported in *Gmelina* plantations in other parts of the tropics.

[4]Although changes in the scientific names of organisms may appear confusing to a lay person, it is a necessary process to improve the precision of the classification of living beings in the world.

[5]In most Latin American countries the leaf-cutting ants are known as "*hormigas arrieras*", but in Venezuela they are called "*bachaco*", and in Brazil they are know as "*sauva*".

[6] Leaf-cutting ants do not form solid aerial structures or towers as do some species of termites that live in the American and African savannahs.

[7]The common name of *Pachira* (*Bombacopsis*) *quinata* in Venezuela is saqui-saqui.

[8]The breeding of stink bugs in cages is relatively easy and is described by Zanuncio (1993).

[9]Nematodes are mostly microscopic worms and are well known as causal agents of diseases in agricultural crops, especially in the Solanaceae family, which includes the tomato, the potato and some tropical fruits such as lulo (*Solanum quitensis*), a species indigenous to Colombia and Ecuador. Before planting potatoes or tomatoes in the tropics or subtropics, it is a common practice to fumigate the soil to eliminate nematodes.

8

Wildfires

Causes of wildfires
Prevention
Detection
Personnel training
Organization of fire suppression brigades
Fire suppression tactics
Documentation of wildfires

This chapter is a brief summary of the compact disk training program "*Fire control in forests and wild lands*" (ZFA, 2010; Ladrach, 2006b). A good fire control organization is based on effective prevention, detection and fire suppression. The key elements for effective fire suppression are a good organization, well trained fire personnel and adequate mechanical equipment. The same organization is generally used for control burning as for fire suppression.

Causes of wildfires

Natural phenomena such as lightening can cause fires to start and can be important for certain types of forests, especially in the natural coniferous forests of the Sierra Madre ranges of Mexico, in the mountains of Central America, in the open woodlands of Venezuela and the "cerrado" forests of northern Brazil. Wildfires have been an integral part of the formation of the environments of nearly all natural savannahs such as the eastern prairies of Colombia and the southern prairies of Venezuela, as well as the African savannahs and the *outback* of Australia. Such open forests, prairies and savannahs owe their existence to periodic natural wildfires. In has been shown that the flora and fauna of such ecosystems not only have adapted to regions of wildfires, but have progressed historically due to the presence of occasional wildfires.

However, in the modern world, the primary cause of fires in prairies and forests is humans, due either to land clearing, carelessness, or to malice. Wildfires are all too frequent and can have negative effects on the

development of wild lands, even in those ecosystems adapted to wildfire. In ecosystems that have developed where fire has not been a common occurrence, wildfires can cause negative impacts on the flora and fauna. Similarly, fires can be a real threat to tree plantation management.

Many of the fires in forests and wild lands are due to carelessness. When a farmer wants to clear off brush and debris with fire, or when a cattle rancher wants to “green up” the pastures at the end of a dry season, fire is a common method for doing these things. The problem is that all too often the person setting the fire does not take the time or the precaution to make a firebreak around the area to be burned in order to keep the fire contained within the target area. Such burns without firebreaks can easily move into adjacent lands and burn brush or secondary forests, climb up slopes into forests and burn over large areas of natural vegetation.

There is also the risk of fire due to carelessness by smokers who throw away a lighted match or a lit cigarette but without paying attention to where it lands beside a trail or road adjacent to grasslands or forests. Many people make fires in the field to prepare the morning coffee and breakfast without bothering to clear a circle free of grass around the fire, and, afterwards, leave the fire without putting it out. In the mountains, people may start little fires on a cool morning while waiting for the bus to arrive and then get on the bus without putting out the fire.

Prevention

The best way to reduce the incidence of wildfires is through prevention, by means of well organized publicity campaigns that educate the public (Figure 8-1). Officials of forestry companies both private and public need to cooperate regionally and nationally to create a public awareness of causes and effects of wildfires. Local communities need to work in concerted efforts to protect forest reserves, watersheds, private properties and national forest reserves.



Figure 8-1. The squirrel is the fire mascot in Mexico.

Reporting of wildfires by the public is a very valuable source of information on fire starts and needs to be promoted. Forestry organizations should keep records of all reports made of wildfires. The reports should include the date, the hour the report of a fire was first received, the location of the fire, the climatic conditions, the spread of the fire, the time required for suppression crews to arrive at the fire, the time required to bring the fire under control, the probable cause or causes and other key information. Since fires are usually sporadic, these records of past fires can provide information useful for predicting patterns of possible future fire outbreaks.

Large, devastating fires typically occur infrequently, not every year. Where there have not been large fires for several years, there may be a tendency among administrators and forestry personnel to lower their guard and to reduce the budgets of fire protection organizations. To avoid such lapses, it is important to keep all forestry personal alert to the potential danger of wildfires, reminding them of past fires and to the fact that they could occur again at any time. A good idea is to post a record of previous fires on bulletin boards in forestry offices and work stations showing areas burned and the number of fire starts per year. This can be a stimulus to maintaining an active interest in protection against wildfires.

One fact that may seem illogical, but that often happens, is that the losses due to wildfires tend to be greater in those tropical ecosystems where the dry season is short rather than in those ecosystems where there is an extended dry season. The reason for this dichotomy is simple: In dry environments where the threats of wildfires occur every year, governments and companies can justify substantial investments in fire protection personnel, training and fire suppression equipment. Thus, when fires are

reported, such organizations are prepared and capable of controlling wildfires with minimal losses. On the contrary, in more humid climates where fires are infrequent, it is difficult to justify budgets for fire equipment and personnel may lack critical training under the stress of real fire situations. When an unusually dry year occurs in such locations, there is often a lack of good fire detection and fire suppression and the losses can be devastating.[1]

The risk of losses due to wildfires can be reduced by maintaining permanent firebreaks around plantations and natural areas. These can be made by removing the vegetation with discs or with tractor blades, such as a bulldozer or a motor grader or they can be maintained manually (Figure 8-2). Permanent firebreaks are normally between 10 and 20 meters wide and most are designed to create breaks in the forest cover creating units no greater than 100 ha in size. At the beginning of each dry season, the firebeaks are cleared by removing the surface vegetation.



Figure 8-2. A permanent firebreak constructed manually within pine plantations on a mountain in Zimbabwe.

Detection

Early detection of a wildfire is the key to reaching a fire while it is small, and to allow for a quick response by combat crews. When the fire danger is high, fire suppression crews and personnel in watchtowers are kept ready for the detection and suppression of any fire. The use of a fire index is a method for defining the level of risk of wildfires and the corresponding level of preparedness of people and equipment. One fire index that is useful in tropical climates is based on four factors which can be determined daily in the field and which represent the potential for wildfires in the area of interest (Figure 8-3).[2]



Figure 8-3. A fire danger indicator board.

Relative humidity is an indicator of the potential velocity that a fire can advance.

Days since the last significant rainfall is a relative measure of the dryness of the surface litter, grasses and light brush.

Total precipitation during the past 15 days is a measure of the moisture content of heavier fuels.

The condition of fine fuels is a measure of the overall dryness of fuels such as the litter, grass and weeds.

The earlier that a fire start is detected, the smaller will be the fire and the more quickly it can be extinguished. Thus, vigilance in forests and wild lands is one of the prerequisites to effective fire control. Watch towers are a very useful for the early detection of wildfires. The towers are located based on maps of the forest properties to be protected, choosing those points where the tower operator can observe the greatest panorama. In mountainous terrain it is best to locate the watch towers on top of the highest points that have a broad view. On level land the towers are best located at strategic points within the forest area with a 360o visibility for greatest effectiveness (Figures 8-4 & 8-5).

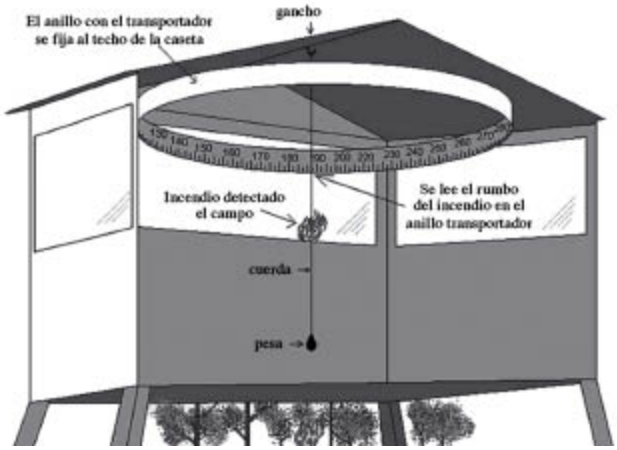


Figure 8-4. A fire watchtower with an azimuth ring that allows the tower operator to define the bearing of a fire that is detected.

Watch towers are important for the detection of fires. Also important are personnel on roads and in the field, on foot or mounted on horses.

A command center is organized where all incoming reports can be coordinated with the activities of suppression personnel and equipment. The center needs to maintain maps of all the forest properties, access roads, as well as information on how to contact critical management personnel. There should also be an updated registry of the location of all fire personnel and equipment.

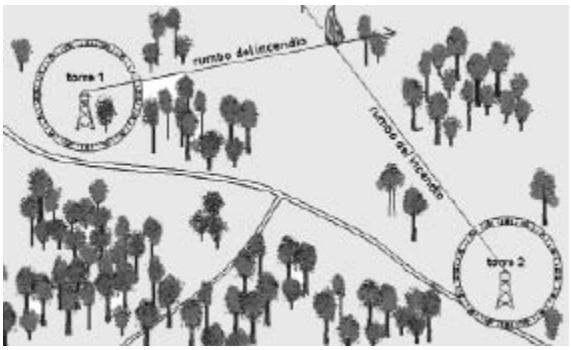


Figure 8-5. Locating a fire report by triangulation using the bearings reported from two watch towers.

Personnel training

The most important element in the development of a fire suppression organization is the training of personnel. Machines, tools, tractors and mechanical equipment are of little worth if the organization does not have people who know how to use them efficiently and effectively. Above all, there is the need for practical experience where the fire personnel can see and analyze different types of fires and determine which suppression tactics to use. Slides, PowerPoint presentations and other visual tools can be very helpful for this endeavor. Periodic field practices are also needed where personnel obtain first hand experience with fire, such as making practice burns in a brusy lot that has a good firebreak constructed around it so that the suppression personnel learn the necessary tactics for management of personnel and equipment in critical situations (Figures 8-6 & 8-7).



Figure 8-6. A practice constructing fire lines.



Figure 8-7. A practice lighting a backfire with a drip torch.

Detailed accounts of past large fires are useful for traininng personnel in the planning and organization of fire suppression tactics. Maps or drawings on acetates can be projected from a computer or overhead projector to demonstrate how a fire starts, how it expands and how to control it. Accounts of how past fires were handled, good, or badly, can also be quite useful for training a fire organization.

There are specialized fire schools for training fire protection personnel. Several of the state forestry organization in the United States have annual training courses, along with courses offered by the national Forest Service. The Chilean forest service holds fire training courses periodically. The CVG-Proforca in Venezuela has held seminars and practical training courses for forest protection against wildfires. The Government of Spain also holds fire training courses periodically. Various other organizations, both private and public offer courses on this subject. There are many written documents on fire protection including those in Chile (Haltenhoff, 1989), Spain, (INCONA, 1981) and the United States (USDA Forest Service, 1989), among others. Another alternative is to organize a local

training course for fire brigades and to invite a professional consultant to assist in field training.

The use of controlled burns for forest management is an important method for training fire protection personnel as to fire behavior and to allow the participants to gain experience with the tacics of fire control. In addition, control burns are an important method to reduce the fire hazard by reducing fuel loads in forested areas. Legislation that prohibits the use of fire for forest management is counter-productive. It does not reduce the incidence of fires, nor the damages caused by fires. To the contrary, such prohibitions promote the accumulation of organic material in the forest which will eventually result in greater fire losses when a wildfire occurs (Ladrach, 1978c).

Organization of fire suppression brigades

Fire suppression crews are responsible for protecting the forests against wildfires. Fire suppression is different from other forestry operations, not only because of the gravity of the work and the danger involved, but also because there is always the risk that a fire can get out of control. An uncotrolled fire or a control burn that gets out of hand can have social and political repercussions. For these reasons, fire protection personnel must be serious about their work, disciplined, capable of working efficiently under very difficult conditions and working under pressure.

It is a good idea to rate fire suppression personnel based on their training, experience and ability. Persons who are best qualified at planning for the actions to take under the pressure of a wildfire situation are those that need to be put in charge of fire suppression activities, regardless of their position within the normal hierarchy of forest management operations (Figures 8-8 & 8-9).



Figure 8-8. Fire suppression personnel are organized prior to initiating a suppression operation.



Figure 8-9. Fire suppression personnel must work in a coordinated effort among all members of the brigade.

Similarly, the act of lighting a backfire during a wildfire or lighting a controlled burn is not just to make flames, but rather *it is to manage fire*. The person who handles the drip torch to light a backfire or start a control burn must take into account many environmental functions prior to initiating a burn as well as being aware of many details involved in such an action if the burn is to be done safely.

Manual fire fighting tools need to be kept at a location such as work stations where there is easy access and the tools need to be in good condition for their use during a fire emergency (Figures 8-10 & 8-11). There are several special tools used for fire fighting including backpack pumps, drip torches, fire rakes and McLeod or combi tools (Figures 8-12 & 8-13).



Figure 8-10 Fire fighting tools are kept ready for an emergency and in good condition at a work station.



Figure 8-11. Manual tools are best kept in a portable box for carrying to the site of a wildfire.


Figure 8-12. The fire rake is an effective tool for constructing fire lines in tree leaf litter.


Figure 8-13. A combi or McLeod tool is the combination of a fire rake and a hoe and has double utility.

Fire suppression tactics

Fire suppression can be divided into two general categories:
Direct attack: Eliminate oxygen and/or reduce heat.

Indirect attack: Eliminate fuels.

When making a direct attack, the fire suppression personnel attack the burning fuels with manual tools such as shovels, fire swatters and fire rakes.

Water can also be used with a direct attack, either from a tanker truck or from backback pumps. These methods are effective when the flames are not too large or hot and the fire personnel can work near the flames without incurring unnecessary risk.

Indirect attack involves the tactics of constructing a fireline and then backfiring from the fireline towards the wildfire (Figure 8-14). With the indirect attack the fireline is made by hand and/or with tractors and plows and the backfire is then set and has sufficient time to burn a wider strip away from the fireline prior to the arrival of the wildfire. This method is more effective for the large fires because the fire suppression personnel are not in direct contact with the heat of the fire.

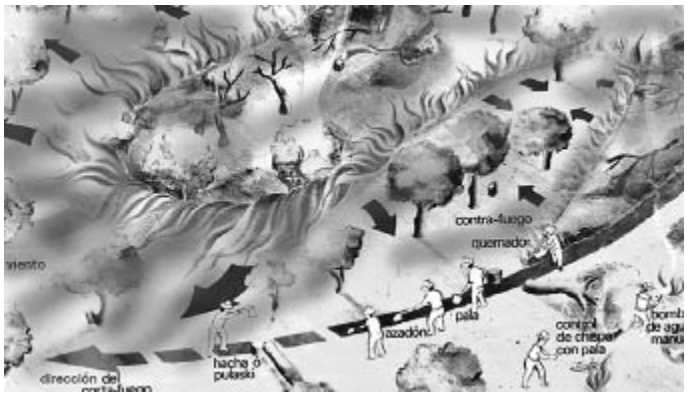


Figure 8-14. Fire suppression using fire lines and backfiring.

When a fire brigade arrives at a fire, the crews generally begin to work from the rear of the fire, closing in the back and then the flanks. The fireline line is always anchored to a secure area, such as a road, a river, a rock outcrop, a plowed field or a similar location without combustible material. The anchor point also acts as a secure zone to which the fire personnel can retire if the wildfire changes direction and it becomes necessary for the fire crew to use an escape route to reach the secure zone for personnel safety. A good general rule is to make the fireline 1.5 times the width of the height of the nearest flames. The entire area within the fireline, that is, between a fireline and the wildfire is burned out as the wildfire progresses. Obviously there are no two fires that are exactly alike; each one is different and unique. This is why the experience and knowledge of the fire suppression personnel is of key importance, in order to continue adjusting the positions of personnel and available equipment during a fire suppression operation.

Natural barriers can be used as firebreaks: roads, trails, streams, and ponds, among others. During the backfiring operation, the coordination of the drip torch operators working on either flank of a fire is of critical importance. One drip torch cannot advance past the head of the wildfire until the entire fireline has been constructed on both flanks of the fire and the drip torch operators must work in a coordinated operation. Once the firelines have been completed, the two drip torches advance rapidly, lighting the backfire before the headfire reaches the fireline. During this operation it is absolutely necessary that both drip torches reach the closing point simultaneously. The closing point is the most distal point of fireline downwind and in the direction that the wildfire is traveling. If one torch reaches the closing point before the other, and then moves back along the other flank, that will invariably produce heat and fire whirlwinds along the fireline that do not allow the other drip torch operator to complete the other side of the backfire. Then the fire will escape and cross over the fireline through the breach left open. It is very important for the drip torch operators to practice these tactics in order to perfect them in coordination and to learn to know how to work as a team during a wildfire event.

An indirect attack can also be used in front of the headfire, if and when there is sufficient time to carry out the required operation and the fire personnel have sufficient time to retire to a safe position before the headfire reaches the point of attack. Figure 8-15 shows the use of fire retardant in front of a headfire which has the purpose of creating a wide strip between the heat of the arriving headfire and a road or firebreak. Once the headfire reaches the retardant barrier, this allows the fire suppression personnel to enter from the flanks more quickly to put out any sparks that have jumped over the fireline.

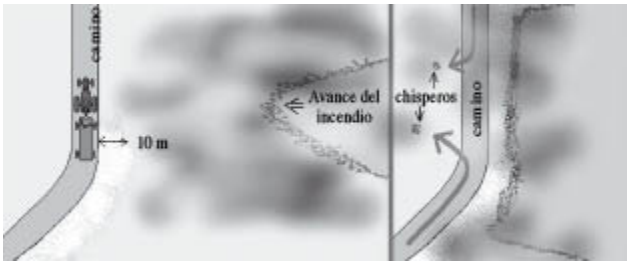


Figure 8-15. The use of fire retardant to slow down the advance of a wildfire.



Figure 8-16. A crawler tractor with a fire plow is quick and effective in forest fire suppression.



Figure 8-17. A crawler tractor and fire plow loaded on a truck with a tilt bed in Colombia.

The use of mechanical equipment is important for indirect fire suppression tactics. The drip torch is a key element in this operation. A crawler tractor and fire plow plus a transport truck are also basic units for indirect fire fighting (Figures 8-16 & 8-17).

Documentation of wildfires

Evaluation and review of the activities during a fire suppression operation is an integral part of fire fighting (Figure 8-18). It is important to document all fires and to developed information that can be useful for determining the probability of future fires. Such information can be useful to maximize the efficiency of the fire suppression personnel, machinery and available budget. The dispatcher in the forest protection center is the person responsible for initiating the fire report when the first notice of a fire is received by two-way radio, telephone or other means of communication. The written record should include the hour and day of each event involved in the fire suppression procedure. This information is later used to complete the general report for each fire.



Figure 8-18. Once a fire has been controlled and prior to leaving the site, a brief summary of operational activities is made.

Upon receiving a notice of a possible wildfire, the communications officer immediately begins to fill out a standard fire report form which will be completed once the fire has been brought under control. In most cases, all that is necessary is to fill in one page of data. The report contains all pertinent information regarding the fire (Table 8-1).

Table 8-1. Standard format for reporting a fire.

Falta tabla, no aparece.

[1]Between September, 1997, and May, 1998, wildfires in the Indonesian islands of Sumatra and Kalimantan (Borneo) burned over between six and seven million hectares, including 800,000 ha of natural forests and forest plantations. These islands seldom have a dry season lasting more than one month, but during that 5-month period there was a severe drought which created conditions for wildfire propagation.

[2]Zobel Forestry Associates, Inc. has developed a computer program for calculating the fire danger index based on these four factors. The factors in the program can be modified for use by an organization so that it best fits the local conditions. This program is included in the CD mentioned previously (ZFA, 2010).

9

Wood harvest and transport

Harvesting
Land-based extraction methods
Short wood
Field debarking, a bottleneck for harvesting operations
Long wood
Tree length wood
Directional felling
Wood extraction with cables
High lead cable logging
Gravity feed skyline cables
Modified North Bend skyline cable
Skyline carriage with a mechanical brake
Skyline with a hydraulic brake
Wood transport by truck
Coordination of harvesting and wood transport
Construction and maintenance of forest roads
Wood transport by rail
Water transport of wood

Harvesting[1]

The major expenses for plantation management are invariably harvesting and wood transport to the point of sale. For this reason, it is very important to define the harvesting methods to be used and the delivery point for sale of the wood when initiating a reforestation or plantation management plan. Unfortunately, it is all too common with new projects that the investors concentrate on the immediate costs of land acquisition, the cost of the tree nursery and the cost of plantation establishment, but put little or no attention to the greater costs of timber harvesting and wood transport.

Harvesting and transport systems should be designed in such a way that they maximize wood production, minimize unit cost of delivered wood and

that fit well with the other phases of plantation management. The design of these systems depends on various factors such as:

- The local availability of machinery and of parts for equipment repair. If a machine is purchased that is low cost, but doesn't have good local availability of parts or a qualified repair shop, the machine cost per unit of wood harvested can become excessive in the long run. First of all, it is important to determine which brands of machinery exist in national or local markets and if the machine dealers provide good maintenance and repair services for the machinery that is sold.
- Machines must be of a size and type that can be profitable for the conditions of the plantations where they are to be employed. For example, if a plantation has a low stumpage volume, say less than 150 m3/ha to be harvested, it is better to consider using medium to low-cost harvesting tractors, rather than high-cost harvesters that cannot produce enough wood to pay for the fixed costs of the machine, let alone its operating costs. A machine may be efficient on relatively level land, but if there are many plantations on slopes or hills, it is important to ascertain if the harvesting machines under consideration will work efficiently on such sites as well as on level land. If not, it is best to look for other alternatives.
- If rural roads are narrow and have minimal public maintenance, it may be best to consider transporting wood with small, single axle trucks that can carry 10 to 12 tons of logs instead of using larger trucks that have greater hauling capacities. Where plantation lands are interspersed with local farms, and where there is a lot of local farm traffic, wood transport systems need to be designed so that they don't cause undue hardships for local residents. That can cause serious social problems and a negative public attitude towards the forestry company which could affect the long term effectiveness of its operations.
- Another important factor is the availability of labor for harvesting operations. On those sites where the harvesting operations can be mechanized, the demand for labor is reduced, but it does require skilled workers to operate machinery. For plantation projects located in hilly or mountainous regions or where the forest properties are scattered and not contiguous, the demand for harvest labor is generally higher than for projects situated in relatively level land and where

several forest properties are in contiguous units. In a study conducted in the Andes mountains of Colombia, the demand for labor for harvesting was much greater than for all other plantation management functions put together (Table 9-1). An important consideration is the employment of unskilled labor in rural locations, which may be an important means of creating good relations between a company and the local communities (Figures 9-1 to 9-4). Another advantage of manual harvesting is the relatively low capital cost, since there is minimal up-front investment in equipment. On the other hand, the use of labor requires the necessary cash flow to be able to pay workers weekly or bi-weekly. Excuses for delayed payments to labor are never a good option.

Table 9-1

Labor requirements for a pine plantation project in the Andean Mountain region of Colombia, including wood harvesting and placement at roadside (Ladrach, 1987) [2]

Plantation management function	Man-days/1000 ha/year
Soil preparation	5.1
Planting and fertilization	1.6
Weed and grass control	6.9
Maintenance of internal roads, firebreaks and fences	1.3
Low pruning to 2 m height for fire hazard reduction	2.3
Thinning at eight years	4.6
Fire protection	5.5
Supervision of labor by crew chiefs for all functions	3.9
Final harvest at 15 years	34.5
Internal wood transport to roadside	3.9
Property administration	4.0
Total labor requirements	73.6



Figure 9-1. Labor continues to be important for wood production in small lots and isolated locations.



Figure 9-2. Animals are important for skidding wood in mountainous areas or where truck access is limited.



Figure 9-3. Pine sawlogs being skidded by oxen in the mountains of Colombia.



Figure 9-4. Cypress logs hand sawn in the mountains of Guatemala.

Land-based extraction methods

Most plantation wood is harvested using land vehicles (tractors) or with cable systems. The use of tractors for wood extraction is the most common method in plantations. Wood extraction systems can be divided into three broad categories: short wood, long wood and tree length wood.

Short wood

Short wood is harvested for use as pulpwood, as wood for making pallets, as veneer logs and as logs for other products that require short wood, with lengths usually between 1.5 and 2.4 m. The boles are bucked into logs in the field with chainsaws and hand loaded onto a trailer or truck bed or loaded with a small hydraulic grapple. Logs 2.4 m wide can be loaded crosswise on the truck bed where the ground is level (lowland style), but in hilly regions and where wood is transported very long distances, it is common to load the wood along the length of the truck bed (mountain style) for greater stability. Shortwood is often debarked in the field, either by hand or with small semi-mechanized debarking machines. Short wood harvesting requires less capital expenditure for machinery and can use more unskilled labor than semi-skilled labor. Agricultural machinery can be adapted to short wood operations, such as wheel tractors with trailers (Figure 9-5). Short wood operations tend to be small and they are often more efficient on slopes where larger tractors are less useful.

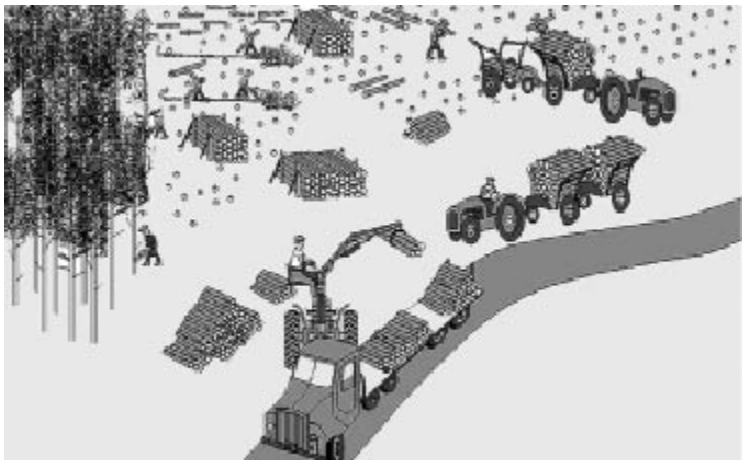


Figure 9-5. Short wood harvesting. The wood is cut to length with a chainsaw and manually piled in the field. Then it is transferred to roadside with a wheel tractor and trailer.

Some large pulp and paper companies also harvest shortwood, with hand debarking and hand piling of wood at the roadside (Figures 9-6, 9-7). This is a reasonable alternative in those regions where there are high rates of unemployment. It is important that contractors and company logging operations follow safety guidelines for all workers to minimize the incidence of work accidents in the field.



Figure 9-6. A chainsaw operator in South Africa is using personal safety protection, including a hard hat, face mask to protect the eyes, ear protection against noise, gloves, steel toed boots and pants with Kevlar inserts for protection agains chainsaw cuts. The operator also carries a tool kit for reparing the chainsaw in the field.



Figure 9-7. Felling, bucking, debarking and hand transport of short wood to roadside is a standard procedure in acacia plantations of large pulp companies in Sumatra, Indonesia.

There are several alternatives for moving wood to roadside where it can be loaded onto trucks. The most simple is to carry a single log on the shoulder (Figures 9-8, 9-11). However, this method is very hard work and prone to accidents when laborers must carry heavy logs and walk through land covered with harvesting debris, stumps and other obstacles. Normal manual transport of logs is effective to a maximum distance of 100 m. Beyond that, manual transport of logs is inefficient.



Figure 9-8. Eucalypt wood is debarked in the field and piled at roadside in South Africa.



Figure 9-9. Debarked eucalypt wood in Veracruz, Mexico, is piled in the field so that it can dry.



Figure 9-10. Manual transport of *Gmelina* logs in Costa Rica.



Figure 9-11. Eucalypt wood debarked in the field and piled at roadside in Brazil.

A simple and relatively low-cost method of moving short wood to roadside is with wheel tractors and trailers (Figures 9-12 & 9-13). It may be necessary to modify the axels and frames and to use heavier tires to haul wood with agricultural equipment. Sugarcane trailers with large tires are an alternative for moving shortwood. In some companies, agricultural trailers are modified to handle heavier loads of wood.



Figure 9-12. A sugarcane trailer has been modified and strengthened for use to transport short wood.



Figure 9-13. Short wood being moved to a concentration yard using a wheel tractor and modified sugarcane trailer.

An alternative is to hand load trucks at the stump to eliminate manually carrying wood to roadside (Figures 9-14, 9-15). This is an option when thinning a plantation where the soils are dry and firm. However, there are limits to this method; when it rains, loaded trucks can become stuck in mud and can easily be damaged by scraping over stumps. There is also the danger of puncturing a tire with logging debris lying on the ground. In most cases, it is not economically viable to take trucks to the stump due to the higher cost of repairs and maintenance, plus the lost time when trucks are stuck in mud or break down in the field. Another important factor to consider is that trucks cause soil compaction and the pressure of tires on loaded trucks compacts the soil and reduces the growth of future plantations. Loading trucks at roadside is the most common practice when harvesting short wood (Figures 9-16 to 9-19).



Figure 9-14. Loading pine short wood manually on a truck in Colombia.



Figure 9-15. Four laborers load a teak sawlog on a truck in Java, Indonesia.



Figure 9-16. Wood can be loaded on a truck using a grapple loader, which transfers the wood from the forwarder directly to the trailer placed at roadside.



Figure 9-17. A truck being loaded with short pine wood from a thinning operation, using a small hydraulic grapple mounted on a wheel tractor.



Figure 9-18. A trailer is loaded with short wood in Colombia using a grapple mounted on a tricycle base.



Figure 9-19. A trailer in Indonesia is loaded with short wood using a grapple mounted on a tricycle base.

Field debarking, a bottleneck for harvesting operations

Many pulp mills use large debarking drums to remove the bark from logs at the mill. The bark is then used as fuel for producing steam or for generating electricity. This is an efficient method for debarking pine logs, but the capital cost of drum debarkers is high as well as the cost of boilers that can use multiple fuels, such as coal, wood waste & bark and fuel oil. Such multiple fuel boilers can be much more expensive than boilers that operate on fuel oil only. In those countries that produce oil or produce hydroelectric energy at reasonable prices, such as Venezuela and Mexico, it is difficult for a pulp mill to justify the capital cost of installing a multi-fuel boiler. Thus, many companies prefer to debark logs in the field, avoiding the bark problem and the capital cost of debarking at the mill site (Figures 9-20 to 9-23).



Figure 9-20. Debarking eucalypts in Argentina with an axe. The fresh bark comes off easily.



Figure 9-21. Manually debarking fresh *Gmelina* logs in Venezuela with machetes and axes.



Figure 9-22. Debarking fresh cypress logs in Colombia with machetes.



Figure 9-23. Debarking Caribbean pine logs in Brazil using a debarking spud.

Field debarking also has its difficulties. In order to use labor for debarking, the wood must be cut into short logs, 2.4 m or less, so that they can be manipulated. As a result, debarking is generally done by small groups of laborers who work with short wood, rather than with long wood or tree-length logs. For many tree species the fresh bark can be removed quite easily, but after drying for a couple of days the bark tends to stick to the wood and is much more difficult to remove, thereby increasing the cost of the debarking operation. The problem arises when trying to coordinate the felling, debarking and wood transport to the mill. The laborers who fell the trees and buck the logs are not the ones who do the debarking, which is a job for unskilled labor. What usually happens is that the trees are cut and allowed to partially dry before other workers debark the logs. Sometimes local people are contracted to do the debarking and all persons in a family may participate in the debarking job.

In humid climates manual debarking presents serious logistical problems. The trees may be felled and bucked into logs during a relatively

dry period. Without having to debark the logs in the field, it would be a simple operation to move the wood to roadside and even load the wood on trucks and deliver it to a mill the same day as the trees are cut or just a few days later. But when debarking in the field is required, the logs must be left scattered in the field for manual debarking to take place. Manual debarking may take days or even weeks. After that, the debarked wood is piled in the field in order to measure the volume of stere meters of logs as a means for paying the field labor for their work. Piling in the field is an unproductive but necessary part of the manual debarking process. If the weather changes and the rains begin, the piled wood does not dry much in the field, and it may not be delivered to the woodyard for weeks or even months. During the rainy season when the soil is soft, attempts to load trucks with wood will cause increased soil compaction and risk damage to the trucks themselves. If the wood is left piled in the field for months until the weather improves, the wood may even begin to rot.

Wood is sometimes left piled at roadside to allow it to dry before trucking it to a mill woodyard. This reduces the weight of the wood on trucks and is a good alternative for many pulp companies that use short fiber wood (broadleaf species). In the case of conifers, the dry wood loses some of its quality for pulp and, for that reason, many companies prefer to have pine logs delivered fresh and with bark. In the case of sawlogs, it is better to deliver logs fresh to the sawmill and with bark to minimize blue stain infection (primarily a problem with conifers) and to minimize the incidence of cracks and physical-mechanic defects prior to sawing.

There are portable debarkers that operate from the power take-off of a wheel tractor (Figures 9-24, 9-25). Two persons place the log in the debarker and two others remove the debarked log. The advantage of this machine is that it can debark dry wood with bark that is difficult to remove, a job that is slow and difficult to do by hand. This debarking method is not used much because it requires a stationary tractor as a power source, four laborers to feed the debarker and other workers to pile the accumulated debarked wood. A disadvantage of the debarker is that is does not work with crooked or forked logs which still have to be debarked manually.



Figure 9-24. A portable debarker activated by the PTO of a wheel tractor. Log are fed in and removed manually.



Figure 9-25. Crooked wood does not go through the debarker and these pieces will have to be debarked manually.

There are larger portable debarkers that are sometimes used in the field. These are high yield units. However, they require knuckle-boom grapple loaders to feed and unload the wood. Some debarkers work with short wood (Figure 9-26), while others accept long wood and tree length logs (Figure 9-27).



Figure 9-26. This large rosser head debarker can handle logs up to 3 m long. It is mounted on a trailer with its own diesel power unit. A grapple loader feeds logs into it and another grapple removes the

debarked logs. Productivity is greater than for the small debarkers, but the capital cost is also much greater. Moving from site to site is time consuming. The debarker may stop working if an oversized or crooked log is put into it and it must then be taken apart to remove the log.



Figure 9-27. This is a flail debarker that operates with rotating short chains that strike the logs to remove bark and small limbs. The unit works well with tree length pine logs. A grapple loader feeds wood into the unit and another unloads it. This unit will accept crooked and forked logs as well as multiple stems simultaneously. It is mounted on a trailer with its own diesel motor.

Although the capital cost is less when wood is manually debarked in the field, there are additional costs to that method. Workers who fell and buck the wood must be paid as well as those that debark the logs. When there are delays between felling and delivery of the wood to the mill, there is a cost of the inventory held on the ground, since the workers must be paid for their labors while the wood is still in the field. This inventory is an investment that does not produce any profit and may require bank loans to pay the field workers. The real cost of delayed wood delivery with manual debarking needs to be included in the financial analysis when comparing the capital cost of debarking in the mill versus hand debarking in the field.

Each time a log is lifted and laid down, a cost is added to the total wood harvesting cost, and this is usually around US$1 to $2/m3, depending on the harvesting methods utilized. Although field debarking eliminates the problem of debarking at the mill, this field manipulation increases the number of times that the wood is moved, thus increasing the cost of wood delivered to the mill. The following examples describe different wood handling situations which can occur depending on the size of logs and the number of times they are lifted and placed again on the ground:

Short wood with manual debarking in the field

1. Logs 2.4 m long are lifted manually from beside the stump to be debarked on site with a spud, machete or axe,
2. Debarked logs are lifted to the shoulder to be placed in a pile in the field for measurement of stere volume in order to pay the fellers, buckers and debarkers,
3. Logs are lifted onto a trailer pulled by a tractor and carried to a concentration yard or to roadside,
4. The wood is dropped manually and piled at the concentration yard or at roadside,
5. The wood is lifted onto trucks,
6. The wood is unloaded from the trucks in a mill woodyard.

Short wood with mechanical debarking in the field

1. Logs are lifted beside the stump and carried on the shoulder to a pile near where the portable debarker is operating,
2. Logs are lifted and placed in the mechanical debarker,
3. Debarked logs are removed from the debarker and piled in the field,
4. Logs are lifted and placed on a trailer and moved to roadside,
5. The wood is piled at roadside or in a concentration yard,
6. The wood is loaded on trucks,
7. The wood is unloaded from the trucks at the mill woodyard.

Tree length logs with mechanical debarking at roadside

1. Logs are lifted beside the stump with a grapple mounted on a skidder and then dropped at a log deck at roadside,
2. Logs are lifted with a grapple loader and placed in a machine that cuts them to 2.4 m lengths with a hydraulic saw,
3. The bucked logs are placed in the debarker using another grapple loader,
4. Debarked logs are lifted out of the debarker and piled at roadside by a third grapple loader,
5. Logs are lifted from the piles with a grapple and loaded on trucks,
6. Logs are unloaded from the trucks in the mill woodyard.

Shortwood without field debarking

1. Logs are lifted and loaded onto a field tractor and trailer and carried to a concentration yard at roadside,
2. The logs are passed directly from the trailer to a truck with a knuckle-boom loader,
3. The logs are unloaded at the mill woodyard.

These examples demonstrate the effect of field debarking on the overall cost of wood handling. In the last example, there must be close coordination between the delivery of wood on the trailers which is passed directly to the trucks. Such an operation is not always feasible, but it can work where a tractor works with more than one trailer in the field. The loader can move wood from a standing trailer to a truck while the wheel tractor returns to the field with a different empty trailer. When the tractor returns with a load of wood, the trailer with logs is left by the loader and the empty trailer is carried back to the field.

Of course, there are other factors that affect the cost of wood delivered to a mill woodyard and all of them need to be considered when making a cost analysis. Among these, it is important to understand all of the costs involved in field debarking when making a comparative financial analysis of wood harvesting alternatives.

Long wood

Long wood, also called cut-to-length, is bucked into lengths between 4 and 6 m. Long wood is felled and bucked using a harvester machine or a chainsaw (Figure 9-28). The harvester head is a device that is mounted on an articulated tractor base or a track base such as a backhoe. When used with eucalypts, the harvesters can debark the tree and leave the wood cut and piled (Figures 9-29 to 9-31). The piled wood is transferred to roadside by an articulated forwarder, which has a built in knuckle-boom grapple and a frame to hold the wood (Figures 9-32 to 9-34). This harvesting method is commonly used by pulpwood companies in Brazil. Cut-to-length wood with the harvester is efficient where there is more than 250 m3/ha of stumpage, but is not as efficient when there is less, since the yields are reduced and the unit cost of wood produced increases.

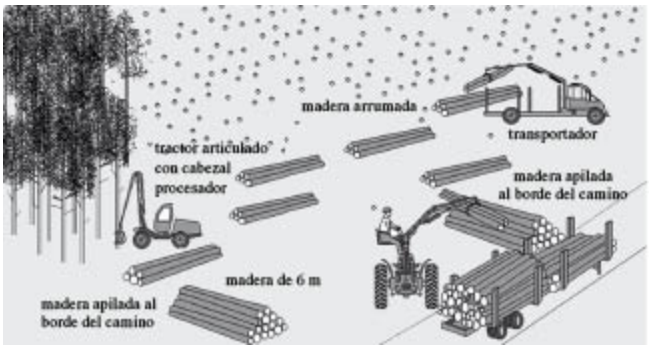


Figure 9-28. A processor working with long wood.


Figure 9-29. This processor head is mounted on a backhoe track base. The processor fells, bucks, debarks and piles wood 6 m long. The machine can process more than 100 trees/hour in clonal eucalypt plantations in Brazil and women have shown good ability to operate these units.

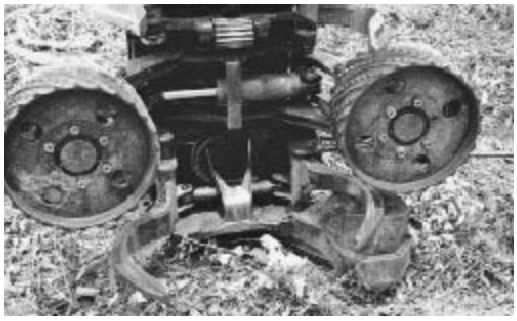

Figure 9-30. Details of a wood processor head. The head can be mounted on diifferent bases, including articulated tractors, knuckle-boom loaders or backhoe track vehicles. The processor head is often manufactured by a different company than the base vehicle unit.



Figure 9-31. A processor head mounted on a track base in Chile. This model can be adjusted to stand vertical even when the track base is on a slope.



Figure 9-32. An articulated forwarder moving long pine wood to roadside during a thinning operation.



Figure 9-33. The forwarder unloads eucalypt wood at roadside. Later, the wood is loaded on trucks and transportedd to a pulp mill.



Figure 9-34. Collecting 6 m long euclaypt wood using an articulated forwarder in Brazil.

When all field workers are mounted on machines, the need for personnel working on the ground is eliminated and it then becomes feasible to continue the harvesting operations during more than one shift per day.[3] Many harvesting companies in Brazil operate this type of equipment continuously, three shifts per day, working six days per week. It becomes feasible to work at night using lights mounted on the top of the tractor operator's cab. In this way the capital investment in equipment can be reduced as fewer machines are needed to produce the required amount of wood. Highly skilled and trained operators are needed to operate such machines. The operators must be alert to the work being done and are well paid for their efforts. The use of highly qualified and trained operators also extends the life of the machinery, creating additional savings. Only a few years ago the operating life of a harvester was considered to be around 15,000 hours, but now it is common to find machines operating 25,000 hours or more in the most progressive companies. The increase in machine life is due in large part to the uniformity of the clonal plantations being managed, to the high quality of the workers and to good machine maintenance.

The processor head grabs the standing tree and a hydraulic chainsaw cuts the tree off at ground level. The processor maintains a hold of the tree as it falls to the ground. Once on the ground, wheels on the processor head move the tree forward, cutting off logs to exact lengths specified by the computer in the operator's cabin, and leaving all the logs in an organized pile.

The processor head has knives shaped like half moons that remove branches and bark from the log as it is moved forward and back by the processor wheels. In the case of the eucalypts, the branches and bark are totally removed by this action, but for pines the debarking action is not complete. Processors are designed to work with straight, well formed trees. The machine is efficient when working in plantations of genetically improved trees produced from seed orchard seed where the trees are straight and the branches are small. There are processor heads working well with *Pinus radiata* in Chile and with *Pinus taeda* and *Pinus elliottii* in Brazil, but the form of *Pinus caribaea* var *hondurensis* tends to be rough and the branches larger in diameter and this species does not work well with a processor harvesting head. The productivity of these machines is also related to the size of the plantation: The larger the trees in a plantation, the

more efficient the machine will work, if it designed for that particular size of trees. As stated previously, the machine is not efficient in plantations where trees are short or where they are crooked or forked.

Tree length wood

In this process, the trees are cut using a feller-buncher and several trees are piled or bunched together (Figure 9-35). Then the bunched logs are picked up by a grapple skidder which drags the tree length logs to roadside. This method of harvesting is common in southern United States and is also being used in the tropics. One advantage of tree length logging is that it allows individual logs to be selected and cut to the appropriate lengths for sawlogs or pulpwood at roadside or at a woodyard. This is more efficient than cutting out logs in the field and, more important, it allows the removal of all logs at one time and by one machine. The head of a feller-buncher can be mounted on an articulated tractor base or on a knuckle-boom track base. The advantage of the knuckle-boom track base is that it can reach several rows of trees from the same position in less time and with less movement of the tractor base unit. The track base is an efficient unit when there are many trees to harvest during a clear-cut. The advantage of the articulated tractor base is its ability move rapidly among trees and it is more efficient where the stand densities are lower.

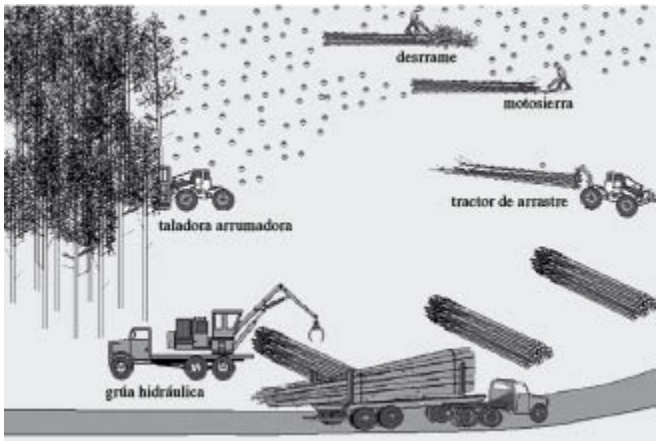


Figure 9-35. Schematic of a tree length logging operation.

The feller-buncher can fell the trees by two methods. One uses a hydraulic saw (Figures 9-36 to 9-38), and the other uses a hydraulic shear to cut the trees (Figures 9-39 to 9-41). The main advantage of the shear is its

lower cost of operation and maintenance. The shear works better in sandy soil or stony soils. The hydraulic saw is more costly to operate because of its high speed of rotation and the need to replace the saw teeth as they wear out. The advantage is that the saw makes a cleaner stump cut without damaging the fibers at the base of the log, an important aspect when cutting sawlogs. Another advantage of the saw mounted on an articulated tractor is that it can cut and grab small trees without having to completely stop its forward movement. This is very useful when harvesting many small diameter trees because it allows for greater productivity than the shear, which must stop in front of each tree before cutting it.



Figure 9-36. A feller-buncher head mounted on an articulated tractor in Amapá State, Brazil. The machine cuts and piles eucalypt trees.



Figure 9-37. This feller-buncher is mounted on an articulated tractor and has a hydraulic saw to harvest Caribbean pine in Venezuela.



Figure 9-38. This grapple mounted on a backhoe track base has an integral hydraulic saw. The tractor

drags tree length logs to roadside and the saw cuts the pile to 4 m lengths for truck transport.



Figure 9-39. A feller-buncher head mounted on a tricycle. This model is cutting trees with a hydraulic shear.



Figure 9-40. The shear cuts the tree while the machine places the tree on the ground. This tree is at maximum capacity for this 40 cm shear.



Figure 9-41. The feller-buncher head is mounted on a backhoe track vehicle and it can reach five rows of trees while moving down one row of trees. The cut trees are piled for a grapple skidder to pick up.

The wood is skidded to roadside with a grapple skidder (Figures 9-42 & 9-43). The key to the operation is for the feller-buncher to make uniform-sized piles for the grapple skidder. If there are too few trees, the skidder is under-utilized, but if the pile is too large, the skidder must make two trips to the same pile of logs. Grapple skidders are efficient for picking up tree

length loads, but they are not efficient at collecting two or more small piles of logs in different locations.



Figure 9-42. A grapple skidder dragging tree length pine logs. This tractor has oversized tires for operating in swampy conditions.

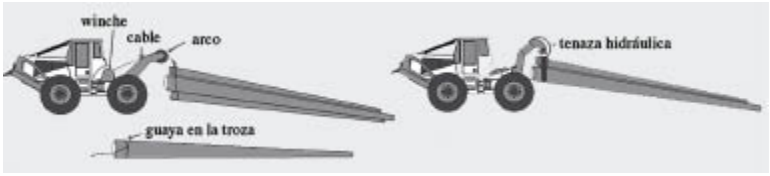


Figure 9-43. An articulated tractor can skid four tons of wood in tree length form and is efficient for moving wood an average distance of 250 m (500 m maximum). The tractor shown above is equipped with a logging arch and winch. The tractor below is equipped with a hydraulic grapple. To use the grapple, the wood needs to be bunched in piles.

A bottleneck for tree length harvesting is removing the limbs and top. If the trees are piled at roadside, it is difficult and dangerous to try to delimb them with a chainsaw and it is inefficient (Figure 9-44). It is easier to delimb the bunched trees in the field prior to skidding them to roadside (Figure 9-45). In the case of pines, an alternative for delimbing is to use a delimbing gate (Figure 9-46). A delimbing gate is a tubular steel frame that is hung between two trees with chains. The skidder backs the load of tree-length logs into the gate, forcing the branches between the bars, which causes most of the branches to break off. A delimbing gate is not effective with other types of trees that have flexible branches.



Figure 9-44. It is not efficient to delimb tree length logs at a concentration yard since there are too many trees piled together. Besides, it is dangerous to walk over the logs with a chainsaw operating and where skidders are constantly bringing in additional loads of trees.



Figure. 9-45. Treee length wood can be delimbed in piles in the field that are left by the feller-buncher.



Figure 9-46. A delimbing gate being used to delimb Caribbean pine in Venezuela. The grapple skidder backs the load into the gate and the branches snap off as the trees are forced through the steel grill.

Tree length harvesting is efficient in hilly land as well as on flat land. This harvesting method works well with large trees as well as small trees since the feller-buncher can carry several trees in its grasp until there is an optimum load bunched for a grapple skidder. It is a useful method in plantations where multiple products are to be produced: sawlogs as well as

pulpwood. The tree length logs can be cut to the desired lengths for sawlogs or pulpwood at a roadside deck or they can be transported tree length to a mill woodyard.

An articulated skidder normally carries between three and five tons of wood, depending on its size. They are efficient for skidding logs at average distances of 250 m from stump to road. There are other, larger skidders called "*clambunk*" which can skid up to 25 tons of wood. The clambunk carries tree length logs between two large vertical arms positioned above the back of the tractor. A clambunk has good flotation which allows it to travel through difficult sites such as swamps. It has an economic haul distance of 500 to 1000 meters. Clambunks are used primarily as skidders, but they can also be mounted with a knuckle-boom loader or even with a feller-buncher head to cut the trees and load them on the same machine (Figures 9-47 & 9-48). To unload at a concentration yard, the tractor opens the vertical arms while it continues to move forward, allowing the load to drop to the ground where it can be processed by a knuckle-boom loader or processor.



Figure 9-47. A clambunk skidder delivers a load of trees to a concentration yard. In the photo, the machine has a feller-buncher mounted on the forward section of the tractor so that it can cut and load trees without assistance. At the log deck the tractor opens the vertical arms and continues to move forward, allowing the load to drop to the ground.

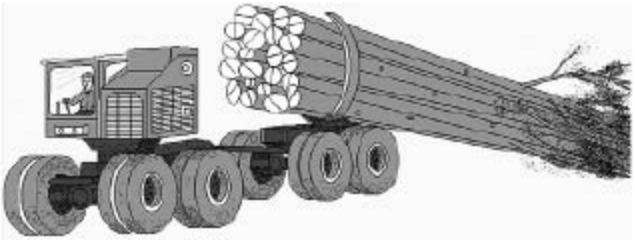


Figure 9-48. A clambunk with 16 tires and the capacity to carry 25 tons of tree-length logs.

Tree-length logs can be delimbed at roadside using delimbing machines. These are units that connect to the hydraulic system of the knuckle-boom loader and that can remove the limbs and the top of the tree. The loader lifts the tree and places it between two half-moon arms that have sharpened edges. The operator then closes the arms around the tree hydraulically and pulls the tree between the half-moon arms which cut or break off the branches (Figure 9-49). This unit also has a hydraulically operated chainsaw which cuts off the top of the tree. Then the clean log is loaded on a trailer by the same loader.



Figure 9-49. The device shown at the right is connected to the loader's hydraulic system and can delimb tree-length logs by pulling them through the half-moon arms. When the top of the tree reaches the device, a hydraulically operated chainsaw cuts off the top. The log is then loaded onto a trailer.

Another device that can be connected to the knuckle-boom loader is a frame for cutting sawlogs to length. Once the tree is delimbed, the loader operator can select and separate sawlogs (Figure 9-50). The tree is placed in the frame on the ground while the grapple holds the log steady, and a hydraulic saw bucks it to the desired length. Afterwards, the loader piles the sawlogs separately until there are enough of them to make a truck load. The rest of the tree length log is loaded on a trailer to be sent to the pulp mill.



Figure 9-50. Besides delimbing and topping the tree, the machine (center) can also cut out sawlogs with another hydraulic saw. This allows the loader operator to select and cut sawlogs and separate them from the rest of the wood that will be trucked to a pulp mill.

A disadvantage of loading tree length logs on a truck is the uneven distribution of weight with most of the weight over the forward axles. This can result in an overload on the front axles and may result in a fine by the highway police. An alternative to hauling tree length logs is to cut them into shorter logs at roadside to be transported as long wood or short wood on the highway truck.

There are machines designed to cut tree length logs to measured lengths. In the southeast of the United States it is common to harvest wood tree length, cut it to 2.4 m at a log deck and load short wood on trucks to be delivered to the pulp mill.[4] Piles of trees are cut as a group using large circular saws or long, oversized chainsaws that are hydraulically operated and the cut wood is then loaded on a trailer.

The cost of harvesting and wood extraction is directly related to the size of the “package” that is being handled. This is important when considering the design of a harvesting system with machinery, since the machine efficiency is related to the number of pieces being handled more so than to the size (volume) of each piece. Thus, the largest package is a whole tree, this being the most efficient system to use to deliver wood to roadside.

Directional felling

On sites where the use of large machines such as a feller-buncher are not justified, or where the terrain or soil conditions are unfavorable for such heavy equipment, another harvesting method that can be used is directional felling with a chainsaw and tree-length log extraction with an articulated skidder mounted with a logging arch and winch (Figure 9-51). This method is useful when thinning or where there are very large trees to be used for

sawtimber or plywood logs. The chainsaw operator fells the trees in the desired direction using felling wedges. With small trees, where a felling wedge does not fit in the cut behind the chainsaw, the trees can be felled directionally using a felling tool (Figures 9-52 to 9-54). Directional felling requires training and practice in order to carry out this maneuver efficiently. Felling wedges are manufactured from a soft aluminum/magnesium alloy or of a hard plastic that will not damage the teeth of the chainsaw in case of accidental contact (Figure 9-55).

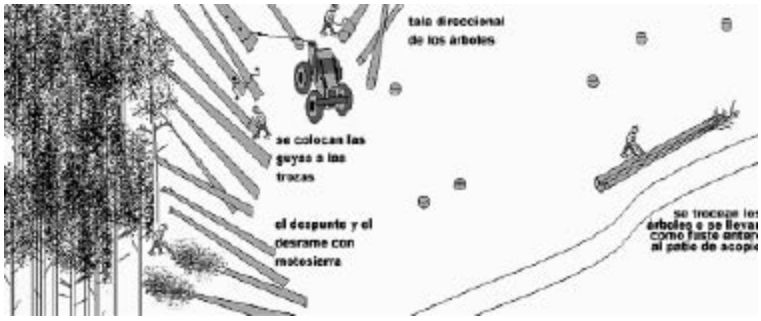


Figure 9-51. Directional felling and skidding using a tractor with a logging arch and cable.



Figure 9-52. A chainsaw operator with personal protection and a tool for directional felling.



Figure 9-53. The operator finishes the back cut on one side and places the felling tool in the cut. Then the cut on the other side is completed and the tool is pulled upwards to tip the tree over.

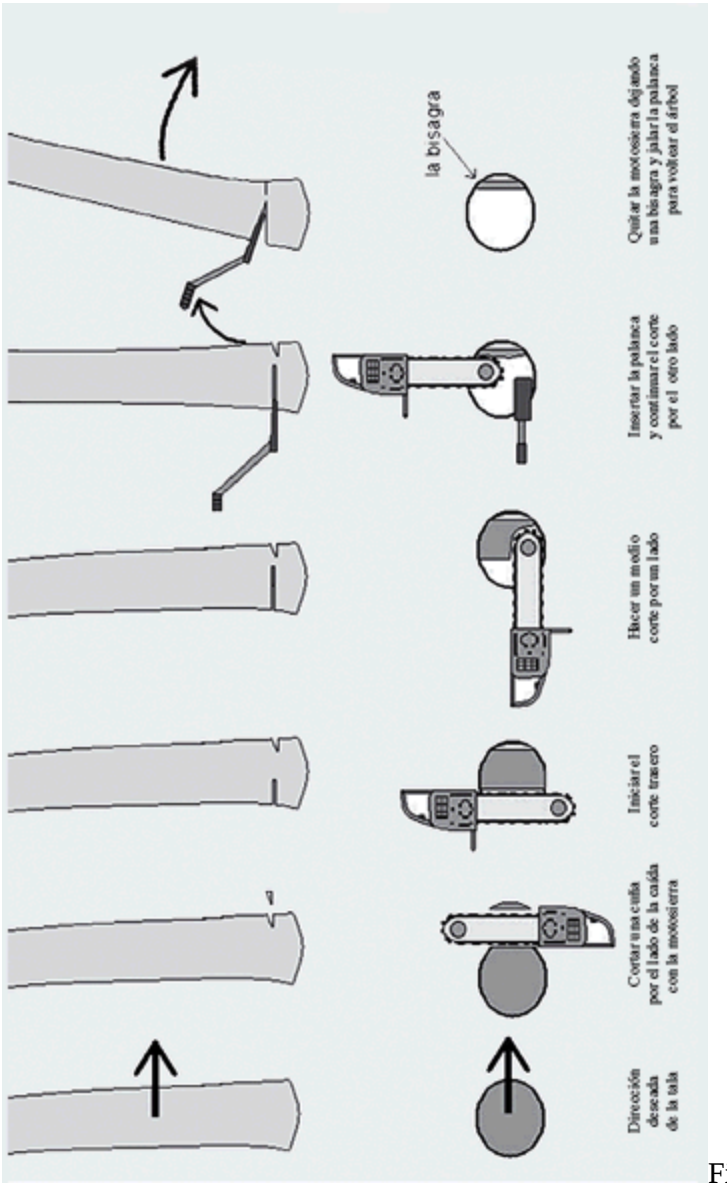


Figure 9-54. Directional felling of small trees using a felling wedge with handle.

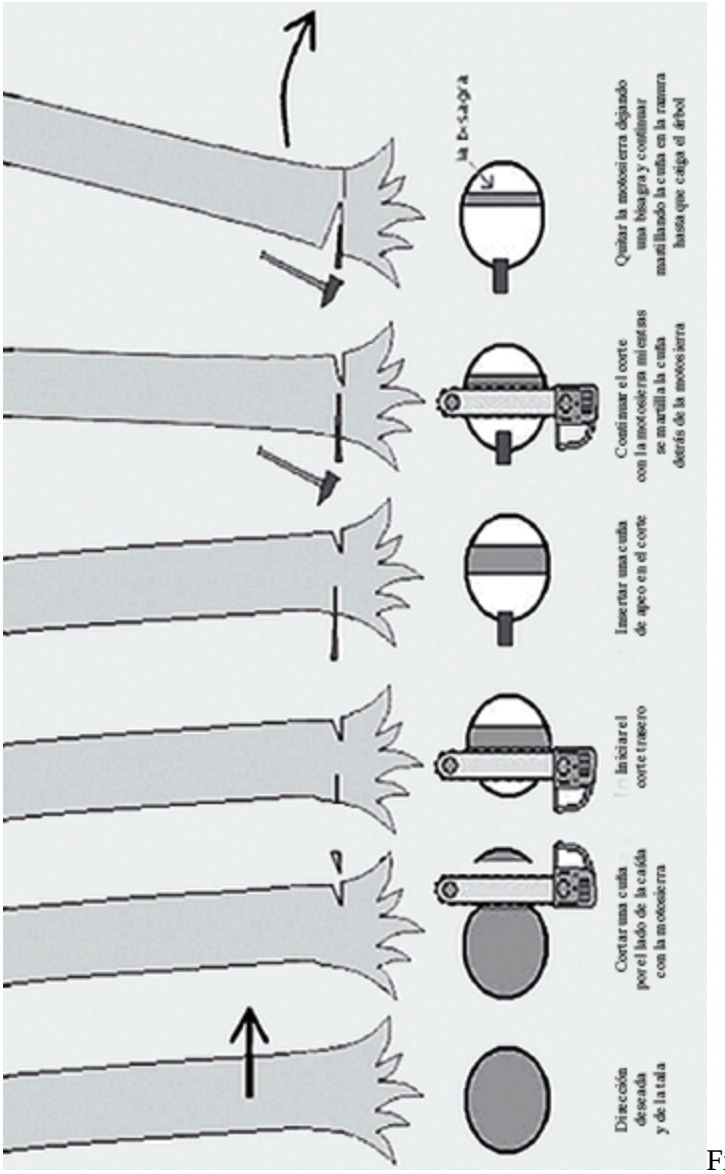


Figure 9-55. Directional felling of a large tree with a chainsaw and felling wedge; always leave a “hinge” of wood intact so that the tree falls in the desired direction.

Choker cables are used to winch the tree-length logs to a skidder. The choker cable is a 2 to 3 m long cable that is placed around the base of the log. This cable is then hooked onto the tractor winch to pull the log to the tractor. Field workers can connect the choker cables to the logs while the skidder is moving a load of logs to the wood deck at roadside. Then, the skidder operator returns the choker cables to the field to be used again. Choker bells and quick couple ferrules on logging cables are very useful because they are fast, secure and cause much less wear on cables than do hooks and lassos. Mini and micro choker bells are used when working with

½” and 3/8” cable. The ferrules are fastened to the ends of the cable by one of three methods (Figures 9-56 & 9-57):

- In the shop the ferrules can be attached using a hydraulic press,
- In the shop the ferrules can be attached by pouring melted zinc into the cone of the ferrule,
- In the field the ferrules can be attached using a larger cone and a wedge.



Figure 9-56. How to attach a ferrule and wedge to a choker bell.

The use of cones and wedges allows for quick repairs in the field, but these can come loose with use, since it is not a permanent connection. Ferrules fastened into the cone by hydraulic pressure are the longest lasting. The use of the choker cables can increase the efficiency of wood extraction using a skidder with a logging arch and winch (Figure 9-58).

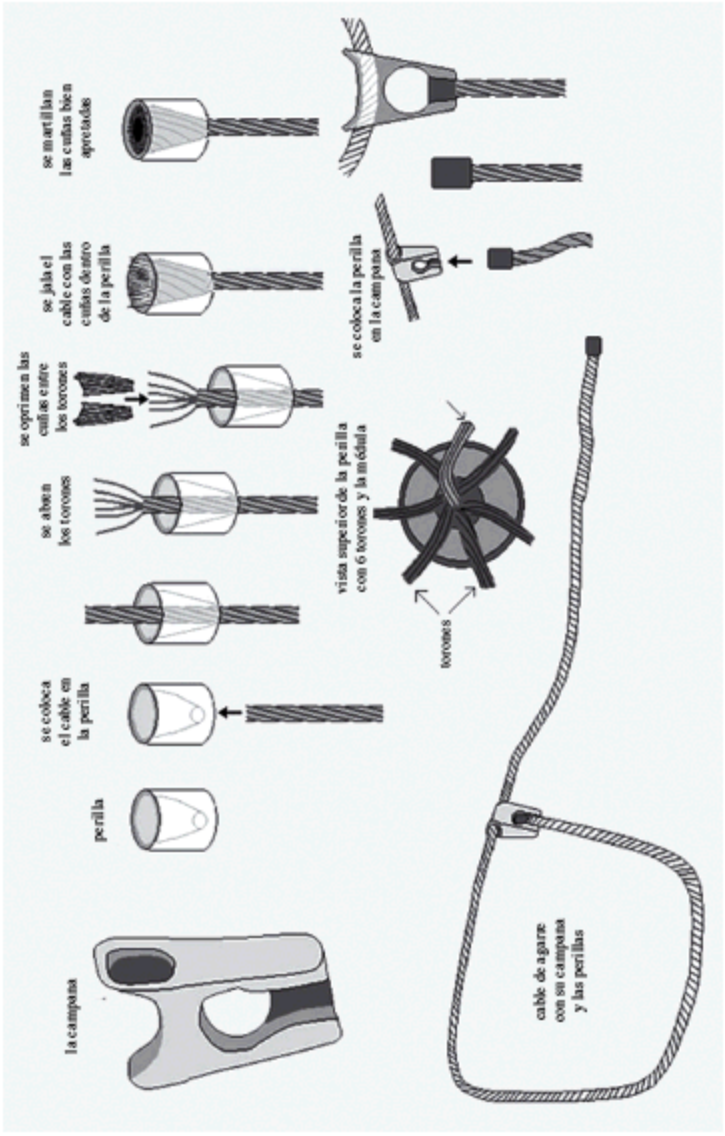


Figure 9-57 A cable bell attached to a cable with the choker ferrulle inserted into the bell.

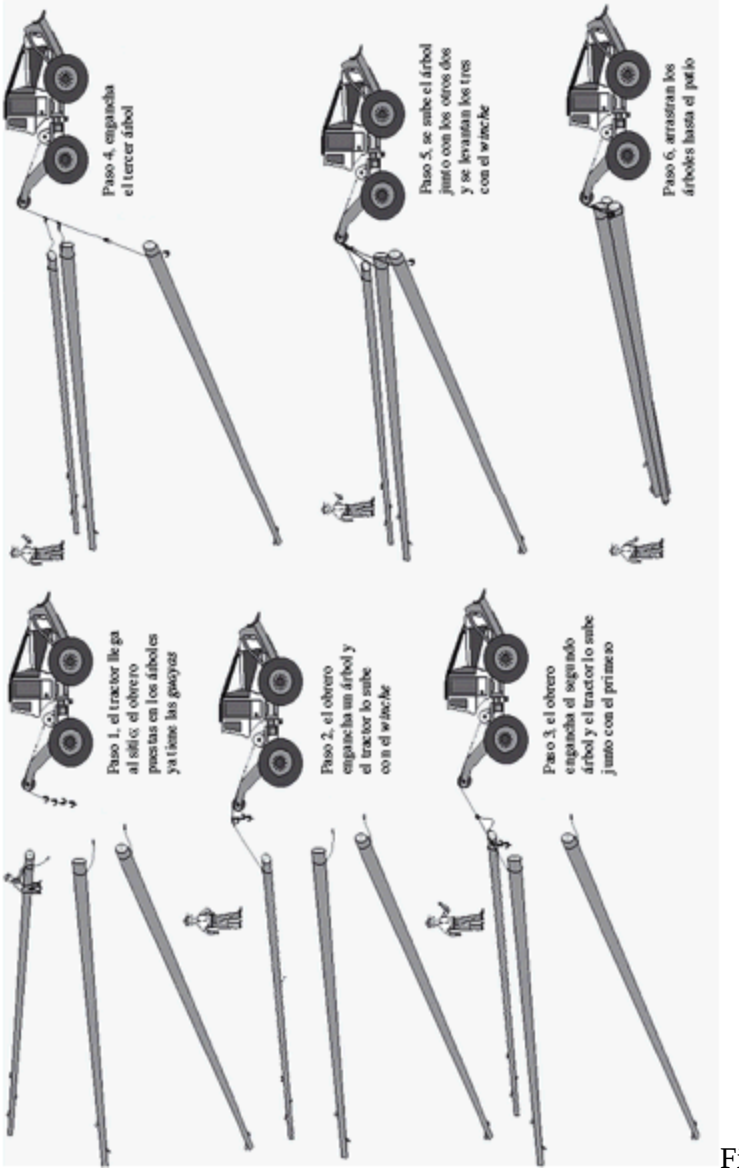


Figure 9-58. How to collect trees using the choker cables and logging arch.

Wood extraction with cables

Cable logging is used primarily where tractor skidding is not an option, such as on steep slopes, in swampy lowlands or where the rainfall is very high. The general concepts of cable logging and their use are presented in this section. Before trying to design a cable logging system, it is important that the reader study the types of cables and cable systems available and learn how they are used in the field.

There are two basic types of cable logging which are known as *high lead* and *skyline* systems. In both cases, wood is most often extracted tree length, pulling the log by the butt end from the stump to roadside. In the

case of high lead logging, the logs are dragged on the ground, without lifting the butt end of the log. In the case of skyline logging, the base of the log or the entire log is lifted off the ground using the skyline or main cable.

Steel cable, or more correctly, wire rope, is made from high tensile, high carbon steel wire that is drawn or extruded cold and pressed into a spiral to form strands. The most common compositions of cables for logging are termed “6 x 19” cables, which have 6 strands and 16 to 26 wires per strand with the strands being woven around a central core to form the cable. The number of wires per strand determines the flexibility of the cable. For general use the cable core is made of jute. For special conditions there are also cables that have a steel core, such as, for example, when working with high tension, high temperatures or cables used in suspension bridges. General use cables are those used with winches on skidders with logging arches. Swagged wire rope is used where greater strength is required, but with the same cable diameter, such as in the case of skyline cable logging systems.

The weight that a cable can support, i.e., the weight of wood that can be skidded, depends on the length of the cable, whether the load is dragged or lifted, the slope of the land, the tension placed on the cable and additional factors. Logging engineers have developed formulas that can be used to calculate the weight of the logs that the cable can support.

High lead cable logging

High lead cable logging is the older of the two methods.[5] The diameter of the cable depends on the size of the wood being harvested. A ½” cable is often used for the size of trees mostly found in plantations. The simplest design utilizes a single drum winch. The cable is pulled out into the field by hand and hooked onto a log. Then the winch is used to pull the log to the deck. In the simplest form, an “A’ frame is erected at roadside and the winch drum is activated with a portable engine mounted on the frame (Figures 9-59 & 9-60).



Figure 9-59. *Gmelina* logs are being dragged using an “A” frame in Indonesia. The winch has a single drum and is run by a small, one cylinder portable diesel engine



Figure 9-60. In this case, the haul line is hooked directly to the logs.

The winch can also be on a truck or tractor with a tower mounted on the same unit. This method, commonly known as a “loggers dream”, was widely used for extracting logs from natural forests in the United States in the 1930’s to the 1950’s. It was also adapted for use in the mountains of Chile and Mexico. The winch is activated by the power take-off (PTO) from the transmission of the truck. It is a rather slow system, but has a low capital cost, especially when using an old truck as the base for mounting the winch (Figures 9-61 to 9-65). One disadvantage of dragging logs on the ground is the accumulation of dirt or mud on the base and underside of the log. In the mill the logs must be cleaned with a pressure washer and a piece is cut off of the butt end to avoid damage to the milling machinery by sand, dirt or small stones embedded in the ends of the logs.

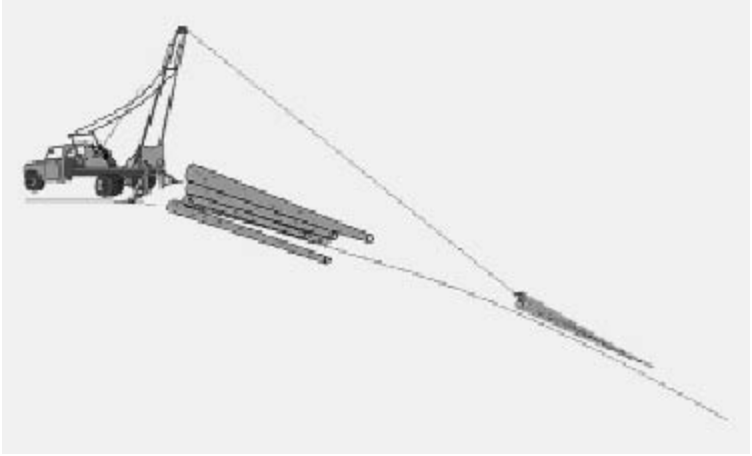


Figure 9-61. Drawing of a single drum high lead unit mounted on a truck.



Figure 9-62. Pine logs are being dragged out of a mountain forest in Michoacán, Mexico, using a "loggers dream" with the winch being powered by the PTO of the truck transmission.

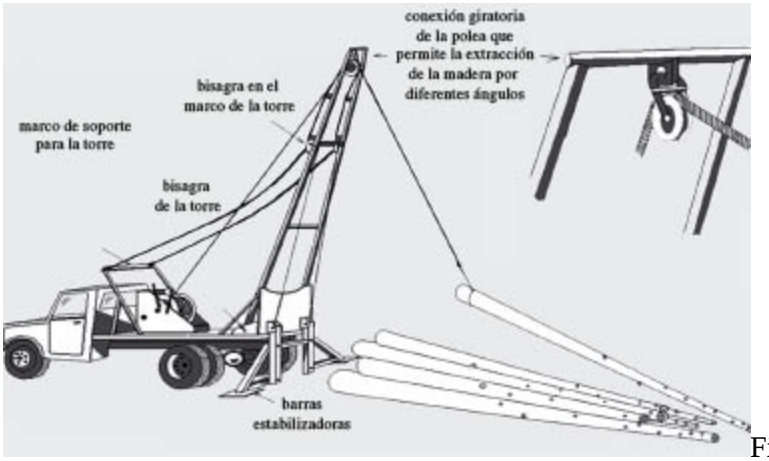


Figure 9-63. Details of the mounting of the drum and tower on the truck.

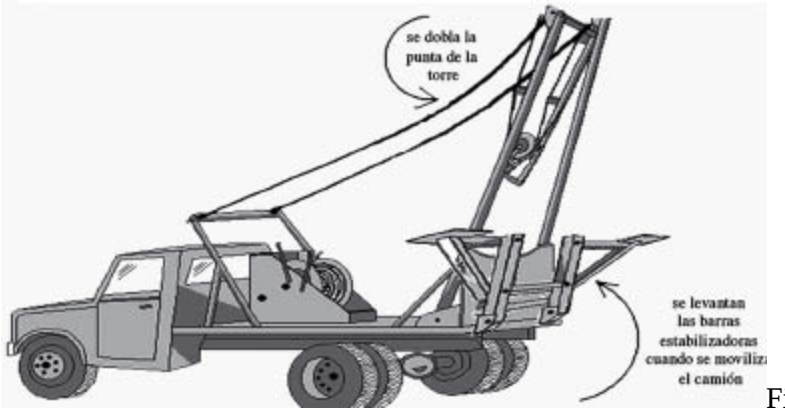


Figure 9-64. Preparations to move the tower to another location.



Figure 9-65. The tower is folded down against the frame for transport.

High lead logging is used in northwestern North America for removal of large logs from natural coniferous forests in the mountains. This method was also widely used for logging the lauan from the natural forests of the Philippines during the Twentieth Century. The winches can have multiple drums, but the two drum winch is common, with a main line (haul cable) and a return line. Choker cables are placed around the logs by a person called the choker setter and the chokers are then hooked onto the main cable. There is a mast tree or tower at roadside with a pulley at the top and the cable is threaded through this pulley and down to the winch. Originally, the mast was a large tree with the top cut off, but now it is common to use a hydraulic tower mounted on a truck for high lead logging. The logs are skidded up to the base of the tower and unhooked. The main line is pulled back into the field using the haul back line, which is of a smaller diameter. Modern systems use electronic choker bells that can be unhooked by a remote device so that workers do not have to crawl up onto the log pile to unhook the chokers.

High lead cable systems work well when clear-cutting on slopes. In fact, the greater the slope, the better the high-lead system works for dragging logs upslope. However, there are some disadvantages to this method of cable logging. When the butt of the log is dragged along the ground it tends to dig a shallow depression in the ground and the winch requires additional power to overcome the drag resistance. There is always the risk that a log will become stuck behind a stump, a large stone or some other obstacle and, if the cable breaks, it can snap back with great force and may cause damage to equipment and/or personnel in its way. The depressions in the soil created by dragging the logs can become erosion ditches and this method is not recommend where there is a lot of rain and where soils are easily eroded. This method of cable logging reportedly caused significant environmental damage in the Philippines when the lauan was harvested.

Gravity feed skyline cables

The gravity feed skyline is a system where the wood is lifted totally off of the ground and does not require a winch or motor for its operation (Figures 9-66 to 9-73). This system works best with short wood. Whereas most cable logging systems are used to pull the logs upslope to a winch, the gravity feed system is designed to be used where the road is located below the wood being harvested. It works on steep slopes or for crossing obstacles such as a rock cliff, a deep gulley or a river. The wood is first decked on the slope near where it is harvested. Two parallel skyline cables are strung from the log deck down to a collection point along a road. Two carriages are used; one connected to each end of a haul line and hung on the skyline. At the upper deck the wood is placed in slings under a carriage and is lowered by gravity to the lower collection point while the other (empty) carriage is pulled up the other skyline by the weight of the load moving downwards. The velocity of the carriage is controlled by a brake mounted above the upper log deck. Although this method does not require a motor, it does require two skyline cables, which is an additional cost. This cable method is justified where sufficient wood exists that can be accumulated at an upper deck and where access by road is difficult or impossible.

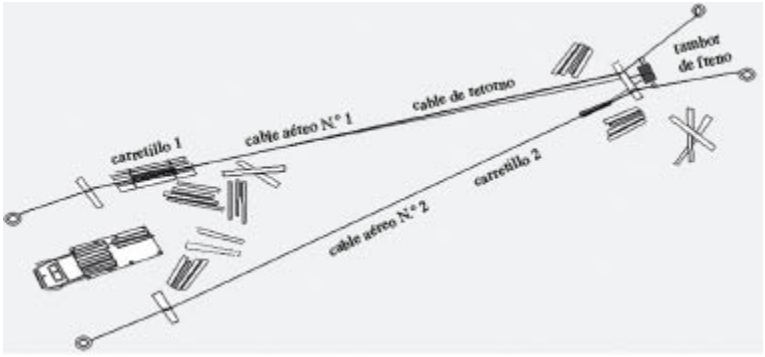


Figure 9-66. A gravity feed skyline cable systems as seen from above.

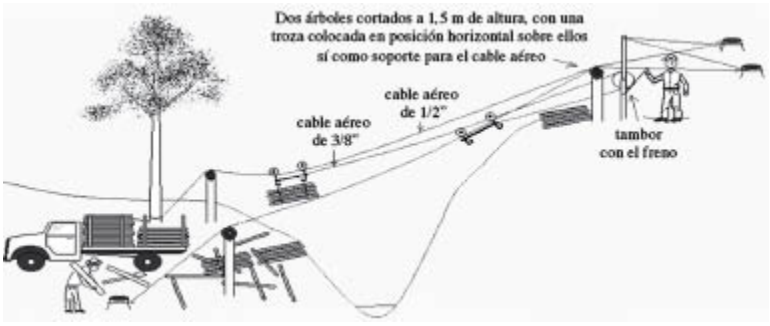


Figure 9-67. Lateral diagram of gravity feed cable with two skylines.


Figure 9-68. View of the upper installation of a gravity feed cable system in Colombia.


Figure 9-69. A laborer is placing 2.4 m long pulpwood in the cable sling that hangs below the carriage of the gravity feed cable system.



Figure 9-70. The travel velocity of the carriage is controlled from above by a brake drum.



Figure 9-71 The carriage drops down by gravity to a log deck below where the wood is loaded onto a truck.

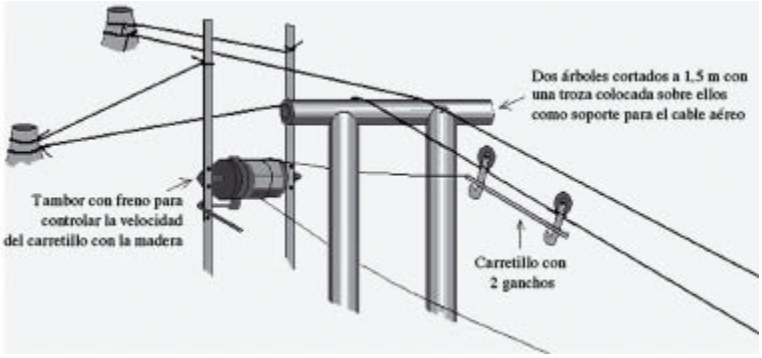


Figure 9-72. Detail of the upper installation of the gravity feed cable system.

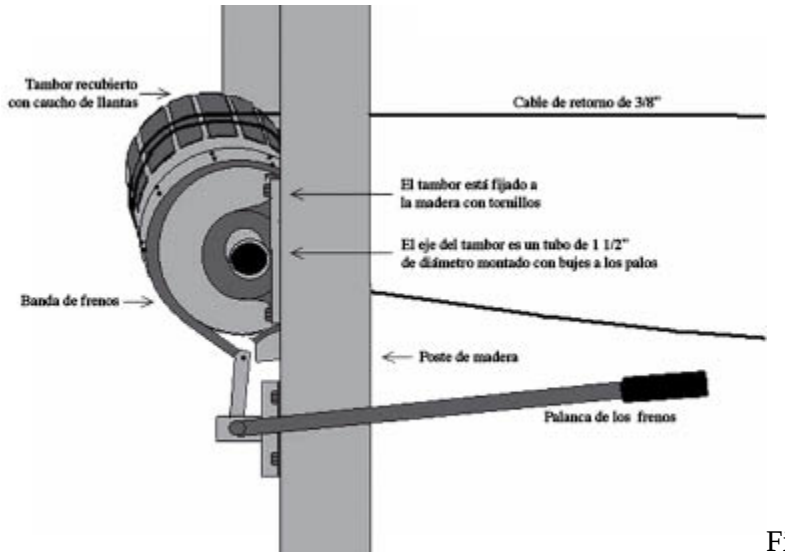


Figure 9-73. Detail of a homemade brake constructed using a small steel drum and the brake band from a vehicle.

Modified North Bend skyline cable

This design uses a two-drum winch with a skyline cable, a haul line and a return line. This system can be used with tree length logs or with short wood. It was used extensively on the Pacific Coast of Colombia for extracting pulpwood from the natural forest (Figures 9-74 to 9-77). The wood is lifted into the air by activating the haul line drum (traction cable) while keeping the brake applied to the return line drum. It is a simple, but effective means for moving wood in terrain where skidders are not effective due to the ground slope and/or high rainfall. With the two-drum North Bend, the skyline is pulled tight and permanently kept at tension between two soil anchors, such as large stumps. A three-drum winch can also be used, where the third drum is used to maintain the tension on the skyline.

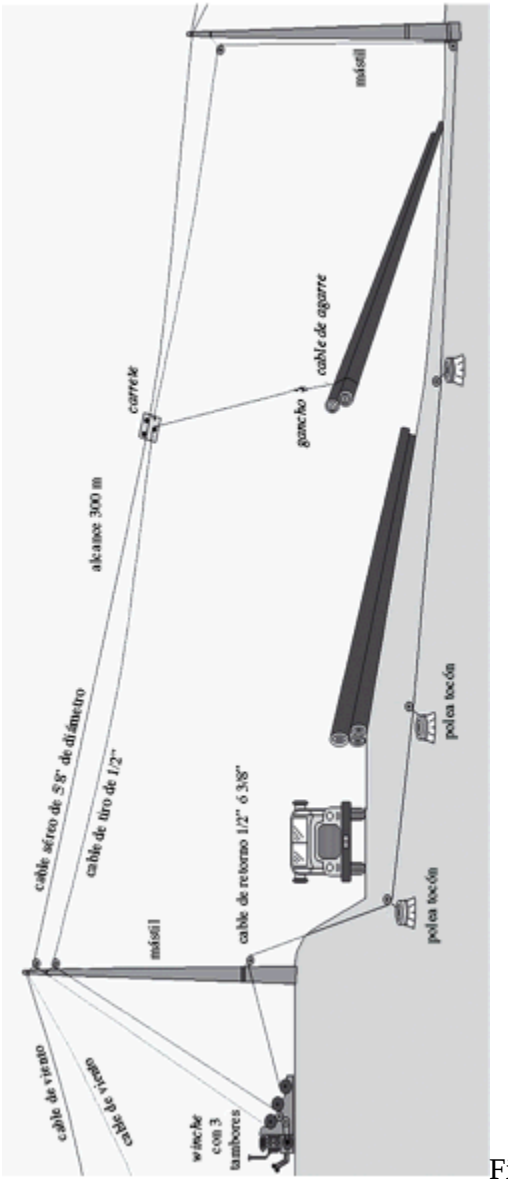


Figure 9-74. North Bend skyline system, with a three-drum winch.

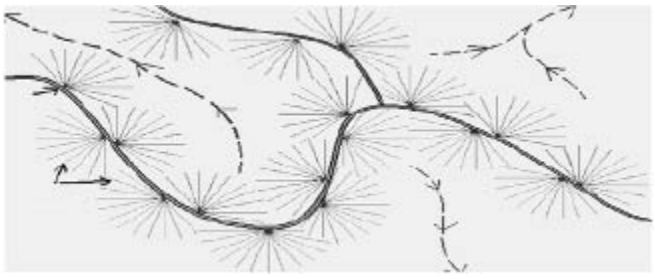


Figure 9-75. Definition of mast points and winch locations for wood extraction by skyline cable logging.

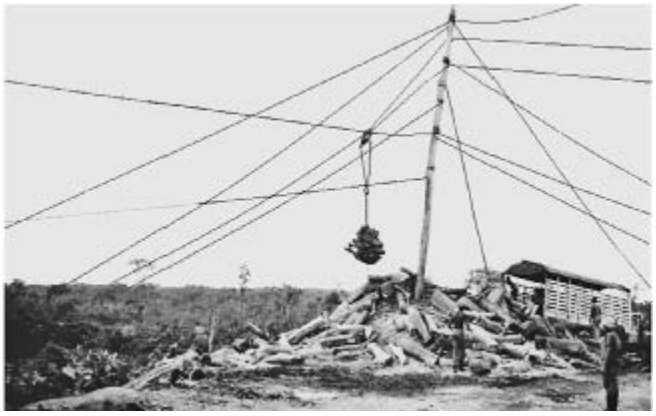


Figure 9-76. A NorthBend skyline moving bundles of short wood to a deck at roadside on the Pacific Coast of Colombia. The additional cables in the picture are guy lines to stabilize the mast.



Figure 9-77. The North Bend skyline cable can carry wood 300 m from the accumulation point by the rear mast up to the road.

Before beginning the harvest and wood extraction process, the first priority is to define the sites where the mast trees (or towers) are to be located (Figure 9-75). Once the mast has been set along side of the road, the rear mast trees must be located at the back end of the harvest lot. Then the skyline is connected through the front and rear mast trees to move the wood to the deck at roadside in a fan shaped arrangement. Once the wood within one of the fans or wedges has been extracted, the skyline is then moved to the next rear mast tree to collect the wood from the next wedge, and so on.

In North America, the winch and main tower are often mounted on a truck. This makes the setup easier and quicker. It is also useful where there aren't sufficient trees available to use as masts along the road. Another alternative is to mount the tower and winch on a crawler tractor (Figure 9-78). The tractor can move away from the road to isolated sites to bring wood to the winch. Then, the accumulated wood can be moved by a skyline to the road with another winch as a second stage. The two-stage skyline

system can reduce the amount of road construction needed in mountainous locations.



Figure 9-78. A 3-drum winch and mast mounted on an old crawler tractor in Indonesia. This mounting allows for faster movement and setup of the main mast.

Skyline carriage with a mechanical brake

This carriage uses a mechanical braking system to make it easier to skid logs to the skyline from both sides of the line. When the carriage moves out from the deck to retrieve logs, it contacts a block that is clamped onto the skyline to stop the carriage. When the carriage hits the block, the brake clamps the carriage to the skyline and releases the main line, allowing the cable hook or bell to fall to the ground (Figure 9-79). A choker setter can then grab the main line and pull it sideways to hook onto logs while the carriage remains fixed to the skyline cable. The braking carriage allows for easier movement of the main cable to the logs and is quite useful when making a thinning, where there is concern not to cause damage to the residual standing trees. When using the cable bell, several logs can be connected to the main line in the same way as is shown in Figure 9-58 for a logging arch tractor with a cable and winch.

Once the logs are hooked to the mainline, the choker setter informs the winch operator by walky-talky or by a portable signal horn so that the winch slowly drags the logs up to the skyline. When the logs are pulled up to the carriage, this action causes the carriage to release the skyline and to grab the main line so that the logs can be held off the ground and dragged to the log deck at roadside. At the main mast at roadside there is another block placed on the skyline; when the carriage reaches it, the carriage grabs the

skyline and releases the main line so that the logs drop to the ground and can be unhooked.

To move the cable block in the field, the skyline can be lowered and the field personnel move the block manually. Another alternative is to keep the block slightly loose on the skyline cable so that it moves back a short distance each time the carriage bumps against it. This can be done several times, if necessary, to move the block to the next position for picking up logs. This work is hazardous and requires perfect coordination between the winch operator on the log deck and the choker setters working in the field.

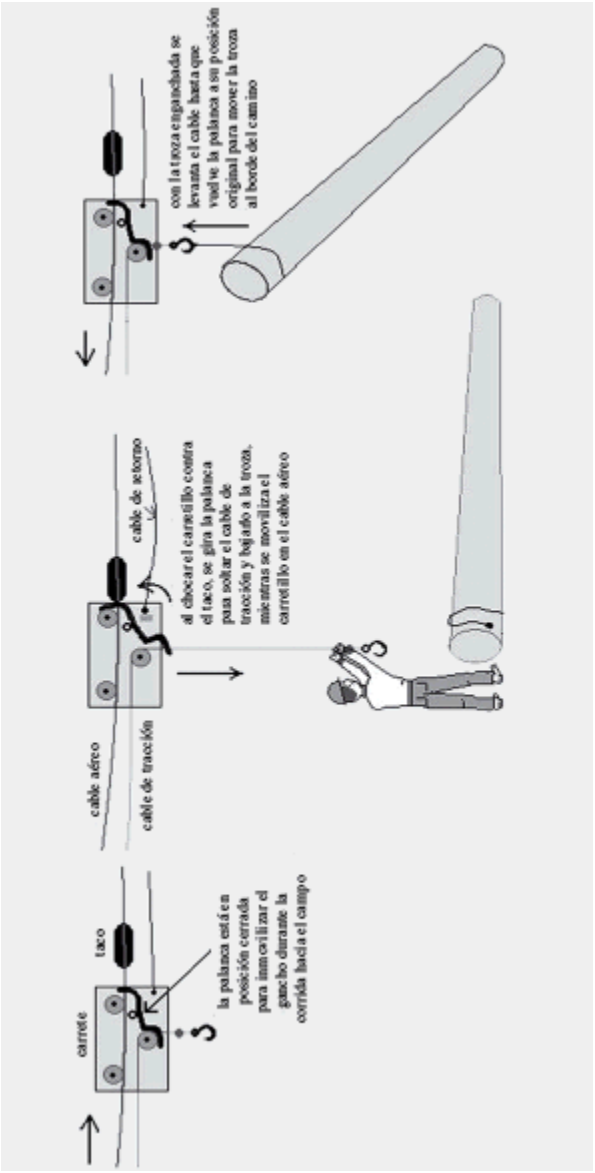


Figura 9-79. Schematic of a carriage with a mechanical braking system.

Skyline with a hydraulic brake

The hydraulic brake system is similar to the mechanical brake, but with the advantage that it does not require a block on the skyline to release the main line. There is a mechanism inside the carriage that generates hydraulic pressure as the carriage moves down the skyline. When it reaches the desired location, the winch operator pulls the carriage back up the skyline about one meter and this action releases the carriage brake on the main line and grabs the skyline. The main line drops to the ground where the choker setter hooks the nearby logs to it. Once the logs are hooked, he calls the winch operator to raise the logs to the carriage. The winch operator runs the carriage back a short distance to release the skyline clamp and clamp the main line. Then the load is pulled to the log deck at roadside. One manufacturer of this carriage is the Austrian company, Koller. The unit includes a portable tower and a winch mounted on a small trailer. In Colombia there are several companies using the Koller model 301 in the Andes Mountains to pull plantation pine logs up steep slopes (Figure 9-80). The same unit has also been employed in Indonesia to harvest *Acacia* plantation wood in hilly terrain.



Figure 9-80. A metal tower with a hydraulic braking carriage working in pine plantations in the Andes Mountains of Colombia.

The metal tower is portable and is useful in plantations since it is often not possible to find an appropriate mast tree. The mast tree must have

sufficient height and diameter to support the weight of the cables along with the load of logs. Many times it is not possible to find young trees that can be used for mast trees at the back end of the site that can support a skyline. On some slopes, it may be possible to use a stump or a short tree on the opposite side as an anchor for the skyline. In other cases, it may be necessary to place a mast at the back end of the site (Figure 9-81). One option that has been used in some operations is to construct a metal tower on a crawler tractor and use that as the back end mast point.

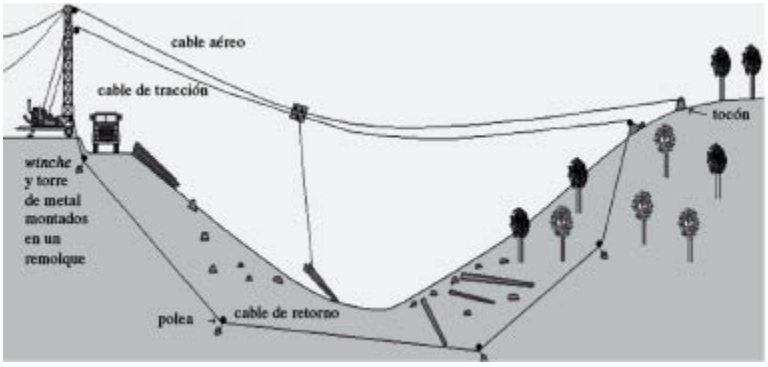


Figure 9-81. When there are no tall trees available for use as a rear mast, it may be possible to use a stump or short tree for this purpose when working in a narrow valley.

The portable tower with a hydraulically operated brake is a useful unit for the extraction of plantation wood on slopes. It can be used when thinning due to the ease of moving the main line between standing trees (Figures 9-82 to 9-84).

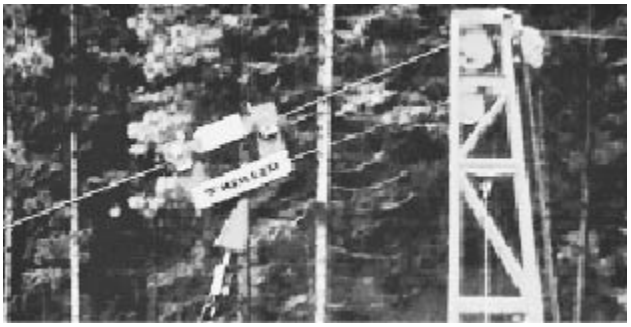


Figure 9-82. Detail of the Koller hydraulic carriage.



Figure 9-83. A metal tower with a hydraulic carriage working in acacia plantations in East Kalimantan, Indonesia. The tower is folded down ready to move.

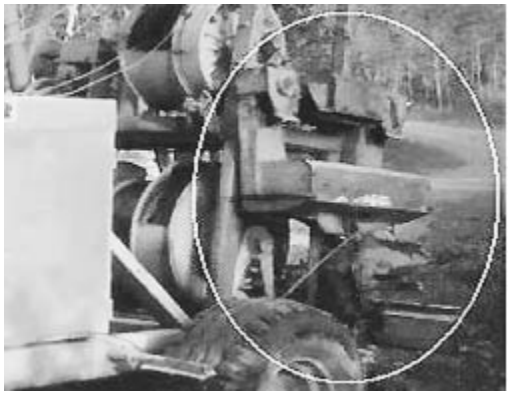


Figure 9-84. The hydraulic carriage (circle) is hung on one side of the tower during transport to a new site.

Wood transport by truck

Wood transport from roadside to the mill woodyard can be the most expensive phase of plantation management. Wood transport cost depends on four primary factors:

- The number of times the wood is lifted and dropped during the transport process,
- The condition of roads and highways,
- The total transport distance,
- The size of the trucks used for wood transport.

In the section about field debarking it was explained that each time the wood is handled there is an additional cost added to the harvest cost. This is important when making a financial analysis of wood harvest and transport costs.

The condition of the roads and highways is crucial to determining the size of truck to use for wood transport and the travel velocity of the truck. A paradigm to keep in mind is that the condition of the roads must be better when transporting large volumes of low value wood, than when transporting lesser volumes of higher value sawtimber. When valuable sawlogs were harvested in natural forests, it was possible to move the logs to a sawmill over mediocre roads with slow moving trucks because the high value of the wood delivered to the woodyard absorbed the cost of wood transport on poor quality roads. When moving large volumes of pulpwood from forest plantations, the roads need to be in good condition to allow for rapid truck movement in order to minimize the transport cost of a lower value log product.

It can sometimes be more expensive on a unit basis to transport wood on a slow moving 10-ton truck over 25 km of unimproved road than to move a 50 ton load of wood on a tractor trailer 100 km on a paved highway. Because of this, a cost analysis of wood transport must include the distance traveled on different types of roads, not just the total distance from the forest to the mill. If the wood can be loaded directly onto a tractor-trailer rig at roadside, it is more economical than to move the wood from a forest property to a log deck at a paved road with a small truck and then transfer the wood to a larger truck to carry the wood to the mill woodyard.

The capital cost of internal forest roads is less when there are large contiguous land areas in a forestry project than when the properties are widely dispersed. This is due to the increase in the number of primary and secondary forest roads that must be constructed and maintained when the land base is wide-spread. When lands are in unified blocks, the use and wear of forest roads by third parties can be minimized or eliminated, using internal roads exclusively for company vehicles. Where there are many farm houses situated along forest roads and there are families using the same public roads as the logging trucks, there exists the probability of conflict between the forest management company and local inhabitants due to damages caused to roads by logging trucks, especially during rainy periods. The result of such conflicts can be a greater road maintenance cost by the forestry company, even on public roads, or there can even be legislation passed to limit wood transport during periods of high precipitation. More than once the mayor of a small community has placed

barricades at the ends of main roads through towns to protest the damage that logging trucks cause to public roads - and for good reason!

Forest roads in steep country and mountains are more expensive to construct and maintain than are roads on level land. Steep land is often used to graze cattle and the cattle owner can move his herd to the road without the need of internal roads. There may be marginal cattle lands available for purchase at relatively low prices, especially when the land is hilly and isolated, but the capital cost of internal road construction and maintenance for access to tree plantations needs to be analyzed when estimating the total cost of delivered wood grown on such sites.

The size of the truck affects the cost of wood transport. Trucks with a load capacity of 10 tons can be economical for short haul distances, but they are not efficient for long hauls. Table 9-2 shows maximum haul distances normally used for different classes of trucks. These distances can vary depending on the cost of fuel in a particular country, the conditions of the roads and legal weight limits per axel or per truck.

Table 9-2

Efficient truck transport distances for hauling logs.

Vehicle configuration	Number of axles	Weight of load tons	Maximum distance km
Wheel tractor and farm trailer	4	3 – 5	2
Straight truck, single rear axle	2	10	50
Tandem axle truck	3	16 – 20	100
Tractor-trailer	5	36	200
Tandem truck plus trailer	7	50	400

An advantage of tractor-trailers is that the unit can be separated, leaving the empty trailer to be loaded while the truck-tractor picks up a loaded trailer and carries it to the woodyard. This procedure increases the utility of the truck by keeping it working more hours, thereby reducing the capital cost of investments in truck hauling. There are different configurations of trucks in different countries. In Brazil, the law allows for up to 74 tons gross vehicle weight (GVW) with 9 axles, which makes it economical to haul wood and other bulk materials greater distances at lower costs. Table 9-3 and Figure 9-85 show examples of truck configurations used in Brazil, along with their specifications.

Table 9-3
Legal limits for truck hauling in Brazil.

Transport units	Total Axles	Weight Gross ton	Maximum Length m	Name in Portuguese
Straight truck	2	16	7.0	camihão
Tandem axle truck	3	23	8.0	camihão
Truck-tractor & semi-trailer with 2 axles	5	40	13.0	carreta
Truck-tractor & semi-trailer with 3 axles	6	44	13.0	carreta
Tandem truck & trailer with 3 axles	6	50	19.8	biminhão
Tandem truck & trailer with 4 axles	7	57	19.8	biminhão
Truck-tractor with 2 semi-trailers*	7	57	19.8	bitrem
Tandem truck & 2 trailers	9	63	30.0	triminhão
Truck-tractor, with 3 semi-trailers*	9	74	30.0	tritrem
Truck-tractor + semi-trailer + trailer with 4 axles	9	74	30.0	rodotrem

*/ Each trailer has a 5th wheel connection to the trailer behind it.

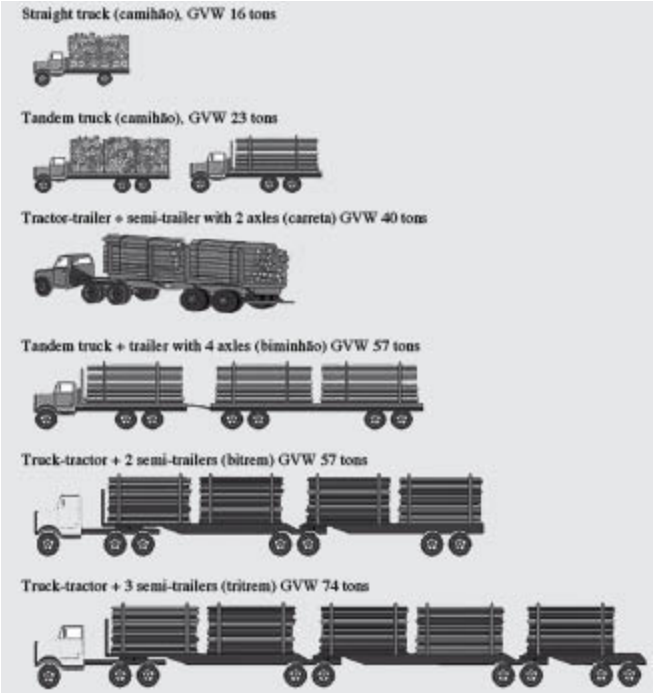


Figure 9-85. Truck configurations in Brazil

A trailer dedicated to hauling wood does not have a floor (Figures 9-86 & 9-87). The bi-train and tri-train have 5th wheel connections to the trailer

behind. This connection method is now being used in several countries including Australia, Brazil, Canada and Indonesia. The advantage of the 5th wheel connection is that it is more stable than the traditional hook and loop connection and it is safer on the highway (Figures 9-88 to 9-90).

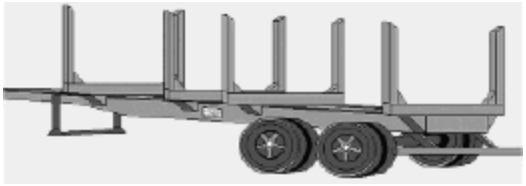


Figure 9-8 6. A log trailer has vertical supports to hold the wood, but it has no floor, to minimize net vehicle weight

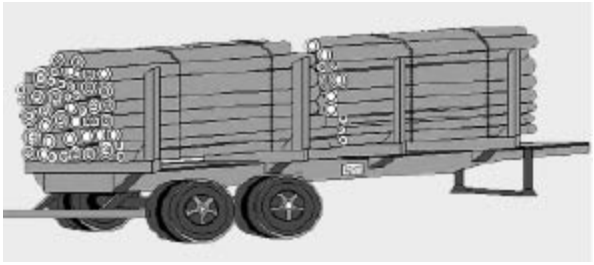


Figure 9-87 The log truck is designed for the length of wood being transported. In this case, there are two banks for 6 meter long wood.



Figure 9-88. Details of the 5th wheel connection at the back of a semi-trailer



Figur 9-89. A bi-train hauling unit.



Figure 9-90. This bi-train in Sumatra, Indonesia has 11 axles. The rig is used on private roads without legal weight limits. It is 3.5 m wide and has a GVW of 105 tons.

Short wood (2.4 m) can be loaded across the trailer or along the length of the trailer (Figure 9-91). Short wood is normally loaded cross-wise on level land, but is loaded length-wise for mountain hauling since the length-wise loading is more stable during transport. Longer wood is always loaded length-wise on a truck.



xxxxxxxxxxxxxxxxxxxxx

Long wood is an efficient harvesting method in tree plantations and is also an efficient method for transporting wood on trucks with multiple trailers (Figure 9-92).

Tree length hauling is always done using a tractor-trailer. Use of a combination rig with multiple trailers is not possible when hauling tree-length wood (Figure 9-93).



Figure 9-92 A tandem truck and 3-axle trailer (*biminhão*) with three banks of pine sawlogs in Paraná, Brazil.



Figure 9-93. A tree-length load of pine on a trailer in southern United States.

Coordination of harvesting and wood transport

It is important to create a coordinated operational plan of harvesting, wood transport and wood delivery to the woodyard. One factor that increases the cost of delivered wood is the time lost by trucks waiting to be loaded at the field log deck or to be unloaded at the mill woodyard. Many forestry companies contract wood hauling and transport separately, and this can result in delays when loading trucks if there is not an efficient plan developed to maintain a flow of wood to the trucks. It is all too common for company employees to consider that time lost by trucks waiting to be

loaded or unloaded is a normal part of operations and is not important. The reality is quite different; any machine or vehicle that is not producing income generates real costs to the truck owner. When truck drivers are being paid to wait in long lines and to sleep in hammocks slung under their rigs waiting their turn for loading, the transport contractor must necessarily increase the price of future hauling contracts to compensate for such losses.

The most common device used to load trucks in the field is the knuckle-boom grapple loader. There are many sizes of grapple loaders depending on the size of the wood, from those designed to handle short wood to grapples designed for loading tree length logs. When planning a wood handling system, the key is to acquire a loader that has the needed capacity for the type of wood to be loaded. It is also important to have sufficient loading capacity to load trucks quickly so that they spend a minimum time at the field log decks (Figures 9-94 & 9-95).



Figure 9-94. A wheel tractor and trailer with eucalypt wood brought from a plantation to a landing beside the Paraná River in Argentina.



Figure 9-95. In this landing, the wood is moved directly from the farm trailer to the highway trailer, a very efficient method that doesn’t require dropping the wood on the ground and picking it up again.

When wood is loaded onto a truck, it is always possible that the logs will settle and move during the trip to the mill (Figures 9-96 & 9-97). The loader operator needs to be certain that the logs are carefully placed on the

truck and that there are no logs placed diagonally or cross-wise that can slide loose during transport. A logging truck must always use chain binders to hold the load secure during transport. After tightening the log chains with a chain binder, the truck driver needs to inspect the load and make sure that the wood is well placed prior to transport.



Figure 9-96. This wood is not well placed on the truck and binder chains are not used to secure the load. A piece of wood has slid sideways and is creating an obvious danger to any vehicles coming in the opposite direction.



Figure 9-97. A log truck arrives at a woodyard with wood sticking out of the load. The truck does not have binder chains to hold the wood in place. This is an unacceptable log transport practice.

A good practice is for the truck driver to drive to the public highway, stop the truck, and make an inspection of the load to be certain that the logs are properly settled and that the log chains are tight.

A good coordination of the loading and unloading of trucks has been shown to produce greater profits to the truck contractor and to the forestry company. In southern United States, trucks are normally loaded in the field in less than 15 minutes. In the woodyards of the larger pulp mills and sawmills, a truck is normally unloaded in less than 15 minutes, with a 30 minute delay being the exception. Such efficiency is achieved by several means:

- Mills locate satellite woodyards in those regions where wood is being harvested and ship wood long distances to the mill by railroad.
- Woodyards are kept open extra hours of the day, in many cases until 11:00 PM to allow the truck driver to deliver the wood harvested the same day.
- Wood is weighed quickly on a woodyard scale.
- Trucks entering the woodyard are identified by a truck ticket or a code number that identifies the logging contract, the origin of the wood, the contractor, etc.
- Trucks are unloaded efficiently with the appropriate size of grapple or fork lift loader.
- The woodyard maintains sufficient loaders working to attend to the volume of truck traffic entering the woodyard.
- There is instant inventory control in the woodyard by computer.
- The accounting office of the company buying the wood makes payment to the trucking contractor and to the owner of the wood using an efficient, rapid and reliable computer system with direct deposits to bank accounts, rather than paying cash to the truck driver.

In small to medium operations where there are no specialty logging trucks, a common haul truck with a flatbed can only haul 2.4 m long wood cross-wise. This can be risky when driving roads with sharp curves, driving through hilly country or for long distances since the wood can move during the trip and some may fall off. Common contract haul trucks often do not have chains and chain binders, which are necessary to secure the load. To avoid highway accidents when contracting common haul vehicles, a forestry company needs to require contract haulers to made adaptations to their trucks for log hauling and/or work with the contractor to make the needed adaptations.

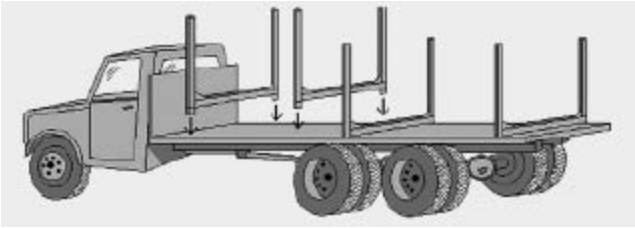


Figure 9-98. A common transport truck can be adapted to hauling logs length-wise by adding vertical side standards that are fit temporarily over the truck bed.

One method to allow for length-wise loading is to mount temporary steel struts over the flatbed with steel upright standards to hold the wood. The units have two vertical standards welded to a horizontal strut that fits over the flatbed and which has two legs that insert into the side sockets in the truck bed (Figure 9-98). Another advantage of the horizontal struts placed over a flatbed is that it makes it possible for a fork lift truck to reach under the load to lift it up without causing damage to the truck.

The use of tractor-trailer rigs has the advantage of being able to park an empty trailer in the field so that it can be loaded, while the truck-tractor hauls another full trailer to the mill woodyard. The capital cost of truck-tractors is much greater than the cost of trailers and it is economical to have more than one trailer for each truck-tractor in order to keep the truck working for as much time as possible. Figure 9-99 depicts the concept of utilizing several trailers with a truck-tractor. In the example, the operations of wood extraction, trailer loading and wood transport to the mill are all independent, permitting each operation to work at its own particular pace. If there is a work stoppage or delay in one operation, the others are not affected and can continue.

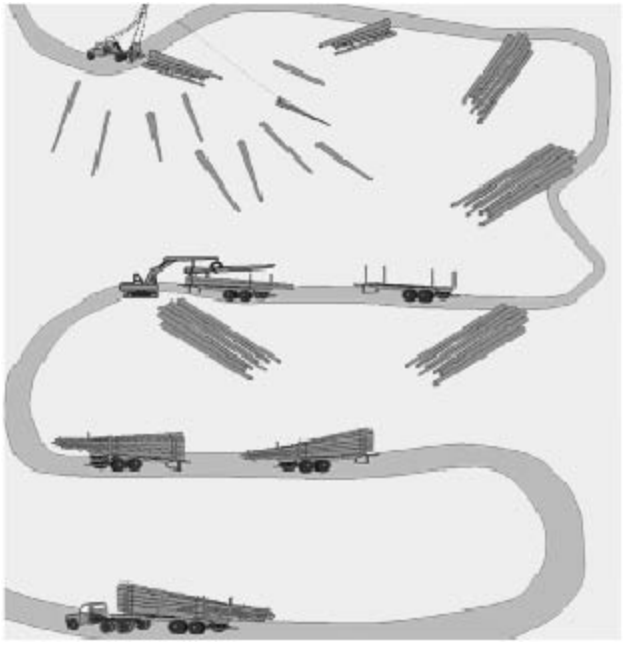


Figure 9-99. Example of a cable logging operation, loading tree-length logs on trailers with a grapple loader and hauling the wood to mill. Each operation operates separately, allowing for greater total efficiency.

Above all, it is important to provide good road maintenance for high value trucks, whether they are owned by the forestry company or by a

contractor (Figures 9-100 & 9-101). Tractor-trailers are highway vehicles and are not designed to be run through woods roads full of mud holes or driven through stump fields. If a loaded truck becomes stuck, it is never a smart move to try to pull it out with a large crawler tractor or by pushing it through mud, over rocks or over stumps, especially when it is loaded. Such actions can damage the undercarriage of the haul unit and even bend the drive shaft or the frame. To drive a damaged truck on a public highway at high speed after it may have been damaged by such action is to risk the safety of the truck driver and other motorists on the road.





Figures 9-100, 9-101. The truck-tractor leaves an empty trailer at the log deck and picks up a loaded trailer, an operation that takes just 10 minutes and requires no additional personnel.

Other alternatives are:

- Open a temporary woods road with a bulldozer for the truck to reach the log deck. In some cases, it may be necessary to use “carpets” made of thick boards or other materials or to fill in low, wet areas with rock so that trucks will not get stuck in mud.
- Pull the trailer to roadside. This can be done by using an old skidder or truck mounted with a 5th wheel to move the loaded trailer to the road

where it is parked and left to be picked up by the highway truck-tractor (Figure 9-102).



Figure 9-102. This skidder is pulling a double axle dolly mounted with a 5th wheel and the trailer is mounted on the dolly. The loaded trailer is forwarded from the deck in the plantation to roadside where the trailer will be picked up by a highway truck-tractor.

When a truck leaves a property with a load of wood, a dispatcher for the landowner needs to record the truck movement. The information that the dispatcher records is as follows:

- Origin of the wood (tract, lot)
- Type of wood (species, age, clear-cut or thinning)
- Identity of the truck (license number, transport company)
- Stere volume of the load (width x length x height)
- Required legal information (transport permit to carry wood, other)

One way to identify these values, except for the stere volume of wood, is to staple a tag on one of the logs in the load (Figure 9-103). Then it is a simple task to check the truck data when it leaves the forest property with the truck data when it enters the woodyard (see the section on mensuration and inventory for more information). The control of truck loads of wood is important, especially when using contract hauling. If the forestry company does not control the flow of wood as it leaves the plantations and enters into the wood yard, there exists the chance for the truck driver to make “adjustments” to the load that will definitely not be favorable to the company. There have been numerous cases where wood was stolen between the truck leaving the forest and entering the mill woodyard due to a lack of control over the flow of logs.



Figure 9-103. Wood movement can be controlled with a tag that has the number of the transport contract stapled to the load. In the woodyard, half of the tag is removed at the scale house and the other half remains with the load for inventory control in the woodyard.

Construction and maintenance of forest roads

At the beginning of a forestry project the cost of land and plantation establishment are considered as the primary costs since they are of immediate concern. Other important costs are the construction and maintenance of forest roads, but these are costs that can sometimes be postponed until beginning the harvest phase. It is for this reason that many times the cost of roads is not considered to be a priority at the beginning of a plantation project, even though the cost should be included when calculating the overall profitability of a project. Not only internal roads, but also the costs associated with the maintenance of rural access roads need to be included in a financial analysis.

The definition of a forest road depends on the use of that road, most of all, the volume of log hauling traffic over a road. Primary roads are those constructed to support traffic by large logging trucks in all types of weather. Such all weather roads are graded to allow trucks to develop high velocities and have sufficient width to allow two vehicles to pass safely. Secondary roads are also all weather roads, but with lower specifications for allowable slope, the radius of a curve, or the maximum truck speed. On secondary roads two vehicles can pass, but slowly and carefully. Primary and secondary roads are kept in optimum conditions on a permanent basis. Such roads are used, not only for log hauling, but for silvicultural activities, for access of personnel to inspect the properties, as well as for emergency access, such as in the case of a wildfire. In a small tract of land, it may not be justifiable to construct primary roads, just secondary and internal roads. Primary and secondary roads may have permanent bridges, culverts (drainage tubes) under the road, drainage ditches and other engineering

works that serve to keep the road open and passable during all weather conditions.

When calculating the total area of roadways in a tract of land, the width of a primary or secondary road is considered to be the width between drainage ditches, this being a non-productive area for tree growing.

Internal roads are normally used to enter a particular lot to harvest wood. Internal roads are maintained during the years when there are harvesting activities, but in other years they may have minimum to no maintenance. These roads may have some rock or gravel applied in certain sections to allow for the passage of trucks, but not over the entire length of the road. Internal roads have little or no construction work, such as culverts, ditches or bridges. An internal road is not considered to occupy any land area in adjacent lots since the trees close crown over the road and tree roots can occupy part of the space under the road. Table 9-4 presents some common specifications used for forest road construction.

By definition, all roads are considered to be firebreaks, but it may be necessary to construct additional firebreaks along ridge tops, on some slopes or in other locations where there is limited road access. These may be designed for access by tractors, by animals or just as foot paths. Roads can be scraped with a bulldozer or by a motorgrader for purposes of firebreaks, or they can be open areas between plantations which are kept in low vegetation. At the beginning of the dry season, the fire breaks are cleaned to remove flammable vegetation and create breaks between adjacent lots.

Table 9-4
Common specifications for forest road construction.

Specifications	Primary	Secondary	Internal
Total width of right-of-way, m	10	6	6
Net width of right-of-way, m	6	4	3
Width of ditches, m	2	2	-
Thickness of clay cap over roadbed, cm	20	15	-
Thickness of rock or gravel over roadbed, cm	10	10	-
Depth of roadbed compaction, cm	10	10	-

Within the concept of forest roads, it may be useful to also include perimeter fences around properties, since these are also linear constructions

which have initial construction costs as well as maintenance costs. Perimeter fences around properties are necessary in many locations to keep out domestic animals, since cattle and sheep can cause damage to young plantations as well as compaction of the soil with their hooves, thereby reducing the soil moisture retention capacity and causing damage to superficial tree roots. Pigs can cause significant damage by digging up tree roots and damaging tree bark. The need for fences and fence maintenance depends on the particular conditions of a given region. Locally obtained wood posts are often used for fences, replacing these every two or three years as they rot off at ground line.

Some important numbers to calculate when making a cost analysis of forest roads are the following:

- Kilometers of roads per hectare of plantations
- Total length of roads in the forest properties, km
- Km of roads/gross ha of total land area for each class of road
- Km of roads/net ha of forest plantations for each class of road
- Proportion of total land area in roads, %
- Total land area in roads, ha

Road construction and maintenance normally requires the following types of road equipment:

- A crawler tractor to make the initial clearing, to cut grades on slopes and sometimes to open and clean out drainages,
- A backhoe can also be very useful to cut ditches, cut openings for laying culverts, and for cutting grades for roads in hill country,
- A bucket loader to load dump trucks with clay and rock at a quarry,
- Dump trucks to move substrate (clay) and rock or gravel to be applied to the roadbed surface,
- A motorgrader to level the road surface and create the crown, as well as to maintain lateral ditches,
- A compactor to compact the substrate and surface of roads.

In large forestry projects, it is best to design the main trunk roads as straight as possible so that logging trucks can maintain their velocity. A common error is to make primary roads following old narrow roads or trails. This method may be cheaper initially, but in the long run, such roads

with many curves will be more costly since the trucks will have to travel more slowly and there will be a greater risk of accidents. For example, if a truck can maintain an average velocity of 40 km/hour, its productivity will be double that of a truck that can maintain only a 20 km/hour velocity. The greater the productivity of a logging truck, the less capital will be needed in new truck purchases to supply the wood to a mill.

When constructing roads through low, wet sites, an option is to use geotextile. The geotextile is a synthetic unwoven cloth that is placed over a prepared road surface. Rock or gravel is then placed over the geotextile (Figures 9-104 & 9-105). Geotextile allows water to pass through, but not gravel. It is relatively expensive to use, but it virtually eliminates road maintenance in low sites where trucks ould otherwise become stuck and damaged. The elimination of mudholes in roads is key to keeping a constant flow of wood on trucks as well as minimizing the cost of truck repairs and wood transport.



Figure 9-104. Use of geotextile over a clay substrate for a forest road on the Pacific Coast of Colombia, with 20 cm of river rock placed overtop of the geotextile.



Figure 9-105. Rock or gravel is spread evenly over the geotextile using a motorgrader.

Wood transport by rail

There are not too many places where wood is shipped by rail, but it is always an alternative worth investigating. The use of railroads for wood

transport from plantations depends on several factors, but the following are key factors to consider:

- The type of public rail system available and the gross car weight that is allowable compared to weight specifications for highway trucks carrying wood.
- Opportunities for obtaining wood from locations that are too far away to be economical for truck transport. The advantage of rail shipping increases with distance from the forest to the mill, since rail shipments are cheaper per kilometer once wood is loaded on the train.
- Opportunities for a sawmill to sell chips to a pulp mill or a particle board mill located a long distance from the sawmill. Bulk chips can be moved by truck, but if there is a stationary point for loading chips, such as a sawmill, and there is a rail line nearby, it can be more economical to ship by rail.
- Opportunities to export chips by moving them by rail to a seaport.
- The price of fuel and its effect on the cost of truck transport.

Rail transport is mostly used to move wood from a satellite woodyard to a mill woodyard, when the distances between them is great or when truck transport is inefficient. Wood transit by rail requires specialized rail cars (Figures 9-106 to 9-109).



Figure 9-106. Six meter long wood in rail cars at Ngodwana, South Africa. The cars have vertical standards to hold the wood. The cars are loaded and unloaded utilizing large fork lift loaders that can lift an entire bank of logs at one time.



Figure 9-107. Four meter long wood on rail cars at Montevideo, Uruguay. The wood is unloaded using an overhead crane that can pick up an entire bank of logs at one time.



Figure 9-108. Unloading 2.4 m long pulpwood from flat cars using a knuckle-boom loader in Jari, Brazil.



Figure 9-109. Wood transport without specialized cars is inefficient and is only justified in very special cases.

An important factor that determines the feasibility of the use of rail transport is the weight capacity of rail cars versus the capacity of trucks. When a national rail system does not allow for loading greater weights on rail cars than can be carried by truck, it is seldom economical to use the railroads, due to the cost of setting up a satellite woodyard beside a rail line and the infrastructure required to operate the additional woodyard. In those

countries where there exist light rails that do not support gross car weights over 40 tons, but where trucks have similar GVW limits, rail transport offers little or no advantage. Mexico has a standard rail system that allows for the use of 80 ton rail cars, a situation that offers potential advantages for long distance wood transport by rail.

Another consideration is whether or not there are tunnels along the rail route. Most national railroads do not permit round wood transport in open cars when the train must pass through tunnels since there is a risk of a log falling out, derailing a rail car and causing a train wreck.

In the 1970's, Jari Celulose in Brazil constructed a private railroad for the exclusive transport of wood from its plantations to the mill, located beside the Jari River. At that time, it was more economical to build a rail line with a narrow right-of-way because of the need to make several major cuts through hills. Later on, the company built roads alongside the railroad and began transporting the wood by truck, which was cheaper than maintaining satellite woodyards to accumulate wood delivered by truck from plantations and then loading it onto rail cars.

Where there are several small landowners with plantations that wish to sell their wood to a company, it may be easier to haul the wood to a satellite woodyard on small trucks, such as those that can carry 8 or 10 tons, due to the small amount of wood at each site and where rural roads are not conditioned to handle larger truck traffic. Then, at the satellite woodyard, the wood can be loaded onto rail cars and shipped long distances to a mill or to a port for export.

In southern United States, rail transport is common for moving wood chips in high cars without roofs. Many sawmills buy an entire plantation and truck tree length logs to their mill. The logs are then cut to length on a sorting table where an automated laser system is used with a computer to determine the optimum selection of logs for the sawmill (Figure 9-110). Sawlogs are sent to the sawmill and the rest of the wood is sent to a chipper and blown into special chip rail cars that are placed adjacent to the chipper. In the sawmill the logs are squared using a chip-n-saw to produce chips instead of using a head saw. The squared logs are then sent through a resaw to cut boards or dimension stock. This chip-n-saw method is quite common for plantation sized logs. The chips produced by the chip-n-saw are also blown into the rail cars. At the pulp mill, the chip cars can be emptied

quickly by opening compartments underneath the cars, allowing the chips to fall onto conveyors and be moved to chip piles.



Figure 9-110. A sorting table where tree-length logs move up an incline on chains and where saws move up or down hydraulically, activated by computer to cut logs to optimum lengths.

In swamp forests where tractor skidding was not an option, a lot of wood was once extracted using small railroads. Wood extraction from swamp forests by railroad has been utilized for plantations in the delta of the La Plata River in Argentina, as well as in natural forests along the Savannah River in the United States and in the swamps forests of northwestern Borneo in Sarawak, Malaysia, among others.

The basic structural components for building a rail line through a swamp can be quite simple. Wood poles are placed length-wise along the path where the rail line is to be placed and then logs are placed cross-wise over these. In some cases, more than one level of length-wise and cross-wise wood layers is used in order to raise the level of the rails above the swamp and to create a stable base. Then, small iron rails are fastened to the top layer of the log bed (Figure 9-111).



Figure 9-111. Swamp logging of meranti (*Shorea albida*) in Sarawak, Malasia, in 1986, using a small railroad.

Another method for making a swamp railroad is to drive piles (long logs) into the water and into the soil beneath as a base along the rail path. Wood beams are fastened horizontally between the pilings and rails are then

fastened to the wood beams. In this way, sawlogs can be hauled out of sites that flood. The logs are skidded to the rail line by oxen, mules or they are rolled to the rail line by laborers working with cant hooks. Where the water is deep, the logs are sometimes floated up to the rail line one by one and then lifted onto the rail cars with a loader. In some cases of deep water, a simple cable system has been used to pull the logs to the rail line. A loggers dream (single drum winch) mounted on a rail car, has also been used to drag the logs to the rail line.

The rail systems described above are quite small, with minimal weight carrying capacity and with small locomotives and small rail cars. A diesel locomotive may have a small, 50 HP motor. In some cases, the cars are made totally of wood with the only iron being the axles, wheels and fasteners. When the wood arrives at the deck beside a river or road, it is rolled off the cars manually with a cant hook (Figure 9-112).



Figure 9-112. When the meranti logs arrive at the deck beside the river, they are rolled into the river and formed into rafts to be pulled to a sawmill downstream by a tugboat.

Water transport of wood

River rafts were used to exploit the great coniferous forests of Canada and northern United States during the Nineteenth Century and into the Twentieth Century. The trees were cut during the winter months and long logs were stacked in large piles at the edges of the rivers. In the spring, when the snow melted, the rivers increased their flow. Dynamite was exploded under the river side of the log piles so that the piles would fall into the swollen rivers and float downstream. This was the time when there were many stories and legends created about those loggers, the most famous being that of the giant Paul Bunyan and his giant blue ox, Babe. Stories were told of men risking their lives by jumping across logs floating in the

rivers, guiding them downstream and freeing logs that became stuck in the ice cold water. Many of those American loggers were immigrant Swedes, Fins and Frenchmen. The fascination with the loggers of that period continues even to the present in stories and songs.

There has also been a large amount of river transport of logs in the tropics, and this continues today in some locations. In Malaysia and Indonesia, the meranti logs are moved in large rafts to plywood mills. In 1964, the author participated in the collection and formation of lupuna logs into rafts on the Marañon River in Peru, transporting them down the Amazon River to a veneer plant near the city of Iquitos.[6]

Tropical plantation wood has also been moved by river rafts and river barges. The rafting of small logs has been documented in Colombia as well as in Indonesia. Normally the wood is allowed to dry for several weeks at a log deck beside the river. Then the bundles of wood are fastened together with steel strapping or polyethylene rope (Figure 9-113), and the bundles are placed in the river with a crane and floated to a nearby location where they are organized into rafts. The rafts are held together using poles tied to the bundles. When there is a large enough raft, it is carried out into the river by a tugboat, which is often a small river boat that guides the raft and keeps it away from sand bars along the route (Figures 9-114 to 9-120).



Figure 9-113. A bundle of *Gmelina* logs on a log deck in East Kalimantan, Indonesia.



Figure 9-114. The bundles of *Gmelina* are placed in the river with a crane.



Figure 9-115. The bundles float to an accumulation point.



Figure 9-116. The bundles are tied together using wood poles to form them into rafts.



Figure 9-117. A raft of *Acacia mangium* logs floats low in the water due to its greater wood density.



Figure 9-118. A river raft being guided down the Mahakam River in East Kalimantan, Indonesia.



Figure 9-119. Bundles of *Gmelina* and red ceiba logs being formed into rafts along the Magdalena River in Northern Colombia.



Figure 9-120. A raft of plantation logs initiates its trip on the Magdalena River to a particle board mill in Barranquilla, Colombia.

Plantation round wood is also transported on ships in the open sea. There is a sizeable movement of plantation wood on the South China Sea from Malaysia and Indonesia to Hainan, China, to supply wood to a pulp mill. Plantation round wood is also shipped from Uruguay and Argentina to pulp mills in Spain. When shipping round wood by sea, it must be on barges or ships. Ocean salt water can cause serious problems in the pulping process as well as in the manufacture of fiberboard or particle board. Cranes are used to load wood onto ocean-going ships, similar to those used for loading logs from natural forests. The most common method is to strap logs into bundles and stack the bundles on the deck of a ship. When using barges, it

is important to take into account the size of barges normally used in a region, the transport distances over open sea and the availability of shipping ports for loading and unloading the barges (Figures 9-121 & 9-122).



Figure 9-121. Loading a 2000 ton barge with plantation *Gmelina* wood in Indonesia. The crane is a track-base dragline that remains on the barge to unload the wood at the destination dock. Volume, rather than weight, is the determining factor of the size of the load of logs that can be carried on the barge.



Figure 9-122. A 500 ton barge being towed up a narrow river by a tug boat to pick up acacia and melina wood from plantations in Borneo. The tug boat and barge will contue to travel down the open sea lane to a mill located at the mouth of another river.

If the barges are loaded in a river or in the sea, the water must be deep enough for the draft of barges to be loaded. The barge must float when loaded at high tide so that it can be pulled out to the open sea. When hauling wood locally, barges are usually between 500 and 2000 tons, but for long distance hauling in the open sea barges must be larger, usually holding 4000 to 8000 tons of logs. In many cases, the determining factor for water transport of plantation wood is not the weight of the wood, but the volume piled on the barge. The height of the piles determines how much wood can be loaded safely on a barge, particularly so when the wood is transported on the open sea (Figures 9-123 & 9-124).



Figure 9-123. Bundles of eucalypt wood with steel straps are delivered to an ocean-going ship at a port in Montevideo, Uruguay.



Figure 9-124. The bundles are placed on the deck of the ship and transported to a pulp mill in Spain.

The largest buyer of wood chips world-wide is Japan. Japanese companies buy hardwood and conifer wood chips from temperate, sub-tropical and tropical countries. Ships that are used to transport wood chips can carry loads of 60,000 to 80,000 tons. Thus, if a chipper has a capacity to chip one million tons of wood per year, the mill can fill one 80,000 ton chip ship per month (1,000,000 / 80.000 = 12.5) (Figures 9-125, 9-126).



Figure 9-125. A pile of wood chips at a port near Puerto Montt, Chile, ready for export to Japan.



Figure 9-126. The chip mill has a conveyor for loading ships that are moored to a quay in the sea.

Chip transport is a specialized business with ships especially designed for chip transport. The ports must also be designed to accommodate chip ships for loading and unloading (Figures 9-127 to 9-131). The international market for chips is generally based on BDU (bone dry units). The chips being transported normally contain some moisture and are not totally dry, but the BDU value is determined upon arrival at port and the price of the shipment is determined based on this calculation. For this reason, woods with the highest bone dry density are the most widely shipped and of the greatest value to the seller.



Figure 9-127. A chip ship is being unloaded at a port in Nagoya, Japan. The conveyor carries the chips from the ship to a concrete pad at the port.



Figure 9-128. A clam bucket picks up chips in the ship's hold and places them in a hopper on the deck of the ship.



Figure 9-129. The chips move from the hopper to conveyors mounted on top of the ship.



Figure 9-130. A ship-to-shore conveyor carries the chips to concrete pads at the port.



Figure 9-131. Chip piles at the Port of Nagoya, Japan. Chips are imported from many different locations around the world.

[1]In this text, the term harvesting is used for wood extraction. The term *timber exploitation* has been traditionally used when referring to wood removed from natural forests. Forest plantations are really crops, similar to agricultural crops and the term *timber harvest* is more descriptive and correct. The forestry investment is not being exploited, but rather the tree crop is being harvested.

[2]This example involves a continuing cycle of planting, maintenance and harvesting of trees with a rotation age of 15 years. Labor costs shown are averages per 1000 ha over a 15 year period. The wood is felled and bucked into logs with a chainsaw and is debarked manually in the field to produce sawlogs and pulpwood. Wood is moved to roadside using a wheel tractor and a farm trailer.

[3]In eastern Canada, a forestry company makes thinnings and clear-cuts of spruce plantations using harvester heads mounted on articulated tractors, working two 10-hour shifts each, producing long wood during the entire year, even during the winter months when there can be a meter of snow on the ground.

[4]Many pulp mills in the United States were built years ago and, due to their design, cannot accept long wood. For such mills, the wood must be cut to 2.4 m lengths prior to delivery. It is more economical to harvest tree length wood and to cut the wood to 2.4 m lengths at the log deck before it is loaded on trucks to be delivered to the mill.

[5]The higher the mast or tower used at roadside, the greater the lifting force and the less effort is required to drag or skid the logs.

[6]Lupuna is the common name for a species of tree in the genus *Chorisia*, family Bombacaceae, exploited in Peru. The low density wood was used as to make veneer centers for decorative plywood.

10

Forest certification

During the last half of the Twentieth Century there was a marked expansion in the production and marketing of woods from natural tropical forests. There were numerous international press reports on television and in other communication media showing that the tropical forests were being exploited in an unsustainable manner and that this was causing environmental damages. In the countries purchasing products made with tropical woods, especially in Europe and North America, there were criticisms expressed to wood marketers by consumers as well as by environmental groups that tropical forests were being exploited unsustainably. Boycotts of products made with tropical woods were organized in some countries. At that time there was no mechanism in place to show the origin of wood products with exactitude. There was much public pressure to establish methods for certifying the origin of wood products so that consumers could feel certain that when buying a piece of furniture, a decorative panel, a musical instrument or other wood product that this was not causing the destruction of the tropical forest. During the same period the term tropical rainforest gained acceptance and became popular in the public vocabulary in the temperate countries. There were multiple campaigns initiated to save the tropical rainforests.

Recognizing the importance of tropical woods in international markets, the initial purpose of certification was to establish mechanisms to protect tropical natural forests through sustainable forest management. The basic premise is that it is possible to manage natural forests in such a way that wood can be harvested on a continuous basis (Davis, 2007). Instead of removing all commercial wood at one time, the logging company would make a partial cut, that is, a selective cut, removing just a part of the wood, but leaving the residual forest intact to continue its growth. After a defined time lapse, it was considered feasible that the logging company could return and remove a similar volume, for example, in 25 or 35 years, by selective cutting and again leave a residual forest that would continue to grow until the next entry to harvest wood. This plan was originally developed for teak

in Burma as the "*Brandis Selection System*", which involves timber removal every 30 years and a final harvest between ages 120 and 150 years (Kahrl *et al.*, 2004). Another advantage of a partial harvest was the idea that this would cause minimum disturbance to the forest with harvesting machinery and without causing damage to the remaining commercial trees left standing.

The Forest Stewardship Council (FSC) was founded in 1993 in Toronto, Canada, with 130 members from 25 countries, for the express purpose of establishing guidelines for the management of natural forests along with the auditing of related activities by independent groups (FSC, 1994). The result of this endeavor was the creation of a greater public awareness of the role that wood users had in contributing to the destruction of tropical rainforests. In 1994, FSC published a series of certification guidelines for natural forests (FSC, 1994; Upton & Bass, 1996).

Initial certification of natural tropical forests included the following guidelines:

1. Compliance with national and international laws regarding wood marketing,
2. Clearly defined rights for the long term utilization of the forest,
3. Respect the rights of indigenous peoples that live in the region,
4. Maintain or improve the well-being of workers in local communities,
5. Optimize the benefits provided by the forest,
6. Maintain critical forest functions and minimize the impacts on diverse ecologies,
7. Implement a management plan consistent with the objectives of forest management,
8. Direct the monitoring of the conditions of the forest, wood yields, the custodial chain, the operations and the social and ecological impacts,
9. Natural forests will not be replaced with plantations; rather the plantations must complement natural forests and reduce the pressure over them.

   At a later date, FSC added an additional guideline to include plantation forests in the process of certification (Synnot, 1993; Upton & Bass, 1996).
10. Plantations must be designed and managed in a manner consistent with guidelines 1 through 8.

FSC does not do forest certification itself, but rather is the organization that defines the guidelines for certification and authorizes and licenses other organization to carry out the certification process. When a forestry company complies with the requirements of the FSC, it receives a certification for the management of its forests. Once it has been certified, the forestry company can use the FSC green label on its wood products. It was postulated that the use of a green label would allow the wood manufacturer to command a higher price for its wood products than would those companies in the market that did not have a green label. The following organizations have been authorized by the FSC to use their certification guidelines:

- SGS Silviconsult Ltd. (Oxford, United Kingdom)
- SGS Qualifor[1] (Geneva, Switzerland)
- Rainforest Alliance (Smart Wood), New York, United States
- Scientific Certification Systems (SCS) Oakland, California, United States

There are several steps involved in the certification procedure, including the following (Forest & Trade Asia, 2006):

- Step 1. A forestry company wishes to become certified, anticipating the benefits of better access to markets and a better company image.
- Step 2. The company contacts a certifying organization which makes an initial visit to the forest properties to evaluate the feasibility and cost of certification. An initial report is made. At the same time, the company can contract an independent assessor to make the initial valuation and develop an action plan for improving its forest management procedures and adjust them to the requirements necessary for certification.
- Step 3. The company decides to make a total evaluation with a group of specialists in forest management, social services and environmental conditions. The results of the evaluation are written in a certification report and reviewed by independent persons. The report recommends one of four alternatives for the entity that is requesting certification.

1. Certification without conditions.
2. Certification, but subject to preconditions.

3. Certification is granted with the condition that some corrective actions be taken.
4. Certification is rejected.

- Step 4. The certifying body evaluates the report and, if it is positive, defines a time period for the implementation of the preconditions or corrective actions of the company to be certified. Once there are positive results, a certification contract is signed which defines the responsibility of both parties, the area that is certified, and the duration of the certification (normally for a period of five years).
- Step 5. If the forestry company wants to obtain the rights to use a green label to authenticate its forest products, the company or its clients (buyers) must make an evaluation of a chain of custody (i.e., a history of the handling of the wood products), in order to assure an adequate and reliable mechanism between producer and the final consumer and to certify that the wood originated within the certified forest.
- Step 6. Periodically, the certifying agency makes visits to the forestry company to monitor its forests, the visits normally being once a year.

There are other agencies that certify forests and/or forest products:

- **Pan European Forest Certification Council (PEFC),** The purpose of the Pan European Council is to incentivate the European private forestry sector; define standardized management processes, certify the chain of custody and to grant green labels for specific products.
- **International Standards Organization (ISO)** assures the manufacturing quality and the integrity of the environment. The ISO does not have specific guidelines for forest management, but recognizes forestry related activities within its specifications ISO 14001 and ISO 14004. The ISO does not certify the chain of custody nor does is it grant green labels for forestry products.
- **Canadian Standards Association (CSA) & Sustainable Forest Management System (SFM)** focuses primarily on Canadian industries. The Association is voluntary. Each organization makes its own certification and standardization of forestry activities. There is no chain of custody nor a green label offered for specific products.

- **Sustainable Forestry Initiative (SFI)** deals primarily with North American forestry industries in the USA and Canada. SFI is an initiative of the forest products industry, developed by the American Forest & Paper Association. The SFI focuses on the quality of forest management with third party auditing as an option. There is no chain of custody nor does the SFI offer green labeling for specific products.
- **American Tree Farm System (ATFS)** works with North American forestry properties. ATFS defines forest management systems for individual landowners. It does not certify a chain of custody nor offer a green label for specific products.
- **Lembaga Ekolabel Indonesia (LEI)** works with the Indonesian forest industry. It is an initiative of the Ministry of the Environment to give national accreditation to certifying agencies. LEI works with the FSC to label wood products.
- **Malaysian Certification Council & National Timber Certification Council (NTCC)** works with the Malaysian forest industry. It is an initiative of the Malaysian Government. The Council standardizes guidelines, and produces a certification for the chain of custody so that green labeling can be applied to wood products.
- **Helsinki Criteria (Pan European Process)** is a standardization of forest products ratified by the Forestry Ministries of 14 European countries. Its focus is on the European forest industry.
- **Montreal Criteria** is similar to the Helsinki Criteria, but with its main focus on the Canadian forest industry.
- **ITTO Guidelines for Sustainable Management of Natural Tropical Forests** works with members of the International Timber Trade Organization (ITTO) with respect to wood products derived from the natural forests in tropical countries.[2] ITTO does not certify a chain of custody nor does it offer green labeling for specific forest products.
- **African Timber Organization (ATO)** works with the 13 member countries in Africa. It standardizes forest management practices, but does not certify a chain of custody nor does it offer green labeling for specific forest products.

There are additional initiatives for forest certification in other countries, including those of Brazil and Ghana (Atyi & Simula, 2002).

In January, 2002, the total area certified by all certification agencies was 109 million hectares, with 54% of this being in Europe, 38% in North America, 3% in South and Central America, 3% in Africa, and 2% in Asia and the Pacific (Atyi & Simula, 2002). The FSC accounted for 19% of the certification in developing nations.

Approximately 7% of the world's forests were certified in 2006 (UNECE/FAO, 2006). The two organizations with the most area certified were the FSC with 28% and the PEFC with 26% of the world's forest certification (Davis, 2007).

The impact of forest certification efforts with respect to the certification of the natural forests of the tropics has been quite low. Just 6% of the area certified has been in the tropics (Sarre & Buang, 2002). Ninety-two percent of the certification has been in the industrialized countries: United States, Finland, Sweden, Norway, Canada, Germany and Poland. Only four tropical countries had more than 100,000 ha certified in 2002: Bolivia, Brazil, Guatemala and Mexico (Atyi & Simula, 2002). There have been criticisms of forest certification, including the fact that the standards are too high for many tropical forestry companies to meet and that the standards are too inflexible (Sarre & Buang, 2002).

In spite of the good intentions of certification, it still remains a point of international political contention. Certification is a mechanism related to the marketing of wood and many countries feel that it can affect the competiveness of their industries and their access to international wood markets. In practice, the results of certification are not all that influential with regards to the pricing of wood products. In public surveys and polls in consumer nations, the public often says that it is willing to pay more for certified wood, but when it comes to selecting certified products selling at a higher price over non-certified products at a lower price, many other factors are considered more important than certification, including the quality and price of wood products (Forsyth *et al.*, 1999).

One of the challenges to wood products certification is defining with reasonable certainty the chain of custody. Normally the wood produced in a sawmill or plywood mill passes through the hands of several middlemen before arriving to the consumer. For example, China is known to import wood of questionable sources from Russia and Indonesia before it is then converted into export products (Stone, 2006). Even if the activities and processes of the Chinese wood manufacturers are certified, there still

remains the uncertainty of the value of certification as a means for protecting the natural forests from which the wood was obtained.

There may be several levels of certification according to the national and international wood marketing legislation and there may be several certifications of origin on a piece of wood, some for manufacturing processes, and others for forest management. If, for example, a final product is a piece of furniture, and it has several seals for certification during the different phases of its manufacture, the consumer may be confused as to what all the seals mean. This continues to be an obstacle to the consumer, who may not be well informed as to the significance of the different certification seals.

There are ecological institutions that are not in agreement with the certification of tree plantations (Lang, 2006). It is troubling to such groups that there are increasing numbers of tree plantations being certified. There are groups opposed to the inclusion of the #10 Principle of the FSC that allows for certification of tree plantations, saying that plantations really are not forests (WRM, 2001). They argue that plantations are the result of deforestation and the degradation of ecosystems, particularly in the case of natural grasslands which are converted to plantations and swamps that are drained to make them productive for tree plantations.

The certifying agencies are under much pressure by ecological groups to not certify tree plantations where any chemicals are used during the management process, such as herbicides for weed and grass control, and insist that the certifying agency recommend the use of native species, not introduced (exotic) species. There are further pressures not to authenticate management methods that include clear-cutting. The result of all this is that all too often the review of a forest management company includes requirements to not use any type of herbicide in the management of its plantations and to use only local, indigenous species, even though these may not have been shown to be profitable by testing in research studies.

Besides the pressures applied by environmental groups to include absurd requirements for plantation management, the inspections of forest properties are not always carried out by persons with the necessary experience to make a qualified evaluation and audit in a totally professional manner. The evaluation of forestry operations requires persons with much experience in the fields of interest, in the species and in the particular conditions of management in a region. When the persons employed by the

certification agency to make the field evaluations are young, recent university graduates, they may have the best of intentions and the desire to work in the field, but may lack the needed experience and operational know-how to make a qualified evaluation. However, such people may be more disposed to doing this type of work which requires travel and time away from home and who may also work for lower salaries than persons who have more experience. Thus, the certifying agency is under pressure to contract younger persons with lesser levels of experience in order to maintain lower costs and to compete with other certification agencies, when, in reality, the inspectors that make the evaluations need to be those persons who have many years of experience in the fields of endeavor under scrutiny.

A certifying agency evaluated plantations of a client in South America. The plantations were primarily composed of teak and yellow bambu (*Bambusa vulgaris*), both species being originally from southern Asia. Although there was no mention of other (native) species in the evaluation report, the conclusions of the report recommended the use of native species including guadua (*Bambusa guadua*), a local bamboo species. The report did not justify the recommendation to replace teak, a species with good commercial value and good growth with other, unspecified, native tree species. Another problem with the recommendation was that guadua is a species that is very demanding of site characteristics, which grows well along the banks of streams or rivers, but does poorly on upland locations such as those where the client was planting bamboo. Experience elsewhere with the planting of guadua has generally been mediocre to poor. Obviously, the person making the evaluation was not an expert in the bamboo species recommended nor in their environmental requirements for growth.

A certification agency evaluated plantations of melina (*Gmelina* arborea) for a client in South America. The objective of the plantations was to produce wood for solid wood products. The use of the herbicide, glyphosate is considered to be essential for the initial management of such plantations to control the very aggressive competition of commercial grasses, weeds and vines. Past experiences in that particular region with the planting of trees without the use of herbicides were disastrous, with the trees growing crooked and being pulled to the ground by the weight of vines that climbed on them, as well as the abundance of grasses and weeds that competed for moisture during the dry season. The importance of the use of herbicides during the first years of plantation establishment had been clearly proven by the forestry company. Nonetheless, one of the conditions of certification was to totally eliminate all use of herbicides in the plantations, this without justifying the reason for making such a recommendation. Glyphosate is among the least noxious of chemicals (see the chapter on Silviculture for details of the toxicity of chemicals). In order to comply with the requirements for certification, the company abandoned its use of herbicides and the subsequent plantations were a disaster. Eventually, after seeing the failure of its plantations without the use of

herbicides, the company decided that it was better to use herbicides and produce commercial wood than to be certified and lose its plantations!

A company in South America received certification and the use of a green label on its lumber products due to its sustainable management of natural forests. The company had a 500,000 ha concession of natural forest and, according to information in its brochures, the forest had an average of 45 m3/ha of wood of commercial sizes and species. Of this total, the company would cut just 25 m3/ha, or 56%, during selective cuts, leaving the rest standing to grow and, hopefully, to produce enough wood to allow for a later return to the same locations for another selective cut in the next 30 years. The management plan was certified by a well-known international certifying agency.

Given the fact that the volume of standing timber will vary among sites and that not all of the area has the same volume per hectare, it would be necessary to make adjustments to the selective cutting methods according to the amount of wood to be left standing and in good condition after each cut. In the company mill offices, when the managers and foresters of the company were questioned as to how the process of inventory and monitoring was done to comply with this stipulation of certification, the author did not receive a satisfactory reply. Later, during a visit to the forest, we ran into a crew making a pre-harvest forest inventory. The author asked the vehicle to stop and went to talk to the inventory crew. The crew leader was asked about the procedures used and how he determined which trees were marked for cutting and which were to be left standing. The reply was the most simple that can be imagined. His reply was: “Look, here in my hand I have this wooden club. I hit the tree and listen to the sound. If the tree sound is solid, I measure it and mark it for cutting; if the tree sound is hollow, I don’t mark it and I leave it standing.” What unimaginable scientific technology was being applied to the sustainable yield of that forest!

Obviously, the persons who certified the management of that forest did not visit the forest and inspect how the work was actually being done in the field; or still worse, they may have known about the inventory and selection process, but didn’t tell their boss.

International banks normally request forest certification as a requirement for making loans, since the banking industry has been severely criticized by environmentalists for making loans to projects that are not ecologically sound. Certification of companies by the ISO is considered valid for many banks, even though it is a self-evaluation, not an independent certification by an outside agency. Without a valid certification, the company is unlikely to obtain the loans it is seeking.

Forest certification is still a relatively new concept. Although it still is not a process that is totally efficient and functional, it will, without doubt,

be a process that will continue into the future and forestry companies will need to certify their plantations and their management procedures for several reasons, including that of obtaining loans and for the green labeling of the products they sell. The participation of the forest industry in the process of developing and modifying the standards of certification is crucial. It is important that the managers and administrators of forestry companies and associated wood products manufacturers participate in discussions regarding the formation and revision of the processes of certification. Without such participation, there exists the real risk that certification will evolve into a negative tool manipulated by environmentalists and anti-industrial organizations, in which case the concept of certification will eventually lose its validity and purpose.

[1]SGS is the *Societé Générale de Surveillance*.

[2]The International Timber Trade Organization has its headquarters in Yokohama, Japan.

11

Forest research

Perspectives
Efficiency versus effectiveness
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How to calculate the total area of a study
The concept of check plots in field studies
Volume measurement in growth studies
Uses of regression analysis in forest research
Effective communication of information generated by forest research
Format for a research working plan
Format for an establishment report
Format for a research report
Annual research goals
Field guides
Annual forest research report

Perspectives

The product of industrial forest research is the information generated which can help operational managers to increase forest productivity and the quality of tree plantations, as well as to reduce the cost of forest management.

Forest research is an absolute necessity when working with introduced species and when beginning industrial plantations where there has been no previous experience with reforestation (Zobel *et al.*, 1987). Besides having the potential to increase plantation production, many companies justify forest research as a mechanism or tool for reducing the risk of losses, such as those that occur when planting species or provenances that are incompatible with a given site, or planting species that do not have

acceptable wood properties for the manufacture of the desired wood products (Burley & Wood, 1971).

In other words, besides searching for methods to improve plantation productivity and quality, research personnel must also be aware of the real or potential dangers that can occur due to diseases, insect attacks or damages by other agents that can affect the plantations or the quality of the wood products derived from them. Forest research studies can be designed to define optimum management parameters, such as the best species to plant, the best provenances of those species for the local environment, the needs for fertilization as well as other aspects. Additionally, researchers must keep up to date with respect to problems that occur in similar plantations in other parts of the country as well as in other parts of the world by maintaining good communications with research colleagues in universities, government forestry institutes and in other forestry companies.

It is indispensible for research personnel to have time and opportunities to keep updated regarding biological, genetic and ecological happenings in forest science by reading publications in these fields, by attending meetings and symposia and by maintaining good contacts with colleagues outside of the company. In this way, research can be justified as a type of “insurance policy” against risks and losses in the forest. The concept of industrial cooperatives is a mechanism for achieving this. Universities and companies that collaborate in cooperative research have clearly demonstrated the advantages of such collaboration and the importance of the interaction of forest scientists. This runs contrary to the traditional concept of “closed doors” common in many industries and where all information is proprietary. The magnitude of the achievements of forest research is, in reality, of a global scale. The most successful forestry companies are those that understand the importance of this collaboration of their research personnel with other scientists outside of their own organization.

In the long run, a research unit must “justify its existence” by increasing the income and profit of the company by an amount greater than the cost of the research investment. The key to the success of research is to contract a research manager who has knowledge of statistical design and computer analysis and who has the ability to write technical reports. In the majority of companies that have an effective research group the director of research is a person with a postgraduate degree in forest genetics, either at a level of an M.S. or a Ph.D., and who can communicate in English, the

scientific language most commonly utilized for international communication with other research personnel and research organizations.

Tree improvement is an investment that can produce gains in the growth and quality of plantation trees (Penty *et al.*, 2005). In the tree improvement of *Pinus taeda* in southern United States, there have been gains of 8% to 12% in the harvestable volume of wood through just one generation of tree selection. There have been additional gains of 28% and 60% in harvestable volume after two and three generations of tree improvement (Wier, 1996). Besides the volume gains, tree straightness has improved by 27% (Wier, 1996). In New Zealand, increases in the volume of *Pinus radiata* have been achieved on the order of 15% to 34% (Carson *et al.*, 1999). In Australia, hybrids produced between *Pinus elliottii* and *P. caribaea* var *hondurensis* have resulted in growth gains of 10% in Queensland, when compared to the growth of the individual species (Rockwood, 2000). In China, genetic research with eucalypts is producing very promising growth gains with internal rates of return (IRR) of between 35% and 40% (van Buren, 2004).

In a small company that lacks the budget for a research director, an alternative is to contract a forestry professional from a local university who can work as a technical advisor responsible for directing the forest research within a company. For this to be effective, there must be personnel dedicated to research within the company who will carry out the instructions of the technical advisor.

In many countries there are research cooperatives that provide technical research support to companies and government institutions for the benefit of all members. Such cooperatives have had great success in the area of genetic tree improvement. The advantage of a cooperative is that a core group of scientists can process information from many sites and generate results more effectively and economically than can a company or individual institute working on its own. The forestry cooperatives have shown that the exchange of information among companies, even large companies, produces benefits and profits for all. Experience has shown that it is much more to the advantage of a company to exchange technical forestry information with other entities, both public and private, than to attempt to keep all information secret within a particular organization. This is because of the magnitude of the effort required to develop genetically improved material along with the processes required to increase forest productivity

with such material. The freedom of researchers to attend national as well as international meetings and symposia is very important to the progress of a particular research organization. Congresses and symposia of forest research personnel, where there is an exchange of technical information, can be extremely important to the research effort of an individual institution or company.

Efficiency versus effectiveness

The efficiency of applied and industrial research is measured by the production of useful information that can be applied operationally at the least cost for resources, personnel, land and budget. To produce useful results and to provide increased profits to a company, the researcher must design studies in such a way that they will produce the desired information. There may be a research forester who works diligently and who generates results from studies, but if the results are not applicable to the needs of the company, the effectiveness may still be low. This point is particularly important when dealing with long term growth studies, where decisions made during one year can have repercussions during many years.

The objective of studies is to evaluate variations among tree populations (species, provenances, progeny) and among silvicultural treatments in order to determine the best treatments to be applied to operational plantations. In genetic studies, the differences in growth among different tree populations are studied in order to select those populations of greatest interest for their desirable and useful traits. Such traits are defined at the beginning of a tree improvement program. The most desirable traits that are commonly selected include trees with greater growth in height and volume, wood with qualities that best fit the products to be produced, trees well adapted to particular environmental conditions and those that are least susceptible to diseases and insect attacks. Similarly, silvicultural studies evaluate differences in growth responses to different treatments among the trees being tested, with the objective of developing plantations with the best growth and quality to produce the greatest financial returns to a forest industry.

There will be the best probability of producing quantitative information that can be used to improve the growth of operational plantations when research studies are well designed, well established and well documented and when using designs that are compact in area. In such studies, it is

possible to determine significant variations among treatments in less time and with greater certainty of the results. Once the best treatments (or seed sources) have been determined by research, this information can then be applied to the operational reforestation of large areas so as to increase company profits.

Purposes of field studies

Field studies are designed to:

- Produce information than can be applied operationally,
- Obtain information for the continuation of the research process.

The success of research involves six key factors:

- Make correct and clear definitions of the variables to study and avoid wasting time with studies that are poorly designed,
- Use study designs that are appropriate to providing the desired information,
- Make uniform and precise field installations of studies,
- Make timely measurements and professional evaluations of the results obtained from field studies,
- Document all stages of the research project precisely and clearly,
- Interpret the results of study analyses and write research reports in a timely manner, and in a form that is intelligible to managers who are not specialists in the subject matter; make recommendations for operational application of the results.

Experience has shown that a large number of field studies do not produce useful results due to failures in one or several of the six points mentioned.

The principal weaknesses that cause the failure of forest research studies are:

- Designing studies that include too many variables (i.e., trying to solve all of the world’s problems in just one study),
- Inadequate field identification of plots in the field,
- Lack of adequate documentation of field studies in the research files,

- Not budgeting sufficient time for the analysis of study measurements and not writing the study results in a timely manner in technical reports.

Huge, unmanageable studies with way too many variables will always result in a waste of budget, time and resources. It is much more effective to design several studies, each with a few variables included, instead of putting many variables into just one study. Very complex study designs with very large installations are an indication that the purposes and reasons for the study were not clearly identified at the beginning and that there was a lack of initial planning.

Good marking is key to the success of field studies. It is important to prepare corner stakes for plots and individual tree stakes prior to going to the field to lay out a study. Without proper field marking, there exists a high risk that other persons who were not involved in the initial establishment, but who make subsequent growth measurements, will commit errors in identifying field plots. Even after establishing a field study, it is not unusual to find errors in the documentation when reviewing the field layout on paper and comparing it to the actual markings on field stakes. Without good field marking, such errors will not be corrected and the study will be a total waste. Field marking and double checking of field markings against the layout on paper are fundamental practices for forest research.

Plot corner stakes should be of a material that will last until the end of the study, or at least until the trees grow tall enough to place markings on the trees themselves. In Colombia, the guadua bamboo was found to make good plot stakes when split and cut to one meter lengths and pointed. The tops of the stakes were dipped into orange paint and allowed to dry. When placed in the field, the plot code could be written on the stakes with a large pencil, such as a carpenter’s pencil. To mark individual tree locations in studies, 40 cm bamboo sticks worked well, all with the tips having been dipped in orange paint. When the stakes were prepared, they were bundled into units of 25 and the sticks were bundled into units of 50 or 100 to take to the field. For long-term studies, posts made of resistant woods were made out of rot-resistant woods that were sunk 1.5 m into the ground and cut off at 30 cm above ground so that they would not be of interest to people to remove them and use them for fence posts on their farms. Another alternative for marking plots is to use a thick aluminum paper which is cut

into small tags. The aluminum tags can be marked with the plot code using a ball point pen which makes indentations in the tags and these indented markings will last many years, whereas ink on paper will quickly weather and be lost. Where there are problems with people or animals that may remove the aluminum tags, these can be buried in the litter or dirt around the base of the seedlings. When doing this, use care not to twist the wire tightly that holds the tag and that can later on girdle the tree as it grows (Figure 11-1).

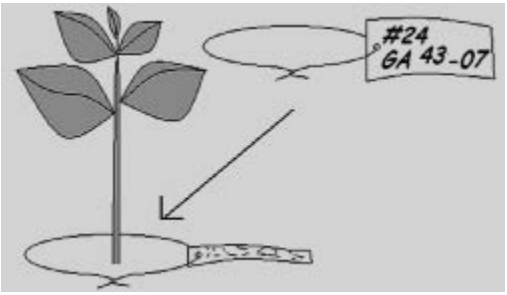


Figure 11-1. A tag made of heavy aluminum paper is fastened with a thin wire that is placed at the base of the seedling, but the wire is connected with a simple bend, not with a twist so that it can open as the tree grows. The tag can be covered with litter or dirt to hide it from view. Later, as the tree grows, the tag can be hung on a branch of the tree.

Documentation of all phases of research is extremely important. Without good documentation of study establishment, there will be losses in continuing studies if there are changes in personnel. A good policy for planning for studies is to suppose that: “Tomorrow, I will not be here,” for whatever reason, maybe there will be a traffic accident, a promotion to a new position, etc. Thus, considering the researchers responsibility to the company and to colleagues, it is important to write each establishment report in such a way that it can easily be understood by others. After writing the report, the writer should reread the report as if he or she were a new employee and is able to locate the study in the field and make required measurements.

A researcher must budget sufficient time for study analysis and for writing research reports of study results. Research studies that are begun, but not carried to their completion have no value. When a researcher is always installing new studies, but leaves measurement data from older studies in the file cabinet without having been analyzed or reported, that person is really not producing any value to the company. The accumulation of data in files and the lack of sufficient time to write reports of results are

cardinal sins of research personnel, and this represent a waste of time, money and salaries paid for research work.

Statistical concepts

A research forester needs to be trained in the use of statistical methods for designing effective studies and be able to analyze the information generated in such studies. Knowledge of the application of mathematical statistics is necessary for the development of a forest tree improvement program. Similarly, it is important that research personnel are trained in computer skills for the evaluation of the measurements of field trials. The use of electronic spreadsheets is fundamental for recording field data and evaluating data and measurements. The use of a word processor is vital for writing technical reports.

One of the most useful statistical parameters is the *average value of a population* which is expressed as follows:

$$\bar{X} = \frac{\Sigma X_i}{n}$$

where $\bar{x}$ = the average, Σ = the sum, Xi = individual observations and n = the number of observations. In other words, the population average is the sum of the individual observations divided by the number of observations.

In a natural population, it is assumed that there will be variations among individuals measured, with an average for all of the individuals. For example, if the heights of all of the trees in a plantation are measured, there will be variations among trees, some taller, others shorter, but there exists an average height for the population. When a sample is taken of some of the trees and the average of this sub-population is determined, it is expected that this average will approximate the average value for the total population. Obviously, the larger the sample measured, the greater will be the probability that the sample average will approximate the total population average.

In normal distributions the parameter most often utilized to describe the variation among individual observations around the population average is called the *variance*, a value that is calculated using the following formula:

$$\sigma^2 = \frac{\Sigma(X_i - \bar{X})^2}{n-1}$$

where δ2 = variance, Ẍ = average, Σ = the sum, Xi = individual observations and n = the number of observations. The variance is the squared sum of the differences of the individuals from the average divided by the total number of observation minus one. The term (n – 1) defines what is known as the number of *degrees of freedom* for the estimated variance.

Another useful parameter is the *standard deviation*, which is the square root of the variance. When the observations or measurements are distributed in a normal curve around the average, approximately 67% of these will be within one standard deviation and 95% of the observations will be within two standard deviations of the average. The measurement of a populations can be described as the population average followed by the standard deviation, in the form:

$$\bar{X} \pm \sigma$$

For example, the average height of 102 trees of *Eucalyptus grandis* is 28 m and the standard deviation is + 4.2 m.

If several random samples are taken within a population, each sample may have an average that is slightly different from the average of the total population. These differences can be expressed in a percentage value utilizing the *coefficient of variation*:

$$C = \frac{\sigma}{\bar{X}}$$

In the example above, C = 4.2/28 = 0.15 (15%). When designing a study or when sampling a population of trees, it is useful to know the minimum number of samples necessary to produce a reliable average. In Figure 11-2, various coefficients of variation are graphed for random samples of a population of heights of *Eucalyptus grandis* trees measured in Colombia. The graph shows that when the samples contain less than 20 trees, the variation among the coefficients of variation is greater than when there are 25 or more trees in the sample.

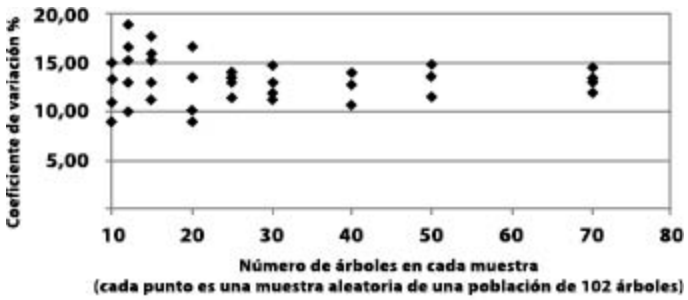


Figure 11-2. Coefficient of variation for height measurements of *Eucalyptus grandis.*

Experience with the establishment of many research trials has shown that when there is a minimum of 25 measurements of tree parameters the trial will produce an average with the confidence of one standard deviation (Zobel *et al.*, 1987). For a greater confidence, 35 individuals can be measured with a population and for maximum confidence 50 to 55 individuals are measured for each treatment. For example, the design of the initial progeny trials of Camcore has a total of 54 individuals per trial variable, with 6 trees per plot and 9 replications per site (Dvorak *et al.*, 2000)

For short term trials, such as a fertilization trial carried for three years or for trials where very large differences are expected among treatments, such as in the case of growth differences among species in an arboretum trial, 25 trees per treatment (or species) would be sufficient. In trials carried for longer time periods or trials comparing very similar treatments, such as variations among the progeny of trees of the same species, it is best to have 50 to 55 trees per treatment to obtain reliable results. The limits expressed by the number of observations or measurements refer to the population within a given site. When the research design includes trials on two or more distinct sites or regions such as on different types of soils, at different altitudes, where there are distinct rainfall patterns or on sites that are on different forest properties, there must be a minimum number of individuals per treatment in each location.

Concepts of field plots

The number and size of plots to use in a research trial will vary according to the subject under study, the expected duration of the trial and the information that is to be obtained from a particular study. There is no one ideal size or form for plots for all types of studies. Generally, plots are established in rows or in area. There are also single tree plots that can be

very efficient, statistically speaking, and they can be useful for genetic selection.

The advantages of row plots are:

- Require fewer trees per plot than do area plots,
- More replications of a treatment can be established within the available area,
- With less area in a study, there normally will be less natural variability in the soils and the site among treatments,
- For provenance and progeny tests, row plot designs allow for the study to be converted into a seed production area or a seedling seed orchard by leaving the best trees of the best provenances or families as seed producers.

The disadvantages of row plots are:

- Trees in rows are not useful for long term studies and the plots lose their effectiveness once the trees begin to close crown, since the competition among trees in different rows distorts the differences among treatments. Row plots are normally considered useful for a maximum of three years under tropical conditions and for fast-growing species such as the acacias, eucalypts or *Gmelina*.
- Row plots do not allow for the development of reliable data on growth yields per hectare; only comparative growth values among plots and treatments can be determined reliably.

The advantages of area plots are:

- Square or rectangular plots can provide reliable information with respect to growth and yield per hectare in long term growth studies,
- The border effect is minimal when border rows are established around each plot and only internal sub-plot trees in the study are used for measurements.
- The disadvantages of area plots are:
- Require large areas to carry out a study,
- Variations within a site increase when studies increase in size due to natural site variations,

- A provenance trial with area plots does not lend itself to conversion to a seed production area.

The advantages of single tree plots are:

- Allow for many more treatments within a given area,
- Site variation within a study are minimized,
- Trial designs with many replications for each treatment are statistically more efficient when determining significant difference among study variables,
- The studies are useful for making selections of plus trees among progeny of families already proven superior in previous studies.

The disadvantages of single tree plots are:

- If a tree dies, the plot totally disappears,
- There is a much higher probability of making mistakes when installing a study with single tree plots due to its complexity,
- Plots do not have any isolation and are only useful for short term studies; the effect of competition among plots begins even earlier than in row plots;
- These plots are used primarily for progeny tests, they are not commonly used for other types of silvicultural studies,
- The information obtained is relative among plots and does not allow for developing information regarding absolute growth rates.

Table 11-1 provides examples of the number of individuals per plot for various types of trials, when taking into account the number of individuals to use per treatment, the plot design and the objectives of the study. The selection of the number of replications depends on the priorities of a particular research group, the availability of uniform sites for establishment of trials and the resources (personnel, budget) available.

Table 11-1

Relationships among types of plots and the number of replications to use for various study designs.

Type of plot	Number of replications	Number of trees per treatment			

Minimum	Good	Optimum	Minimum	Good	Optimum	
square plots (arboretum)						
7 x 7 trees per major plot	1	1	1	49	49	49
5 x 5 trees per interior measurement plot	1	1	1	25	25	25
square plots for long term growth and yield						
10 x 10 trees per major plot	3	4	5	300	400	500
8 x 8 trees/interior measurement plot (spacing)				192	256	320
6 x 6 trees/interior plot (fertilization, site preparation)				108	144	180
rectangular plots (fertilization, site preparation, short term)						
3 x 10 trees/major plot	4	5	6	120	150	180
1 x 8 trees/interior measurement plot				32	40	48
row plots with 10 trees each (provenance tests for a given species)	3	4	5	30	40	50
row plots with 6 trees each (progeny tests for a given species)	5	6	9	30	36	54
single tree plots (progeny tests for plus trees)	30	36	54	30	36	54

Table 11-1 shows the importance of the selection of the type of plot according to the variables being studied (species, provenance, site preparation, spacing, etc.) and the large differences in the number of trees required according to the design of the study.

In an arboretum style species trial, the objective is to observe “macro” differences among species and to select the species that merit further study in the form of provenance or seed source tests. In this type of study there is no need for replications of plots within a site of uniform quality; an arboretum can be established with just one plot per species.

In square plots where volume and yield information is the objective, there must be border rows around the measurement trees so as to create a uniform tree-to-tree competition on all sides. This can be accomplished by planting additional rows around each plot or by defining an interior measurement plot within the larger plot. For example, if there are 7 x 7 trees in the major plot, and one outside row is left as a border, there will be 5 x 5

(=25 trees) in the interior measurement plot. In spacing trials designed to generate yield data, such as for a site preparation test carried to rotation age, it may be necessary to utilize 10 x 10 tree major plots with two exterior border rows, leaving 6 x 6 (=36) trees in the interior measurement plot. In progeny tests in rows, it is necessary to plant two rows of trees of the same species or provenance around the outside perimeter of the trial to maintain a homogeneous competition among trees in all plots. Similarly, when designing tests with single tree plots, outside border rows are required around the perimeter of the study for this purpose.

Borders are also needed when establishing fertilization studies to keep the roots and surface litter in one plot from contaminating adjacent plots. For short term studies, a single border row can be used (Figure 11-3). Because of normal soil and site variations, fertilizer studies usually require a minimum of four replications per site. When a study is to be continued even after crown closure, one option is to subsoil the line between plots so that the superficial roots from one plot do not grow into adjacent plots. Subsoiling can be done with a shovel or similar tool to a depth of 20 cm to cut superficial roots, or, where there is sufficient space, a tractor with a subsoiler can be used to cut a slit to a depth of 50 cm. This technique can be used to extend the life of a fertilizer trial one or two additional years, but when the objective is to generate long term growth and yield information for fertilizer treatments, area plots need to be used with two or more border rows around plots; for example plots of 10 x 10 trees with interior measurement plots of 6 x 6 trees.

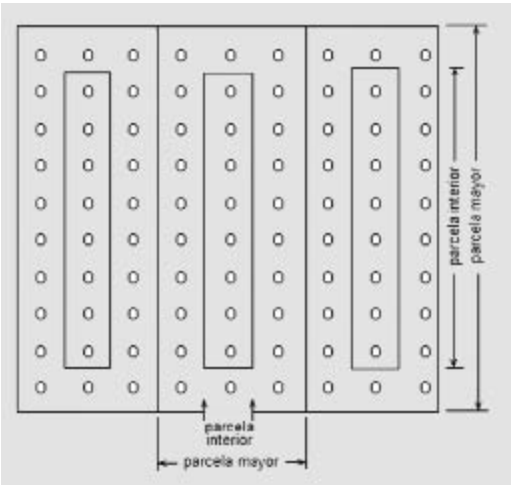


Figure 11-3. Fertilizer plots with a border around each measurement (row) plot.

It is important to have the correct orientation of plots on slopes so as to obtain the desired results and to minimize the effect of slope on the variables being studies. Ideally, row plots should be oriented with the slope and the replications aligned along the contour (Figure 11-4). In the case of site preparation studies, obviously it is not wise to align treatments such as subsoiling, bedding or plowing with the slope, since that would accelerate erosion. In such studies, the site preparation needs to aligned along the contours to minimize erosion.

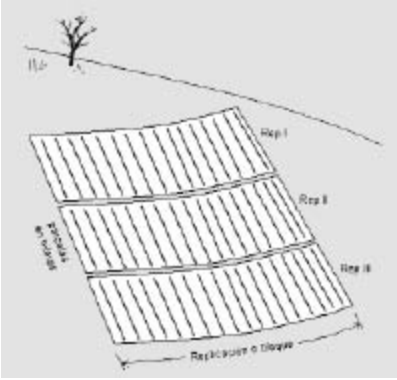


Figure 11-4. When row plots are laid out on a slope, the rows are aligned with the slope and the replications follow the contours.

When making a site preparation study, it is important to leave spaces or aisles between blocks for the tractor and disks or other implements to turn around and to move without causing damages within the plots (Figure 11-5). After terminating all of the treatments that require machine use, the remaining spaces are given a final touchup with a disk so that they are prepared for planting filler trees with the same species that is used within the blocks. These aisles or turnarounds need to be included in the initial design of the study when calculating the area required for establishment of the study.



Figure 11-5. When establishing a site preparation study, leave turnaround spaces between blocks for the movement of the tractor and implements.

Common designs for field studies

The correct design for a study will enable the researcher to obtain the desired results. The analysis of variance (ANOVA) is a mathematical mechanism for evaluating the variations among treatments in a study. The ANOVA evaluates the variation of the treatments against a residual variation (error term) and is based on the *null hypothesis*, which states that there will not be differences among treatments unless the ratio between the value of the squared mean of the treatments divided by the squared mean of the error term is greater than the value of a tabular "F" value for the number of degrees of freedom of the treatments and of the residual. With more replications of the treatments within a study, there will be a greater number of degrees of freedom for the treatments and this will result in a greater mathematical sensitivity. The different study designs are explained in detail in several texts (Freese, 1970; Cochran & Cox, 1957; Snededcor & Cochran, 1967). When designing studies with various treatments, it is always important to place the plots randomly within a replication or a block.

Unreplicated plots on a uniform site

This design has no replication and has no analysis of variance. However, it is a good design to use for species studies in the form of an arboretum.

Randomized complete blocks

This design is commonly used for forest research trials. It is simple but good for evaluating differences among diverse treatments.

Example: Test three provenances of *Pinus oocarpa* with four replications:	
ANOVA	
Source of variation	degrees of freedom (df)
blocks or reps.	3
treatments	2
residual (error)	6
Total	11

The degrees of freedom for the treatments (provenance) is the number of treatments minus one in simple designs. The total degrees of freedom is the total number of plots minus one. This design requires that there are uniform site conditions within each block, but the conditions among blocks

can vary. A block can be separated from the others to avoid non-uniform site conditions.

Randomized complete blocks with subplots or split plots

This design is utilized when one treatment is nested within another treatment. It is often used to evaluate site preparation treatments that require large plots prepared with tractors or where there are tests of controlled burning. Then, smaller plots are established within the larger plots, such as different species or different fertilizer treatments.

Example: Test two site preparation treatments (A, B) with three species (1, 2, 3) and with three replications or blocks. The site preparation treatments are the major plots (A & B), while the species are the minor plots (1, 2 & 3).

ANOVA	
Source of variation	df
blocks	2
site preparation	1
residual, major plots	2
species	2
species x site preparation	2
residual, sub-plots	8
Total	17

The residual for the major plots is the difference between the total of the major plots minus one (6 – 1), minus the degrees of freedom for the replications (2) and for the treatments (1), or: 5 – 2 – 1 = 2. The analysis for the minor plots includes an interaction term between major treatments (site preparation) and minor treatments (species) with the product of the degrees of freedom for these two, or 2 x 1 = 2. The residual for the sub-plots is the difference between the total (18 – 1) and the other degrees of freedom: 17 – 2 – 1 – 2 – 2 = 8.

Latin squares

This is a design where the number of replications is equal to the number of treatments and each treatment appears in each column and each row of the design. It is a strong design and useful when there is a small number of treatments, such as for a site preparation or an operational fertilizer study. The study should be located in a homogeneous site so that the design can be laid out with the plots occupying their respective places within the plan. The design has two variables to eliminate environmental effects in the

analysis: columns and rows, whereas a similar design with randomized blocks only has one variable for eliminating environmental effects. For this reason, the Latin squares design is good to use for determining growth and yield among treatments in long term studies.

Example: Test four site preparation treatments with four replications.	
ANOVA	
Source of variation	df
columns	3
rows	3
treatments	3
residual (error)	6
Total	15

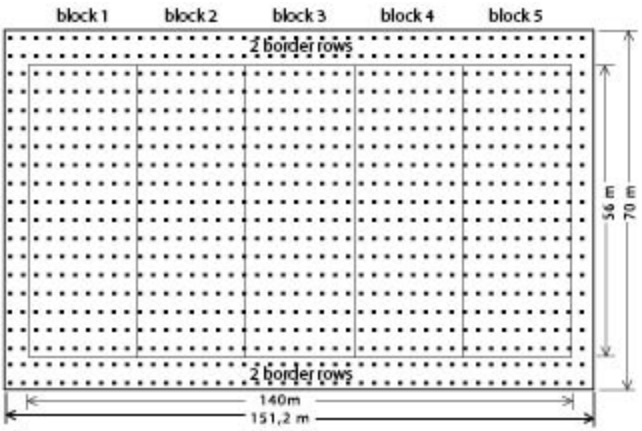
A double Latin square can also be used with two blocks. This gives greater statistical strength. In the above example, the double Latin square has the following analysis of variance:

ANOVA	
Source of variatio	df
columns	7
rows	3
treatments	3
residual (error)	18
Total	31

Randomized complete blocks on more than one site

When a study is established on more than one site, it can be analyzed as a unit, treating it as a randomized block design with sub-plots. In this case, the sites are treated as replications, the blocks as treatments and the treatments as sub-plots.

Example: Establish a study on three different sites with five replications per site and with 16 provenances of *Eucalyptus urophylla* in row plots with 10 trees per plot and with two border rows around each site. Spacing between rows is 3.5 m and within rows is 2.8 m.		
Source of variation df		calculation
sites	2	(s-1)
blocks within sites	12	(b-1)s
provenances	15	(P-1)
sites x provenances interaction	30	(s-1)*(P-1)
residual (blocks x prov. x sites)	150	(b-1)s*(P-1)
Total	239	



0Factorial experiments

Factorial experiments make possible the analysis of differences among individual treatments when interactions are suspected. Factorial experiments are commonly used within randomized complete block designs to analyze differences among chemical elements in fertilizer trials. The concept is that each treatment variable is represented with each other treatment variable. The following example shows a study with three levels of nitrogen (N) and two levels of phosphorus (P). This design allows for the statistical analysis of possible interactions for each combination of N and P.

When attempting to include more treatments and more variables in each treatment, the size of the study can quickly become extremely large. The researcher must recognize this and avoid falling in the trap of creating studies that are too large and difficult to handle efficiently.

For example, to evaluate four levels of N and three levels of P and to also add two fertilizer application methods (in bands or in holes beside the seedling), the design would be 4 x 3 x 2 = 24 plots/block. With three replications there would be 72 plots to establish on a site. In such a case, it would be better to design more than one study to evaluate the variables of interest.

Alternative: The study could evaluate the effect of fertilizer placement with one level of N and one level of P. In the tropics many soils can have deficiencies in available phosphorus and there is considerable literature showing the importance of applying P when applying N (Ballard, 1984; González, 1993; Ladrach, 1978a; Kane & Ladrach, 1995; Von Christen, 1980). Therefore, the size of the study could be reduced even more by making a study of the interaction of two levels of P with three levels of N. Instead of 72 treatments, there would be:

Trial 1: two levels of fertilizer placement with one level of fertilizer 100g N + 50g P = two plots.

Trial 2: three levels of N (0, 25, 100 g/tree) and two levels of P (50 and 100 g/tree) = (3 x 2) = six plots.

Thus, with eight plots per replication (instead of 24 plots/replication), most of the desired information concerning levels of N and P as well as the effect of fertilizer placement could be obtained with a total of 24 plots instead of 72, i.e., with one third of the plots. With two smaller studies using a factorial experiment, less area is required to install the studies. This reduces the risk of undesirable within-site variation within a study replication. Additionally, the study could be designed with more than three replications of a randomized block design per site, which would provide for greater statistical sensitivity for the treatments under study.

Example: Test three levels of nitrogen and two levels of phosphorus with three replications per site.		
N levels:	0, 25 & 100 g N/tree at time of planting	
P levels:	0, 50 g P/tree at time of planting	
Trees	10/treatment in row plots with one border row around each row plot	
Replications	3/site	
Total	18 plots/site	
Plot no.	Treatment	
	N	P
	g/treel	g/treel
1	0	0
2	25	0
3	100	0
4	0	50
5	25	50
6	100	50

This example shows the importance of reviewing the technical literature on the subject of interest prior to designing a field study to avoid installing plots with low priority variables and wasting time with measurements and analyses of data which would have little possibility of supplying any added value. The time utilized by reading technical reports and reviewing the available literature in the library is time well spent by research personnel. *There is no need to reinvent the wheel.*

Heritability analysis of a progeny test with multiple factors

When making an analysis of a randomized block study on one site, the analysis of variance is made for just one factor: treatments. To evaluate the heritability of a progeny test with several families, the analysis of variance is made for individual trees within each plot (family), as well as the variation among families; this is called an analysis of variance for two factors. When making an analysis of heritability for a progeny test established on more than one site, this then becomes an analysis of variance for three factors: variation within families, variation among families and the interaction between families and sites.

A three factor analysis allows for the evaluation of the interaction between the genetic component and the site component, which is termed the genetic x environmental interaction. When designing an analysis of variance for more than one factor, the researcher needs to understand quantitative genetics, a branch of advanced mathematics. The heritability estimates are useful for determining which factors being studied are more controlled by the genetic component of the individuals and families (progeny). In a progeny test of *Pinus patula* in Colombia, the following heritability estimates (h2) were determined for seven-year-old trees (Ladrach & Lambeth, 1991):

Parameter	h2
Total height	0.80
Total volume	0.86
Bark volume	0.83
Bole straightness	0.61
Bole forking	0.46

These heritability values are considered high and are due to exceptional differences among the tree populations tested, as well as the installation of trials on very diverse sites, one at 2500 m altitude, the other at 3050 m. Normally the heritability values are no greater than 0.25 for height, volume or straightness, as well as traits such as bole forking (Camcore, 2004).

The heritability estimate for a family is the percent of variation measured in a study at a given age that can be attributed to additive genetic variation among families. Heritability is a mathematical calculation of a particular study; it is not an absolute ratio for a species, provenance or family. The heritability can vary for different ages of the same study as well

as for different studies. Heritability also depends in part on the size of the study, i.e., the number of degrees of freedom for each factor.

Using time as a variable in studies

When planting a study, all plots and border rows should be planted at the same time, ideally within the same day or week. If some plots are planted months later than others, this will create unwanted variation within a study and can even produce erroneous results. For example, if a study is planned to test 15 provenances of a species, but only 12 of the provenances have seedlings ready in the nursery to plant, the study must be redesigned to include only 12 rather than 15. This may seem obvious to some researchers, but there have been provenance and progeny tests planted following initial designs when there were insufficient trees of some families for inclusion in the initial planting. The remaining families were then planted the next year to complete the design, incorrectly, instead of modifying the design so as to use the material available in the nursery. Such errors in study establishment introduce variables that make growth results and the statistical analyses invalid. Another common error is to plant a study, but to delay planting the border rows for six months or a year after planting the body of the study, and this creates unwanted variation due to non-uniform competition effects for trees along the border rows.

On the other hand, time can be used as a replication in a study, if it is part of the initial design. When a study is replicated in different years, the effect is similar to replicating the study on different sites. The key is to replicate a complete design in time as would be done on another site. For example, a progeny test could be planted one year and the same test planted a year later, so that the effect of climate variations between years can be analyzed as would be the planting on two different sites.

Time can also be used as a treatment variable within certain types of studies. For example, a study may evaluate fertilizer applications at time of planting as one treatment with another treatment having fertilizer treatments at time of planting plus an additional application at six months (or one year) of age. Similarly, a study may have herbicide control of grass and weed competition applied at different times as variables in a study to determine the optimum time(s) of herbicide application for operational planting. One treatment may have herbicide applied prior to planting only. Another treatment may have herbicide applied prior to planting and again at three months after planting.

In a thinning trial to determine the optimum time for thinning to maximize sawtimber production, one treatment may have a pre-commercial thinning of teak at three years of age and a second commercial thinning at seven years of age. Another treatment may have an initial thinning at six years of age and another thinning at 10 years of age, etc. These variables are contemplated in the initial design of the study and are applied at the proper plantation age to determine optimum thinning regimes for sawtimber production.

How to calculate the total area of a study

Before beginning a study, it is important to calculate the area that it will occupy to determine if there are available areas of the required size in the field and also to get an idea of the size of the work to be undertaken. This determination will provide an idea of the resources required (personnel, budget and materials) for installing and maintaining the study. At the same time, the amount of seed and the number of seedlings required need to be calculated for the proposed study.

If it is found that the study is too large, then the design can be modified and reduced to an acceptable size. As has already been mentioned, it is always better to make several small studies than one global study that contains too many variables.

The study area includes the area of the treatments, non-utilized areas within the study and the borders around it. For purposes of this exercise, let's assume that there will not be any unused spaces within the area of the proposed study. In the example shown above of a randomized complete block design with 16 provenances of *E. urophylla* on three sites, the area that the study will occupy can be calculated as follows:

Spacing: 2.8 m between trees x 3.5 m between rows =	9.8 m2/tree
Planting density = 10,000 m2 /ha divided by 9.8 m2 =	1,020 trees/ha
Trees per row plot =	10
Number of provenances per block =	16
Number of blocks per site =	5
Thus, the study area on one site = 9.8 x 10 x 16 x 5 =	7,840 m2
The length of the study is: 16 provenances x 3.5 m =	56 m
The width of the study is: five replications x 10 trees/treatment x 2.8 m =	140 m
(Confirmation: 56 x 140 = 7840 m2)	
The total area of a site with borders is calculated as:	
56 m + (4 border rows x 3.5 m) =	70 m long

140 m + (4 border rows x 2.8 m) =	151 m wide
Area = 70 x 151 = 10570 m2 =	1.06 ha/site
Thus, the total study area on three sites = 1.06 * 3 =	3.2 ha
For one site:	
The number of seedlings required per provenance is: 10/row x 5 blocks =	50 trees
The number of trees required/site-study is: 15 x 16 provenances =	800 trees
The number of trees required for borders per site is: (1.06 ha – 0.78 ha) * 1020 =	286 trees
For the total study:	
The number of trees required per provenance is: 50 x 3 =	150 trees/provenance
The number of trees required for borders is: 286 x 3 =	858 border trees
The total number of trees for the entire study is: (50 x 3 x 16) + 858 =	3,258 trees

In the nursery, it will be necessary to produce more trees per provenance than the minimum, in order to be able to make a selection of the most representative seedlings of each provenance. Thus, there should be at least 10% more trees per provenance so as to have sufficient for the study. The extras can be used in the border rows. If we assume the seed viability in the nursery to be 70%, the following amounts of seed will be required for each provenance:

(150 trees/provenance x 10%) / 70% = 165 seedlings / 0.70 =	236 seeds/provenance

In this way, it is possible to calculate how much seed will be required for the study and it there exists sufficient seed for the anticipated needs of the study.

The concept of check plots in field studies

Check plots need to be included in each study for comparative purposes. The check can be of several types: an operational check, a zero check, a minimum check or an optimum check. When planning a new study, it is a good idea to review the design to determine if the proper checks have been included.

Example: Ten provenances of *Gmelina arborea* are being studied, along with one lot of seed from a local seed stand that is being used for commercial plantations. The seed stand seed is included as an additional plot, making a total of 11 seed sources per replication. This is a commercial or operational check. It allows us to quantify the growth of the provenances being tested in comparison with the currently used seed source.

Example: Current site preparation for planting is done by clearing or scalping an area of sod and making a hole in the middle where the seedling is to be planted. When making a site preparation test of bedding, subsoiling and bedding plus subsoiling, the manual site preparation with the scalp and hole is included as an operational check in order to evaluate the advantage (or disadvantage) of the treatments being studied.

Example: A fertilizer test is being made using nitrogen, phsophorus and boron at time of planting. There is currently no fertilizer being applied to commercial plantations. A check plot is thus an area without fertilization, which, in this case is an operational check as well as a zero check.

Example: We want to test different planting densities. The operational density is currently 1300 trees/ha (2.5 x 3.0 m). The study proposal is to test planting densities of 1100, 1000 and 950 trees/ha to determine if teak will produce large trees for sawlogs with lower initial stand densities. The commercial check is thus 1300 trees/ha. A minimum check may also be useful to include, for example, 750/ha. Thus there will be five planting densities tested: 1300, 1100, 1000, 950 y 750 trees/ha. The reason for including the minimum check is to gain time. Let's suppose that the 950 trees/ha density turns out to be the best after 20 years of study. Then the question becomes: Could it be better to plant even less than 950 trees/ha? With the minimum check of 750 trees/ha, there will be an indication of the effect of a lower density than those being considered. Without including the minimum check, it would be necessary to go back and make another test to study lesser densities and wait another 20 years for the results.

Volume measurement in growth studies

The three most important variables to measure in growth studies are total height, diameter (DBH) and survival. The researcher makes an analysis of each variable to determine the average and the standard deviation. Unfortunately, it is uncommon to find reports that show the growth of young trees in terms of total volume per plot or per tree, even though volume is much more sensitive in an analysis than are height, diameter or survival separately. Let's take the example of the volume of a geometric cone: when the diameter of the base and the height are doubled, the volume increases by eight times (Figure 11-6).

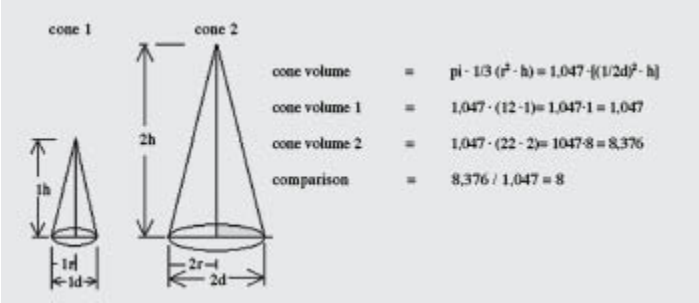


Figure 11-6. Comparative volume of two cones.

Trees do not have the exact form of a cone, but the ratios of tree diameter and tree height are similar. The following example demonstrates the relationship of height, diameter and volume:

Parameter	Tree A	Tree B	Difference %
Diameter, cm	5	6	20
Height, m	5	6	20
Volume	0.00375	0.00648	73

In studies with very young trees, the diameter is measured as soon as the tree has sufficient height to have a DBH, i.e., when the tree is 1.5 m tall, it has sufficient height to measure the DBH at 1.3 m. Of course, if the tree is less than 1.3 m tall there is no DBH and, therefore, tree volume is not calculated. An analysis of variance of tree volumes in plots with different treatments will have a greater probability of indicating significant differences among plots at early ages than an analysis of height or diameter separately. However, it is still useful to make a statistical analysis of all three parameters.

Survival can also be included in the analysis of volume differences among plots and treatments. First, make an analysis of variance of survival to determine if there are significant differences in survival among plots. Before evaluating survival statistically, it will be necessary to transform percentage values because survival does not follow a normal distribution. [1] The method most often utilized for transforming survival values is the arc-sine distribution. A table of arc-sine transformations can be found in many statistical books (Freese, 1970; Snedecor & Cochran, 1967). If the analysis of variance for the transformed survival values is significant, then the total volumes of plots are used for the analysis of variance of plot volume, in order to include survival in the analysis. However, if the analysis of variance for the transformed survival values is not significant, the average volume of trees in a plot is used in the analysis of variance so as to not include the factor of survival.

The total volume of young trees of similar sizes varies very little among species, due to the fact that the form of all young trees is quite similar. There actually exists the danger of creating artificial differences among species by using different volume formulas due to intrinsic differences among formulas, especially when the formulas were created for commercial

trees, not for very young trees. A volume formula for young trees that was developed and can be used with all young species is:

$$V\ m3 = 0.00003\ D2H$$

Where volume is in cubic meters, DAP (D) is in centimeters and total height (H) is in meters (Ladrach, 1998a). This formula is useful for calculating the volume overbark for trees up to approximately 15 m height and 17 cm diameter.[2]

To calculate the volume underbark, the trees are measured with bark in research plots and, then, a sub-sample is taken to measure the bark thickness of some trees, either using a commercial bark gauge or by removing a small 1 x 1 cm square of bark near DBH with a sharp knife and measuring the depth to the cambium with a milimetric rule. The volume underbark is calculated using the DBH measurement less two times the bark thickness to calculate the diameter at breast height underbark and using this value as (D) in the formula. Of course, by definition, DBH continues to be the diameter at breast height overbark.

Uses of regression analysis in forest research

A research forester requires training in the use of regression equations and to know how to apply them to forest measurements. Regression analysis is a valuable statistical tool for making comparisons among two or more variables as well as for developing formulas that represent such ratios. They are often used to make comparisons among field populations and to predict relationships among populations.

Regressions are utilized for developing tree volume and weight formulas and to generate forest yields. Normally, volume (or weight) formulas use tree height and DBH as the independent variables and volume (or weight) as the dependent variable. For yield calculations, independent variables can be the tree or stand age, the number of trees standing, the site index (site quality) and other factors such as basal area. The researcher tries to determine those relationships that best adjust to the independent and dependent variables and to evaluate the regression fit through an analysis of variance among variables.

Regressions can also be used to evaluate relationships among such things as the size of seeds versus the germination percent, or the size of a pine cone and the size of seed versus the germination percent. They can

also be used to evaluate the productivity of harvesting equipment versus the average diameter or total volume of trees in different lots. Regression analysis makes it possible to predict the time required for harvesting different logs according to tree size, or to help define the optimum tree size in a plantation for harvesting with a given type or size of harvesting equipment. Environmental factors can be evaluated simultaneously with respect to the growth of trees. What is required to make such evaluations is that each parameter must be quantifiable. For example, tree growth of *Gmelina* could be evaluated in comparison with the number of months of dry season (ex: months with rainfall less than 40 cm), the average annual temperature, the percent clay in the surface soil, the soil pH, the PPM of phosphorus in the soil, the slope percent, etc. Such regressions provide a tool for the researcher to evaluate and separate out important factors (significant) from non-important factors (non-significant) with respect to the development of plantations.

It is also important to understand the limits of regressions. When the population used to generate a regression varies from the population where it is to be applied, there is always the risk that the information generated will lack precision. For example, if trees of *Pinus patula* between 15 and 20 years of age are measured, these can be used to create a volume formula for this species that can be used with a final harvest of stands near to these ages. However, if the same formula is applied to young trees 8 to 12 years of age to calculate the volume of a thinning, there is a risk that the information will not be precise due the fact that the trees are of smaller sizes than those used to create the initial volume regression. Remember; when trying to extrapolate a formula beyond the limits of the population used to create it, there is always the risk that the results will vary. Because of this it is important to not only have a volume formula for a species, but also to know something about the population of trees used to create the formula.

It is very important to understand the mechanisms of regression analysis in order to avoid making errors in their use. The person who plans to use regression formulas needs to compare the similarity between the two populations: that used to generate the regression formula and that of the plantation where it is to be applied, and to take this into account before employing a volume formula.

In Brazil, many companies make new volume formulas annually in order to be sure that they fit the plantations being inventoried for a harvest. In some cases where clonal plantations are to be harvested, companies go so far as to make regressions for tree volume for different clones. The generation of field data and the construction of volume regressions becomes a routine part of the forest inventory process. For this reason, it is important to know the minimum number measurements of trees required to produce a reliable regression for tree volume or tree weight. In comparative regressions of *Eucalyptus camaldulensis* and *Eucalyptus grandis* in Colombia, it was found that 50 trees were a sufficient sample for measuring the variation within a tree population for these species (Ladrach, 1978b). The same minimum number of trees was needed to calculate tree weight regression formulas for *Pinus taeda* and *Pinus echinata* in southern United States (Ladrach, 1966; Owens, 1969).

Linear regressions are useful for making many types of field comparisons. A simple linear regression is defined as one independent variable and one dependent variable:

$$Y = Co + C1 * X$$

Where Y is the dependent variable, X is the independent variable, Co is the intercept on a vertical axis of a graph and C1 is the slope of the line on the graph.

For example, the format for a simple linear regression of tree age and tree height can be:

$$\text{Total tree height (meters)} = Co + C1 * \text{age (years)}$$

Where age is the independent variable (known) and total height is the dependent variable (to be calculated). The following formula was calculated using data for trees of *Eucalyptus grandis*:

Total height = 3.4 + 3.1 age coefficient of determination (r2) = 91.1%

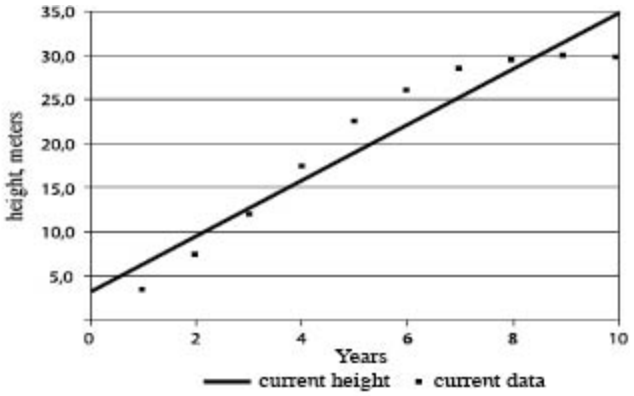


Figure 11-7. The linear relationship between age and height in a measured sample of trees of *Eucalyptus grandis.*

Therefore, a straight line doesn't adjust very well to the data points, even thought the r2 value is 91.1%. To obtain a better fit, the independent variable (age) can be transformed. Common transformations that can be used include: X2, logarithm of X and 1/X. When the independent variable is transformed, the regression produces a curvilinear equation. Figure 11-8 shows that the blue line, which is the logarithm of age, best fits the plotted data points.

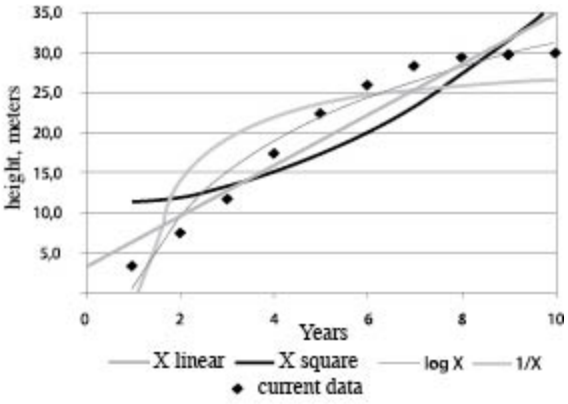


Figure 11-8. Linear regressions between the total height of *Eucalyptus grandis* and transformations of age, the independent variable.

By analyzing the formulas, it can be seen that the coefficient of determination for the transformation "log10 age" has the highest value and the best fit to the data.

Height = 0.55 + 30.68 * log10 age	r2 = 95.9%
Height = 3.39 + 3.14 * age	r2 = 91.1%
Height = 30.01 - 31.86 * 1/age	r2 = 78.5%
Height = 10.95 + 0.25 * age2	r2 = 75.0%

Even using the formula with the variable log10 age, the curve still does not adjust perfectly to the data. What is important in this exercise is to observe how the different transformations modify the lines:

- X2 produces a smooth curve (in the case a concave curve, but this depends on the data set)
- log X produces a slightly sharper curve than that of X2 ([3])
- 1/x produces the most severe curve of the three transformation

In any regression test it is important to draw the graph and observe the fit of the curve to the data points. The fit can be improved by using the appropriate data transformations of the independent variable. Linear regressions are really not that difficult to calculate, but the researcher needs to study the mathematics of regressions and understand how they work. There are commercially available computer programs that will calculate different types of regressions. Linear regressions can also be programmed on an electronic spreadsheet program such as MS Excel.

Non-linear regressions have distinct formats from those of linear regressions and allow the user to make complex and quite useful calculations.

Taper equations are commonly made using non-linear regressions where the diameter of a tree can be calculated at any height or the height can be determined for any given diameter. A simple format for a taper equation is the following:

Top diameter = C0 D((Ht-Hc/Ht-1.3))C1
Where C0 = constant for the diameter of the formula
D = DBH, cm
Ht = total height, m
Hc = commercial height (height at the point where the diameter is to be calculated), m
^C1 = exponential constant for the height term of the formula.

A taper equation was developed in Indonesia for sawlog-sized teak trees and is as follows:[4]

Top diameter = 1.0124 D((Ht-Hc/Ht-1.3))0.8351

Thus, with this formula it is possible the calculate the top diameter of any log in trees with different DBH values as is shown in Table 11-2.

Table 11-2

Top diameters of 3.0 m long logs in teak trees calculated with a non-linear regression.

	Diámetro al tope de la troza a la altura indicada									
Altura total	tocón 0,3 m	DAP 1,3 m	troza 1 3,3	troza 2 6,3 m	troza 3 9,3 m	troza 4 12,3 m	troza 5 15,3 m	troza 6 18,3 m	troza 7 21,3 m	troza 8 24,3 m
m	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm
20	21,2	20,0	18,4	15,6	12,7	9,7	6,4	2,7		
22	26,3	25,0	23,3	20,1	16,8	13,4	9,9	6,0	1,5	
25	31,4	30,0	28,2	24,9	21,5	18,0	14,4	10,6	6,4	1,6
25	36,7	35,0	32,9	29,1	25,1	21,0	16,8	12,3	7,5	1,9
25	41,9	40,0	33,2	28,7	28,7	24,1	19,2	14,1	8,6	2,1

In order to generate this formula, trees need to be measured in the field, measuring diameters and heights at several points along the length of tree. This method has been used to generate many taper equations for trees species (Córdoba, 1982; Ladrach, 1998b; López, 1988; Martin, 1981; Omerod, 1973; Vallejo, 1991).

Effective communication of information generated by forest research

The research director is not only responsible for developing new forestry technologies, but also of explaining their advantages to operational administrators and managers. The principal means for communicating new information and new findings is through written research reports. The following questions and answers refer to the importance of clearly transmitting research results to company management through the research report.

To whom should research information be directed within a company or organization?

The research report should be understandable by the immediate supervisor (the forest manager) of the writer of the report and also the company president or the head of the institution. Technical terminology that is not part of the normal vocabulary of such persons should be explained in footnotes or removed from the report. If key readers who are not experts in the field can understand the report, the technical forestry audience will also be able to understand it.

Phrases need to be clear and easy to read.

It is better to write: “The average tree diameter of *Eucalyptus grandis* was 10 cm.”

than to write: “The DBH of EG was 10 cm + 2.3.”

For readers, it is easier to understand: “The average tree height of treatment “X” was 6.5 m and that of treatment “Y” was 5.2 m, with differences being significant at the 95% level.”

Than: “There were statistically significant differences in heights of treatments X and Y at the 95% level with heights of 6.5 and 5.2, respectively.”

What type of language should I use to explain research to the readers?

As far as is possible, it is best to use simple or lay terminology for all reports. It is OK to use technical terms when required, but these need to be explained. In this way we can continue educating the readers in the subjects being reported. It is best to avoid large scientific terms, especially when referring to statistical information or basic biological concepts.

How important are statistical data in a report?

Just say “There were statistical differences at a (95%) level of probability”. Tables of results can include multiple range lines such as those of the Duncan test or similar, always explaining the meaning of them in footnotes. There is no need to include details of an analysis of variance or the numbers of standard deviations in this type of report, unless there is a specific reason to do so. It is understood by the reader that the researcher knows statistics and made the correct analyses; it is not necessary to show this to the readers just to impress them. Nonetheless, the analytical data should be kept in the file so as to be able to explain what was done in case someone has doubts regarding the methods applied.

Should conclusions be drawn and a report written about a study even though the study does not have a strong statistical design?

Example: There were large growth differences among treatments at the end of eight years, but there were no replications of plots.

Example: A long term growth study lost two of four replications to a fire, but the remaining two replications had similar results after several years of growth in the field.

Of course, if the researcher considers that the differences are important. Statistics is just a tool, but the research forester must make the final decision as to the validity of the work with or without the help of statistical analyses. Remember that time is crucial to an industry and the researcher needs to make tentative recommendations at the least, based on the information available rather than to wait many more years to obtain more "positive" results. Many times an operational manager has to make decisions based on little information. The researcher should make available the information at hand to operational personnel with the pertinent recommendations.

If a company authorizes a research forester to make a presentation of research results during a national symposium, is it necessary to change the style of writing?

No, not much. Simple language is the best to use. The primary readers continue to be the forest manager and the company president so that they know what was presented by the researcher. It may be necessary to include additional information to explain some additional background details regarding the locations of studies for readers who are not familiar with the land or the company. When statistical analyses are required, these are best placed at the back of the report or as an annex. The researcher must be sure that the report is compatible with the company policies with regards to the confidentiality of information.

Format for a research working plan

A working plan defines the guidelines for a study prior to beginning field work. The working plan can be brief and simple if the study is to be installed by company personnel, or it can be formal and more detailed if it refers to a cooperative study which involves scientists outside as well as within the research organization.

The working plan defines the following points:

1. Justification for the study. The reason why a study is required at this point in time,
2. Specific study objectives and treatments to be included,
3. Study design and the proposed physical plan, including a drawing or layout,

4. Site(s) where the study is to be installed and a calculation of the area it will occupy,
5. A calendar of activities and tentative dates for each phase, such as:

- Obtain seeds and other materials,
- Sow seeds in the nursery,
- Select study location(s) in the field,
- Site preparation required for the study,
- Plot location and placement of plot corner stakes,
- Plantation establishment (and initial fertilization),
- Other treatments that will be required (examples: fence construction, herbicide applications, placing a sign, etc.),
- Make an initial inspection to be certain that the field markings and the written plan are in agreement and then make adjustments to the plan to fit the field installation, if needed,
- Write an establishment report.

1. Assign responsibilities for each phase of study establishment,
2. Assign a consecutive study number (key) to identify the study in the research files,
3. Make a study budget.

Format for an establishment report

A well written establishment report is key to the continuity of effective forest research. It is a guide to the future management of the study that has just been installed. It should contain all the pertinent and necessary information regarding the development of the study and the proposed continuing management:

1. A chronological history of the development of the study up to the plot installation in the field,
2. When to make measurements and what variables are to be measured,
3. How the plots are to be maintained after establishment,
4. When the study is to be terminated.

An establishment report can use a standardized format or have its own report generated, depending on the particular policies of the company. It is

important to write the establishment report immediately after the study is established. If the report is not written as soon afterwards as possible, details will be lost and errors will occur. A good method for evaluating the quality of the report is: *Assume that the author of the report will not be in the organization tomorrow (for whatever reason) and to determine if a new research forester could continue the study based on the information presented in the establishment report*. In reality, this is a frequent situation, and it often occurs that the person who makes future growth measurements and writes a research report of a study is someone besides the person who established the study. This is especially true in long term growth studies.

The following is a suggested format for writing establishment reports:

- Study title: specific and short
- Consecutive number or key to the study. Studies need to be numbered in a way that is useful to the research organization. Numbering is important since, over time, there will be may studies which deal with similar subject matter or that have similar titles.
- Date the establishment report is written.
- Introduction. It should contain background information with regards to the concepts of the study, why the study was needed and how the study fits into the overall objectives of the research program. Pertinent literature references can also be included to demonstrate the importance of the study to the company. Be careful not to convert the *Introduction* into a *Summary*, a common tendency among research personnel with little experience writing technical reports.
- Purpose. Explain in a precise manner and in one phrase the reason for the study.

Good example: "C*omparison of growth and development of 20 provenances of Pinus caribaea of Guatemala, Honduras and Nicaragua in two soil types in Eastern Venezuela"*.

Unacceptable, vague example: *"Growth and development of provenances of Pinus caribaea in Eastern Venezuela.*

Procedures/Methods. It is a chronological description of what was done during the planning phase, the preparation and the establishment of the study. Example:

1. Description of the treatments. In the case of a provenance trial, include a table that shows the origin or provenance of each seed lot. In the case of a site preparation or fertilization study, describe the treatments used in detail.
2. What seed was germinated (species) in the nursery (name and date) and the handling and treatment of the seedlings in the nursery?
3. Describe the site preparation methods used prior to planting and the prior use of the site.
4. Give the name of the site(s) where the study was planted, the date(s), the initial spacing, along with a description of the size and condition of the seedlings as well as a description of the climatic conditions at time of planting, etc. Make a description of the plots (and the borders). Describe how the plots are marked in the field (stakes, cement markers, posts) and their position with reference to the plots, for example: corners, heads of rows, or other).
5. Describe any fertilization used: elements applied, rates of application, when and how they were applied.
6. Draw a map of the study location which clearly shows to other company personnel how to reach the study from known points, such as roads, fences, houses, etc., and the compass bearings and exact distances to a study corner from those points.
7. Draw a detailed map or plan of the study that shows the treatments in the rows or blocks, the location of corner stakes, plus the bearings and distances of the plots within the study layout. The information shown on the map must also coincide with the information shown on the location map. Both maps must have clear titles, a north arrow, and a legend for distances. The test of the validity of the map is if another person can find the study installation easily, correctly identify the measurement trees and carry out a future measurement using the maps in the establishment report. If this can be done, the maps are clear and well made.
8. Describe the study design and the statistical analysis that is to be used for its evaluation.

9. Describe any additional treatments that are to be applied along with the date(s) of the application(s).

- Observations, measurements and maintenance. In this section are listed all additional routine treatments including maintenance, weed control, fertilization, etc. that are to be done in the future. A calendar of programmed events should be included by month and year and a list of the information to be recorded at each measurement. The date of the anticipated termination of the study is also noted.

Example:	
Pine species and provenance trial (list the pine species)	
Age	Parameters to measure
1	Survival, total height
3	Total height, DBH, abnormalities (forking, pests)
5	Total height, DBH, straightness, abnormalities
8	Total height, DBH, straightness, abnormalities, take wood samples for measuring wood specific gravity

- Summary. This is a summary of the establishment report. The summary is usually placed at the beginning of the report, before the *Introduction*, but it is written last, after all the information in the report is recorded.
- Report by: (name of author)
- Developed by: (names of participants). Include the names of professionals and technicians for future reference. Thus, if a person is transferred to another department or location, it will be possible for a new researcher to contact that person to obtain details regarding the establishment of the study, if needed.
- Distribution: Include a list of persons to whom the report was sent. Normally the list is limited to research personnel, operational personnel who are responsible for the properties where the study is located, the forest manger and the research file. It is very useful to annex this list to the research file copy for future reference.

Format for a research report

Internal research reports are used to present research results in a useful form for operational as well as research personnel. The report is directed to

the highest administrative authority on the distribution list as well as to the operations foresters.

A research report is written in an easy to read manner, so that the reader doesn't have to "study it" or take a statistics course in order to understand what is being presented, and it should contain information useful to the company or institution. Certain details and statistics can be included in the report when needed to support the information presented and to substantiate the conclusions. The more technical phases of the report are presented in the *Methodology* section. Persons that are not experts in forestry should be able to read and understand the *Summary*, *Discussion* and *Conclusions* without difficulty.

The following standard format is commonly used by research personnel for internal research reports.

- *Distribution list*. It is a list of those who receive copies of the report. The distribution list is fastened to all copies sent out.
- *Title*. This is a clear description of the report in a few words. It should be short and specific and avoid words such as "preliminary", "study of", "analysis of", "report of", but it should contain sufficient information to be of interest to the reader. The title does not have to be the same as that of the establishment report; rather it should reflect the specific purpose of the research report itself.
- *Author*. Write the name of the author of the report so that it is possible to send comments or request additional information when needed. Anonymous reports are a no-no.
- *Report number*. Normally, the research reports follow a consecutive numbering system for a particular organization.
- *Date*: Month and year of release or publication of the report.
- *Summary or Abstract*. This is a summary of the report itself, not just a repetition of the conclusions. The summary should provide the reader with a good idea of what was done and what was learned. The summary is placed at the beginning of the report for the reader's benefit, but it is not written until the rest of the report has been written. Never try to start writing the summary before the rest of the report.
- The summary should include important data, not just generalities.
- A good example: "*There was a 25% volume gain for Pinus caribaea after three years, fertilizing with 50 g of NPK (10-30-10) at the time of*

planting.

- A poor, vague example: “*”The fertilization trial resulted in a statistically significant growth increase of Pinus caribaea in the best of four treatments*”.

Note: When writing a report to be published outside of the organization or for presentation at a symposium or conference, it is a common practice to include an “*Abstract”* in English after a *Summary* of a report written in another language. The *Abstract* is a brief statement, usually a paragraph, which can be included in an international data bank and that allows research personnel around the world to have access to the report. In such presentations, it is also common to include five “*key words*” after the *Summary* that help readers who search for information placed on the Internet.

- *Introduction* establishes the basis and background for the study: It is a review of previous research plus a literature review referring to the subject of interest. In also includes the reasoning, the subject matter and the justification for what was done in the study, and how the study fits into the overall research objectives of the organization. A statement of the purpose of the study is given in a clear and concise phrase.
- *Materials and Methods* is a chronological description of how, when and where the study was established, maintained, measured and analyzed. Statistical analyses are explained in this section, when necessary, to describe how the study was established and analyzed.
- *Results* describe what was learned from the study. The results are objective statements (not opinions) regarding the study findings.

  Figures and graphs help to explain results in a more complete form. These are tools for clarifying the text. When referring to a figure or graph in the text, it is best to write, for example: “*Four families of Tabebuia rosea showed significant height growth, greater than the other 20 families tested (Table 3)”*. Rather than: “*Significant differences in the heights of 24 families of Tabebuia rosea are shown in Table 3.”*

  Positive and useful data and results are presented first. Negative or less important results are reported at the end of the section, with less emphasis on these. Never begin a report with excuses or hedging; if the data are not valid, don’t included them in the report, but if they are valid, there is no need to make excuses. Not all

research studies are successful, but what is important is to learn from the mistakes as well as the successes.

When referring to statistical analyses, the author should state differences among treatments first and in absolute terms, and then mention their statistical significant, not vice versa.

- *Discussion* is a section where the author presents commentaries and personal opinions regarding the study results and places those results in perspective, comparing them to other research work and to the existing literature on the subject. This section is important because it contains the researcher's opinions regarding the importance of the findings to operational personnel in the company or institution.
- *Conclusions* need to be operational and based on the *Results* and *Discussion*. Do not draw conclusions about things that were not written in the *Results* and *Discussion*. Never conclude that more research is needed! It is permissible to discuss future and continuing research in the *Discussion* section, but not in the *Conclusions*.
- *References* is an alphabetical list by author of the literature cited in the research report. A universal format for referencing reports is as follows:

  Author(s) name(s), year of publication, title of the report, source (magazine, book, symposium, etc.), publishers address (city/country), volume/number/page of the publication.[5] (See the *Literature Cited* section at the end of the book for examples).

- Tables are included to help the reader to understand the report. The titles to tables are placed above each and numbered consecutively. Tables should be easy to read and understand by themselves, without requiring that the reader refer back to the text. Highly technical terms are explained in a footnote to the table. Tables should not have separation lines, except between the titles of each column and the data below it, or between the first column and the other columns. When many boxes and lines are drawn in a table it makes it harder to read and understand.
- *Graphs and figures* are used to clarify data included in tables, or photos can be used to show important points. The title of a figure is

placed below each and they are numbered consecutively. A graph or figure needs to be self-descriptive so that the reader does not have to consult the body of the text to understand it. Each line or curve in a graph requires a description beside it, avoiding the use of codes for treatments shown. If it is necessary to use some codes, they are placed in a legend with the graph and describe it.

- *Appendix or annex* includes reference material that is not needed for the reader to understand the report. Don't make direct references in the report to material included in an appendix; direct references are only made to figures and tables in the body of the report.

Annual research goals

Advanced planning of research activities is important so that all programmed work is completed in a timely manner. Too often, the lack of adequate planning of personnel duties leads to a lack of sufficient time to make analyses of research results and to write reports of those results. At the end of each year, the director of forest research needs to review all existing studies and make a list of all work that is planned for completion during the following year. This task is made much easier when the study establishment reports include the proposed work schedule for each study. A good way to make a list of the annual work schedule is by use of an electronic spreadsheet that includes columns for the following information:

- Study number and study name,
- A description of activities for each study,
- The month in which the work is to be done,
- Names of the persons responsible for each task.

Each month, the research director meets with his/her staff and reviews the progress made for each study, marking all work completed. The administrative functions are also included in the annual goals as is shown in the example in Table 11-3.

Table 11-3
Example of a format for annual forest research goals

Estudio N.º	Título	Actividades	Mes	Personal encargado	Fecha cumplida

Estudio N.º	Título	Actividades	Mes	Personal encargado	Fecha cumplida
1-02	*Arboretum* San Isidro	medición 5 años, finca San Isidro análisis de datos escribir informe de investigación	julio julio septiembre	JLM JLM JLM	
1-05	Procedencias de *Gmelina arborea* con la UNA.	medición de 3 años, finca El Vergel análisis de datos enviar datos al Prof. Jiménez, UNA	junio junio julio	RCG RCG RCG	
1-06	Procedencias de *Eucalyptus grandis*	medición de 1 año, finca Aguas Frías análisis de datos	julio sept	JLM JLM	
1-07	Procedencias de *Acacia mangium*	Pedir semillas de Indonesia, Australia y Papúa Nueva Guinea Pedir *Rhizobium* de CSIRO, Camberra, Australia	enero enero	RCG RCG	
2-03	Preparación de suelo de *Gmelina arborea* con el subsolado y glifosato	selección del sitio para el estudio en dos fincas siembra de semillas en el vivero marcación de parcelas en el campo preparación mecánica preparación química plantación de los ensayos escribir informe de establecimiento inspección de supervivencia 1 mes	febrero febrero abril mayo mayo junio junio julio	JLM JLM JLM JLM JLM JLM JLM JLM	
9-01	Biblioteca Forestal	añadir nuevas publicaciones actualizar lista de publicaciones	continuo marzo	CAJ CAJ	
9-02	Guía de campo	organizar nueva guía de campo hacer copias de nueva guía de campo distribuir copias de guía de campo	octubre noviembre noviembre	JLM CAJ CAJ	

Estudio N.º	Título	Actividades	Mes	Personal encargado	Fecha cumplida
9-03	Metas Anuales de Investigación Forestal	reunión para definir estudios nuevos con personal operacional aprobación de estudios nuevos escribir metas para año entrante distribución de copias de las metas	noviembre noviembre diciembre diciembre	JLM JLM JLM JLM	
9-04	Informe Anual de Investigación Forestal	definición del tema para la reunión anual organización de los temas para la reunión asignar temas por escribir al personal escribir informe anual presentación anual	agosto agosto agosto noviembre enero (año)	JLM JLM JLM JLM/CAJ JLM	
9-05	Viajes y Reuniones	proponer asistencia al Simposio de Silvicultura por RCG y JLM escribir informe por presentar asistencia al Simposio de Silvicultura informe de viaje	febrero abril mayo mayo	JLM RCG JLM/RCG RCG	
9-06	Presupuesto Anual	Definir presupuesto Aprobación por la gerencia forestal Reunión anual de presupuestos	agosto agosto septiembre	JLM JLM JLM	

At the end of the year, the research director submits to his/her superior a copy of the goals, marking the work that was completed and that which was not done. A brief explanation is written for each activity that was not completed. These annual goals allow the forest manager to be aware of what the research group is doing and it also provides a means for evaluating the quality of the work done by the research organization.

Field guides

As more and more field studies are established, it becomes increasingly difficult to maintain a registry of the location of all plots that are active. This is especially true for operational personnel who must work in those

same locations without causing damage to installed and valid studies. Also, when the research organization decides to abandon old plots, but doesn't advise the operational personnel, the field administrators may not know which plots are still in use and which are not. Close contact between operational and research personnel is valuable to maintain field studies and to avoid accidental damages. Even so, the situation can reach critical levels when harvesting begins in a tract around the area where research has valid and ongoing plots. The research personnel must be aware of this and take necessary precautions to protect their plots.

A good way to minimize accidental damage caused to field studies is for the forest research group to produce a list of valid field plots along with a location map of these in the form of a field guide. This guide is distributed annually to the operational personnel, i.e., those persons who are in charge of land management, forest inventory, wood harvesting, as well as the forest operations manager, so that they all know where the active field plots are located. In the guide, there is a brief description of each study along with the pertinent maps. The information to include is as follows:

- Study name and title
- Duration of the study
- Study number
- Study location(s)
- Purpose of the study
- Study area
- Date of establishment

The maps that were generated for the establishment report can be used for this purpose.

It is also a good idea to include an initial summary of all studies by region (province, state, municipality, tract or farm), so that these can be easily identified by operations personnel.

Annual forest research report

The annual forest research meeting and report is an opportunity to demonstrate research results in the field and to summarize research gains to operations personnel. The annual research meeting is an excellent forum where forestry personnel can discuss silvicultural management aspects of

plantations. The annual meeting and report can become the most valuable research contribution to a company or institution. When the meeting is held annually, it can become an event anticipated by everyone; with the participation of upper management, it is a great opportunity to educate the entire organization regarding aspects of reforestation and silvicultural practices.

In many sectors of an industrial enterprise the annual report is a summary of production gains and profits presented at the end of the year, plus an accounting summary. In the particular case of forest research, much of the work continues for more than one year and a simple review of what was done during a single year is best presented in the format of the annual goals, as has already been mentioned. On the other hand, the annual research report is a mechanism for summarizing gains attained through work over several years and for specified subjects.

In the research group there are often results from many research studies that deal with different phases of a similar topic. For example, the research group may have planted several provenance trials for a species in different years and evaluated the growth of trees from seed sources in different regions or countries. To operational personnel, it may appear that one provenance is the best, according to one trial, but another trial shows that another provenance is best. Thus, it is important to summarize the information generated by various studies and to make general recommendations based on all the available information to date. The annual report is an excellent mechanism for making such summaries and general recommendations.

An effective manner for conducting an annual meeting is to select a theme about which there is sufficient research information to write an overall summary. The report theme could be, for example, *"Species and Provenances"* or *"Site Preparation Methods for Reforestation"*, *"Disease and Insect Pests in Plantation"* or *"Forest Fertilization*". The annual report, then, is a summary of all of the research group's experiences to date in a specific field of endeavor, and it can also include a review of pertinent literature from other sources concerning that particular subject. A field trip to view some of the pertinent study results can be included as a part of the annual meeting.

For example, there could be a field trip in the morning to visit research studies, and then hold an indoor meeting in the afternoon, at which time the

participants are given a copy of the annual research report and where brief presentations are made by several of the forest research personnel. An outside expert on the subject, such as a university professor, could be invited to participate and make a presentation on the theme of the meeting. At the end of the report, a summary of operational recommendations can be included, based on this updated body of information. It is very useful to include photos of field work. This type of annual research document can become a reference text that is useful for many years.

Writing an annual research report and planning a field trip requires considerable time and effort, especially on the part of the forest research director. An allotment of time for this work must be included in the annual goals to insure that there is sufficient time for its completion.

[1] The *normal distribution* of a measurement of natural variation within a population takes on a bell-shaped curve when frequency of occurrence is plotted against the measured variable (such as height or volume). However, survival percentages rarely follow such a normal distribution curve and must be modified or transformed so that the transformed values approximate a normal distribution prior to making an analysis of variance for a study.

[2] This formula con be modified to record diameter in meters as follows:
V m3 = 0.3 * D2H where D= DAP in meters and H = total height in meters.

[3]In this case a logarithm, base 10, is used. A natural logarithm “Ln” can also be used as another base for calculations. The base 10 and the natural logarithm are the most commonly used logarithmic transformations in forestry regressions.

[4]This unpublished formula was developed by Suhartono Wijoyo based on measurements he made of teak trees in plantations of Pernum Perhutani in the Central Java Province in Indonesia.

[5]In the case of the reference to a magazine, the address is normally not included.

12

Wood physiology and pulping processes for making paper

Perspectives
Wood cell differentiation
Wood density
Pulping processes

Perspectives

The quality of wood for manufacturing varies among the types of trees planted, by species and also by the age of the trees when harvested. The silvicultural management of plantations can also affect wood quality (Zobel, 1992). This chapter provides some basic aspects of this subject for the readers regarding the importance of wood physiology with respect to forest products. There is much information available regarding wood physiology in technical reports and text books. There are post-graduate specializations in this field in forestry faculties of many universities. It is a subject of great importance to the forest industry, since wood quality has a very significant influence on the quality of manufactured wood products (Zhang *et. al.*, 1997). Wood quality is an integral part of tree improvement research (Zobel & Talbert, 1982).

Wood density is among the must highly inherited genetic traits of trees and, as such, can be modified through selection of desirable traits for forest products (Valencia, 1994; Zobel & van Buijtenen, 1989). There are important differences between the quality of juvenile wood and mature wood. As the area in new tree plantations increases, there will be more juvenile wood entering into the mills of the forest industry (Malan, 1997).

Most forest tree plantations are established for the production of wood pulp for making paper. Of the global pulp production, 90% is made from wood with the rest being produced from other fibers, such as bamboo, kenaf, flax, sisal and cotton (MPA, 2007). Because of the importance of wood for making pulp, it is important to have a basic knowledge of the physiology of wood and the pulping processes. There are several pulping methods used by the pulp and paper industry. This chapter presents a brief

description of the different classes of pulp being produced in order to give the reader some orientation to this forest industry.

Wood cell differentiation

Wood in live trees has multiple functions, which is the reason why there is variation in wood characteristics that will eventually affect manufactured forest products. Tree cells transport water from the tree roots up to the crown and they transport sugars produced in the crown to the other parts of the tree. This implies that wood is a porous material. Wood also acts as a physical support to the living plant.

Tree diameter growth is initiated in an outer thin sheath of undifferentiated cells called *parenchyma cells*, which lie under the bark and surround the tree bole and branches. This sheath is called the *cambium* (Figure 12-1). All other cells are propagated from these parenchyma cells and differentiate into the specialized cells of the tree required for sustaining life and growth. The cells that transport water and minerals from the roots to the foliage are called *xylem*. The cells that transport sugars from the leaves in the crown downwards are called *phloem*.

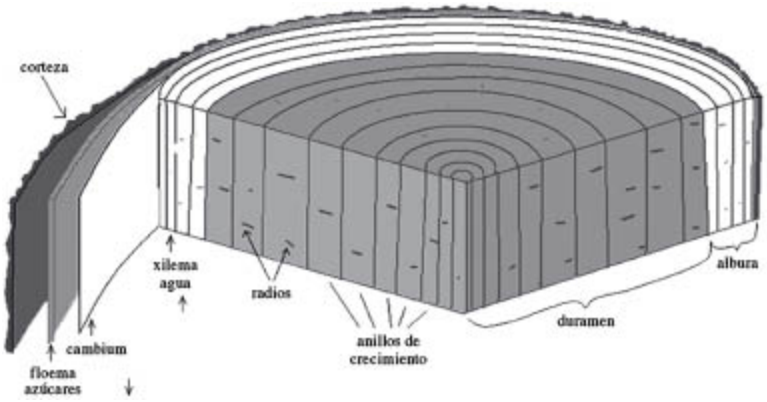


Figure 12-1. Typical section of wood in a tree.

Xylem cells regenerate inside of the cambium, where they form the wood of the tree. The phloem cells regenerate outside of the cambium and, when they die, they become the bark of the tree. There are other parenchyma cells that are grouped into bands that are known as *ray cells* and these bands of cells move nutrients and water transversally or horizontally in the tree bole and branches. The xylem that is nearest the cambium is living tissue and is known as *sapwood*. The wood towards the

center of the tree has many dead cells that no longer function as transporters of liquid and this part of the wood is known as *heartwood*. In many tree species, the interior or heartwood tends to accumulate minerals or other chemical deposits which darken the color of the wood, depending on the species. In some species, the heartwood can have greater resistance to rot and insect attack. Species such as cedar, walnut or mangrove are known to have resistance to rot and insects in their heartwood.

The wood produced at the beginning of the rainy season or in the spring is called early wood. These cells tend to be larger, have thinner cell walls and produce wood that is lighter in weight. The wood produced during the dry season or the summer has cells of lesser diameter, with thicker cell walls and this wood is heavier. This phenomenon of varying cell size during the year is what produces the *annual rings* or the wood grain, which can be seen in a cross-cut of wood. In the temperate regions, the growth rings are normally annual rings and, in many species, can be counted to determine the age of the tree by the number of rings from the pith to the bark.

In the tropics, trees can produce various growth rings during the year, each time there is a rainy season. The visibility of the growth rings and their frequency varies among tree species. In some species, such as teak and mahogany, these rings are quite easy to distinguish, while in others, such as eucalypts and poplars, they can barely been seen. On those tropical sites where there is no defined dry season, the growth rings may or may not be visible to the eye, but they can easily be seen under a microscope. In places where there are highly defined changes between the rainy and dry season, the growth rings are more distinguishable.

The wood physiology of conifers is different from that of broadleaf species. In conifers, there are cells called *tracheids* that function in the transport of liquids and also provide wood structure.[1] Around 90% of the conifer wood volume is composed of tracheids (Zobel & van Buijtenen, 1989). In the pulp and paper industry, coniferous wood with tracheids is known as “long fiber”, where the cells have lengths between 2.5 and 6.0 mm and cell diameters of approximately 0.03 mm. The tracheids have pits that allow for the selective movement of liquids between cells (Figure 12-2**)**. There are radial cells, similar to parenchyma cells that move liquids transversely and these cells are short, generally between 0.1 and 0.2 mm long. Conifers also have *resin* canals in the wood. The importance of long

fiber is that it produces a pulp with a high tear factor for the manufacture of corrugated boxes and paper bags.

In leaning trees there is the formation of *reaction wood*. In conifers, the reaction wood occurs on the lower side of the lean and this is also known as *compression wood*. In such wood, the tracheids are shorter and have thicker cell walls than normal wood. In the case of the broadleaf species, reaction wood forms on the upper side of the lean and is known as *tension wood*. In conifers, reaction wood has more lignin and 20% to 25% less cellulose (Ahmed *et al.*, 2000). In broadleaf species, the reaction wood has shorter fibers and less lignin than in normal wood. Reaction wood is not desirable for producing pulp due to the shortness of the cells, nor is it desirable for sawn wood since reaction wood tends to bend, twist and have less structural strength in boards.

Broadleaf species (Angiosperms) have other types of cells as well. There are wide cells, called *vessels*, that grow in columns to form tubes or capillaries that allow for liquids to pass vertically through the wood. Vessels are typically 0.2 to 1.3 mm long and 0.05 to 0.5 mm wide. After their formation, vessels die and lose their end membranes, thus creating tubes for the movement of liquids and these tubes can be several meters long (Figure 12-2). In some species, when the living cell contents die, they form blockages called *tyloses* that do not allow for the passage of liquids and cease to function. Besides vessels, broadleaf species have small diameter cells called *fibers* which are the cells that provide strength and structure to the wood. In the pulp and paper industry, wood of broadleaf species is known as *short fiber*. Fibers are approximately 50% of the wood volume of broadleaf species (Zobel & van Buijtenen, 1989). Radial cells or rays can be between 5% and 30% of the wood volume, depending on the particular species. Most common broadleaf species do not have tracheids.

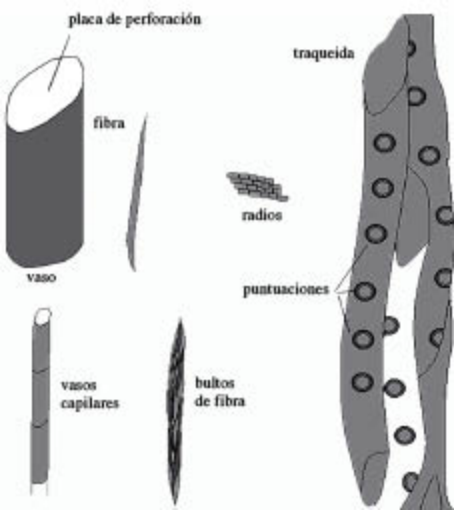


Figure 12-2. Wood cells.

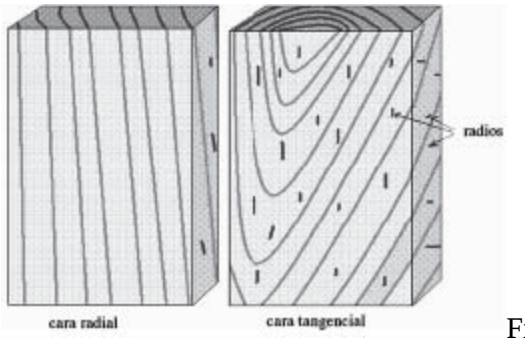


Figure 12-3. Differences between the grain appearance of woods according to the sawing method.

When a log is sawn as slabs, the wood grain is seen in an open or tangential view, and when the wood is sawn through the log diameter, the wood grain is seen in a closed or radial view (Figure 12-3). Radially sawn wood has greater structural strength and tangentially sawn wood has a grain that is desirable for many decorative uses and for furniture.

Some tree species produce chemicals near the cambium or in the wood as a method of protection against invasions by insects or fungi and the chemicals are deposited in the central region of the tree called the heartwood. The durability of the heartwood of cedar and mahogany is due to the accumulation of chemicals that inhibit wood rot. In species such as the eucalypts, phenolic resins are produced in mature trees (Zobel *et al.*, 1987). In pines, the resins are formed in the wood or cambium as a response to boring insects. Bark tannin and aromatic chemicals in the leaves of trees of some species are other mechanisms for the trees to protect themselves against attaks by pests.

Wood density

Wood is primarily composed of four organic components: alfa-cellulose, hemi-cellulose, lignin and extractives (Ona *et al.*, 1995). Together, α-cellulose and hemi-cellulose are known as “holocellulose” which are the chemical components of the cell walls of the wood. The ratios of wood components vary among different types of trees (Table 12-1) and among species in a group, such as the eucalypts (Table 12-2). Lignin is the organic glue that holds the cells together.

Table 12-1
Wood components of four classes of trees in Argentina*

Group	α-cellulose %	hemi-cellulose %	lignin %	extractives %
eucalypts	54	15	23	8
pines	58	10	26	6
willows	56	17	21	6
poplars	55	18	22	5

* According to Repetti, 1990.

Table 12-2
Wood components of five species of *Eucalyptus* **

Species	Age years	α-cellulose %	hemi-cellulose %	lignin %	extractives %
Eucalyptus dalrympleana	2	34	41	17	8
Eucalyptus nitens	2	41	36	16	7
Eucalyptus camaldulensis	35	32	38	21	9
Eucalyptus globulus	36	41	36	19	4
Eucalyptus grandis	unspecified	42	37	16	5

** According to Ona *et al.*, 1995.

The basic wood density or specific gravity is the ratio of the oven dry weight and the green volume of the wood. The higher the specific gravity, the thicker the cell walls and the less space inside the cell lumens (Figure 12-4). Young cells tend to have thinner cell walls and wider lumens.

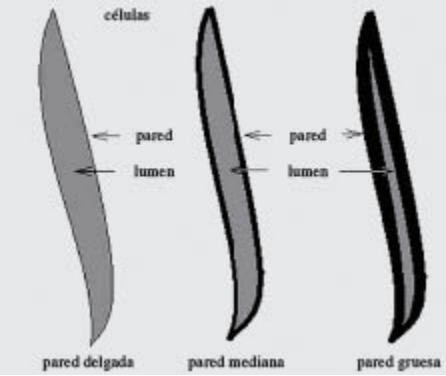


Figure 12-4. Differences among wood cells. The trees with the thicker cell walls have higher wood densities.

Specific gravity is important with regards to pulp yields and also to the structural strength of wood.[2] If the specific gravity is, for example, 0.45, this means that there are 450 kg of oven dry wood per cubic meter.

$$\text{Specific gravity} = \frac{\text{oven dry weight of wood}}{\text{green volume of wood}}$$

To determine the specific gravity, wood samples are taken from different parts of the tree and analyzed in the laboratory. Wood discs 1 to 2 cm thick are cut out and then these are cut into wedges. For the analysis of the specific gravity of a disc, the volume of a wedge can be measured by water displacement when the wedge is totally immersed (Figure 12-5). Afterwards, the wedge is dried in an oven and the specific gravity is calculated using the formula shown above. The water displacement method is acceptable for large samples, greater than 50 cc, but it doesn't have sufficient precision for determining differences in wood density for smaller pieces of wood.

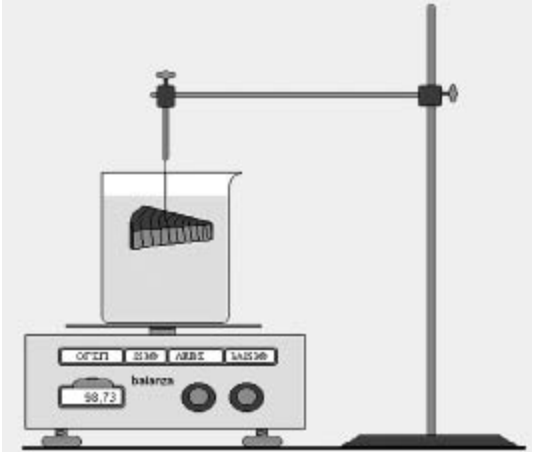


Figure 12-5. Volume measurment of a wood wedge by water displacement. The volume of water displaced is equal to the weight of water displaced.

To measure the wood density of small pieces or core samples taken from a tree with an increment borer, the method of wet weight in air and weight in water is used. First, wedges are cut from a disc in the laboratory. Normally it is best to cut pieces following the growth rings (Figure 12-6). Each piece or sample is given a laboratory code which is written on the sample using an indelible pencil which will not wash off in water. The weight of water is subtracted from the wet weight in air (not the water displaced). This is the green volume of the sample. This method allows for measuring samples to a precision of one hundredth of a gram (Figure 12-7). The samples are then dried in a laboratory oven at 105° C and then weighed. Small samples can dry completely in 24 hours, but larger samples may take longer to be completely dry.[3] With the green volume and the oven dry weight the specific gravity can be calculated.

This method allows for the remeasurement of a sample by putting it back into water and allowing it to become saturated. This is useful to double check initial test results.[4]

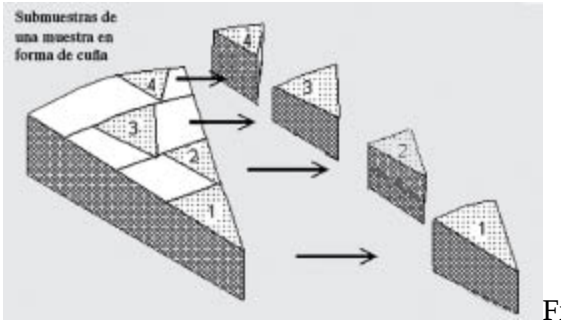


Figure 12-6. Wedges are separated from a disk of wood. Then the wedge can be cut into pieces of similar size for analyzing the specific gravity of the wood.

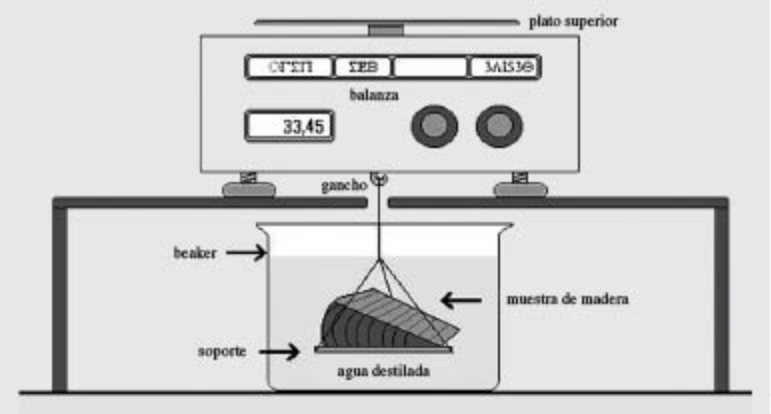


Figure 12-7. The technique for measuring the weight of wood in water for small samples.

Wood produced towards the center of the bole is called juvenile wood. Normally, this wood has a lower density with thinner cell walls. The wood produced towards the outside of the bole is called mature wood and has cells with thicker walls. Although all trees produce juvenile wood and mature wood, the characteristics of these will vary among genera and even among species of the same genus. Most pines produce juvenile that is quite distinct from the mature wood. Broadleaf species normally have lesser differences between juvenile and mature wood, but there are exceptions. It is important for the forest industry to recognize the differences between juvenile and mature wood and their impact on manufactured products (Zobel & Sprague, 1998). The mature wood of many tree species has extractives (resins, phenols and other chemicals) that can affect the apparent density of the wood. In such cases, it is necessary to eliminate the resins and extractives with a solvent before attempting to determine the specific gravity of the wood (Ona *et al.*, 1997).

In many pine species, the wood at the center and in the upper part of the bole is juvenile wood (Figure 12-8). When producing chemical pulp of young tropical pines (eight years old), most of the wood is juvenile, which produces pulp with a low tear factor, low pulp yields, high paper densities, and high paper opacity. When making chemical pulp using older tropical pines (over 15 years old) the tear factor is higher, pulp yields are higher, paper density is lower and paper opacity is lower.

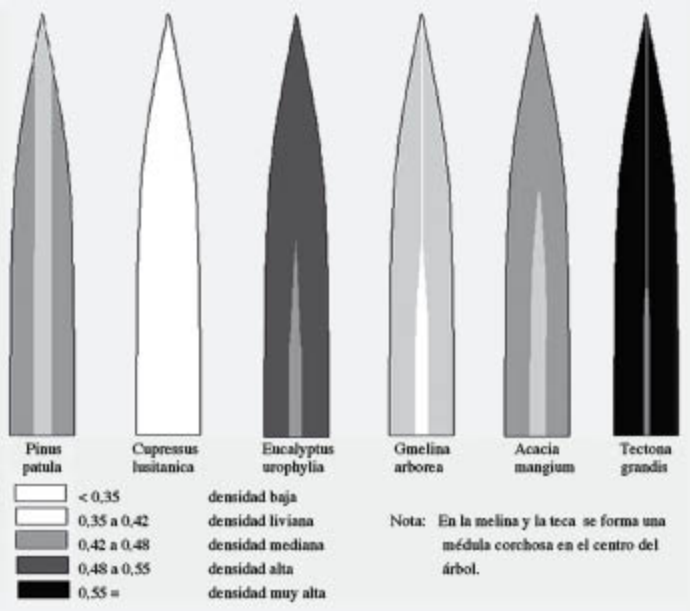


Figure 12-8. Juvenile and mature wood densities of several tree species.

In the case of cypress (*Cupressus*), the juvenile and mature densities do not vary with tree age, but the length of the tracheids is greater in older trees (Ladrach, 1986).

In the case of the eucalypts, the wood density increases slightly between the first and seventh years, but usually does not increase more with greater age (except for accumulating phenols in the wood that can give higher readings of wood density if they are not removed first with solvent). In the eucalypts, the wood at the top of the tree tends to be slightly heavier than the wood at the base of the tree. In the case of *Gmelina* there is little difference between juvenile and mature wood, but for *Acacia mangium* the difference between juvenile and mature wood is significant (Ladrach, 2000).

The pulp produced from pines and other conifers tends to have a higher tear factor and is good for making corrugated boxes and paper bags. Conifer chemical pulps are also added to ground wood pulps to produce newsprint since this increases the resistance of the paper to tearing when run on high speed newspaper presses. Chemical pulps produced from eucalypt wood and that of other high density broadleaf species has greater pulp yields per cubic meter of wood than that of conifers, greater paper opacity, a longer breaking length and a good print quality for writing and copy papers (Valencia, 1994).[5]

Low density woods have lower yields of pulp per cubic meter of wood, higher opacity, better printing characteristics and greater paper density.

Pulping processes

In the oldest civilizations, writings were carved on stone or pressed into clay tablets. The inside of tree bark and animal skins have also been used as writing media. The Egyptians produced a writing surface by pounding papyrus reeds into mats, but these are not considered to be “paper” in the strictest sense of the word. Ts’ai-Lun of the Han Dynasty is generally recognized as the inventor of paper, when he used fibers from old rags, old fishing nets and fibers from hemp to form writing sheets in the year 200 BCE (Patrick, 2007). Later, the Chinese developed techniques for making paper from cooked bamboo fibers (Repetti, 1990).

For many centuries, the materials most utilized for writing were parchments produced from skins of sheep or other animals, papers produced based on agricultural fibers such as flax or cotton and also fibers from old rags. The use of wood fibers as raw material for producing paper is relatively recent. In 1719, the Frenchman, René de Reaumur, observed wasps making paper from partially digested wood fibers and his notes became the basis for the development of paper from wood fiber. Later, in 1798, another Frenchman, Nicholas Robert, developed a prototype of a paper making machine using metallic screens to produce an endless sheet of paper (Patrick, 2007). The process of grinding wood to produce paper was invented by Keller, a German, in Saxony in 1843. The first chemical pulping process was developed in 1854 by the Englishman, Mellier Watt. In 1957, Benjamin Tilghman, an American chemist, invented the acid sulphite (H_2SO_3) pulping process, which made possible the construction of large pulping digesters (NTDC, 2007). The kraft pulping process with sulphate was invented in Germany by Carl Dahl in 1884 (Patrick, 2007). At the beginning of the Twentieth Century there were many improvements to the industrial pulping process, and in 1950 Kamyr introduced the continuous pulp digester, a process that increased pulp production capacity. The following is a summary of the common wood pulping methods used in the modern pulp industry.

Kraft or sulphate pulp (wood free pulp, free sheet)

Eighty percent of the chemical pulp produced in the world is made using the kraft process (EDF, 1995). The kraft pulping process uses caustic soda (sodium hydroxide and sodium sulfide) with heat and steam pressure to cook wood chips in digesters so as to dissolve the lignin and extractives, leaving mostly cellulose. Then the cooked pulp is run through refiners where clumps of wood fibers are separated mechanically. Pulp with the lignin removed is known as "*wood free pulp*" in the pulp and paper industry. The cooked pulp is brown in color. Yields of kraft pulp are approximately 55% (weight of pulp:weight of wood) (Tappiphils, 2003).

In the case of plantation pines, bleached pulp yields are approximately one ton of pulp at 10% moisture content to 6 or 6.5 m3 of wood. For eucalypts, the ratio is approximately 1: 4 or 4.5. Current economies of scale for chemical pulp mills are between 400,000 and one million metric tons per year, but some mills are now being constructed with even greater capacities. Initially, pulp was produced in batch digesters which were filled individually for a cook and then emptied. With modern continuous digestors, the wood chips are inserted and the pulp is removed on a continuous basis.

This process separates the fibers or tracheids well which results in a very high tear factor in the pulp and also in the paper. White or bleached papers produced with this process maintain their whiteness, even when exposed to sunlight, since the lignin, which causes the paper to yellow over time, has been removed.

In the kraft pulping process, 20% of the caustic soda or "white liquor" is consumed, and the other 80% is removed with the cooking liquid, which is called "black liquor" due to the high content of dissolved lignin, which gives it a dark color. The soda can be recovered by separating the organic solids and lignin in a recovery unit, using a chemical process where hydrated lime is added to the black liquor to precipitate out the organic material. Then, the precipitated organic material is burned in a recovery boiler to generate steam while the remaining soda ash is again used in the pulping process, being added to the digester as a solution called "green liquor".

In the digestor, the green and white liquors, heated by steam, enter into the wood chips of broadleaf species through their vessels, which results in a uniform cooking of the fibers throughout the wood chip. The liquor enters the coniferous woods through the tracheids, when the chips are fresh and

this also results in the uniform cooking of the chips when the liquor can penetrate into the chips. However, when conifer wood has been allowed to dry out, the pits on the tracheids close permanently and the cooking of the chips is from the outside towards the inside, which produces a less uniform cooking process than when the chips are cooked fresh. It is for this reason that woodyards like to keep low inventories of pine wood and mills like to pulp the wood chips as fresh as possible.

Uses of kraft pulp:

- Brown kraft long fiber pulp: Products which require a high tear factor: packaging, liner board for corrugated boxes and brown bags.
- Brown kraft short fiber pulp: Low tear factor papers: cardboard, multi-wall boxes, corrugated medium (the undulated centers of corrugated paper),
- Bleached long fiber kraft pulp: Papers with a high tear factor for packaging, cardboard with a white surface layer in multi-layered boxes, mixes with other pulps to increase the overall tear factor, such as in newsprint.
- Bleached short fiber pulp: Printing papers, magazine papers, absorbent papers.

Pine woods have resins that are removed as a sub-product in the black liquor in the form of *tall oil* and turpentine. The tall oil is composed of fatty acids that can be refined to produce chemicals used in the manufacture of cosmetics, paints, sizings and other chemical products. The juvenile wood has few resins and the mature wood has more. Some species of pines have very useful resins, (alfa-pinenes and beta-pinenes) whereas others have resins of less value in the chemical industry (delta-pinenes). In the United States, the southern pines have very useful resins for the chemical industry, especially slash pine (*Pinus elliottii*). Species such as *Pinus caribaea*, *Pinus oocarpa and Pinus kesiya* have relatively large amounts of useful resins, but *Pinus patula* produces little resin, comparatively speaking. For resin recovery to be profitable there must be sufficient production to justify the installation of the recovery equipment. Normally, it is considered that there must be at least 200,000 to 300,000 tons per year of pine wood to make tall oil recovery feasible. When there is no tall oil recovery, the resins are burned in the recovery boiler along with the black liquor.

Broad leaf species do not have sufficient useful resins to make their recovery profitable during the kraft pulping process. Eucalypts tend to produce phenols in trees that are older than eight years. Old eucalypts can have large amounts of phenolic resins in the wood and this can cause problems in the evaporators of the recovery boiler installations. For this reason, it is best to pulp eucalypt woods that are five to eight years of age. In the pulp industry, it is known that species such as *Eucalyptus globulus*, *E. camaldulensis* and *E. tereticornis* produce more phenols than do *E. grandis* or *E. urophylla.*

Semi-chemical pulp

The semi-chemical pulping process is similar to the kraft pulping process, but it uses less caustic soda and the chips have a shorter cooking time. This leaves the chips partially intact and undercooked. The partially cooked chips are run through refiners that separate the fiber bundles mechanically. Semi-chemical pulp yields are approximately 70% (Tappiphils, 2003). The yields are higher than those of kraft pulp because some of the lignin is left in the pulp along with all the hemi-cellulose.

Semi-chemical pulp is used primarily for making corrugated medium, molded pulps and other products that do not require a high tear factor. The pulp is not bleached. This pulp is seldom sold on the market; rather it is used within the same company that manufactures it for use in corrugated boxes.

Dissolving pulp

This is an old chemical pulping process. The pulp is totally dissolved, removing all lignin and leaving only cellulose which is then bleached. It is used for making acetates, rayon, photographic film, plastics and specialty products. Bleached pulp yields are between 40% and 45%. The economies of scale are much less than for kraft pulp, approximately 100,000 metric tons per year, but the final product has a higher value. The process utilizes sodium sulphite and coniferous woods (fir, spruce and pine); short fiber species are rarely used in this process. No new sulphite pulp mills have been constructed since 1979 (Tappiphils, 2003).

Groundwood pulp

In the groundwood process, logs 1.2 m long are ground against a long cylindrical stone. Originally, natural sandstone was used for grinding, but

since 1924, artificial stones made of carbon silicate or aluminum oxide have replaced the natural stones for grinding (NTDC, 2007). The logs are placed in a steam chamber and pressed against the stone to scrape off and separate fibers from the logs. Logs must be of an exact length, uniform and round. Crooked logs or logs with many knots or defects are not used. Groundwood pulp is used for making newsprint, mixing it with approximately 25% long fiber kraft pulp. The fibers are rough and have a low tear factor, but the yields are high. Since the pulp is not cooked, and light colored coniferous wood are used, this pulp has a lighter color than do chemical pulps. However, for making newsprint, the pulp requires some bleaching to reach an acceptable level of whiteness. Yields are between 90% and 95% and the economies of scale are between 30,000 and 50,000 mtpy.

Pressure groundwood pulp (PGW)

PGW pulp is a technique developed by Tampella in Finland in 1970. It is used for making pulps for newsprint, the same as groundwood pulps. The process is similar to groundwood, but with the difference that the steam chamber is sealed and pressurized which helps to separate fiber bundles from the wood more easily than groundwood alone. When making newsprint, approximately 15% long fiber kraft pulp is mixed with PGW pulp for added strength. Yields are a little lower than for groundwood pulp, approximately 90%.

Thermal mechanical pulp (TMP)

This technique was developed in 1970 and has the advantage that it can use wood chips, rather than round wood. This allows for the use of all classes and sizes of trees to be used to make TMP pulps. The process uses heat and superheated steam to grind the wood chips as they are fed between two rotating platens or disks.

The process consumes much energy and requires high pressure steam, and there is a better separation of fiber bundles during the process. Yields are around 85%, and for bleached pulps the yields are five points lower.

For the thermal mechanical pulp process to be profitable there must be a low-cost source of electricity due to the large requirements of electricity in this process. There must also be an integrated pulp and paper industry, since high pressure steam is a by-product of the pulping process and it needs to be utilized for drying the paper or for other uses to reduce the total cost of the production of superheated steam.

TMP pulp is used for similar products as for groundwood pulp. Besides being used for paper manufacture, TMP pulps are also used for manufacturing MDF board.[6] MDF is an important component of the manufacture of cabinets, desks and other types of furniture, replacing particle wood use in such products. MDF is also used for making decorative panels with printed and embossed wood grains over the panels.

Chemi-thermal mechanical pulp (CTMP)

CTMP is a process that began in 1980. It is an intermediate process between TMP and semi-chemical pulp. Approximately 5 kg of caustic soda are added to a ton of chips to soften the lignin prior to pulping. The soda is not recovered, but it lowers the energy requirements for the pulping process. CTMP is made primarily with short fiber woods. Yields are around 85% to 95% (Abbey Newsletter, 1993).

[1]Included among the conifers are the pines, spruces, firs, larches, yews, and sequoias.

[2]In Spanish, specific gravity is called *peso específico*.

[3]To determine how much time is needed to fully dry wood samples, some samples are periodically removed from the oven and weighed. When the sample no longer loses weight, then it is totally dry and that is the total time required for drying that size of sample.

[4]To take a second measurement, the sample is wetted in water until it expands to the volume of a fresh piece of wood, normally between 6 and 24 hours, depending on the size. The ratio between the measurements of wet weight in air and the weight in water remain the same, although the individual scale readings can vary between those for the first measurement with a fresh piece of wood and later measurements made after the wood has been dried and moistened again.

[5]Low density cellulose fibers flatten more during the paper making process, which results in higher density paper, whereas high density cellulose fibers tend to remain rigid, they flatten less, resulting in a lower density paper product.

[6]MDF is the market abbreviation for *medium density fiberboard*.

13

Environmental influences of forest plantations

The relationship of forest tree species and soils
Eucalypts and the environment
Teak and the soil
Diseases and insects
Clear-cutting versus selective cutting
Allelopathy
Tree plantations and wildlife

There are frequent concerns expressed regarding the effect of tree plantations on the environment, especially those established for industrial wood production. Some concerns are based on scientific information, others are just popular myths that are propagated among people. This chapter deals with both and will try to clarify and explain some of the concerns that appear in the news media, that are heard in conversations within the general public, or that are reported in the international scientific literature.

Ecological and environmental aspects must be taken very seriously by a forestry company. Each professional employee needs to have clear ideas as to the activities of the company and how these can affect the environment, either positively or negatively. Likewise, companies need to make available to employees well-founded information regarding these subjects; to the contrary, employees will obtain their information from the popular media such as the press, television or from those critical of industrial reforestation. Knowledge regarding the ecological aspects and repercussions of company activities is of special importance for those employees involved in product sales, since such people have frequent contact with the general public. Wholesale buyers of forest products are generally aware of environmental concerns and of the importance of these to the consumers of their finished products.

The relationship of forest tree species and soils

Soil formation is due to five primary factors: parent material, climate, topography, vegetation and time (Brady, 1984). Soil formation is more rapid

in hotter climates and in those sites with the highest precipitation. The composition of parent material is the primary factor in the soil formation equation and is modified by the other factors, especially climate and time. Vegetation can have an effect on the soil surface and within the framework of the other factors. It is not possible to say categorically that pines or any other species acidify the soil. Rather, forest species, whether in plantations or in natural forests, adapt to the soils formed from the parent material.

On the island of Borneo, which straddles the equator, the sedimentary parent material was formed under the sea many millenia in the past. Later, during the geologic formation of the Pacific region, those maritime sediments morphed into sedimentary rock and were lifted up to form the island. In Borneo there are highly acid soils, in some cases with pH values as low as 3.5.* On such acidic soils there are natural forests composed of many broadleaf species, including the majestic trees of the Dipterocarpaceae family (meranti, kapur, keruing), which can grow as tall as 35 to 50 m. Interspersed within the very acid soils, there can be found outcrops of limestone, which were formed from deposits of the shells of marine life in coral reefs and where the soil pH is between 8.0 and 8.2, due to the high content of calcium carbonate in the limestone. On such alkaline soils there occur natural forests composed of the same majestic trees of the same species and with similar tree heights to those described for the very acid soils. In other words, the trees adapted and survived on the existing soils of the island, rather than the trees changing the chemical configuration or pH of the soils.

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* The author has measured the pH of forest soils on many sites in Borneo: in Sarawak, Sabah and in East Kalimantan.

There exists a widely held belief that the conifers acidify the soils. Without doubt, the vegetation has had an effect on the soil formation, as has already been explained, but on the other hand, the species that are found in a given forest environment owe their existence to their ability to adapt to the given site conditions that exist. Interactions between the environment and natural forests take thousands of years to develop and for the vegetation to adapt. Many of the conifer species have successfully adapted to those sites where there have occurred wildfires during millenia and where soils are infertile and acid.

Without doubt, the human influence has accelerated the environmental interactions. The disappearance of forests is due more so to human activities than to climatic changes or other natural factors (During, 1993). At first glance, the lack of forests in the Mediterranean watershed may appear to be a natural phenomenon, but, as has been explained in the

chapter on the history of tree plantations, it is logical to suppose that there were sizeable extensions of natural forests around the Mediterranean forests that were cut for the growth of multiple civilizations that developed during the past millenia in that region.

The belief that conifers acidify soils appears to be based on the history of Central and Western Europe. Most of the lands of Central-Northern Europe, the same as occurred in the northern latitudes of North America and Asia, were under glaciers from ten to seventy thousand years ago (Millar & Woolfenden, 1999). The soils thus formed due to the action of glaciation tend to be acid; the application of lime to increase the pH of such soils has been a common practice of farmers in much of Europe and North American for many years.

The natural coniferous forests of Mexico and Central America are mostly found on acidic soils (pH 4.5 to 6.5). However, on the high plains of Chiapas, in southern Mexico, there are large extensions of calcareous soils with pH values between 8.0 and 8.2 due to the parent material having a high content of limestone.** On the high plains of Chiapas there can be found natural forests with the same coniferous species that are found on acid soils in other parts of southern Mexico. On Andros Island, The Bahamas, the soils are likewise calcareous and *Pinus caribaea* var *bahamensis* occurs on such soils. In both cases of Mexico and The Bahamas, the pines found growing in natural forests on the alkaline soils are of heights and development similar to the pines that are growing in the natural forests on acid soils.

** The author has measured the pH of soils in Mexican forests in the states of Chiapas, Oaxaca, Tabasco, Campeche, Veracruz, Nayarit, Guanajuato and Chihuahua. The pine species growing on the high plains of Chiapas include *Pinus douglasiana*, *P. oocarpa*, *P. teocote*, *P. michoacana*, *P. montezumae*, *P. maximinoi*, *P. tenuifolia* and *P. pseudostrobus* (Perry, 1999).

There exists a high probability that changes found in the pH of soils under European spruce and pine plantations is due more to the cultural practices of local peasants and farmers than to the trees themselves. During the Medieval Period, most natural forests were cut to provide wood to support the frequent wars among nobles, princes and kings who used it for fortifications, for other constructions and for firewood, or they eliminated the forests and converted the land to agriculture (Westoby, 1989). There were other reasons for eliminating forests. There are the many legends that arose during famines when bandits and lawless men used the forests as hiding places and to assault and rob travelers as well as to raid farms and villages for valuables, food and clothing. Seeing the importance of wood for

ship and fort construction, in the Eleventh Century the Norman conquers of the British Isles were recognized for their reforestation efforts (Westoby, 1989). During the Sixteenth and Seventeenth Centuries, princes, nobles and rich landowners in France and Germany established plantations of oaks and beeches, since the forests provided refuge for deer as well as mast as food for the deer and pigs, important sources of meat and skins. Conifers such as spruce, larch and pine were also planted as sources of construction wood for their mansions, furniture, wagons and fortifications. Local peasants often went to the conifer forests to collect dry branches (faggots) for firewood and pine straw (dry pine needles) as bedding for animals, since the conifer plantations produced an abundance of such useful materials. After many decades (or even centuries) of this practice of removing leaf litter under the conifers, the soils necessarily turned more acid.[1] When researchers in the Twentieth Century analyzed soils under tree plantations, it was no great surprise to find that those soils had slightly lower pH values than did adjacent soils under oak forests or where there was no forest cover or where the land was in cultivation.

Tree species selected for planting on marginal pastures or depleted agricultural soils are normally those that are termed “pioneer species”, being the species that can grow successfully on depleted soils. Pioneer species are known for their ability to produce large quantities of litter, which covers the soil and protects it from erosion and which promotes the formation of a humus layer as it decomposes. In Colombia, in a 7-year-old plantation used as shade for coffee trees, it was found that litter production under a stand of *Eucalyptus grandis* was 8 tons/ha/year (field weight), under *Pinus oocarpa* it was 5 ton/ha/year and under *Cordia alliodora* (laurel) it was 5 tons/ha/year (Urrego & Farfán, 2002). In another study, there were significant differences in the oven dry weight of litter under plantations of different species between nine and 12 years of age (Table 13-1). The litter of conifer species, the same as broadleaf species, contains nutrients and bases that are recycled by fungi and bacteria found in the soil and which decompose the litter, releasing available nutrients that are then reassimilated by the tree roots. This recycling is fundamental for the development of trees and for soil recuperation under plantations. If this nutrient cycling is broken, the growth and health of the trees is compromised.

Table 13-1

Oven dry weight of organic matter in litter under plantations of four conifer species in the highlands of Popayan, Colombia (Ladrach & Gómez, 1984)

Species	Organic matter tons/ha (oven dry weight)
Pinus kesiya	3.35
Pinus patula	2.09
Pinus oocarpa	1.89
Cupressus lusitanica	1.59

Eucalypts and the environment

There are more than 500 species in the genus *Eucalyptus*, family Myrtaceae, that are distributed in natural forests of the Pacific from 7° N of the equator in Papua New Guinea and Indonesia, to 43° S in Tasmania, Australia (Hall *et al.*, 1970; Hillis & Brown, 1984). There is also one species of eucalypt (*Eucalyptus deglupta*),which occurs naturally in the Philippines. Some taxonomists feel that the total number of species could actually be divided into more than 600. Of all of these, there are just 30 to 40 species of eucalypts that are used in tree plantations (Lima, 1993).

Contrary to the claims of some critics that within 30 or 40 years there will be infertile soils under eucalypt plantations, experience has shown just the opposite. In industrial eucalypt forests that have been planted and harvested multiple times, the succeeding plantations produce more, not less, wood per hectare, thanks to the genetic improvement and the selection of the best trees to be used as seed producers. Good soil preparation, weed control, fertilization and other silvicultural practices have also helped to improve plantation growth significantly (Evans, 1982). In Brazil, the productivity of industrial eucalypt forests doubled in wood harvested between 1987 and 2004, while the forest plantation base remained nearly constant at 5 million ha.[2]

There are many examples that contradict the notion that eucalypts cause infertility in soils. In Chile, eucalypts have been planted since early in the Twentieth Century. Eucalypts have been planted in many parts of Africa for more than 100 years. In Portugal, there have been plantations of eucalypts for more than 150 years, while the growth and productivity of those plantations has increased by more than 50% during the past 30 years.

In Australia, the watershed that supplies the city of Melbourne covers more than 120,000 ha and most of it is covered with natural forests of

Eucalyptus regnans. The quality of the water produced in this watershed is so good that it is not necessary to treat the water before distributing it to the city (MMBW, 1980).

In a study carried out in India, no differences were found in the pH of water nor in the quality of subterranean water under a 14-year-old plantation of *Eucalyptus globulus*, a natural forest of *Shorea robusta* (sal) trees or a nearby pasture (Mathur *et al.*, 1984). In another study comparing a plantation of *Eucalyptus globulus* with a natural forest of *Shorea robusta*, no differences were found in the nutrient content or the pH of water coming from the two sites (Samraj *et al.*, 1988).

In a study carried out in Brazil, it was found that eucalypts have a similar capacity to absorb water from the soil as do pine plantations and natural forests of broadleaf tree species (Lima & Freire, 1976). In another Brazilian study comparing native species and eucalypts in plantations, it was concluded that the native tree species consumed more soil water during dry periods when soil moisture resources were limited, but, to the contrary, the eucalypts consumed more soil water during the rainy period; therefore, Dr. Heladio Mello (1961) concluded that the eucalypts were more effective for soil moisture conservation.

In India, a study compared soil moisture extraction rates under young plantations of *Leucaena leucocephala*, a small tree species frequently used in agroforestry projects, and *Eucalyptus tereticornis*. It was concluded that average annual water use by the two species was similar, but that *Leucaena* had a greater ability to remove water from dry soils (Das *et al.*, 1990). In other words, the eucalypts used less water during the dry season than did *Leucaena.*

Although some critics claim that the eucalypts have deep root systems that remove more ground water than do other species, a study in Brazil on sites where the water table was relatively deep, the soil moisture regime was not found to vary under a stand of eucalypts, or pastures, or fields with weeds; likewise, it did not vary between deep rooted and shallow rooted species (Lima, 1984). Soil moisture extraction was found to be similar for pine plantations and for eucalypt plantations of similar ages and stand densities (Lima, 1984).

Without a doubt, Dr. Walter de Paula Lima, Professor and soil scientist at the University of São Paulo, Brazil, is the leading authority on the relationship of soils and eucalypts. Professor Lima has directed numerous

field studies and has written many technical reports and several books on this subject. His book in Portuguese *Impacto Ambiental do Eucalipto* (1993) (*Environmental Impact of Eucalypts*) makes detailed reviews of nearly all aspects of eucalypts and their effects on soil and on watersheds and includes citings of 850 references from world literature on the subject. The following is a brief summary of some of the conclusions reached in that publication.

- The available scientific information does not support the idea that eucalypts or any other forest tree species use such large amounts of water that they can alter rainfall patterns.
- Losses of rainwater through interception by the foliage are less for eucalypts than for the average of other species in plantations or in natural forests.
- Eucalypt plantations can contribute positively to reducing surface sheet erosion of soils and thereby help to minimize soil erosion and soil nutrient loss.
- Water that drains from watersheds that are covered with natural forests of eucalypts is generally of high quality.
- Surface and subsoil water levels found under eucalypt plantations and under natural forests or other types of vegetation are not markedly different.
- Although there is limited information available, the existing data indicates that the efficiency of biomass production per unit of water consumed is relatively high for eucalypts when compared with other tree species.
- The hydric balance of watersheds reforested with eucalypts has not been observed to be different to that of watersheds that have other types of forest cover.
- In the long term, eucalypt plantations are demonstrating positive effects on soil chemical properties.
- The soil nutrient demand of fast-growing eucalypt plantations is relatively high when compared with that of slow-growing species, but is of the same order of magnitude as the soil nutrient demand of other fast-growing tree species and is much less that the soil nutrient demand of agricultural crops.

- The available evidence does not support the argument that eucalypts are invasive species that will take over and supplant native flora, nor that they have allelopathic effects that will suppress the growth of other plant species. With time, local native species can develop a rich and varied understory of growth within eucalypt plantations and, when marginal agricultural soils have been covered with eucalypt leaf litter, the original forest species can eventually return and prosper on such sites.

Teak and the soil

Teak (*Tectona grandis*) is originally from the South of Asia, where it grows in the natural forests of India, Bangladesh, Myanmar (Burma) and Thailand. It is a very important species planted to produce fine woods and is the most widely planted tree species for high quality woods in the world. In Thailand, there are more than 800,000 ha in teak plantations (FAO, 2001). The Royal Forestry Commission of Thailand plants teak as the primary species for erosion control on deforested sites and for the recovery of such sites.

Although teak is not native to Indonesia, plantations were first established on the islands of Madura and Java more than three centuries ago and it is now considered to be a *naturalized species* (White, 1991). About 150 years ago, the colonial Dutch government began planting teak in Java and this continues to the present, under the responsibility of Perhum Perhutani, a government corporation that is in charge of tree plantation management on the island of Java. There were once more than 2 million ha of plantations on Java with forest tree species, and of that total, 1.2 million were teak. Teak was planted in Central and Eastern Java, where there are many small to medium-sized hills surrounded by fertile lowlands which are planted to paddy rice, corn and other agricultural crops to sustain the more than 100 million inhabitants of the island. When the teak plantations were begun on a large scale during the Nineteenth Century, teak was not scarce, as there were still extensive teak forests in Southern Asia. The teak was planted, not only for its fine wood, but also to reforest those hill sites in order to protect the soils from erosion and to prevent the sedimentation of the lowlands where there are rice fields. After 150 years of experience in Java, it can be concluded without any reservation that teak is a good species for soil protection and that it is does not cause erosion.[3]

The key to the success of reforestation and to the recovery of soils is the ability of a species to form leaf litter to cover the soil and protect it from erosion (Kanowski & Savill, 1992). In Darjeeling, India, a study compared the litter accumulation under a plantation of teak, a plantation of rubber trees and under a natural forest; it was found that there were no significant differences in nutrient levels in the soils under the three types of vegetation, except that there was more calcium in the surface soil under the teak plantation. The study also found that there was a greater accumulation of leaf litter under the teak plantation than under the rubber plantation or under the natural forest (Krisnakumar *et al.*, 1991).

In Costa Rica there are more than 30,000 ha of teak plantations (FAO, 2001). In that country there are also persons who claim that teak trees are causing erosion around their own roots. The best means to clarify this difference of opinions between studies and long term histories of teak plantations in Asia and the criticisms and reports that people have developed regarding recent plantations in Costa Rica is to go to the field and see what is actually happening in Costa Rica. The author has personally visited sites in the western peninsula of Guanacaste where sizeable commercial teak planting programs exist. These sites are hilly where cattle grazing was the primary land use during many years and where there occurred severe overgrazing and soil erosion. There are sites covered with young plantations of teak and pochote (*Bombacopsis quinata*) and where there are gullies visible. However, on the other side of the same road there are pastures with the same levels and conditions of erosion and with the same gully formation. Criticisms of pochote are not heard, most likely because it is a native tree species; the criticism is directed at teak which is an introduced species. The obvious conclusion is that the reforestation with teak (or pochote) did not cause the erosion, rather the teak was planted on sites that had been eroded and gullied due to the previous land use as pasture, and that the teak plantations are a means for protecting and recovering soils that were degraded by the prior overgrazing of the land.

Diseases and insects

A common criticism directed at tree plantations is that they are more susceptible to disease and insect attacks than are natural forests. In spite of the frequency of this criticism, it is difficult to find scientific evidence that supports this belief.

In 1977, a literature review was made of the 13 most important forest tree disease and insect problems in the United States since 1900 (Ladrach, 1977). Among the trees severely affected is the American chestnut (*Castanea dentata*, family Fagaceae), the most important tree species for construction and furniture wood that existed in the natural mixed broadleaf forests of North America. The chestnut blight (*Endothia parasitica*) was introduced from Asia and first detected in 1904; by 1940 that disease had devastated all mixed natural forests causing the total disappearance of this species in wood markets. Similarly, the Dutch elm disease (*Ceratocystis ulmi*), caused the total demise of the American elm (*Ulmus americana*) in natural mixed forests. In 1950, 50% of American furniture was made using elm wood, but by 1970 the species had totally disappeared from wood markets due to this disease. Each time there is a prolonged dry season of multiple years, the pine bark beetles (*Dendroctunus frontalis*) attack the forests of southern United States, causing the death of thousands of hectares of trees in mixed natural forests. The beetles have never caused so much devastation in pine plantations. The gypsy moth (*Lymantria dispar*, family Lymantriidae) was introduced into North America from Europe in the 1860's and it continues to defoliate multiple species of eastern North America, primarily in mixed natural broadleaf forests. The spruce budworm (*Choristoneura fumiferana*, order Lepidoptera) is an indigenous pest that was first identified in 1807 and which continues to infest the mixed natural conifer forests of northern United States and Canada and cause serious damage and the death of fir and spruce trees. These pests mentioned above have never been a significant problem in plantations established in the same regions where there are chronic to severe attacks of trees in the natural forests.

Of all the disease and insect problems reported in North American forests during the Twentieth Century, the only one that has had an important economic effect in plantations is the fusiform rust (*Cronartium fusiforme* or *C. quercum*), which attacks pines and oaks in southeastern United States the same as it attacks mixed natural pine forests. However, research and genetic selection has been able to develop strains of pine species that are genetically resistance to this disease and it no longer has an important impact on plantations, whereas it continues to cause significant damage in mixed natural forests.

There are multiple reasons why plantations tend to be healthier than natural forests:

- Competition among trees is controlled in plantations by using regular tree spacings, which allow individual trees to have sufficient soil and light to grow in a healthy manner. Tree density control, i.e., silvicultural control of stand density, is one of the most effective means of avoiding damage by defoliating insects of the Lepidoptera order. On the other hand, in natural forests there is strong competition among trees for space, soil nutrients and light during the life span of trees and this results in the death of most of the trees that germinate in a forest environment leaving only a few to remain standing in the mature forest.
- Disease and insect attacks in plantations are often associated with the planting of species that are not suited to a particular environment. Control of such problems is then a question of making species trials to evaluate their adaptation to a given site or location and selection of the species (or provenances within a species) that adapt best to a given environment.[4]
- Plantations are harvested when they reach commercial maturity and while the trees are healthy. In natural forests, the trees that survive the strong tree-to-tree competition become over-mature and eventually decrepit, thus becoming more susceptible to attacks of opportunistic biological agents.
- If there is a pest attack in a plantation, the affected trees can be eliminated before the problem becomes severe and spreads. In mixed natural forests this is seldom a viable alternative.
- When there are diseases that cause important economic losses by attacking plantation trees, such as the case of the *Eucalyptus* canker (*Chrysoporthe cubensis*) in Brazil and the fusiform rust of the pines of North America, resistant strains have been identified through research and then used for establishing future plantations. Currently, the eucalypt strains planted in Brazil are resistant to the *Eucalyptus* canker and most pines planted in Southern USA now have tolerance or resistance to fusiform rust.

Why is it, then, that there exists the popular belief that plantations are more susceptible to disease and insects than natural forests?

The greater part of tree plantations have been established near rural populations where open land is available for planting, where there is a source of labor and where there is road access for the movement of equipment as well as forest products. It is quite normal that when any problem occurs in a plantation that is visible to the nearby public, it will become a subject of general speculation and gossip.[5] Also, companies themselves as well as the local press often report on problems that occur in the plantations. To the contrary, when some disaster occurs in a natural forest, these are usually a long way from local populations, are not observed by the public and are of little or no local interest. In the humid tropical rainforest of the Pacific coast of Colombia, one study registered 78,000 trees/ha in the natural regeneration at one year of age, but by eight years that number had diminished to 11,000 trees/ha and in the mature forest, the average density of commercial sized trees was 325 trees/ha (Ladrach, 1985a). When trees in the natural forest are debilitated by severe tree-to-tree competition, they become susceptible to insect pests and pathogenic fungi. However, if they are not of local economic interest, there is little, if any, interest whether one or a group of trees dies and falls over due to rot, since this is perceived as a normal part of nature. It is important to remember that this is the concept known as *natural equilibrium*, where some trees die and others grow up in their place in a continuous cycle. This process, however, has an *overall net growth of zero*. Disease and insect attacks are important vectors in this process.

When major industrial forest plantations were begun during the Twentieth Century, there were many errors committed by foresters that resulted in plantation failures. The blame for such failures was seldom attributed to human errors such as planting the wrong species, planting the wrong provenance or just a lack of good supervision of laborers during the planting process. More than likely, the blame was attributed to natural conditions, such as droughts, insect attacks or diseases (Zobel & Sprague, 1993). This tendency of foresters to "*blame nature*" for plantation failures helped to form a public perception that plantations are weaker and more susceptible to pests than are natural forests.

The tree planter, the same as the farmer, must be aware of any problem or condition that arises in the crop. There must be periodic inspections and

if there are any anomalies, these must be evaluated as to their potential impact on the crop. Forest research is the best defense for a tree planter as a method for evaluating problems that may be found in tree crops. A large forestry company normally has its own forest research personnel that provide technical assistance to forest operations. For small landowners this is seldom an option. Nonetheless, large gains have been made by forest research in the United States, Brazil, Chile and in other countries, especially where there are cooperatives for such efforts among public institutions and private companies. High quality technical assistance by research personnel is one of the most crucial and necessary incentives to the development of a crop, be it in agriculture or in forestry.

Clear-cutting versus selective cutting

One criticism directed at industrial plantation owners is that they make clear-cut harvests. Given the fact that tree plantations are a tree crop, this is rather curious because the great majority of agricultural crops are harvested at one time by some form of clear-cut, the land is site prepared and then replanted for the next crop. As has already been mentioned, most forest tree plantations are established by companies that use wood as furnish for making pulp and paper or particle board. When the trees reach financial maturity, they are all harvested and the site is then replanted.

However, when managing tree plantations to produce lumber, periodic thinnings are needed to eliminate trees with poor form and also to reduce the stand density so that the residual trees add more diameter and greater value. In other words, the harvest system is defined by the management objective and the products desired. Nonetheless, it is not profitable for any company to consider making multiple cuts where just a few trees are removed each time and where some trees are left standing long past the time of their financial maturity, as some environmentalists propose.

On the other hand, where plantations are established for erosion control, for watershed management or for tree cover in public recreation areas, the most appropriate method for management may well be to make multiple thinnings so that trees are left to grow large and tall, allowing for an understory of other species to grow and prosper. If the management plan is to allow the trees to continue growing for many years, such as in a park or forest reserve, without a final harvest, it is important to make periodic thinnings to open up the crown to provide more crown and root space to the

remaining trees so that they grow large and healthy. If no thinnings are made, what will happen is that the older plantations will stagnate, the trees will begin to die and fall down, leaving a disastrous condition with thick, skinny trees, dead tress and unhealthy trees susceptible to attack by diseases or insects.

In summary, there is really no one management system that is appropriate for all plantation management. The harvesting plan depends on the objective of the plantation landowner and the products that are to be produced from the plantation trees.

Allelopathy

Allelopathy is a natural defense mechanism by which plants compete with other plants in the environment. The dictionary definition of allelopathy is “The act of one plant species suppressing the growth of another by generating toxic substances”. Rice (1984) utilizes another definition: “Allelopathy is any effect, direct or indirect, beneficial or otherwise, of one plant or micro-organism over another plant, by the production of chemical compounds that are liberated into the environment”. When such substances are liberated in sufficient quantities, they can cause allelopathic effects on the germination, growth or development of other plants and micro-organisms (Carvalho, 1993). In a broader context, Durigan and Almeida (1993) describe allelopathy as the use of diverse substances, which can affect the decomposition of seeds, interfere with seed dormancy and also produce effects on other plants, insects and even higher animals.

The use of chemicals as defense mechanisms is common in the natural environment and can be found in many diverse types of plants. However, the effectiveness of organic compounds is lost as they decompose after the death of the plants or plant parts that produce them. In the case of particular chemicals, their duration can be shorter or longer, according to the chemical structure and the ability of micro-organisms in the environment to decompose them. Various types of organic compounds have been identified as allelochemicals produced by micro-organisms and plants, including the following (Rice, 1984):

- organic acids,
- simple unsaturated lactates,
- fatty acids and polyacetylenes,

- naftoquinone, antraquinone and quinone complexes,
- basic phenols, benzoic acid and derivatives of gallic acid,
- cyanidic acids and derivatives of chlorogenic and ferrilic acids,
- quamarines
- flavonoides
- tannins
- terpenes and steroids
- amino acids and polypeptides,
- alcaloides and cyanodrines (strychnine, atropine, codeine, cocaine and a-midaline),
- sulfates and glycosides,
- purinenes and nucloeocides

It is difficult to separate and quantify the allelopathic effects of trees in the presence of the complex factors of a forest environment. In a field study it is difficult to separate and identify the allelopathic effects of a tree species from the tree's ability to compete with plants in the understory shade or its ability to compete for the available soil moisture. The lack of flowering and the production of seeds in lesser plants in the understory can be due to a lack of sufficient sunlight to carry out such biological functions, not necessarily the effects of toxic chemicals produced by the overstory trees themselves.

There have been criticisms and claims that some tree species, such as eucalypts, acacias, pines, cypress and teak are allelopathic and that after they have been planted on a site for just one rotation, other vegetation will not grow on the same site due to allelopathic effects from such trees. It is worth noting that in Central America and Mexico, where the largest number of the world's conifer species occur naturally, the natural pine lands are prized for conversion to corn and other cultivated crops as well as for use as cattle pasture. Claims that pines poison the soil in just one rotation are simply not logical when considering that the pines in Mexican and Central American have been growing on the same soils for thousands of years and that such sites are being converted to agricultural crop production. In Brazil, where there had been plantations of eucalypts, such sites have been successfully replanted to coffee after harvesting the eucalypt trees. In Colombia, plantations of cypress, pine and eucalypts have been harvested and the sites successfully planted to corn, tomatoes and vegetable crops.

There may be some phytochemicals in trees and bushes that have allelopathic functions, but studies demonstrating such effects are scarce. One species known for allelopathy is the North American walnut (*Juglands nigra*). Although tannins, phenols and resins in foliage of some tree species can have allelopathic effects, it does not appear that allelopathy is a primary mechanism for competition among trees or for competing with understory vegetation. In plantations of teak, eucalypts, pines, acacias, *Gmelina* and other forest tree species with closed crowns, it is common to find that a large number of other species germinate and grow in the understory just a few weeks after a silvicultural thinning is made. If those tree species had significant allelopathic tendencies, the understory regeneration would not have germinated in the litter under the trees after a thinning. As has already been cited, Dr. Walter Lima concludes that the available evidence does not support the argument that the eucalypts have allelopathic effects that suppress the growth of other flowering species (Lima, 1993).

On the other hand, it is well known that grasses and weeds tend to be highly allelopathic (Sánchez–Moreiras *et al.*, 2003). There is even research to study the possibility of using such toxic substances of some grass species as a method for weed control in agricultural crops without the use of manufactured chemical herbicides (Paulo *et al.*, 1997; Anjum *et al.*, 2005; Souza *et al.*, 2006). In research carried out in Colombia, it was found that the exotic grasses: yaraguá (*Melinis minutiflora*), kikuyu (*Pennisetum clandestinum*) and *Brachiaria* sp. have strong and damaging allelopathic effects on young tree plantations of *Eucalyptus grandis*, *Eucalyptus globulus* and cypress (*Cupressus lusitanica*) (Cannon, 1981; Ladrach, 1982, 1983b, 1985b; Lambeth, 1986). In Brazil, it has been shown that the grass *Brachiaria decumbens* has the capacity to significantly reduce the growth of *Eucalyptus grandis*, when it is incorporated in the soil of a tree plantation (Souza *et al.*, 2003). Allelopathic effects have been found in the alang-alang grass (*Imperata cylindrica*) when it grows under plantations of *Pinus merkusii* and *Acacia auriculiformis* in Indonesia (Santoso, 1987). Alang-alang has also shown allelopathic effects when growing with other grass species (Koger & Bryson, 2004). A report by Rezende *et al.* (2003) presents a good general summary of the allelopathy of tropical grasses.

In Australia, rainwater dripping off the foliage of trees in a eucalypt forest was collected and analyzed for concentrations of natural foliar extracts. It was found that extract contents were 10 parts per million (10

ppm) (May & Ash, 1990). Using similar concentrations of extracts from eucalypt foliage sprayed over seeds and over the foliage of several agricultural and tree species, there were no noxious effects found on germination rates or growth.

In India, there have been several laboratory studies where extracts of sap from foliage of eucalypts and other tree species were sprayed over seeds and succulent plants that had just germinated, demonstrating that that sap had noxious effects on the target seeds and plants. In one Indian study, the concentrations of such phototoxic extracts from *Leucaena leucocephala* were evaluated at a 1% rate (10,000 ppm) (Chaturvedi & Jha, 1992). (*Leucaena* is a small tree often used in agroforestry plantations.) The researches found phytotoxicity from the *Leucaena* sap extracts on recently germinated seeds of rice and on *Casuarina*, another tree species, but the concentrations used in that study were *one thousand times greater* than would be found naturally from water that dripped off of the leaves of the *Leucaena* trees!

It is quite possible to obtain sap extracts from leaves and roots of a plant or tree and apply these at high concentrations over seeds or small sensitive plants and find a noxious effect *in the laboratory*. However, that does not mean that the particular tree or plant in the field is noxious in its environment; it simply means that it is possible to make noxious concentrations of extracts in the laboratory. Attempts to use such laboratory results to claim that they show allelopathy are a complete exaggeration of the concept. Such studies do not demonstrate allelopathy, rather they simply show a "*laboratory induced phytotoxicity*" and a false interpretation of the data.

Tree plantations and wildlife

Most tropical reforestation occurs in areas that had already been cleared for agriculture and grazing and were marginalized for such uses.[6] In such locations, the existence of wildlife is limited by the absence of a natural habitat due to the efforts of the farmers to control wildlife which to them can be a threat to crops or to compete for resources with their own domestic animals. Another factor is hunting, which has eliminated large animals, birds and reptiles from many localities. Dr. Jose Ignacio Borrero, a Colombian biologist observed that, in the Popayan highlands of southwestern Colombia, 97% of the mammal species and 80% of the bird

species that originally inhabited the region had disappeared due primarily to the traditional agricultural land use (Borrero, 1978).

According to Lima (1993), a eucalypt monoculture, as with any other plant, can result in a diminished availability of resources for a varied wildlife population, but a tree plantation, whether with eucalypts or another species, has never been shown to be totally lacking in fauna. Additionally, the general conditions for wildlife prosperity can be improved in the regions where there are plantation forests by practicing adequate forest management methods for the total land area.

When tree plantations are established where there were previously agricultural crops or pastures, it is not logical to expect that a plethora of wildlife will appear simply because trees have been planted. The logical and normal process for wildlife conservation in industrial forest properties is to conserve the remnant natural forests that exist and to allow them to recover their natural flora so as to protect and promote wildlife development.

In Colombia, Pizano, S.A., provides an excellent example of how a forestry company collaborates in the protection of local wildlife. The company initiated wildlife inventories when it began planting trees on land that was previously used for cattle production in the Atlantic Coastal Plain in 1981 and it prohibited all forms of hunting. The company also cooperates with the Colombian Government and with research personnel from other countries in the study of wildlife in its forest properties. Among the varied groups of animals found in its properties is the tiny whiteface tití monkey (*Saguinus oedipus oedipus*), a species of tamarino endemic to Colombia and considered to be endangered. The Pizano forest properties are recognized by national and international primatologists as one of the best reserves for this species within its natural range.

In the Andean region of Colombia, the common squirrel (*Sciurus granatensis*) has been observed to adapt to pine plantations and has learned to eat the seeds of pine cones (*Pinus maximinoi*) as well as the acorns of the red oak (*Quercus humboldtii*) (Ruiz, 1994). In 1997, CONIF (National Forest Research Corporation) studied the flora and fauna of two properties of a company which had pine and eucalypt plantations (Agudelo & Castillo, 1998). The conclusion of the research was that “the existence of adequately managed forest plantations favors the presence and permanence of the local biota, when compared to nearby lands that are principally used for grazing.”

In Brazil, Aracruz Celulose maintains natural forests on its forest properties which are planted with eucalypts and the company produces millions of seedlings of indigenous tree species in its nurseries on the Atlantic coast for planting on its own forest properties, as well as to provide seedlings of native tree species to other landowners in the region. Of its more than 200,000 ha of forest properties, Aracruz maintains one hectare of natural forest for each two hectares of eucalypt plantations. Studies promoted by Aracruz since 1993 have identified more than 450 different species of birds which depend on their timberlands, including both natural forests and eucalypt plantations (Antas & Almeida, 2005). There are multiple examples of animals that have adapted to eucalypt plantations and that live within them. Among the birds identified are 10 that are listed as endangered by IBAMA (Brazilian Environmental Institute). The Atlantic Forest (*Mata Atlántica*) of Brazil is a unique region that has many endemic species of flora and fauna, but most of this once extensive forest type has been cleared and eliminated over the years since the country was first colonized. Aracruz maintains the largest private forest reserve of this forest type in Brazil.

Although there is still a considerable lack of technical information regarding the abundance of fauna in tropical plantations, the available indications are generally positive and the forest industry has contributed to the conservation of the natural tropical remnant forests within its industrial forest properties.

[1]When the branches and litter of conifers are burned, the remaining potash contains base nutrients including calcium, magnesium and potassium.

[2]Source: SBS: Sociedad Brasileira de Silvicultura, 2005, www.sbs.org.br

[3]The sad part of this story is that, with such a large human population on Java, teak is disappearing. Of the 1.2 million ha originally planted to teak, there is an estimated 350,000 ha left today and this continues to be reduced further, due in large part to the demographic pressure that exists to use these hills for agricultural production. Besides, teak wood is valuable in local markets for construction and craft work and, unfortunately, Perhutani is cutting much of it to generate income. Further complicating the situation is the ease of stealing teak trees and the difficulty of controlling such losses due to the disperse distribution of the plantations in the hills interspersed with many small rural villages.

[4]There is the case of the *Gmelina* canker (*Ceratocystis fimbriata*) which occurred in Brazil in the 1980's. This fungus is present world-wide as a blue stain in wood, but has never been a pathogen to *Gmelina* except in the plantations of Jari Celulose in the Amazon region where it was planted on sandy to sandy loam soils. *Gmelina* is a tree species that adapts best to clay loam

or silt loam soils, but it seldom does well in sandy soils. Jari changed from planting *Gmelina* to planting eucalypt hybrids that adapt well to such soils and thereby eliminated the problem.

[5]In 1981, Pizano SA began planting red ceiba (*Pachira quinata*) in Bolivar Department of Colombia. Red ceiba occurs naturally in this coastal Caribbean region; it is common in natural forests and the wood is used in construction locally and throughout the country. Local residents have observed that the red ceiba trees in natural forests drop their leaves at the beginning of the dry season and then sprout new foliage when the rainy season begins. Nonetheless, when the first plantations of Pizano entered the dry season and the one-year-old trees dropped their leaves, the local gossip in the surrounding villages was that “The Pizano trees had died!” As humans, we love to spread gossip, without much concern as to its veracity.

[6]An important exception is Indonesia, which has the fourth largest human population in the world with more than 200 million inhabitants. Between 1988 and 2002, the Indonesia Government promoted the conversion of degraded and logged over natural forests to industrial tree plantations to stimulate the economy, especially on the islands of Sumatra and Kalimantan (Borneo); those incentives have now expired.

14

Administrative organization of a forestry company

Organizational concepts in business
Company ethics
Employees' manual and functions
Responsibility versus authority
Do's and don'ts for employees and managers
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Organizational structure
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Industrial safety
Social and community relations
Problem resolution
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Organizational concepts in business

This chapter is a summary of the principles of business organization (Drucker, 1954; Koontz & O'Donnell, 1972), along with what has been learned by observing the operations of many forestry companies. The following concepts are key to the administration of a forestry company.

The purpose of an organization is to *facilitate the completion of the objective or objectives in an efficient manner, using the knowledge and experience of the participants.* The basic components of a company are:

- Management, the administrate resource
- Personnel, the human resource
- Capital, the financial resource
- Raw material, the natural resource

There are three primary groups operating within a manufacturing business:

The group responsible for making long-term decisions as to direction of the company includes:

- Board of directors
- President or chief executive officer

The production group (line functions*)*

- General manager or chief operating officer
- Planning and scheduling
- Purchasing
- Manufacturing
- Marketing and sales

The logistical support and technical services group (staff functions*)*

- Finances and accounting
- Personnel management
- Research and quality control
- Product development
- Engineering
- Industrial safety
- Social and community relations

Each company needs to have a general directive or mission statement, which describes in a few words the general objectives, the outlook and the reason for the company's existence.

Company ethics

Each company needs to have ethical regulations as a guide to employee behavior. This document summarizes the expected general behavior of all the employees and their relationships with the public, as well as the safety policies of personnel working in the company.

Employees' manual and functions

Each employee within an organization must have a written job description. This is a reference framework that describes the employee's obligations, duties and limits of authority. The employee's job description is provided to each new employee so that they can know their duties within their work area. The job descriptions within a group are defined by the group leader during a meeting with subordinates and these are then approved by the superior of the group. Once defined and approved, these descriptions remain unchanged unless there is another meeting of the personnel within the group and any changes proposed and defined are subsequently approved by the corresponding superior. The employee manual and job descriptions are

crucial to maintain continuity within the organization, especially when there are personnel changes. Each new employee must be required to read the job description and sections of the manual that pertain to that position and to comply with them. An organization cannot allow new employees to make changes in procedures or processes at will, which would result in reduced productivity, disasters and uncertainty within the organization.

All employees within a company need to understand the requirements of their position. The terms of reference for each employee are:

- The job description of each position within the company, which describes each employee's duties, authority and responsibility,
- Work goals: What are the tasks assigned by the superior for the production of goods and services?
- What are the employee's obligations regarding the execution of the functions and reports required by the superior?
- What are the employee's obligations to subordinates, such as defining goals, supervision, training and follow-up?

Responsibility versus authority

The authority of an employee is understood within the following standards of employment:

- The company's general mission statement,
- Compliance with management policy and ethics of the company,
- Compliance with the job description,
- Completion of the goals and duties assigned to the employee,
- Use of subordinates in such a way as to meet the assigned goals and obligations,
- Planning and requesting resources (personnel, materials, machinery) necessary for carrying out the assigned goals in an efficient manner.

Responsibility is not delegated. When a supervisor gives a subordinate the authority to execute an action or function, the responsibility for such actions continues being that of the supervisor. It is the obligation of the supervisor to define tasks in terms that are clear, to supervise the tasks of subordinates and to request timely reports on the work in progress. One of the most common errors of a superior is to give orders to a subordinate but not do the follow-up and supervision necessary to make sure that the jobs, tasks or goals are being completed as requested. In a forestry company where people work in disperse locations, the concepts of supervision and follow-up are even more critical.

Do’s and don’ts for employees and managers

An employee who commits an error while working within the assigned limits of authority should not be criticized for the error; rather it is an opportunity to evaluate the reason for the error with the purpose of improving future work behavior. On the other hand, if the employee commits actions that go beyond the authoritative limits stipulated, then it is grounds for sanctions or even dismissal. Does a subordinate have the right to contact the boss of the immediate superior? Yes, when the immediate superior requires a task that goes beyond the job description or limits already described. The employee has this right if the immediate superior does not provide the necessary assistance, training and/or tools to carry out the assigned task in an effective manner. However, this right should only to be used in very special and critical situations.

The superior should be accessible to the subordinates, who have the right and obligation to contact the superior whenever there is some doubt or question regarding the tasks to be completed. Similarly, the superior should make time available to hear concerns, comments or complaints from subordinates regarding the requested tasks. Subordinates directly under the authority of a superior are the highest priority of that superior, because it is through those persons that the superior completes his/her obligations to the company. The boss has the obligation to make certain that the subordinates have the necessary resources to complete the tasks assigned efficiently, correctly and on time. (This includes the necessary training, budget and equipment to complete the assigned tasks).

Persons who take the time to carry out constructive conversations with their subordinates are those who show the potential to assume greater responsibility within a company. The persons that are always searching for contact or favors from the superior, but, at the same time, ignore the requests of his/her subordinates are destined to failure.

Chain of command

The chain of command is a line of authority within an organization. The manager has the authority to give an order or request a given action or service from the immediate subordinates, but cannot abuse that authority and give direct orders to those employees who are under the subordinates. Rather, the manager must make known orders through the immediate subordinates. It is not good policy to jump over the chain of command. (The rights of one person are limited by the rights of another).

During a visit to a forest tree nursery, a forest manager observed an incorrect action by some of the nursery laborers. However, the forest manager does not have the right to correct the actions of these same laborers. Rather, the manager’s concern must be communicated to the regional supervisor who then communicates it to the nursery manager who communicates it to the supervisor of nursery labor and that

person then makes the correction to the actions of the nursery laborers. If the forest manager does not respect this chain of command and decides to give direct orders to the laborers, it will break the continuity of command and the subordinates under the manager will not know what are their limits of authority in cases of future activities. The result will be an ineffective and stagnate organization that does not make decisions, waiting for the "big boss" to make all decisions down to the smallest details. This situation occurs frequently in forestry organizations where the managers do not have a clear concept of the chain of command and the effect of abuse of authority.

Organizational structure

A horizontal or flat organization has few management levels (Figures 14-1, 14-2). It is an effective structure for a small organization and also for organizations where there is a certain level of independence among the various units. Examples:

- Schools: A principal and the teachers who work directly with the students,
- A law firm: Members and associates work independently with particular clients,
- A small computer software company where there is a manager and programmers who develop their programs independently.



Figure 14-1. Schematic of a horizantal or flat organization.



Figure 14-2. Example of a horizontal organization for a medium-sized forestry company with five managers.

A vertical or deep organization has many management levels (Figures 14-3, 14-4). This is an effective structure for large organizations and those organizations where there is close interaction among the different units. Examples:

- Military: Commander – generals – coronels - majors – lieutenants – sergeants-specialists– reclutes

- Hospital: Administrator – emergency services - operating room – patient rooms – maternity section - kitchen and food service – patient services – visitors' reception – personnel services – doctors, - anesthesiologists – laboratory services – blood bank – nurses – orderlies – outpatient services – pharmacy – laundry – cleaning and maintenance, etc, etc.
- Chain stores: General administration – purchasing – sales – planning – store managers – department managers – sales personnel – bookkeeping – security – personnel services – warehouses – transportation – insurance – maintenance, etc.

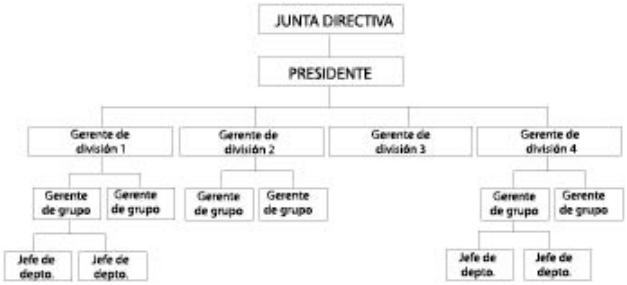


Figure 14-3. Schematic of a vertical organization.



Figure 14-3. Schematic of a vertical organization.

Horizontal and vertical organizations in forestry

In a new forestry organization it is common to create a flat hierarchy with a large number of subordinates reporting directly to the forest manager, and where the general manager makes "all of the decisions". In new reforestation companies it is quite common to find the forest manager involved in all decisions regarding nursery operations as well as silvicultural operations in the field. This type of organization can be highly effective when establishing the first plantations for a new project. However, as the organization grows, the general manager who makes all the decisions creates the tendency for subordinates to become lethargic, since there is not sufficient time to attend to all the details and decisions required; the subordinates waste time waiting for orders "from above" and the business becomes inefficient and stagnates. Experience has shown that the general manager who handles all the

details of an initial organization and does not delegate authority to subordinates becomes ineffective and is often replaced by another manager as the organization grows. The point where this exchange commonly occurs is when the organization ceases being just a reforestation project and is transformed into a mature forest management organization which includes all normal phases of forest management, such as forest inventory, planning, fire protection, road construction, mechanization and wood harvesting.

The number of subordinates that can be managed effectively varies according to the management level and the nature of the organization. The following list provides a frame of reference:

Level	No. of subordinates
President	3 to 6 managers
Manager	3 to 6 professionals
Forestry field manager	3 to 6 technicians
Nursery supervisor	20 laborers
Planting supervisor	20 laborers
Supervisor of weed competition control	10 to 20 laborers
Supervisor of pruning and thinning	20 laborers
Fire suppression boss	10 fire fighters

Line and staff functions

Employees in line and staff functions must work together to meet the objectives and production goals of the company. The current trend of modern companies is for all personnel to work as one team and to communicate directly among employees in order to accomplish tasks and meet goals. Nonetheless, the structure of line and staff functions needs to be clearly defined in case of conflicts that may occur within an organization, so that there are persons in authority who can resolve such conflicts quickly and effectively.

The line functions derive their authority through the vertical hierarchy of the organization. Normally, line functions are those that are directly involved in production. Operations such as site preparation, plantation establishment and stand management are defined as line functions in most companies. For example: Line authority follows a vertical ladder down from the general manager to the forest manager, to the district head, and to the forest technician responsible for the management of a given tract of land.

Line functions can be organized by (1) processes or (2) by geographic region. Organization by process is common where all production is located within a relatively compact geographic region. In this case, line functions may include: planning, nursery, plantations, inventory, harvesting, woodyard and timber sales. Where there are two or more isolated regions, the line functions are often organized by region. In that case, the regional managers are the line managers. When there are

several forestry regions, fire control may be a staff function with a central fire protection center that works with the regional mangers, but reports directly to the general manager.

Staff or logistical support functions operate in a horizontal manner within the hierarchy among the line functions. Where there is a need for specialized personnel, it is common to place such people in a staff function so that they can utilize their specialization and provide support throughout the organization. For example: the authority for the accounting department comes down from the general manager to the administrative manager and then down to the accounting department, which works directly with personnel in all areas of the company. Their authority comes down from the general manager, but the persons in the accounting group have authority to make direct contact with personnel in other departments. Other specializations are often placed in staff positions, such as a purchasing department, a machine shop, a road maintenance crew, forest inventory or forest fire protection.[1]

The forester or technician in charge of a forest property is similar to the adminstrator of a cattle ranch. The cattle buyer who comes with a truck does not have the right to select the animals to be loaded onto the truck and taken to the slaughter house. Rather, that decision is made by the ranch administrator under authority of the landowner. Similarly, the timber harvesting boss does not have the right to select which trees to cut, but rather must harvest those that have been selected under the authority of the forest manager or the chief of silviculture.

In practice, the selection of plantations to be harvested is defined ahead of time by the planning group and is approved the the forest manager. Thus, the harvesting boss knows where and how the trees are to be harvested. Nonetheless, it remains the responsibility of the administrator of the forest property to supervise the activities of the harvesting group when harvesting is being carried out on that property.

The use of consultants is common among forestry companies. Many times, the company can obtain information and recommendations from an expert who can help to resolve problems and/or improve the operations of the company. On the other hand, where there are several experts providing advice to a company on different operational aspects, the situation can reach a point of confusion among employees as to how to utilize the recommendations of the consultants effectively. The integration of consultants with employees is important to maximize the usefulness of recommendations made by contracted experts. Companies that promote the interaction of employees with outside experts get the most out of the consultations. After a visit, there needs to be a review meeting to evaluate the advice given by the consultant and to decide whether to accept or reject the recommendations. When recommendations are accepted, these are then utilized. Table 14-1 provides a standardized format for the evaluation of recommendations made by consultants.

Table 14-1

Example of a follow-up format for the evaluation of recommendations made by consultants and advisors

Nombre de la empresa								
División forestal	**Recomendaciones del Consultor y Seguimiento**							
Nombre del consultor	**Localidad**							
Fecha de la visita	**¿Acepta?**							
N.º	Síntesis de la recomendación	Sí	No	Si “sí”, depto., sección Si “no”, razón de por qué no	Persona responsable	Tiempo total	Fecha inicio	Fecha conclusión
Fecha					Firma del gerente			

Operational functions and reports

As a rule, each work center, work group or division within a forestry company is managed as an individual cost center. Plantation functions are programmed according to the area to be planted and the planting goals. Harvesting functions are programmed according to the wood requirements of the mill and/or by the volume of wood to sell. Overall goals of the forestry company are distributed among operational centers according to the specific conditions of each. Each year, the head of each center plans a budget according to proposed goals.

In many companies, costs are defined by three variables:

- The location where the cost is generated (tract of land or management unit).
- Operation (subsoiling, fertilization, road maintenance, fire control, forest inventory, etc.).
- Unit of equipment or personnel that generates the cost (tractor, motorgrader, contractor, inventory crew, fire crew, etc.).

Table 14-2 provides an example of a work report that is filled in daily by the tractor operator.[2] Similarly, operating reports are kept for the vehicles of foresters and technicians recording their activities and the uses made for each vehicle. Each day, the operator or driver records the initial hours and final hours of the machine by reading the hour meter or odometer of each machine. At the end of the accounting period (weekly or monthly), the field technician collects all of the hourly cards or time sheets from each company equipment operator and delivers them to the accounting office.

Table 14-2

Example of a daily time card for work done by forestry equipment.

EMPRESA FORESTAL EL GUAMO								
Actividades de Maquinaria								
Unidad	Motoniveladora CAT 1203				Clave	M024		
Periodo	1.a quincena, marzo, 2008							
Fecha	**Finca o lugar**	**Función**	**Código de función**	**Horas iniciales**	**Horas finales**	**Horas netas**	**Operario**	
2-Mar	Tres magueyes	I-13	Mantenimiento de caminos	910	1 542,3	1 549,5	7,2	FTM
3-Mar	Tres magueyes	I-13	Mantenimiento de caminos	910	1 549,5	1 557,2	7,7	FTM
4-Mar	Aguaclara	IV-04	Mantenimiento de rompefuegos	909	1 557,2	1 561,5	4,3	FTM
4-Mar	Aguaclara	IV-04	Mantenimiento de caminos	910	1 561,5	1 564,9	3,4	FTM
5-Mar	Primavera	IV-07	Construcción de caminos	902	1 564,9	1 572,0	7,1	OFJ
6-Mar	Primavera	IV-07	Construcción de caminos	902	1 572,0	1 578,2	6,2	OFJ
////////////

costs for each cost center. The summary shows the monthly budget, the monthly expenses and the variation (%) between the budgeted and the actual expenditures. The annual budget is also shown, along with the accumulated expenses to date, the variation (%). and the remaining balance for the rest of the year. The General Management receives all of the summaries and each cost center receives its part of the summary. Ideally, the monthly summary report is sent out to the respective cost centers within a week after the closing date for the month.

Machinery often works outside of its primary cost center. For example, during a forest fire, personnel and equipment from other cost centers may participate in fire suppression. To maintain an accounting of the costs generated in such cases, the costs are assigned to the appropriate cost center. On the equipment time card, the operator of a machine writes the code for the tract or work center where the work was carried out. Then, in the company's accounting department, the costs are charged to the corresponding cost center. Similarly, salaried personnel record their time and the code for the tract or center where the work was carried out. In this way it is possible to maintain realistic costs for the management of each forest property or cost center.[3]

Table 14-3

Examples of cost accounting codes (adapted from a forestry company in Brazil).

EMPRESA FORESTAL EL GUAMO					
Clave	Descripción		Descripción		Descripción
	Limpieza de Área		**Mantenimiento**		**Infraestructura forestal**
012	Limpieza mecanizada	072	Limpieza manual en línea	901	Prevención y combate de incendios
013	Apilar desperdicios, mecanizado	073	Limpieza manual entre líneas	906	Limpieza de cortafuegos internos,manual
014	Destoconar, mecanizado	075	Limpieza mecánica entre líneas	907	Limpieza de cortafuegos externos, manual
015	Apilar tocones, mecanizado	079	Eliminación manual de enredaderas	908	Limpieza de cortafuegos internos, mecanizada
016	Quema controlada de residuos	081	Aplicación química mecanizada, Sistema I	909	Limpieza de cortafuegos externos, mecanizada
017	Recolección manual	088	Aplicación química mecanizada, Sistema II	910	Mantenimiento de caminos
018	Quema II de residuos	092	Limpieza mecánica de cortafuegos	910	Mantenimiento de cercas
019	Control de hormigas arrieras			913	Mantenimiento de portones
020	Corte de rastrojo, mecanizado		**Materiales**	914	Mantenimiento de quiebrapatas
021	Levante de compartimentos	502	Insecticida Mirex S granulado	915	Construcción de cercas para ganado
		506	Glifosato herbicida Roundup	917	Producción de estacas para investigación
	Preparación del suelo	507	2,4 D (DMA) herbicida	919	Construcción de puentes

034	Aplicación de herbicida, mecanizada	508	Gasoil agrícola	921	Transporte
036	Subsolado con fertilización integral, mecanizado	518	Garlon herbicida	923	Vigilancia en torres de incendios
037	Control II de hormigas arrieras	519	Scout insecticida	924	Servicios generales (hombre-mes)
		559	Insecticida Attamex	925	Servicios generales (hombre-hora)
	Plantación	560	Insecticida K-Orhrine 2P	926	Asistente del técnico de campo
051	Plantación manual	601	Alambre liso	927	Apoyo a la brigada de incendios
054	Aplicación mecanizada de herbicida en líneas	657	Alambre de púas	930	Vigilancia
055	Replante a los 30 días	658	Grapas para cerca	932	Mantenimiento de las casas en fincas
056	Control III de hormigas arrieras			933	Comunicaciones en las fincas
057	Fertilización manual por planta				

Work relations among employees within an organization

Horizontal contact between personnel of different sections of a company requires the tacit approval of their superiors, which is understood within the organizational structure (Figure 14-5). When joint tasks are undertaken by employees in different sections of the company, it is their obligation to keep their superiors informed as to the progress of the particular task being carried out by sending them copies of relative correspondence and reports. The final decisions for such work always requires the approval of the respective superiors.

Example: Technicans in both the engineering and the harvesting groups recommend that a motor overhaul be made for an articulated skidder. This recommendation requires the approval of the regional manager and the engineering manager before the requisition can be made into a budget request for the required work.

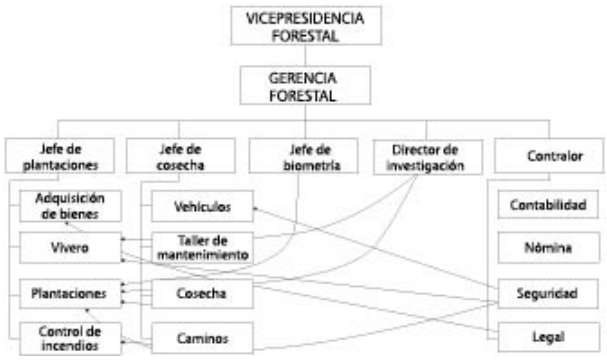


Figure 14-5. Examples of interactions of staff and line functions.

Vertical contact: For employees to work outside of their assigned group there must first be approval by the superior.

Example: A field forester needs to hire an operator for a crawler tractor that is assigned to that working group. Permission is requested to discuss this with the Personnel Manager. Once permission is given, the forester can talk to the Personnel Manager and present the requirements of a candidate for the job. When the Personnel Department finds a candidate, the forester and his superior interview the candidate. If the interview is positive, the forest manager requests the approval of the Personnel Manager who then hires the candidate.

Contact by committee: This is cooperation among several employees who represent different disciplines and/or functions for the purpose of developing solutions to assigned tasks. Normally, a committee does not have the authority to make decisions, but rather makes recommendations for an action to be taken, unless one of the superiors acts as chairman of the committee and is vested with the power or authority to make a decision. A forestry executive committee can include the forestry vice-president, the forest manager and the section managers. Such a group can approve any change in the policies and operations of plantation management.

Example: The nursery committee recommends a change in procedures for all nurseries to wash tubetes in water at 80° C for one minute prior to their reuse and to discontinue the use of a 10% bleach solution for this purpose. The committee chairman presents a draft of this modification, along with a memorandum to the nursery managers, the plantation managers and the head of forest research. With the approval of these managers, the final decision is made by the General Manager, since it is a decision that affects all management groups within the company.

Another method for demonstrating interactions among different sections of an organization is shown in Figure 14-6. In this example, the inner circle, administration, is equivalent to the highest management levels within the organization in a horizontal organizational chart. The second ring (green) is the operations or line functions. The third ring (blue) includes the logistical support functions. The fourth ring (yellow) shows the importance of community relations in the company and is associated with all the other parts of the company.



Figure 14-6. The organization represented by concentric rings.

An organized manager keeps a “FU” or follow-up file for all letters, memos, e-mails or other types of pertinent communications that are made. When a memo or e-mail is sent to subordinates with orders, a copy of that communication is placed in the FU folder or file, noting the date on which the follow-up is to be made; on that date the manager inquires as to the progress or completion of the task in question. The FU file is reviewed every day to determine pending activities. When a task is completed, the memo is removed or deleted from the file and placed in a normal correspondence file. One way to maintain the FU file at hand is to place it in the “Desktop” of the computer if MS Windows is being used. When all files are organized by the review date, it is easy to make a FU file and check the progress of the correspondence included in it.

Positive leadership

Leadership is a management quality that can motivate employees and subordinates so that they contribute positively to the organization. According to Rudy Giuliani, ex-mayor of New York City, “A leader does not have to know everything, but must know how to motivate people to use their best skills to meet defined goals.”

Positive leadership is a necessary management style where productivity depends on a close integration of all sectors of the organization and where there are clear lines of authority. A positive leader expresses authority with clarity to the subordinates. When giving orders, the task is described clearly and concisely:

- What is to be done (a description of the task and the expected results)
- When is it to be done (when to begin, when to finish and the approximate time required)
- Why is the task required (the purpose of the task within company objectives)
- How to proceed (what tools, capital and personnel are available and what are the expected limits of precision).

A positive leader takes charge of meetings if that person is the highest level manger at the meeting. Even when a meeting is conducted by subordinates, the manager opens the meeting and defines the purpose and limits of the meeting.

- What is the purpose of the meeting?
- Is the meeting to be an exchange of information only?

Will policy decisions be made during the meeting?

It is very important to define the parameters of the meeting at the beginning. During an exchange of information, the participants, including the leader, can express opinions, but these are opinions, not decisions regarding company policy. During a meeting to define policy, the objective is to formulate a consensus in order to reach a decision regarding the subject of concern.

A positive leader communicates decisions taken in meetings in writing with copies to the superior and to the subordinates. If decisions affect other parts of the organizations, those persons are also sent copies of such correspondence.

A positive leader maintains good communications with subordinates. The manager contacts subordinates personally to request work, to explain concepts and to ask questions regarding the progress of ongoing projects. Written information is distributed among subordinates using a distribution list, whether it is on paper or by electronic e-mail.

A positive leader demands quality work from subordinates. When a task is given to subordinates, the positive leader does the follow-up on that order by periodically checking on the progress and completion of the task. The positive leader supervises the activities of the subordinates. This includes periodic visits to review the operations under the control of the subordinates. If the order that was given is not completed within the predetermined time period, the positive leader can then help the subordinate to make the necessary adjustments in order to complete the task in the best possible time.

The positive leader shows interest in the development and progress of the subordinates, including professional progress and personal progress (family situation, personal problems, etc.). This is helpful to make good relations between employees and managers and to help create positive interest in the overall progress of the company.

The positive leader promotes close cooperation among subordinates and employees in other sectors of the company and interacts with them.

The positive leader maintains transparency and adequate documentation of all activities under his/her charge. If the case arises where the manager is incapacitated for any reason, another person within the group should be able to assume the responsibility for the operations of the group with a minimum of lost time. When a leader creates an environment of secrecy and mystery within the office, it is an

indication of the insecurity of that manager and it demonstrates to subordinates a lack of loyalty to the company.

Examples:

- When there is a visit by the company auditor, the positive leader asks for all subordinates to provide total cooperation with the auditing team.
- When there are training courses for subordinates, the positive leader attends the beginning of the course or shows intererst in the courses being taken by subordinates. Additonal training helps the employees to improve their knowledge, effectiveness and productivity within the organization.
- When subordinates express concern over the quality of work being done by other employees in other sectors of the company, the positive leader promotes total cooperation with the subordinates to resolve such concerns.

The positive leader cultivates good relations within the communities where the company operates by participating in community actives and by making him/herself available to hear and receive concerns and criticisms by persons outside of the company. The positive leader is one who gains the respect of the neighbors within the communities where the company operates.

Communications

As a company increases in size, upper management levels grow further from the daily operational decisions and an effective communications structure becomes even more important to the efficient operation of the organization. Information must move up and down the lines of communication within the organization. Progress reports go up the communications lines. Company policies, overall business conditions and any changes in standard operating procedures go down the lines of communication. Managers need to keep employees informed regarding new technologies that relate to the organization. This communication moves down by means of electronic memoranda, written correspondence, technical magazines and other information that is sent to subordinates. Similarly, subordinates must circulate or pass on information quickly to other interested employees.

Electronic mail is effective for moving information throughout the organization quickly. Written information is sent through the internal mail system with a routing slip that is fastened to the front of the report or magazine being sent out. The routing slip shows the names of those to whom the correspondence is to be circulated (Figure 14-7). After reading routed information, the employee crosses off his/her name and puts the information back into the company mail system. If the employee does not have time to read all the information in larger reports or magazines, these

are still sent on to the other persons on the circulation list after briefly looking at them and a request is made to recirculate the document at a later date.

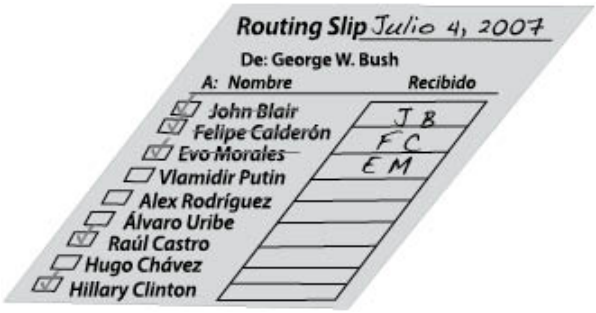


Figure 14-7. A routing slip is used to circulate written correspondence among employees and contacts. The person who initiates the correspondence indicates to whom the information is to be sent by marking the box beside their name.

In those organizations where work sites are isolated, as is common in forestry organizations, it is important to maintain an internal mail system that moves written messages to outlying sites quickly and securely. A mail bag or briefcase is used for this purpose. The briefcase is given to an employee or driver who delivers it to a designated person at each work site (a watchman at the gate, a secretary, or others). This person opens the briefcase and passes the information or materials to the persons indicated on the routing slip. After reading the material, the employee returns the written information to the designated person who then puts it back into the briefcase to be sent to the next location or person indicated on the routing slip.

Due to the continuous technological advances in many fields of endeavor, it is important for all professional employees to have the opportunity to read reports and technical magazines related to the specific processes or products of the company. When a company maintains a library in the central offices, the librarian organizes a briefcase for sending out magazines, newspapers or books to the various work sites. The method is similar to that used for sending internal reports and correspondence. When a library valise or bag is received at a work station, it is opened by the designated person and the publications are placed on a shelf in the dining room, recreation room or hallway. Employees can remove publications from the shelf to look at them and then return them promptly to the shelf. Material that includes a routing slip is sent to the indicated persons and, after being at a given site for a few days, is sent along to the next site. Finally, it is routed back to the central library.

Similarly, the central library makes available to all professional personnel a list of publications, either printed on paper or by computer connection to the library web site. The employee who wishes to receive a particular book or magazine fills in a format and requests the publication. After receiving the request, the central library sends out the publication in the library valise or in the company mail briefcase and allows the employee to keep the publication for a defined time period, for example,

two weeks. The value of a technical library to a company cannot be overestimated. Experience has shown that in the most successful forestry companies there is always a good technical library which is available to employees and is used by them. It has also been found that where companies have been unsuccessful, there was little or no importance given to maintaining a technical library.

Industrial safety

According to the International Labor Organization (ILO), accidents and work-related diseases result in the deaths of more than two million persons annually at a cost of US$1.25 billion (ILO, 2003). The death rate for laborers in developing nations is four times that of laborers in industrialized nations. The ILO declares that such losses could be eliminated if companies and governments respected international safety standards.

The timber harvesting sector is among the most dangerous in the forest industry. By nature, it is a work area that holds many dangers due to falling trees, log extraction and the use of heavy equipment. For this reason, it is an industry that requires much attention to worker safety. Although many companies are conscious of the importance of industrial safety for employees, there are still many cases where there is little respect given to its importance.

In South Africa, before contracting a tree feller to use a chainsaw, the candidate must show certification as a trained operator in the form of a diploma from one of the technical training schools. The schools train students how to use correct chainsaw procedures, personal safety, how to repair a saw in the field and the proper clothes to wear when working with saws (Figure 14-8).



Figure 14-8. Work safety elements for a trained chainsaw operator.

Industrial safety can be complicated by the use of contractors and third parties that carry out many of the field jobs, especially where there are personal risks to unskilled labor. Just by looking at the photos in this book the reader can appreciate

the lack of adequate protection for many of the laborers working in the field. Work contracts invariably require that contractors comply with all labor laws and safety regulations. This removes the legal obligation from the company when accidents occur to contracted personnel. On the other hand, the contractor may or may not require that laborers utilize safety equipment during their employment. Where unskilled labor is employed on a daily basis at a minimum wage for temporary work, there is little incentive by the contractor to train laborers in safe working parameters, to give them the necessary safety equipment for the job or to even pay them the legal benefits. All too often, the company that uses contracted temporary labor is exempt from labor laws which are required for permanent employees.

Making the situation even worse is the fact that in many cases unskilled laborers have little or no education and do not understand existing laws for personal work safety. In locations where there is an acute competition for few jobs and a high rate of unemployment, a worker may not want to raise concerns about job safety when asking for a temporary job. If the worker is severely injured or killed on the job, the family often accepts the situation as being normal, without any means for asking for recompensation or help from the employer.

There can become an insidious situation where administrators and bureaucrats have the false perception that the cost of complying with labor laws, especially where they relate to temporary and/or unskilled labor, will increase their costs of operation and the cost to produce a given product. In such a situation there is little will to correct bad labor situations. In many governments, there aren't sufficient agents working within the Ministry of Labor to investigate all of the accidents and deaths of laborers. Rather, the accident reports are received, if they are even made, they are put into a file and then forgotten. Such an attitude of apathy allows for the loss of life and working ability for laboring persons in a company and/or a country. In such circumstances, there exist very fertile conditions for the formation of labor protection organizations, and labor unions.

In 1964, as a recent university graduate, I worked in a plywood mill that produced decorative paneling. The job of one worker who had been working in the mill for 15 years was to select and cut strips of veneer of fine woods with a gilllotine to be made into face veneer for high value paneling. One day, he asked his supervisor for an increase in pay, because the company had just contracted several younger workers giving them higher pay that those who had more seniority. The reply of the supervisor was: "I can get all the workers I need from the lines standing outside the mill waiting for a job. If you don't like your work, I can replace you tomorrow!"

A few months later, the workers in that mill voted to introduce a labor union, went on strike for one month and obtained increases in pay along with two weeks yearly vacation at a time of their choosing, not the one week they were given previously during the mill shut down. After all of this, the management was very bitter about the lack of consideration of the workers and could not understand why the workers voted to bring in a labor union!

The International Institute for Management Development (IMD) is a non profit business school located in Lausanne, Switzerland. Each year the IMD grades countries as to their competitiveness. The ILO made a comparison of the IMD scale with that of the ILO with reference to workplace safety. The results showed a close relationship between the level of industrial safety and a high level of competitiveness (ILO, 2003). A similar analysis was made by the World Economic Forum of Geneva which produced similar results. These studies confirm the importance of industrial safety as an integral and necessary part of a company's competitiveness. Industrial safety produces profits for investors as well as protecting the health and lives of employees and workers.

An accident to a worker reduces income to the family. For example, in the United States, if there is a partial incapacity due to a work-related accident, the worker can lose approximately 40% of income during a five year period (ILO, 2003). Besides the direct losses by the worker, other members of the family can lose their jobs if they have to stay home and care for the injured worker.

The traditional mentality of accepting work-related accidents as something normal and without a solution is changing. The certification of the origin of wood and manufactured wood products requires that a company and its contractors comply with local labor laws in the country of origin. Thus, there is a world-wide awareness of the importance of complying with labor laws and making sure that industries abide by the laws, regardless of the size of the company or where it is located.

Statistics clearly demonstrate the importance of industrial safety in the work place with regards to industrial productivity. The cost of an accident is not only to the worker for the loss of wages, but is also a loss of time for associated personnel that cannot work at maximum efficiency when an accident happens, a loss of productivity to the company, the costs of insurance, the time required to fill out required safety and insurance forms, the legal cost in the case of suits for non-compliance with the law, the time required to find replacement personal and to train them as well as other "hidden costs". As a general rule, a company normally considers that the indirect cost of an accident is between three and five times the direct costs.

Social and community relations

There have been many instances where forestry companies have had conflicts with neighboring communities, indigenous groups or with individuals that live near forest properties. Examples:

- One mountain community placed barricades at both ends of the main street with large letters reading "Transit by log trucks is prohibited."

- “No Pines!” appeared on signs near tree plantations owned by a public company which had begun planting pines just three years earlier. The sign “No Pines” was painted on large rocks, on the sides of buildings along streets, on the sides of houses and even on the entrance gate of the forestry property.
- A pyromaniac started fires and caused significant damage to tree plantations of a large company for several years. People in the local community knew who lit the fires, but no one would tell the company who it was.
- One company purchased land in a region where there were indigenous villages. Each time certain lots were planted, the local people pulled up the planted trees the following night. They claimed that those lots had been given to the local community by the previous owner. However, there was no mention of those lots being donated to the people in the land purchase agreement nor in the official deed to the land.
- Some local groups burned recently planted tree plantations in public land concessions granted by the federal government, saying that it was their land and that the government did not have the right to grant such lands to a forestry company without consulting with them and without giving them any form of compensation for the lands taken from them, which were the basis for their own economy and welfare during many generations.
- Groups of indigenous women invaded a forest tree nursery and destroyed it claiming that the tree plantations would cause irreparable damage to the land of their ancestors by drying out the soil, acidifying the soil and causing erosion.
- In one community, some local residents took possession of the properties of a forestry company claiming that the land belonged to them and was illegally sold by someone else who was not the legal owner.
- Residents of one local area made a formal claim against a forestry company because they used a common road to take out wood during the rainy season, causing serious damage to the road. Because of such damages, they could not get their milk to market nor their children to school, but the company would not accept responsibility for repairing the damages to the road saying it was the duty of the local government to maintain the roads.
- The government of one county passed an ordinance excluding one specific company from buying additional forest land within the county limits. Obviously, the ordinance was not constitutional, but the company was unable to acquire more land in the county until a judge declared the ordinance invalid, a process which lasted several years in the courts.
- A large fire occurred in the center of a tree plantation during the dry season and it caused large and severe losses. A week prior to the fires, the company had let go a contractor for non-compliance with the contract that dealt with work in the same plantation where the fire was set.

- A forestry company began planting trees in a region where there had been a large international agricultural company operating but which closed its operations and left the country. During two years, the local residents were very happy to have the new forestry company there because it provided local employment and paid its workers punctually and with all the legal benefits. However, after a few years, there began to arise criticisms of the tree planting, claiming that it was causing ecological damage to the environment. Four years after beginning the tree plantations, the Ministry of Forests sent the company an official letter demanding that they justify their actions by planting trees and, if they did not, the Government would stop the company from planting any more trees. Finally, it was learned that an international environmental activist group was behind this effort and had been pressuring local people and the government to shut down the company.

These are just some real examples of conflicts that have arisen between forestry companies and persons, communities and governments. In all the cases mentioned above, the companies had acted correctly under the law. Nonetheless, the results were setbacks to the companies with losses of time, added expenses and losses of productivity. Many of the cases mentioned were resolved through dialog and by agreements made with the persons or communities affected. In other cases, the companies had to give some lands that had been purchased or contracted to indigenous groups. Some companies found that it was necessary to participate in the maintenance of public roads where there had been damages caused by logging trucks.

The social, civic and community relations are among the most important activities of a forestry company. In some companies there is a manager dedicated exclusively to community, civic and social relations. This is a cost that needs to be considered and calculated when planning a forestry investment.

Employee participation in local communities

Community relations are not simply an obligation of company management, but rather it involves the development of a positive attitude by all company employees towards the communities. It requires a “Good Neighbor” policy, where the employees act as an integral part of the community and participate in community activities. Examples of participation:

- When company foresters travel through a town or village, they should occasionally take time to stop at a local store, buy a soda or snack and talk with local people. Every person merits the respect of another and when company people take time to greet others and treat them with respect they practice this principle. If residents have concerns about what the company is doing, the forester is available for conversations and to hear their concerns.

- A company needs to maintain a policy of making purchases in local towns and villages whenever possible. It is a good policy to purchase items such as common tools, barbed wire, nails, paint , fuel, fertilizers, etc. in local municipalities, even if the price is slightly higher than buying such items wholesale in larger cities. This helps the local economies and promotes good will. The common purchasing policy of requiring three quotes prior to a purchase and then selecting the lowest bid can exclude local communities from doing business with the company which can cause resentments and which may result in even greater long term costs to improve community relations.
- Company vehicles need to pass through the streets of towns and villages at a moderate speed, without creating clouds of dust. Drivers should open their windows to greet local residents, instead of having the windows closed with the air conditioner running and with tinted windows that don't allow anyone to see into the vehicle. When it rains, company vehicles need to travel slowly through towns and near people to avoid splashing people with water from mud holes in the street. Such incidents as splashing persons with muddy water can cause severe resentment by local people, and justly so.
- Where there are activities in nearby towns, such as parades, festivals, bazaars, or sports events, the company forester and family needs to attend such events, even if they live in another town.
- If a local village does not have organized activities for children, such as a football or baseball team, a company technician may want to help to organize and coach a local team.

Company participation in communities

The forestry company needs to participate in municipal activities. This must be handled tactfully and with good planning. There are always those persons who want to ask a company for money for whatever new activity. If the company becomes a "cash cow" to be milked at any time, the company "participation" can have the opposite effect to that desired, if and when the company refuses to give funds for certain activities or local campaigns. It is important to clearly define the type of participation that the company will make and to coordinate donations in a way which treats all nearby villages justly, without favoring one over another. The following are types of donations that can be considered for maintaining good local relationships:

- At the beginning of the school year, the company may want to give a bag of school supplies to children in the elementary schools.
- For a national or religious festival, the company may want to give gifts to children who attend the event. A company employee could be in charge of holding a raffle for a special gift.

- Uniforms and/or equipment can be donated to local juvenile sports teams.
- The company may wish to donate the use of some of its road building equipment as well as pay labor costs of local workers to make improvements in the village square, such as paving a street, or creating a local park with trees, paths, benches and flowering bushes.
- If there is a natural disaster such as an earthquake, flood, hurricane or fire, the company may want to donate the use of its machinery and labor to help repair damaged houses or public buildings.
- Events can be organized within the company plantations so that local residents can walk or run through the plantations in special races or other events, and be able to see the trees and how they are managed.

Education concerning the company business

A company can improve relations with communities by explaining what it does and why. Invariably, there are suspicions among people as to the activities of large companies and because of this it is vital to become involved in some form of public awareness programs. It is also important for companies to divulge information about its forestry activities to politicians, bureaucrats and to universities. The following are examples of methods of public education that can be useful:

- Company foresters and technicians visit local schools and make brief presentations regarding the company activities, as well as to have informal discussions with school children about ecology and related issues. This gives children the opportunity to ask questions and for company personnel to answer the questions correctly and honestly. If the forester does not know the answer to a question, it is much better to say: “I am not sure about that but I am going to find out and I will give you an answer tomorrow”, instead of inventing excuses and making up stories about a subject.
- The forest fire protection people can make presentations on fire prevention and suppression at schools. It is an activity that can be carried out during periods of low fire danger when there is time available for such activities. Fire protection personnel that are residents of the local community are the best for making such presentations.
- The company can establish an arboretum with many tree species, including the ones that are locally known and recognized, along with some unique species and also the commercial ones planted by the company.[4] Trips can be planned for visits to the arboretum by school children as well as for the families of company employees. The company forester or technician can explain differences among tree species and what is important about each one.[5]
- The company can publish brochures or booklets regarding forestry topics, such as “Questions and answers about forest ecology”, “How to plant and manage

trees on your own farm", or "Prevention and control of wildfires".

- The company research personnel can make presentations which show results of some its research work during regional or national symposia and meetings.
- The company can invite local, regional or national politicians to visit its tree nursery, plantations, arboretum and forest management activities to explain these concepts in the field. It is always a good idea to show how the company maintains natural forest areas within its forest properties. This is very important since it is not uncommon to find a president, minister of forests or member of the national legislature that does not have a clear idea about what a forestry company actually does.

Education and students

Some companies participate directly in the local education of high school students. In such cases, the graduate receives a high school diploma, but with a forestry specialization. During the high school training, the students are given courses by forestry personnel and are also trained during field trips to the tree plantations. This gives the graduate a specialization that can be used after graduation with a forestry company, public or private. This also allows the company that is participating in the education process to select the best students as future employees.

Companies can also offer scholarships to students that live in nearby communities. This allows for boys and girls to receive an education where family financial resources are scarce. The scholarship may include payment for dormitory accommodation, food, books and school fees.

Another alternative is for a company to offer assistance to college students in forestry schools to visit plantations and to carry out field practices under the tutelage of the professor. In such a case, the company makes available dormitories in some of its forest properties, along with food and field transport. Company foresters can also participate in the field activities in cooperation with the university professor.

When forestry students are required to carry out a research project and write a thesis for graduation, some companies offer some of their field research studies for the current measurement as well as the use of data in the files as part of their project. This allows for the student to make a field study, not just a laboratory study. Such projects have been very successful for improving relationships between companies and universities.

Some companies also offer scholarships for post-graduate studies outside of the country for the student to earn a masters or doctoral degree. Normally, such scholarships include a part of the student's costs, not all of them, but some companies will even pay all student expenses as well as the student's family expenses during studies for a university degree in another country.

Third party technical assistance

When a forestry company is working as an integral business, establishing plantations, harvesting timber, marketing wood products and replanting harvested areas, there will be local landowners who become interested in participating by utilizing parts of their properties for tree planting. There are companies that offer technical assistance to such landowners. The purpose is to help the landowners define the objectives of their forestry activities, how to manage their plantations and what alternatives exist for the sale of their forest products. In this way, a company can obtain additional wood without the need to make direct investments in land and the costs of plantation management.

The most important incentive to reforestation by third parties is to provide a market for their wood. This is especially important for the sale of small wood, that is, chip wood or pulpwood. If a landowner can sell the small wood for pulpwood, charcoal, chips for particle board, pallets or other similar uses, then it is possible to manage the plantations for sawtimber which will command a higher price. The Government of Brazil has recognized the importance of non-industrial plantations for the national economy and for creating employment and is actively promoting non-industrial plantations by landowners.

One type of assistance is for a company to sell tree seedlings to landowners at cost or at a subsidized price.[6] Another means is for a company forester to make an evaluation of the landowner's properties and make recommendations for site preparation, species to plant and for stand management. If the plantations are within the wood acquisition area of the company, it may also include protection against wildfires within its technical assistance package.

Assistance to third parties is usually based on good relations between the company and the landowner. In many cases, the only obligation for the landowner is to give the company a first option to purchase wood when it is put up for sale. If the company does not want the wood or doesn't want to buy it at the price stipulated by the landowner, the landowner is free to sell the wood to other wood buyers at that price.

As a general rule, wood production for sale for pulpwood or chip wood is a marginal business. It is important for the company forester to explain clearly the profitability of the landowner's plantations. It is a good idea to make a brief analysis of costs and incomes for the landowner. The company forester should not try to convince a third party landowner that plantation management produces big returns and profits just as a means to get them to plant trees. Plantation forestry can be economical to a landowner under the following conditions:

- The company offers the landowner genetically improved trees to plant which have high growth rates.
- The company offers technical assistance and advice on plantation management.

- The company offers support to the landowner in case of wildfires, disease or insect attacks, at least if the government does not offer such services.
- The landowner has marginal lands for cattle production or crops where reforestation can be a more lucrative alternative land use.
- The landowner is interested in having trees on the land to improve the landscape and the view, which is an additional non-monetary value, besides the value of just wood production.
- The landowner can use wood from the plantations on the farm for fence posts, poles, firewood, boards, etc.
- The landowner can sell large diameter logs for products of higher value, such as sawlogs.

Problem resolution

A problem is a deviation from an expected occurrence. A problem is generated when an initial decision is defective or when the execution of the decision is incorrect. Without a total comprehension of the root of the problem, an incorrect solution may attempt to correct the consequence or result of the problem instead of the cause. In the forest industry, where timber production is a long term endeavor, it can be quite difficult to determine the initial decision made years previously that generated the problem. Thus, to resolve problems in forestry operations there must be a solid base of information on which to make and implement decisions. If decisions are taken during meetings that are not well documented, there exists a greater risk that personnel will deviate from the initial decision as time goes by. In all meetings where the purpose is to make decisions, it is important that this be clearly understood at the beginning of the meeting and also to have written and well-defined records of the meeting that can be sent to other persons who can or will be affected by the decisions taken. With good documentation it is possible to evaluate the effects of decisions taken months or even years earlier and thereby determine the cause of the problem and correct it.

During a meeting where parameters are defined for taking decisions, the first action is to write the proposed decision on a board or large sheet of paper so that all persons present can study it. Part of the process of making good decisions is to evaluate whether the proposed decision agrees with the stated mission and objectives of the company. Another aspect to evaluate is: “What could be the adverse effects of a proposed decision?“. A critical initial analysis of a proposed decision is even more important in the forest industry because the consequences of a decision may only appear years into the future.

Another aspect to consider is the relative importance of a problem. If a problem is not crucial or does not have important repercussions for a company, the first consideration is whether or not the problem even merits a solution. Sometimes, the best solution for some problems is to do nothing.

There exists a popular belief that the manager who can make quick and decisive decisions is the best manager and that this is the type of person that is needed in top management in a company. Normally, the situation is just the opposite; the person who takes decisions without fully evaluating the problem is the one that usually makes the most mistakes. At first glance, a solution to a problem may appear obvious, but when the problem is evaluated more fully, it may be that it is much more complex than first thought. If a quick decision is made to resolve the problem, there exists the probability that the problem will not be resolved and that the quick solution may actually make it worse. A systematic method of problem solving is the best way to find solutions to many types of problems.

How to resolve a problem



There are some additional steps that may be needed for an effective long-term solution:

- Train personnel on how to utilize the solution,
- Supervise the implementation of the solution,
- Follow up on the implementation of the solution to evaluate its effectiveness,
- Make necessary adjustments to the solution,
- Write a permanent definition of the solution in the procedures manual.

There are special courses given to train employees how to evaluate problems and how to find the best solutions, by thinking in a systematic way and evaluating alternatives in an orderly manner. Such courses help to measure the consequences of decisions in the short and long term. These problem solving courses are an excellent training tool and are recommended for all persons who are charged with taking decisions within a company.

Resources, raw material and products of forest processes

It is important for employees to have a clear idea with respect to how resources are utilized and products manufactured within an organization, so that pertinent and correct management decisions are made. In many companies, a new professional employee is given a tour of all the different departments of the company to meet the management team, learn what is being done in each department, what activities are involved, what machinery is used and how it is used. In large companies, this initial training period may last for several weeks. It is also valuable for a new employee to know the managers of the company and to see them working within their departments so that these people can be called upon if needed. This initial contact also builds a closer relationship among management personnel within the company.

In a company that makes MDF panels (medium density fiberboard), the forestry personnel were asked: “What is the raw material used to make MDF?” The common answer of the foresters was: “Trees”. Actually there are several phases between “tree” and “MDF”:

- The standing trees are the raw material for producing logs during the harvesting operation,
- Logs with bark are the raw material to feed into the debarking drum,
- The debarked logs are the raw material for the wood chipper,
- Chips produced by the chipper are the raw material for use in the TMP mill (thermo-mechanical pulp)
- TMP pulp is the raw material for making MDF panels.

An inventory forester who was unaware of these processes, decided to label trees being measured in permanent growth plots by using metal nails to hold paper tags on the trees. Obviously, the nails in the wood would cause damage to the chipper knives and, even worse, to the plates of the TMP pulp mill which grind the wood chips under extreme pressure and steam heat. The damage that would be caused by the forester who was unaware of these processes could have been immense if the practice had been allowed to continue and the nails were not removed from the trees. This is just one case which demonstrates the importance of making certain that all professionals within the organization clearly understand the processes involved in the manufacture of the final products of the company.

All company operations create products or services. It is important that all employees clearly understand the nature of the products and services being produced

by their department or group. The following is a short list of some of the products and services that are developed within a forest industry:

Location	Product
Nursery	high quality seedlings for planting
Plantations	standing trees of useful species and sizes
Harvesting	logs of diameters and lengths useful to the mill
Sawmill	boards of dimensions that can be marketed (air dried, kiln dried, or planed)
Mechanical pulp plant	mechanically ground wood pulp
Chemical pulp plant	wood free pulp with fibers separated chemically
Forest research	information that can be used to improve the survival, growth and quality of the tree plantations
Forest protection	reduced risk of losses due to fire and fire suppression in an efficient manner
Forest inventory	information that facilitates silvicultural decisions and allows for planning of future timber harvests

[1]Although the forest fire protection group is often designated as a staff position, when there is a major fire emergency with one or several large fires, the forest fire protection chief becomes an operational manager with the authority similar to that of high level operational managers.

[2]In an open tractor, a tube with a threaded cap can be welded to the underside of the tractor cab for easy access by the operator, and the time sheet, usually printed on heavy paper, is rolled up and placed in the tube along with a pencil. In the case of cars and trucks, the time sheet is placed in a clipboard and kept in the cab of the vehicle.

[3]In the chapter of Forest Finance there are examples of how to calculate machine costs per hour or kilometer for each piece of equipment.

[4]A species such as *Eucalyptus citriodora* is interesting due to the lemon fragrance of its foliage, or *Eucalyptus globulus* because of its fragrance of menthol. *Casuarina equisetifolia* looks like a conifer but is really a “broadleaf or short fiber species” where the leaves are segmented. The rubber tree (*Hevea brasilensis*) is good for showing how the latex is collected. Species in the family Lecythidaceae form fruits that have a woody cup with a lid (monkey bowl in Spanish). There are species that have beautiful flowers such as those in the genus *Tabebuia*, the African tulip tree (*Spathodea campanulata*), the red flowering acacia (*Delonix regia*), flowering species of the genus *Erythrina* and yellow flowering species in the genus *Cassia*, such as *Cassia fistula*).

[5]See the chapter on Plantations for details on how to establish an arboretum.

[6]Experience has shown that when seedlings are given away, they are often not appreciated and many times they are left to dry out and die, instead of being planted. When a modest price is charged for the seedlings, the buyer takes more interest in seeing that they are planted correctly and cared for.

15

Forest finance

Profitability of reforestation projects
Interest and discount
Risk versus gain and the importance of fiscal incentives
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What is inflation and how does it affect the forestry investment?
The use of inflation in financial analyses
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Calculating forestry machine operating costs
Machine sinking fund
A cost comparisons for two harvesting methods
Financial analysis of a total forestry project
How to make the decision to invest in forest tree plantations

Profitability of reforestation projects

Three basic conditions are required for an investment to be profitable (Rose & Blinn, 1987):

- The benefits need to be greater than the costs of a project after adjustment of the cash flow for time.
- Each component of a project must provide benefits that are equal to or greater than the costs, after the cash flow is adjusted for time.
- There is no other alternative at a lower cost that would provide the same benefits.

From the point of view of international banks (Keipi, 1997), the five most important factors for the successful development of tree plantations are:

1. Political and macro-economic stability.
2. Free commerce and free access to foreign investment.
3. Legal clarity regarding land ownership.
4. A stable government with an adequate capacity to enforce laws and administrate incentive programs.
5. Good natural growing conditions, adequate technology and a basic infrastructure.

A calendar of events or activities is required for each project with a defined length of time. Some activities generate costs while others produce profits to the investor. The following four steps are required for a financial analysis (Davis & Johnson, 1987):

- Define the time limits for evaluating a project,
- Identify the calendar of activities for the project,
- Convert all activities into their equivalent monetary values,
- Adjust the rates of interest corresponding to the periods in which there will be the expected expenditures and incomes.

The objective of the financial analysis is to compare the relationship between expenses and profits that are expected for a project. Forestry projects are similar to other commercial projects, although there exist some peculiarities that need to be taken into account: The planning horizon is long and the wood production facility (the tree) is also the product (the wood). Thus, when harvesting the wood, the wood factory (the tree) is also destroyed.

Prior to computers, electronic spreadsheets and data bases, financial analyses for forestry projects were mostly carried out by persons with degrees in business administration and who worked in the finance department of the business. With few exceptions, foresters had minimal training in such subjects as economics and finances. Thus, it was not common for forestry personnel to be involved closely with financial decisions in their respective companies. Fortunately, the situation is now changing and recent graduates from forestry schools have had training in the use of computerized electronic spreadsheets and can make forestry growth projections and plans. Nonetheless, training of foresters in the use of these tools to make in-depth financial analyses is still not common, unless

the student has taken post-graduate courses and training in business administration.

The first computers that utilized the “DOS” format were limited in their computing capacity and it was quite difficult to generate complex electronic spreadsheet programs free of errors. Programming was done in computer languages known only to a few people specialized in that field. Many companies contracted computer programmers to generate specific programs to handle their particular information needs.[1] Over time, problems tended to arise when the company wanted to modify a particular program. Due to the relatively high cost of contracting programming specialists and the lack of ability of company employees to make the needed modifications, what happened was that companies continued to use out-dated programs with limited utility, or they simply ignored the old programs and made the calculations on the side using simple calculators.

Due to the availability of personal computers, it is now not only possible for forestry personnel to make financial analyses themselves, but the ability to handle financial analyses in electronic spreadsheets has become a primary requirement for forest managers. It is important to know how to use electronic spreadsheets or data bases to record reforestation goals, harvesting goals and wood growth projections as well as to estimate costs and profits. Monthly production reports and budget balances are now being generated and distributed within a week of the monthly financial closing date.[2] This process also involves field technicians, who must report production data by electronic mail or by other means, such as flash drives, so that it is delivered to the central planning office on the last day of the month. Monthly production information, along with financial information, is transformed into a series of tables and graphs that contain summaries of all information required to manage a forestry enterprise efficiently, from seed inventories in storage to wood harvesting production and wood inventories in woodyards.

The other use for electronic spreadsheets is to analyze production and profitability of potential projects along with their budgets. This requires a basic knowledge of spreadsheet programming and also the know-how to make valid comparisons among management alternatives with computer modeling prior to proposing an alternative or new project to a general manager or before purchasing field equipment.

Interest and discount

The value of money is adjusted by the interest rated charged for its use. Interests that are charged for a loan by banking institutions are expressed as percentages, assuming a one-year term, unless otherwise specified. An interest of 6% means that the bank will loan money (principal) for one year, asking that the principal be returned plus 6% additional for its use. If the loan is made for several years, the annual interests are added yearly to the balance. This is known as compound interest. For example, if $1000 is loaned at 5% interest for five years, the total cost of the loan is shown in Tablel 15-1.

Table 15-1

Example of the compound interest calculation for a $1000 loan for 5 years at 5% interest

Year	Initial amount		Interest rate		Interest earned		Initial amount		Final amount
1	1,000.00	x	0.05	=	50.00	+	1,000.00	=	1,050.00
2	1,050.00	x	0.05	=	52.50	+	1,050.00	=	1,102.50
3	1,102.50	x	0.05	=	55.13	+	1,102.50	=	1,157.63
4	1,157.63	x	0.05	=	57.88	+	1,157.63	=	1,215.51
5	1,215.51	x	0.05	=	60.78	+	1,215.51	=	1,276.28

Instead of having to make the calculations year-by-year, they can be made using formula (1) to determine the final amount:

(1) $V_n = V_o (1 + i)^n$

where : Vo = value of principal in year 0, i.e., the amount loaned
i = interest rate
n = number of years (periods)
Vn = total value at the end of the loan period
In the example in Table 15-1 the formula would be as follows:

V5 = $1000 (1.00 + 0.05)5 = $1000 (1.05)5 = $1,276.28

This formula can be calculated easily using a hand-held calculator or with an electronic spreadsheet in the computer.

Another basic financial operation is the discount, which is the opposite of calculating the accumulated interest. Beginning with a future value, it is possible to calculate the net present value. The formula (2) is:

(2) $V_o = \frac{Vn}{(1=i)^n}$

In the above example, the actual amount to pay at the end of five years is $1276.28, and with a 5% discount rate, the net present value would be:

$$V_o = \$1{,}276.28 / (1.05)^5 = \$1{,}000$$

Costs and incomes may occur anytime during the year, but it is generally assumed that most transactions occur at the beginning or at the very end of the year, as a means to simplify the calculations. It is important to use the correct number of periods for the loan.

A series of payments or incomes that began during the first period can be calculated to the net present value using the formula (3):

$$(3) \quad V_o = a \frac{(1+i)^n - 1}{i(1+i)^n}$$

where a = costs or incomes that occur yearly (periodically) and at the end of each period.

If the uniform series of payments or incomes occur *at the beginning of the yearly payment period*, with the first occurrence in year one, the equation is modified as follows:

$$(4) \quad V_o = a \frac{(1+i)^{n-1} - 1}{i(1+i)^{n-1}} + a$$

Example, If a rent of $50/ha is paid at the end of each year for 10 years and with a discount rate of 5%, the real value of all payments at year 0 is calculated with formula (3):

$$V_o = \$50 \frac{(1.05)^{10} - 1}{0.05(1.05)^{10}} = 386$$

Example: If the rent of $50 is paid at the beginning of each year for 10 years, and with a 5% discount rate, the real value of all payments is calculated with formula (4):

$$V_o = \$50 \frac{(1.05)^9 - 1}{0.05(1.05)^9} + 50 = 405$$

Using these same variables it is possible to generate various useful formulas as are shown in Table 15-2 (Rose & Blinn, 1987).

Table 15-2

Formulas for calculating future and present values with a series of payments and interest

1	$V_n = V_o(1+i)^n$	valor futuro (Vn) del valor inicial (Vo) con (i) tasa de interés por (n) períodos
2	$V_o = \frac{Vn}{(1=i)^n}$	valor presente (Vo) del valor futuro (Vn) con una tasa de descuento (i) por (n) períodos
3	$V_o = a\,\frac{(1+i)^n - 1}{i(1+i)^n}$	valor presente (Vo) de una serie de pagos anuales (a) por (n) períodos con una tasa de interés (i) y con los pagos al final de cada año
4	$V_o = a\,\frac{(1+i)^{n-1} - 1}{i(1+i)^{n-1}} + a$	valor presente (Vo) de una serie de pagos anuales (a) por (n) períodos con una tasa de descuento (i) y con los pagos al principio de cada año
5	$V_n = a\,\frac{(1-i)^n - 1}{i}$	valor futuro (Vn) de una serie de pago anuales (a) por (n) períodos y con una tasa de interés (i)
6	$a = V_n\,\frac{i}{(1-i)^n - 1}$	pago anual (a) con un valor futuro (Vn) por (n) períodos y con una tasa de interés (i) (fórmula para el costo anual de una máquina)
7	$a - V_o\,\frac{i(1+i)^n}{(1+i)^n - 1}$	pago anual (a) del valor presente (Vo) por (n) períodos y con una tasa de interés (i) (fórmula para los pagos por plazos)
8	$V_n = a\,\frac{(1+i) - 1}{(1+i)^t - 1}$	valor futuro (Vn) de una serie de pagos periódicos (a) con (t) años entre pagos, para (nt) períodos y con (i) tasa de interés
9	$V_o = a\,\frac{(1+i)^{nt} - 1}{[(1+i)^t - 1](1+i)^{nt}}$	valor presente (Vo) de una serie de pagos periódicos (a) con (t) años entre pagos, para (nt) períodos y con (i) tasa de descuento

Risk versus gain and the importance of fiscal incentives

Interest is the price of money. If a bank loans money, the bank charges interest until the loan amount (principal) has been repaid. The interest on the loan reflects the price of money in the current market. If there is a great demand for money in various sectors of a free economy, the price of money (interest rate) increases. Sometimes, fiscal incentives are used to stimulate reforestation by lowering the interest on borrowed principal for a forestry project. Forestry projects are long term compared with many other commercial endeavors, such as agricultural production, cattle production, the construction of barns on a farm or other rural projects. As the length of the loan period is extended, the cost of borrowing increases until there is sufficient income to pay off the loan. Table 5-3 shows the cost of money for projects with different time periods, when the total accumulated value of the loan is paid at the end of the term (formula #1).

Table 15-3

The total cost of an initial investment of $10,000 with several rotation lengths at 6% interest on the initial loan

Capital US$	Rotation years	Interest %	Total Cost US$	Cost / Interest US$	Examples of investments
10,000	1	6	10,600	600	agricultural annual crop
10,000	6	6	14,178	4,178	eucalypt plantation for pulpwood or charcoal
10,000	15	6	23,942	13,942	pine plantation for pulpwood and sawtimber
10,000	25	6	42,864	32,864	teak plantation for sawtimber and charcoal

In this example, an investment of $10,000 must produce profits greater than 6% during the investment period, or the investment is not profitable. In other words, the equilibrium point for the investment is 6% and thus the internal rate of return (IRR) must be greater than 6% for the investment to be profitable. In this example it can be seen that long-term forestry projects continue accumulating very high costs for interest. In plantation forestry projects, there is usually little or no significant income until the end of the term (rotation length), while there are greater risks than for projects of lesser duration, such as for annual farm crops.

The example shows why the great majority of forest tree plantations are established by pulp and paper companies with shorter pulpwood rotations. The longer the rotation length, the greater will be the plantation investment and the greater will be the risks of loss due to factors such as wildfires, diseases, insect damages, hurricanes, or other unexpected disasters.

If a government wants to increase tree planting within its territories, an effective incentive is to reduce the cost of money, that is, lower the interest rate paid by the investors. This will result in a more competitive investment since the cost of capital will be reduced. In Table 15-4 there is an example of the effects of a fiscal incentive that reduces the interest to 2%. In such a case, the government absorbs 4% of the total 6% loan cost and the investor is responsible for the remaining 2%.

Table 15-4

The cost of a forestry investment with a net interest rate of 2% and with the final payment at the end of the rotation

Capital US$	Rotation years	Interest %	Total Cost US$	Cost / Interest US$	Examples of investments

Capital US$	Rotation years	Interest %	Total Cost US$	Cost / Interest US$	Examples of investments
10,000	6	2	11,255	1,255	eucalypt plantation for pulpwood or charcoal
10,000	15	2	13,441	3,441	pine plantation for pulpwood and sawtimber
10,000	25	2	16,374	6,374	teak plantation for sawtimber and charcoal

In this example, the cost of the loan is much lower (2%) and the profits must be higher than 2% for the investment to be profitable. Thus, fiscal incentives can have several important functions:

- The investment cost is reduced,
- The government absorbs part of the investment risk by absorbing a portion of the cost,
- The equilibrium point for the investment is reduced to 2%,
- The IRR necessary for a profitable investment is just 2%, not 6%. This opens marketing possibilities for harvested wood that can be sold profitably at lower prices.

In reality, commercial reforestation has been most successful in those countries that have offered fiscal incentives for the reasons mentioned above. Financial incentives can be considered as government auto-investments in the future of the country that can eventually exceed the cost of the subsidies (Haltia & Keipi, 1997). The motives for offering financial subsidies to promote reforestation vary with the history and the policies of each country. Some reasons for creating incentives for forestry investments are as follows (Beattie, 1995; Haltia & Keipi, 1997):

- Modify an anti-forestry feeling of farmers who have traditionally considered forests and wild lands to be a barrier to farming;
- Increase the investment profits so that private investors will establish tree plantations which offer additional benefits to society;
- Reduce the risks and uncertainties that are inherent in long-term investments of capital in forestry projects;
- Reduce the problems of cash flow for forestry companies while capital is tied up in the establishment and maintenance of plantations until

such time as they begin to produce income;
- Establish a critical mass of plantations in order to incentivate investments in the manufacture of forest products. The validity of this reasoning depends in large part on the comparative advantage of the forestry sector with respect to forest production in other countries or in the related activities of other economic sectors in the corresponding countries.

Financial terminology

There are some basic terms used to evaluate the merits of an investment:

- Net present value (NPV)
- Internal rate of return (IRR)
- Payout
- Cash flow

The NPV is calculated for all payments and incomes in an analysis using the formula #3 to bring all values to the present. If the NPV is positive, the proposed investment has profits when using the defined discount rates in the calculations. The NPV allows an investor to make comparisons among various investment alternatives with different terms of investment.

The IRR is, in effect, the discount rate when the NPV = 0. This value indicates the maximum interest rate that can be paid on a loan and not lose money on the investment. If the IRR is positive, it means that the investment produces profits. If the IRR is zero or negative, it indicates that the investment, as defined, will produce losses.

Payout is a traditional measure that was commonly used prior to the advent of computers due to its simplicity. Currently, it is not considered as important as the NPV and IRR. Payout occurs the first year that there are profits resulting from the investment. There may be some income during previous years, but the payout is when the accumulated balance of cost and returns turns positive. For forestry investments, this value is always in the future, which is why forestry projects are seldom attractive for those investors that do not need wood as raw material for a forest industry.

Cash flow is the amount of money required each year or period to keep a project operating. It is an important value since it is the amount that must be generated or borrowed each month or year to pay salaries, invoices, taxes and interest on previous loans. When an investment begins to produce positive cash flow, it is the amount that is available to pay obligations such as deferred payments for incentives, investor dividends or to initiate expansion projects.

Financial analysis using the typical hectare method

Prior to having computers, financial analyses were calculated using the concept of a typical hectare, where all calculations were based on a theoretical average or mean hectare. To determine the total investment, the NPV for one hectare was multiplied by the total number of hectares contemplated for a project. This is a useful method for small projects and for a first approximation of the viability of a forestry investment.

Table 15-5 presents an exercise that illustrates how to calculate the NPV and IRR for a plantation of pachaco (*Schizolobium parahyba*) utilizing the data base of Montenegro (1987b) in Ecuador.[3] In this example, the discount rate is 5%. The initial plantation was established with 420 trees/ha and a pre-commercial thinning was made the 6th year, leaving 125 trees/ha standing. Due to the initial wide spacing (4.6 m x 5.0 m) and working with a species with a wide crown that allowed much light to reach the forest floor, there has to be weed control for many years. The final harvest is made at 18 years, using the wood to produce sawlogs or veneer logs. The stumpage price was calculated at US$5/m3 for sawlogs and US$15/m3 for veneer logs (Montenegro, 1987b).[4]

Table 15-5

Example of a financial analysis for a typical hectare of a plantation of *Schizolobium parahyba* in Ecuador

Faena	Año (n)	Valor (Vn) en el año indicado	Valor actual neto	Fórmula	Tasa de descuento (i) = 0.05
Preparación manual del sitio	0	(80,99)	(80,99)	2	= Vn / (1+i)^n
Plantación	0	(112,57)	(112,57)	2	
Herramientas, imprevistos	0	(214,85)	(214,85)	2	
Control de malezas	1	(87,76)	(83,58)	2	
Control de malezas	2	(87,76)	(79,60)	2	

Faena	Año (n)	Valor (Vn) en el año indicado	Valor actual neto	Fórmula	Tasa de descuento (i) = 0.05
Control de malezas	3	(43,85)	(37,88)	2	
Control de malezas	4	(43,85)	(36,07)	2	
Control de malezas	5	(43,85)	(34,36)	2	
Control de malezas	6	(33,36)	(24,89)	2	
Entresaca precomercial	6	(33,36)	(24,89)	2	
Control de malezas	7	(33,36)	(23,71)	2	
Control de malezas	8	(33,36)	(22,58)	2	
Control de malezas	9	(22,87)	(14,74)	2	
Control de malezas	10	(32,41)	(19,89)	2	
Control de malezas	11	(21,92)	(12,82)	2	
Control de malezas	12	(33,36)	(18,58)	2	
Control de malezas	13	(21,92)	(11,62)	2	
Control de malezas	14	(33,36)	(16,85)	2	
Control de malezas	15	(10,96)	(5,27)	2	
Control de malezas	16	(33,36)	(15,28)	2	
Control de malezas	17	(10,96)	(4,78)	2	
Inventario	17	(2,67)	(1,16)	2	
Administración	1 a 18	(3,93)	(45,98)	3	=a (1-i)n-1) / i(1+i)n
Cosecha final aserrío	18	215,00	89,34	2	
Cosecha final desenrollar	18	2 784,00	1 156,81	2	
Total costos			(943)	2	
Total ingresos			1 246	2	
Saldo			2 189	2	
VAN			303	2	
TIR			7%		

All tasks are listed separately by year except for administration, which occurs the same in all years. Expenses are shown as negative values and income as positive values. The thinning at year six is a cost, since the trees removed do not have sufficient diameters to have market value. The objective of the thinning is to eliminate those trees with poor form and leave the best trees standing. In can be seen that the costs generated in year zero do not change, since the value of n = 0. Income in year 18 loses much of its value at NPV due to the number of years that were discounted to bring the income value back to year 0.

The NPV is the sum of all negative and positive values, discounted to year 0, which is US$303/ha. The IRR is calculated by varying the discount

rate until the NPV = 0. In this case, NPV = 0 when the discount rate is 7%, i.e., the IRR = 7%. The payout obviously is in year 18.

There are several inconveniences when using this method for calculating large forestry projects. There are multiple costs that are not associated with just one hectare, such as:

- Internal road construction and maintenances for personnel access to carry out field work, for emergency access, for harvesting, for the construction and maintenance of perimeter fences around the property, as well as the maintenance of permanent firebreaks,
- Construction and maintenance of a tree nursery,
- Construction of fire watch towers, the organization of fire protection personnel and the purchase of equipment for fire suppression,
- Vehicles for administrative personnel, research costs, participation in tree improvement cooperatives with universities, travel expenses, personnel training expenses, and fees for consultants and specialists,
- Costs associated with community and social relations.
- In a typical hectare analysis, it is difficult to include all risk factors that can cause losses in plantations due to wildfires, diseases or insect attacks, high winds, etc. Experience has shown that it is common for a reforestation company to suffer losses of 20% or more of the area in commercial plantations due to unanticipated disasters. Even the most efficient companies with long experience of good plantation management suffer losses that are seldom less than 15%.
- Commercial forestry companies have significant additional costs for important activities, but which do not produce gains in the form of greater wood production per hectare. It is normal for a company to maintain 20% or more of its total land base in forest reserves or natural vegetation. Such reserves require investments in their protection, including salaries for ecologists, fire protection personnel, protection against cattle entry and other factors.
- Forestry companies absorb significant costs when they have visitors, including national and international visitors, ecological groups, students who do work for there graduate or post-graduate training using company plantations or facilities, as well as visits from government officials (local, state or national). In large companies there are often personnel dedicated exclusively to the coordination of visits

and attention to visitors. Nonetheless, other company employees also can be required to spend time with visitors. Legal suits by groups opposed to industrial reforestation make it necessary to contract lawyers and such cases can also take away time from management personnel to generate reports and attend meetings (or court hearings) to explain the company management processes and policies.

Such indirect expenses are difficult to calculate for a new project and they are seldom included in a financial analysis using the typical hectare method. Thus, the calculated values for NPV and IRR can be much higher for an analysis that only involves direct plantation costs, but ignores the total management costs of the company.

When making comparisons of NPV and IRR values published by different organizations and in different places, it is important to understand which factors were included when making the analysis and the discount values used to calculate the NPV. Also, it is important to understand that the NPV depends on local labor and machine costs, the price of forest products and the soil-site productivity where the analyses are made. For example, if an IRR of 20% can be attained in a plantation of eucalypts which has a mean annual increment of 35 m3/ha/year at six years of age, the value of the IRR will be much lower for another project where the plantation productivity is projected at 25 m3/ha/year. It is also important to make sure that the published wood prices are for round wood, and to know if the prices are for logs with bark or underbark. As is mentioned in the chapter on mensuration, the percent bark can vary significantly among species and even for different ages for the same species.

Sensitivity analysis

A sensitivity analysis is a means for evaluating the costs or gains when costs and/or incomes are modified. For the least reliable variables, which have greater uncertainty, a greater variation is assigned to the sensitivity analysis. This is important when analyzing the uncertainty of a cash flow and when evaluating the behavior of the proposed investment. Using the variables shown in Table 15-5, a series of ranges of uncertainty are assigned to each function in Table 15-6.

Table 15-6

Examples of uncertainties for different variables in the financial analyis of a plantation of *Schizolobium parahyba.*

Function	Year (n)	Value (Vn) in the year indicated US$/ha	Variation due to uncertainty %
Manual site preparation	0	(80.99)	-5, +5
Planting	0	(112.57)	-5, +5
Tools contingencies	0	(214.85)	-5, +10
Weed control	1 a 6	(87.76)	-5, +5
Thinring	6	(33.36)	- 10, + 10
Weed control	7 a 17	(33.36)	- 10, + 10
Forest inventory	17	(2.67)	- 10, + 10
Administration	1 a 18	(3.93)	- 5, + 15
Sawlog harvesting	18	215.00	- 20, + 25
Weneer log harvesting	18	2,784.00	- 20, + 25

The range of variation that is assigned is based on the estimated level of uncertainty for each task or price. Examples:

- Weed control costs are less reliable for older trees, especially after a thinning. A range of + 10% is assigned to those costs.
- The cost of contingencies may increase, but they will probably not go down much, so this category is assigned an increase in uncertainty of 10% and a decrease in uncertainty of 5%.
- When estimating wood prices, these may increase or decrease significantly in future markets and there is much uncertainty as to such values. Thus wood prices are assigned a range of – 20% (lower price) and +25% (increase in price).

Once the levels of uncertainty have been defined, the financial analysis is run again to determine the variations when using these levels of uncertainty (Table 15-7). When making a pessimistic analysis, the increased cost values are used, along with the decreased wood prices. When making an optimistic analysis, the decreases in costs are used, along with the increases in wood prices.

In Table 15-7, the IRR for the minimum analysis is 5% and for the optimum analysis is 9%. An advantage of having the data in the form of an electronic spreadsheet is the ease of varying each factor independently to determine its effect of the increase or decrease of the NPV and IRR. For example, the price of round wood can be varied while other variables are

kept constant, in order to determine how wood prices affect the profitability of the project; or the manual labor costs can be varied similarly to determine their effect on the profitability of the project.

Table 15-7
A sensitivity analysis using the values shown in Table 15-6

	Initial analysis		Minimum estimate		Optimum estimate	
	Value (Vn) in the year indicated	Current net value	Value (Vn) in the year indicated	Current net value	Value (Vn) in the year indicated	Current net value
Total costs	(1,077)	(943)	(1,147)	(953)	(995)	(833)
Total inome	2,999	1,246	2,399	997	3,749	1,558
NPV		303		44		725
IRR		7%		5%		9%

A series of financial analyses of six species in Ecuador show the high and low values of the IRR (McCormick, 1987). Table 15-8 is a summary of the results for good sites and poor sites for each species. Each analysis uses the best available growth information for each species in Ecuador, along with round wood prices underbark and the cost of plantation management.

In the analyses there was no market for pulpwood; rather the intent was to maximize the production of sawlogs and veneer logs. The effect of site productivity for each species can be seen in the IRR values and also the combined effects of costs and wood prices. In each case the combined costs and wood prices had a greater impact on the IRR than did the forest productivity. Nonetheless, growth rates did affect the IRR for all species evaluated. What is important in the example is to demonstrate that there is no one fixed IRR for a given species, but rather the IRR value depends on a combination of factors of site productivity, plantation management costs and the prices of the wood harvested.

It is important to remember that the mean annual increment or (MAI) (m3/ha/year) is derived from the accumulated productivity at the end of the rotation divided by the number of years in the rotation. Thus, when the rotation age is modified, the MAI will also be modified. In the case of eucalypt plantations for pulpwood grown on six or seven year rotations, as is common in Brazil, the MAI can reach values between 25 and 40 m3/ha/year because of the greater growth rates of younger trees. On the

other hand, if the objective is to produce sawtimber and there are no markets for pulpwood, as is the case in Table 15-8, the MAI values will be lower due to the longer rotations.

Table 15-8

Internal rates of return (IRR) for six forest tree species in Ecuador using a disount value of 5%

Especie	Productividad forestal m³/ha/a		Turno años	Densidad inicial N.º/ha	Costos	Precios madera	TIR %	Referencias
Schizolobium parahyba	baja	16	18	420	bajos	altos	10	Montenegro, 1987b
raleo: 6 años	baja				altos	bajos	3	
raleo: 6 años	alta alta	23	18		bajos altos	altos bajos	13 6	
Cordia alliodora	baja	10	23	420	bajos	altos	8	Montenegro, 1987a
raleo: 6 años	baja				altos	bajos	2	
raleo: 6 años	alta alta	14	23		bajos altos	altos bajos	10 4	
Eucalyptus globulus	baja	8	46	1 110	bajos	altos	11	Laso, 1987
Tala rasa: 7, 20, 33, 46 años	baja				altos	bajos	6	
Tala rasa: 7, 20, 33, 46 años	alta alta	6	46		bajos altos	altos bajos	16 10	
Tectona grandis	baja	7	45	1 110	bajos	altos	9	Tobar, 1987
Raleos: 5, 12, 20, 30 años	baja				altos	bajos	5	
Raleos: 5, 12, 18, 25, 30 años	alta alta	9	35		bajos altos	altos bajos	12 7	
Pinus radiata	baja	7	29	1 600	bajos	altos	8	Montenegro, 1987 c
Raleos: 11, 17 años	baja				altos	bajos	4	
Raleos: 5, 8 años	alta alta	24	17		bajos altos	altos bajos	20 8	
Pinus patula	baja	8	25	1 600	bajos	altos	8	Muñoz, 1987
Raleos: 15, 20 años	baja				altos	bajos	4	
Raleos: 13, 14 años	alta alta	18	22		bajos altos	altos bajos	13 5	

Given the fact that there exist differences in the value of IRR according to the factors mentioned above, the following published IRR values are shown in Table 15-9 as examples for plantations and natural forests. In all cases, the IRR values are lower for natural forests than they are for

plantations. It can also be seen that it is uncommon to find IRR values greater than 20%.

Table 15-9

Published values for internal rates of return for some tree species in plantations and in natural forests

Species & region	***Country***	***Management***	***IRR %***	***Referece***
Araucaria angustifolia	Brazil	plantation	12	1
Araucaria angustifolia	Argentina	plantation	7	1
Eucalyptus grandis	Brazil	plantation	23	1
Eucalyptus grandis	Uruguay	plantation	22	1
Eucalyptus grandis	Argentina	plantation	14	1
Eucalyptus dunii	Brazil	plantation	23	1
Eucalyptus globulus	Uruguay	plantation	13	1
Eucalyptus globulus	Chile	plantation	21	2
Eucalyptus globulus	Chile	plantation	10	2
Eucalyptus nitens (Región 10)	Chile	plantation	16	3
Eucalyptus nitens (Región 10)	Chile	plantation	9	3
Pinus taeda	Brazil	plantation	16	1
Pinus taeda	Uruguay	plantation	15	1
Pinus taeda (Misiones Province)	Argentina	plantation	13	1
Pinus taeda (Corrientes Province)	Argentina	plantation	11	1
Pinus taeda	USA	plantation	10	1
Pinus radiata	Chile	plantation	17	2
Pinus radiata (Region 10)	Chile	plantation	9	2
Nothofagus procera (raulí)	Chile	plantation	9	2
Bosque natural, especies coníferas	USA	well managed	8	1
Natural broadleaf forest	Uruguay	well managed	4	1
Natural broadleaf forest	USA	no management	4	1
Natural broadleaf forest	Argentina	well managed	2	1
Natural broadleaf forest	Argentina	no management	<0	1

1 = Cubbage et al., 2005

2 = Toral et al., 2005

3 = Valencia & Cabrera, 2005

Stumpage value

Stumpage is a residual value. There is not an “average” wood price that can be applied indiscriminately to different locations. Stumpage value is

calculated by starting with the price of wood at a point of sale, such as a woodyard at a sawmill. From the sale price, subtract the cost of log transportation from the forest to the woodyard. Next, subtract the harvesting costs, including the cost of forwarding the wood from the stump to roadside. The remaining value is stumpage, which represents the costs of plantation management plus any profit from the wood sales.

Stumpage value = price of wood at a point of sale – transport cost – harvesting costs

There are several factors that determine stumpage value (Straka, 2006):

- The competitiveness of local wood markets; that is, how many wood buyers are there in the region and how many are interested in the logs being sold, as well as the method of sales.
- Species of wood: wood prices vary by tree species and their value for use in the manufacturing of wood products.
- The size and quality of the trees; as a rule, larger diameter trees have greater value per cubic meter.
- The volume of wood per hectare; there are economies of scale when larger volumes can be harvested per hectare.
- The size of the tracts to harvest; it cost money to move harvesting equipment, improve access roads and to organize logging crews; thus, when there are larger, adjacent areas to be harvested it is more economical than where the harvests are scattered over several properties or where the distances between tracts is large.
- The location of plantations in relation to the points of sales; the closer the woodyard where the wood is to be sold, the lower the cost of log transport. There is also greater stumpage value where there is good access to highways that are in good condition for fast travel and without causing damages to the logging trucks. Ground conditions for harvesting are also important factors. Harvesting on wet sites, in swamps, or during the rainy season is less efficient and results in greater equipment damage which increases harvesting costs.

There may be published prices for stumpage of different species and log sizes, but such values are calculated using the variables mentioned above. In a particular tract, if the harvesting costs are higher or the transport distances greater, the stumpage values will be less than those reported in

publications. Thus, when analyzing a forestry project, it is best to start with the sale price of wood at a woodyard (pulp mill, sawmill, etc.) to calculate stumpage value, rather than to use a published stumpage price from another location. Published information is useful as a point of reference, but it is not an absolute value that can be applied to a particular case without knowing the details of the location where the forestry project is to be established.

When there is no local reference point for determining the sales price of wood, or the stumpage values, the alternative is to search for information from other sources to use as a reference point. When doing this, it will be necessary to increase the outer limits of the sensitivity analysis for stumpage values.

Land cost in a forestry analysis

Land value does not depreciate as it does for other capital investments in buildings, roads and machinery. As a general rule, land values increase over time and produce gains for the investor when sold. However, the increase in land value is speculative and it is risky to include it in a financial analysis for a new forestry project.[5]

In financial models for short-term projects, the cost of land is added to the initial project costs and subtracted at the end of the term. This is a common analysis procedure for agricultural projects with a one-year duration, where the land cost is added initially and subtracted at the end; in this case, the cost of the land use is the internal rate of return multiplied by the land cost. There are also similar cases for forestry projects that include land cost in the analysis using the same value for the land purchase and the land sales, by simply adding the interest generated on the loan during the length of the growth rotation. This technique was used with *Eucalyptus nitens* in Chile with a 20-year rotation and with an interest rate of 8%; the forestry IRR was 11% with the land included and 16% when the land was excluded from the analysis (Valencia & Cabrera, 2005).

When making forestry investments, there are several inconsistencies with this economic model.

- In a financial analysis, if the land cost is added in year one and is assumed to be sold the year of the timber harvest, without taking into account other financial considerations, the IRR for the land by itself is, by definition, 0%, since there is no gain nor loss in the value of the

land. However, when the land cost is included in the financial analysis of a long-term forestry project an incongruence occurs, as is shown in the following example:

Example of the effect of inclusion of land value on the IRR in a forestry analysis Let's assume that the land value is 10 million and, for simplicity of this example, it is sold for the same value after 25 years, with zero inflation. If the IRR for the forestry project is 10%, the NPV for the land only is just over 900,000, when using an IRR of 10% as the discount rate. However, if the IRR is, say, 5%, the NPV of the land increases to nearly 3 million and if the IRR is even lower, say, 2%, the NPV of the land increases to 6 million. Thus, as the forestry project becomes more profitable, with higher IRR values, the NPV of the land is discounted more. Logically, the real land value should be discounted at the same rate regardless of the differences of the IRR of different forestry management schemes; it can even be argued that the land value should increase as the forestry IRR increases since there are greater profits which implies greater land productivity.			
Land value, year 1	10,000,000	10,000,000	10,000,000
Land sale, year 25	10,000,000	10,000,000	10,000,000
IRR of the forestry project	10%	5%	2%
NPV of the sale of the land	922,960	2,953,028	6,095,309

- Given the fact that land increases in value over the long term, it has frequently been used as a safeguard or hedge investment (along with gold and jewels) during periods of inflation, war or political chaos. Investment (non-speculative) in rural lands has often been a means for assuring long-term investment stability, where other, riskier investments are also being made. This is one reason why there have been many investments in timberlands in the United States in recent years by insurance companies, pension funds and banks. The truth is that the philosophy of buying land, making one rotation of forestry plantations and then selling the land is not consistent with a rational investment strategy.
- Land prices can vary significantly in the short-term, depending on interest rates or the lack of interest by investors in land acquisition during a given year.[6] When land value is included in a forestry investment, it masks the true IRR of the forestry project itself. Thus, the best alternative is to make two separate models, one for the forestry investment and one for the land investment and combine them on the bottom line.
- Improvements to the land continue more than just one rotation and add future values to the forestry investment.[7] Improvements include intangibles that may or may not add value to a future buyer depending

on how the buyer would plan to use the same property. When the value of land is discounted in just one rotation, the model ignores such values that add future value to the land. In reality, improvements for forest management can become problems for potential buyers who wish to change the land use. Fields full of tree stumps can be an impediment for agricultural use. Drainage systems can be undesirable for cattle growers who want to have water sources within all of the pastures for use by the animals.[8] Thus, the person who would buy the forest land may have to invest in modifications or improvements to the land and the forestry company would need to subtract such costs from the sale price if the price of the land is to be attractive to a buyer who is planning to use it for grazing or agricultural crops. If the land continues to be used for tree plantations, conditions such as tree stumps are not an inconvenience since new plantations can be established between the stumps.

> Most industrial investments in forest plantations in the tropics and subtropics are made by pulp and paper companies (except for those where plantations are established to grow non-wood products such as oil palm, coconut palms, rubber trees for latex, etc.). In such cases, wood production is not a separate business, but is an investment in the production of wood as a raw material so that value can be added by converting it into wood pulp. The financial return on the forestry investment by itself is not the primary concern; rather it is to make profits at the end of the manufacturing process when the final product is sold, be it pulp, rolls of paper or products manufactured from paper or paperboard. It is possible that the forestry IRR can be negative, but forest management may still be a viable strategy if the income for the overall company is positive and profits are made when selling the final products.

- There are very few places where there are true markets with open competition among sellers and buyers of round wood. One place where such a market exists is in southeastern United States, where there are multiple pulp and lumber industries. The *Timber-Mart South* bulletin, published by the University of Georgia, provides monthly prices of stumpage, round wood in woodyards and sawn wood of different

dimensions in the southern states. Under such conditions, the landowner has various options for the sale of wood from timberlands and can determine the timber value in an open market situation.

- Pulp and paper companies in southern United States offer technical assistance to rural landowners. Such programs may provide technical assistance, seedlings and/or management plans for a landowner's timberlands and, in exchange, the landowner gives the company a first option by buy wood in return. This type of technical assistance works well where the land is owned by a rural family that does not wish to sell the land, even though the value of the land for agricultural production has diminished and forest management is an alternative use for the land to obtain some income. In such situations, the forest landowner does not consider land value in the analysis of costs and incomes, since it is a sunken cost.
- When considering investments in forest plantations, it is important to have a good understanding of the available markets for forest products, that is, the log dimensions and quality specifications. If there are no buyers for the wood within a reasonable transport distance, the cost of wood transport becomes a limiting factor. If the supply of round wood increases where there are few buyers, the price of wood tends to decrease.[9] When a forestry project is part of an industrial complex where round wood is used as raw material, the option of selling timberland is not a decision that can be made within the forestry organization; rather it must be made within the scope of the overall industrial investment. In such a financial model it is not realistic to consider the sale of land as an independent option. The land is only sold as a part of the sale (or dismantling) of the total industrial investment, of which the forest lands are just a part of the total.

When investing in timberland, the capital is plowed into the land and is not available (it is not liquid) for investments in other investment alternatives, which is something that an investor must consider. One method for representing capital sunk in land is to assign it a land (or soil) opportunity cost (LOC) in the forestry financial model. If there is a tradition of agricultural land rental in the region, such rental rates can be used as guidelines for developing the LOC. If we assume that the economic potential of agricultural land is greater than that of forest land, it is

necessary to discount such land rental values if these are to be realistic. The obvious problem is how to justify the value of such a discount rate.

Another alternative is to create an annual LOC rate that extends beyond one rotation. In general, economic models show that the differences in repetitive costs for two rotations or models carried to infinity have similar effects on the IRR. Thus, in the case of a 25-year rotation, if the land cost is divided into equal quotas for 50 years, this becomes, in effect, an annual quota of 2%. When comparing land costs for forest tree species with short rotations, such as eucalypts or *Gmelina*, with species grown on longer rotations, such as pines or teak, it is best to use a common LOC in both cases. If different land opportunity costs are used for different rotation lengths, that will favor one alternative over another in the analysis.

Given the arguments expressed above, there are basically three options for considering the land value in a forestry investment:

1. The forestry financial analysis can be made without including land costs. An analysis of land costs is made separately where increases in land value may or may not increase with time. The forestry analysis and the land analysis are combined to determine the overall profitability of the investment.
2. The forestry financial analysis can be made including an annual quota to represent the land opportunity cost, spreading that cost over two rotations or 50 years, i.e., an annual quota of 2%. A financial analysis of the land value is made separately where land values may or may not increase over time. The forestry analysis and the land analysis are combined to determine the overall profitability of the total investment.
3. The forestry financial analysis is made as part of a total forest industry investment, where timberland and tree plantations are portions of the total investment. The total life of the industrial complex is calculated and the land value is removed as a residual value in the year that the mill is to be closed or sold.

What is inflation and how does it affect the forestry investment?

As a rule, prices of materials and labor tend to increase over time. Inflation occurs when there is an increase in the availability of a national currency (more bills are printed, there are more loans, there is a greater use of credit cards, etc.) and/or when there is greater demand than supply of

certain materials and products; that is, when people increase their demand for goods and services which allows sellers to increase the prices of their products and services and/or when the government itself increases its expenditures, such as to finance the military, finance public works (roads, schools, dams) and/or when there are increases in the payments for social entitlement programs or for increases in the cost of public health subsidies or pensions. Central national banks can try to control the availability of money in the economy by varying the rediscount rate that individual banks pay for the use of national currency. The government can modify the inflation rate by varying tax rates (income tax, import tariffs or sales taxes). When taxes increase, the cost of goods and services increase for the buyer and this tends to reduce the buying power of individuals and companies with the cash available. Similarly, increased taxes increase income to the government which allows it to finance the national debt or spend more. In summary, there are many causes of inflation which can be quite fluid and difficult to predict. Projections of inflation are based on historical data of the national economy along with expectations for changes in the future.

The value of the national currency can vary in comparison to other monies in the world economy. Currencies in Latin American countries have historically be compared to the U. S. dollar and to the English pound, although the euro is now being used more as a base for comparison and, sometimes the Japanese yen, especially in those countries that export appreciable quantities of products to Japan and other Asian destinations. The devaluation of a national currency can be due to multiple factors, such as the ratio between the demand for the export of national products and the import of foreign products, the buying and selling of the national currency in international currency markets, the size of the national debt and the support given by the central national bank to shore up the national currency in international markets. In some countries, the central bank calculates a gradual devaluation of its money and publishes that value daily, as was the case for Colombia, where the Central Bank defined the *Tasa Representativa del Mercado* (representative market rate), the exchange rate used by private banks for the exchange of dollars and pesos. In some countries the exchange rate for the national currency remained fixed for many years in its relationship to the U.S. dollar, without variation; but when an imbalance began to occur between the real value of the currency versus the published

value, the government would be forced to make a major devaluation of the national currency, sometimes overnight.

During the 1980's, the real value of the Brazilian currency dropped so much that it was necessary to devalue it three times between 1986 and 1993, reducing its value by 1000 points each time.[10] In Mexico, the peso was changed to the *new peso* in 1994, discounting it by 1000 points. The official policies of devaluation of the currency have serious impacts on the national economy and can cause internal inflation. If the national economy has a deficit between exports and imports and has a fixed official currency rate for international exchange, this can often result in the appearance of a black market exchange within the country. The national policy of devaluation can also have a direct effect on the purchasing power of imported products such as vehicles, machinery, electronics and computer equipment, etc., as well as the cost of air fares and tourism to foreign countries. When the local currency is over-valued as to its acquisition power, there is tendency to buy cheaper imported goods at the expense of the national industries which are at a disadvantage for exporting, sales and marketing of products. When the official value of the national currency is allowed to fluctuate freely, there exists the opportunity to export products and compete favorably in international markets, but, on the other hand, imported raw materials become more expensive.

When countries make unexpected changes in official devaluation rates of national currencies there is less willingness by foreign investors to invest in long-term projects, such as forestry. It is for this reason that incentives for reforestation are important to stimulate the forest industry and investments in new forestry projects.

The use of inflation in financial analyses

The nominal interest rate includes the real interest rate plus a factor for inflation:

Nominal interest rate = [(1 + actual interest rate) * (1 + inflation rate)] - 1

If the interest rate is 5% and the inflation is estimated at 15%, the nominal interest rate is:

Nominal interest rate = [(1.05) * (1.15)] – 1 = 1.2075 – 1 = 0.2075 = 20.75%

Sometimes the nominal interest rate and the inflation rate are known, but not the real interest rate. The formula can be varied to calculate the real interest rate:

Real interest = [(1 + nominal interest)/(1 + general inflation rate)] - 1

The real interest rate is useful when calculating the discount rate for the NPV because it gives a better idea of the real value of a project by eliminating the effect of inflation from the interest charged by the banks.

In some cases, it can be justifiable to use an inflation factor for some product prices or costs when calculating the profitability of a forestry project. For example, the prices of southern pine sawlogs in the United States increased by 5.7% during a period of twenty years, whereas the real interest (without inflation) was between 1% and 1.5% (Zhang & Bliss, 1997). On the other hand, the price of pulpwood in the country stayed below the inflation rate (Hamilton, 1995).

Sometimes a reforestation company will promote its project using high inflation rates for calculating future values for its wood, as a means for showing higher projected profits to attract investors. Before considering such investments, it is important to check the inflation rates used for prices in independent publications by forest economists, in order to be certain of just how inflation is being used by the promoter. When a forestry project advertises that it has IRR rates above 20%, the potential investor should evaluate the potential investment carefully. For example, a rise in the price of wood at a woodyard may be real, but it does not necessarily indicate that the stumpage value has increased; rather it could be the result of a scarcity of wood near that particular woodyard which makes it necessary to transport wood from greater distances and that the price paid by that woodyard reflects the transport cost, not an increase in stumpage value. In Central America the prices of wood are quite stable, with slight variations, but much less than the variations that occur in agricultural crops or cattle sales (de Camino, 2001).

The minimum legal wage for labor in the United States was US$2.00/hour in 1976, and was US$5.15/hr in 2006, an increase of 1.5 times in 30 years, while the gross national product (GNP) increased by four times, the same as did the consumer price index (Federal Reserve Bank, 2006). In that case, the real labor cost decreased significantly when

compared to the consumer price index. As a rule, labor wages in forestry in the USA are normally above the minimum legal wage and therefore it is not a good indication of the cost of labor in forestry. However, in many countries, the minimum legal wage is the real cost of unskilled labor for forestry work.

For a financial analysis, different rates of inflation can be used for different variables when there is a reasonable basis the justify their use. When there is no information to justify the inclusion of inflation as a variable, it is best to make an analysis assuming that all costs and incomes will vary in a similar fashion to the average inflation. According to Professor Straka, of Clemson University: “A good method for managing inflation is to ignore it” by making net calculations using constant values converted to dollars or to another international currency and using a real discount rate (Straka, 2006). That advice is useful for making an investment analysis when there exists much uncertainty regarding the future pricing of wood.

How to valuate plantations for the buying and selling of forest properties

According to Mendoza (1993), the capital of a forestry company is composed of the following items:

- The forest properties, i.e., the land,
- The inventory of standing forest products in the trees,
- The volume of logs already harvested, but still not sold,
- The company installations: roads, buildings, machinery, etc.
- Operating capital, such as company personnel, acquired technology, the inventory of materials and parts, quantitative information regarding the forests and the markets, among others,
- The fluid resources of the company, such as cash on hand, financial deposits, outstanding accounts, and investments outside of the forest industry.

When selling land with existing plantations, there is the real value of the land (soil) and there is the value of the standing timber. However, when the plantations are below merchantable size for harvest, how is their value calculated? There are two basic methods, depending on the status (age) of the plantation.

Cost of pre-commercial plantations. If the plantations do not have commercial volumes, their value is calculated as the establishment cost carried to the present using an interest rate agreed upon by the buyer and seller. Since the plantations already exist, there is no risk associated with their establishment cost and a low interest rate is commonly used for this calculation, such as the LIBOR rate,[11] rather than using the historic nominal interest rate for the period under consideration to bring the value up to the present.

In the example in Table 15-10, with *Schizolobium* in Ecuador, if the plantations were to be sold when they were six years of age, the establishment costs would be calculated for the first to the sixth year, using the following formula to calculate the current (future) value of the initial costs: Vn = Vo (1 + i)n

If a discount rate is assumed to be 5% and the inflation of the national economy is 8%/year between the first and sixth years, the interest rate is calculated as follows:

Nominal interest rate = [(1 + discount rate) * (1 + inflation rate)] - 1

Nominal interest rate = [(1.05) * (1.08)] – 1 = 0.134 = 13.4%

Thus, the value of the plantation in terms of national currency (sucres) is shown in Table 15-10:

Table 15-10

Calculation of plantation costs for *Schizolobium* in Ecuador at the sixth year: Vn = Vo (1 + i)n

Function	Year work done

Years prior to present (n)	Cost in year work done Sucres/ha	Current net value Sucres/ha		
Manual site preparation	0	6	12,148	25,833
Planting	0	6	16,886	35,909
Tools, contingencies	0	6	32,228	68,535
Weed control	1	5	13,164	24,686
Weed control	2	4	13,164	21,769
Weed control	3	3	6,577	9,591
Weed control	4	2	6,577	8,458
Weed control	5	1	6,577	7,458
Weed control	6	0	5,004	5,004
Total cost, sucres			112,325	207,243

Cost of plantations that have reached commercial ages. If the plantations already have trees with commercial sizes of wood, the value of stumpage is calculated as the actual value of the plantation, if and when the stumpage value is greater than the establishment costs. Sometimes it is argued that the future potential value of the plantation should be included as part of the plantation price. This depends on the condition of a particular plantation, the available wood markets and the intentions of the land buyer. If the wood does not have good form for sawtimber or if it is destined exclusively for the production of chip wood (pulpwood, paper board, particle board or fiber board), then the stumpage value increases as a linear proportion to the volumetric growth and does not justify adding a factor of increases in its future value. If the plantation has been managed for sawlog production and is in good condition for this purpose, the seller could argue that the future value will increase at a greater rate than just the volumetric growth. In such a case, it would be necessary to determine an equitable price between the buyer and seller that reflects that future potential.

Calculating forestry machine operating costs

For accounting and budgeting purposes, it is important to maintain good records for costs and productivities of machinery in forestry operations. Many companies maintain records of costs for each event (examples: site preparation, weed control, harvesting) in order to evaluate the profitability of those operations. If the site preparation is done using owned machinery, how do these costs compare with those of contractors doing the same jobs? If there are government incentives for reforestation, are there requirements to present real operational costs when requesting fiscal incentive payments? For income tax purposes, it may be necessary to record the cost per hectare for plantation establishment and then subtract these from profits when the plantations are harvested, in order to minimize the tax payments due on profits.

There are several methods for calculating machine operating costs. Before the use of computers, most calculations were quite simplistic, including only the basic factors in equations. With the use of computers and electronic spreadsheets it is possible to make quick and complete calculations of machine costs. It is important to have all cost factors in hand when making the calculations, including the machine purchase price, the unit cost of fuel, the cost of machine maintenance and others. It is also important to have information as to the expected life of the machine, the quality of its manufacture and the quality of the operators. The useful life is calculated in hours (or km) of operations and is counted as the number of hours until it is necessary to make an overhaul of the motor. In the case of crawler tractors, experience has shown that some brands of large tractors (with diesel motors greater than 160 HP) can have a useful life that may be as low as 12,000 hours working in road construction while others working on the same tasks may have useful lives greater than 15,000 hours.

In countries where the machines are manufactured and employed, some forestry companies buy low-cost machines, knowing that their useful life will be less than that of a more expensive machine. It may be more economical for some timber harvest contractors to do this rather than to purchase more expensive machines with longer useful lives, due to the lower capital investment required for the cheaper machine. However, when machines are imported from another country, the tendency is to buy higher quality and longer-lasting machines due to their greater operating time and lesser downtime. Even when there are local distributors of imported tractors brands, but that do not sell the particular models used in forestry operations, it is probable that the service for such equipment will not be as good as for imported machines that are commonly sold within the country.[12]

The use of highly skilled machine operators to work on forestry harvesters and skidders can increase the useful life of a tractor considerably; some harvesting machinery routinely reaches 25,000 hours or more of service while others working on similar sites, but with poorly trained operators can expect just 15,000 hours of useful life. A professional grade chainsaw can be expected to last one thousand hours of operation, which is about one year of continuous service. However, there are forestry companies that can routinely keep saws operating for 2,000 hours by employing operators who have been trained in tree felling and who maintain their own chainsaws.

Second hand machines can be an alternative when there is limited capital available, since they cost less than new machines, but the useful life of such machinery is difficult to estimate. If the buyer has several machines and has the know-how to repair them, it may be economical for such contractors to use second-hand machines, particularly where the operators are family members who

have a personal interest in the care of the machinery. On the other hand, a forestry company with little experience in the maintenance and repair of machinery and/or with operators with little experience and where minimum salaries are paid, the acquisition of second-hand machinery can result in long downtimes, low productivity and high maintenance and operation costs.

In order to keep good records (and costs) of machines, it is important to keep the hour meter (or odometer) in good working condition on a tractor or vehicle. It is all to common to find machines operating where the operator who has never looked at the hour meter or to find it broken and inoperative, and when the operator doesn't remember for certain when the tractor received its most recent basic maintenance. Large tractors have exact specifications for maintenance based on the hours of operation, such as engine oil, transmission oil, final gear drive oil, fuel filters, oil filters, air filters, hydraulic filters and other parts. If the operating company does not follow the machine maintenance procedures recommended by the manufacturer, there will be system failures and unnecessary additional maintenance costs.

One government forestry agency gave pickup trucks to field foresters for their work. The foresters were also allowed to use the vehicles personally within their own town and its surroundings, such as shopping and visiting friends on the weekends. One of the foresters kept the vehicle in excellent condition, as if it were his own, whereas others didn't make much effort to maintain their trucks and those began to have damages and require constant maintenance.

After a couple of years, the agency saw that it needed to replace the damaged vehicles, but the forester who had cared for his vehicle did not receive a new one. Seeing that the government gave new vehicles to the employees who had not taken care of their vehicles, he decided that it was not to his advantage to take extra care for his vehicle either and, thus, proceeded to treat his truck indifferently, as did the other foresters.

Conclusion: Policy regarding equipment must be designed to promote and incentivate optimum care of tractors, vehicles and other equipment, rewarding those operators who take the best care of their equipment.

Table 15-11 presents an example of a machine cost calculation in Brazilian reales. This generalized format can be used to determine the operating cost of various types of machines and can be used for many applications. Data on a particular machine is placed in the outlined boxes. The other boxes without the outline are automatic calculations made within the spreadsheet using other data sheets and formulas as is shown in the "formulas" column.

During a routine inspection of forest fire protection equipment, the author casually inspected a water tanker truck with a diesel motor. The air filter on the motor was not the correct size and did not fit properly in the metal canister. This allowed dust and sand to pass the filter and enter the motor,

causing excessive wear on the cylinders, resulting in a loss of engine compression and reducing motor life in an alarming manner. When shown the problem, the truck driver replied indifferently that the supply department did not have any other filters and the driver was told to use the (incorrect) ones that were delivered. Worse still, the government agency had eight similar tanker trucks!

This is a classic case of managerial ignorance of basic equipment maintenance, as well as a lack of effective communications within the organization. It is important to train operators how to correctly maintain their equipment, but it is also critical to educate the forest manager and the purchasing staff as to the importance of obtaining the correct elements for operation and maintenance of equipment.

Table 15-11

Example of how to calculate the operating cost of a forestry machine in Brazil, with values expressed in reales (R$). The outlined boxes indicate where the user inserts information specific to this piece of equipment. The formulas refer to the numbers in the respective rows

1	**Cost of machine operation**			
2	Machine description	Timberjack 1210B forwarder, 12 ton capacity, hydrostatic transmission		
3		w/ 12-ton knuckle boom loader		
4	Motor	Valmet 620 DS diésel, 140 HP, 6 cylinders		
5				
6	Prices of machine in Brazil	R$	563,200	Formulas (see numbers for the rows)
7	Additional costs	R$	201,600	
8	Delivered cost	R$	764,800	=row6 + row7
9	Cost of tires	R$	39,200	Est. tire life **9000 hours**
10	Net cost without tires	R$	725,600	= row8 - row9
11	Net cost without tires	USD	334,378	=row10 / data base R$/US$
12				
13	Estimated machine life	hours	19,500	
14	Amortization	years	5.0	
15	Work days per year		277.5	= data base
16	Work hours per year		3,900	= row13 / row14
17	Daily utilization	hours/day	14.1	= row16 / row15
18	Daily utilization	shifts/day	1.8	=row17 / data base hours/shift
19	Residual sales value	%	20	
20	Depreciation	R$/year	116,096	=row10 *((100 - row19) / 100) / row14
21	Annual interest	%	9.4	= interest form data base
22	Loan as % of total value	%	100	
23	Average annual payment	R$/year	194,280	=formula for EXCEL “PMT”
24	Average annual interest	R$/year	49,160	=(row23 * row14 - row10) /row14
25	Insurance as % of total value	%	-	Insurance? **no**
26	Fixed maintenance cost	R$/year	29,024	= row20 * 0,25
27	Variable maintenance cost	R$/year	67,916	=0,015* row20*(row16/100)
28	Fuel consumption	liters/hour	9.0	= specifications from data base
29	Fuel cost	R$/litro	0.75	= fuel from data base
30	Fuel cost	R$/hour	6.75	= row28 * row 29

31	Cost of lubricants	R$/hour	1.69	= row30 * 0,25
32	Cost of tires	R$/year	16,987	= row9 * (row16/9.000 hours)
33				
34				
35	**COSTO SUMARY**			
36	Depreciation	R$/year	116,096	= row20
37	Interest	R$/year	49,160	= row24
38	Insurance	R$/year	,,,,-,,	= row10 * (row25/100)
39	Repair and maintenance	R$/year	96,940	= row26 + row27
40	Fuel and lubricants	R$/year	32,906	= (row30 * row16) + (row31 * row16)
41	Tires	R$/year	16,987	= row32 + row33
42	Net machie cost	R$/year	195,993	= SUM (row37 : row41)
43	Total machine cost	R$/year	312,089	= SUM (row36 : row41)
44	TOTAL MACHINE COST	R$/hour	80.02	= row43 / row16
45				
46	Operator, heavy equipment	R$/month	1,054	= operator, form data base
47	Benefits	%	85	= benefits, form data base
48	Operator cost	R$/year	23,400	= row46*12*(1+row47/100)
49				
50	COMPANY operating cost	R$/year	335,489	= row43 + row48
51	COMPANY operating cost	R$/hour	86	= row50 / row16
52	COMPANY operating cost	US$/hour	40	= row51/ conversion R$/US$ data base
53	Contractor profit	%	20	= from data base
54	CONTRACTOR operating cost	R$/year	402,587	= row50 * (1+row53/100)
55	CONTRACTOR operating cost	R$/hour	103	= row54 / row16
56	CONTRACTOR operating cost	US$/hour	48	= R$/US$ from data base

The following is an explanation of the different lines in Table 15-11:

7 Additional costs include international shipment from Finland, port fees, import fees, port use fees, sales tax in Brazil, transport from port to the point of sales and transport from the point of sales to the forestry center.

9 For tractors with wheels, tires are considered to be consumables, not capital, and are subtracted from the original machine cost.

14 This is operational amortization, that is, the number of years that the machine is expected to be operated. The accounting amortization may be calculated differently.

15 Work days come from another file of general data. The number of work days is calculated for forestry workers. In this case, the machine is considered to work two shifts/day for a total of 5 ½ days per week.

18 It is common in Brazil for harvesting equipment to work two or three shifts per day. This reduces the number of machines needed, which reduces

capital investments for wood harvesting. With 8-hour shifts for operators, the machines normally record less hours of operation. The operator must inspect the machine, fill the fuel tank, and fill out productivity time sheets during the shift. With two shifts per day, the routine maintenance (greasing, oil change, etc.) is done during the night.

19 This is the residual value of the machine at the end of the programmed hours of use (line 13). If there is no market from certain types of used machinery, 0% is written in this box.

20 Depreciation is the capital value (line 10) minus the residual value (line 19) divided by the number of years of amortization (line 14).

21 The interest on the loan comes from the general data sheet. It is the interest the company pays for the loan to buy heavy equipment, whether it is the bank or the equipment dealer.

22 This is the percent of the delivered cost (line 8) that will be financed. For example, if there is a down payment of 20%, interest is paid on the remaining 80%. If the company accounting department calculates a separate budget for interest payments, 0% is written in this box.

23 The average annual payment is a formula in the EXCEL program called (*PMT*) which is used to calculate the annual interest payment on the loan (line 24).

25 Some companies maintain global insurance policies on all capital, not on specific machines, which is the case in this example.

26 Fixed maintenance costs are calculated as a percentage of depreciation (line 20). Even when a machine is not working, it generates maintenance costs. For example a crawler tractor used for fire control may only work 500 hours/year, whereas a crawler tractor working in site preparation may work 2000 hours/year. Thus the fire control tractor will have a greater hourly cost when the fixed and variable costs are added together to reflect the real cost.

27 Variable maintenance cost is a percentage of amortization for each one hundred hours of operation (see formula). Where there exists a history of similar machine use, those values can be substituted into this box.

28 Fuel consumption per hour comes from the motor specifications of the manufacturer, or from historical data for machines with similar sized motors.

31 Lubricant cost (oil, grease) is calculated as a percentage of fuel costs, or it comes from historical data on similar motors of other machines.

32 Annual tire cost is the initial tire cost times the number of hours worked per year divided by the estimated tire life (9000 hours in this case).

42 Net machine cost without depreciation. This value is used when the company accounting department calculates equipment depreciation elsewhere.

43 Total machine cost with depreciation. This is the value when depreciation is calculated for each piece of equipment separately, or to know the total machine operating cost.

51 This is the machine cost when operated by the company.

55 This is the machine cost when operated by a contractor. This value is used to compare costs of company operated machines with contracted machines.

To compare costs of nationally manufactured machines with imported machines, the total cost of the imported machine is calculated in the following manner:

Quote for the price of the machine placed at the port in the country of manufacture (FOB price)

+ shipping cost from the country of origin to a national port

+ national import duties

+ port charges

+ port handling fees

+ national sales taxes

+ delivery cost from the port to the forestry operations center

= Total delivered machine cost

This model is applicable to all classes of capital investments. Table 15-12 shows the same format used for a fire watchtower, but with less variables in the calculation. It can also be used for calculating equipment hourly costs such as a fireplow, a subsoiler or other site preparation implements.

Table 15-12

Cost of an uninhabited structure (fire tower) in Brazilian reales (R$)

Unit	Fire tower

Description	Unit	Fire tower	
Purchase price	R$	20,000	
Amortization	years	20	
Depreciation	R$/year	1,000	
Annual interest	%	9,4	
Loan as % of total value	%	100	
Average annual payment	R$/year	2,06	
Average annual interest	R$/year	1,06	
Insurance as % of total value	%	4,5	
Repair and maintenance	R$/year	100	
Cost summary			
Depreciation	R$/year	1,000	
Interest	R$/year	1,060	
Insurance	R$/year	900	
Repair and maintenance	R$/year	100	
Net equipment cost	R$/year	1,960	without depreciation
Total equipment cost	R$/year	2,960	with depreciation

Description	Unit	metallic, Grazia model, 30 tall	

Machine sinking fund

Because of the high capital cost of mechanical equipment, a forestry company must maintain a strict control over the costs and productivity of its machinery. It is important to maintain records of the dates and hours of use of each machine as well as the costs of each repair and maintenance event.

It is not possible to predict when damages or failures will occur to a given piece of equipment, but it is logical to assume that a new machine will have less risk of mechanical failure than an old machine. In other words, machine cost for maintenance and repair will increase with age to the point where it becomes a better alternative to eliminate a machine and buy a new one. The problem occurs when trying to budget sufficient funds for machine repair and maintenance. This becomes even more important for a company that has many machines working and that are of different ages. For the controller of a company it is not pleasant to have “surprises” coming from operational personnel when they ask for unexpected large amounts of cash to make machine repairs that were not anticipated in the budget and that occur without warning.

The accounting mechanism for estimating and budgeting these costs is called a “*machine sinking fund*”. The machine cost per hour (or km) of each machine is multiplied by the number of hours (or km) it works. This sum is added to the fund as a positive entry. The machine costs (depreciation, insurance, fuel, maintenance, etc.,) are added as negative entries. The balance is the value that is kept in the budget for future repairs and maintenance. During the first few years of machine life, the budget balance increases and during the later years of machine life, the

balance is used to pay for repairs and maintenance. Each year, the balances of all machinery within the company are accumulated and used as an estimate of the funds that will need to be budgeted to keep the machinery operating for the next year.

With funding already budgeted, there are less delays obtaining authorization to carry out necessary machine repairs. The quicker that a tractor, truck or implement can be repaired, the more productive it will be. If there are no maintenance funds, there can be delays obtaining approvals from management as well as delays in obtaining loans from the banks. If a tractor can be repaired in one week, but it becomes necessary to wait two months to obtain the cash for the repairs, obtain the approval to request parts, and then to make the repairs, the machine will lose eight times the productivity in downtime than if the repair were to be made immediately. That means there will be eight time the loss of income to the company by not completing the anticipated goals, but while still generating fixed costs on the machine (capital, insurance, interest and maintenance).

When a machine is shared among various cost centers within the company, the sinking fund is a mechanism that allows repairs to be made quickly without trying to decide “Who is to blame for the damages and who will pay for the repairs?” For example, if a fire tanker truck has transmission damage when moving water to plantations for irrigation during the low fire season, is the plantation group responsible for repair of the truck or is the fire protection group responsible? With a sinking fund for machine maintenance, the question is academic, since not one or the other is responsible. The funds for repair come from the sinking fund that is already budgeted for the truck.

Another important aspect of an equipment sinking fund is to aid the forest manager to make the best decision as to when to repair a machine or when to sell it. Some machines can work well for many more years than the average expected useful life, while others may have larger than normal maintenance costs. Without the life history of the machine in the sinking fund, the company may decide to replace its more profitable equipment and keep some that are less useful, resulting is losses. When a specific operator is assigned full time to a machine, the sinking fund also makes it possible to evaluate the operator as well as the machine.

Table 15-13 is an example of a sinking fund for a crawler tractor used for site preparation, firebreak maintenance and road maintenance. Even though the tractor was amortized for a useful life of 15,000 hours in 8 years, in this particular case it was better to keep it 3 more years. The example demonstrates the importance of making decisions on equipment replacement based on the individual histories of machines and the repairs already made to them.

The sinking fund works in the following manner: If, for example, the tractor works eight hours in site preparation in tract “X”, the sinking find is assigned

eight hours x $49/hour = $392 and the reforestation budget is charged $392. The sinking fund thus receives this amount as a deposit. Similarly, when charges are made, they are subtracted from the fund for depreciation, insurance, fuel, lubricants and maintenance. The balance is the difference between the deposits and the expenses to the fund. In Table 15-13 it can be seen that the balance was positive during the first six years, while the tractor was working the expected hours. This balance is budgeted for future tractor maintenance and repair. In year seven, it was necessary to make a complete motor overhaul, and the amount of the overhaul was removed from the fund. During years 9, 10 and 11 the tractor was spending more time in the shop, resulting in less effective work time. Thus, in year 12, it was decided that it was time to sell the tractor and replace it. The ideal goal of the sinking fund is to eliminate the machine when the sinking fund is zero or near zero for maximum machine utility.[13] (In Table 15-13, the final balance was positive at $1,142.).

Suppositions:

- The initial cost is 30,100 * 8 years = 240,800
- Values are in constant US dollars. If a national currency is used and requires annual adjustments for devaluation, such adjustments are made to the hourly operational costs for the current year and to the balance for the previous year.
- The useful life is estimated to be 15,000 hours, with a work depreciation of 8 years.
- The average annual usage is assumed to be 1875 hours.
- Insurance is calculated as 3% of real cost (initial cost - depreciation).
- There was no interest charge, the company purchased the tractor with its own funds.
- The hourly cost is calculated as is shown in Table 13-11.
- The tractor was sold in year 12 at $13,800.

Table 15-13

Example of a machine sinking fund for a crawler tractor, model Caterpillar D6E in US dollars.

					Withdrawals				
Year	Hours per year	Accumulated hours	Cost/hour	Deposits to fund	Depreciation	Insurance	Fuel & lubricants	Maintenance & repairs	Balance
1	1 600	1 600	49	78 400	30 100	7 224	17 600	9 800	13 676
2	1 890	3 490	49	92 610	30 100	6 321	20 790	10 150	38 925
3	1 970	5 460	49	96 530	30 100	5 418	21 670	15 350	62 917
4	1 580	7 040	49	77 420	30 100	4 515	17 380	53 800	34 542
5	2 010	9 050	49	98 490	30 100	3 612	22 110	39 800	37 410
6	1 970	11 020	49	96 530	30 100	2 709	21 670	16 780	62 681

7	1 360	12 380	49	66 640	30 100	1 806	14 960	89 000	(6 545)
8	1 760	14 140	49	86 240	30 100	903	19 360	56 700	(27 368)
9	1 400	15 540	49	68 600	0	0	15 400	46 790	(20 958)
10	1 250	16 790	49	61 250	0	0	13 750	38 900	(12 358)
11	900	17 690	49	44 100	0	0	9 900	34 500	(2 658)
12	sale			13 800					1 142

Year	History of major repairs to the crawler tractor
4	Replacement of crawler rails, pins and sprockets.
5	The crawler rollers are replaced and the tractor is painted.
7	It was necessary to make an unanticipated complete motor overhaul.
8	With the motor overhaul in year seven, the crawler rails, pins, shoes and sprockets were replaced with the intention of keeping the tractor a few more years.
9	The transmission was replaced.
10	It was necessary to replace the rear axle bearings and to repair the hydraulic system.
11	The operator’s cabin and the bulldozer blade were repaired, along with the oil pump and the machine was repainted.
12	Due to excessive downtime for repairs in year 11, the tractor utility was low. It was decided to sell the tractor and replace it with a new one.

A cost comparisons for two harvesting methods

When planning a forestry project and before buying machinery, it is important to evaluate the different methods available to harvest the wood in terms of efficiency and cost. Harvesting costs are among the largest in a forestry project and merit a well planned analysis. First, the most appropriate harvesting methods are defined for the types of forest land to acquire or that has been acquired. Then information is needed regarding the yields of the different harvesting systems. Information of this type can be obtained from operations nearby with similar machinery or from operations in other countries. Information from technical publications can also be utilized for this purpose. When using information for operations that have been ongoing for a long time, it is best to discount the equipment production rates reported for ongoing operations when applying the information to new operations where there is little or no experience. The following example shows how a comparison can be made between two mechanized harvesting systems:

Method 1: Harvest and transport of tree length logs (Figure 9-35)

1. An articulated tractor (feller-buncher) is mounted with a hydraulic shear to fell trees and bunch two to five trees on the ground.
2. A chainsaw delimbs and tops the bunched trees on the ground.

3. An articulated tractor mounted with a grapple picks up the bunched trees and skids them to roadside.
4. A hydraulic knuckle-boom loader mounted on a trailer loads the logs onto a tractor-trailer unit.
5. Half time for a maintenance truck is included, which carries fuel and lubricants for the tractors and the driver is the field mechanic who does the routine machine maintenance.
6. A pickup truck is also included for transport of field personnel.

Method 2: Harvest and transport of 6 m long logs[14] (Figure 9-28).

1. An excavator base is mounted with a harvesting head which cuts the trees, delimbs them and cuts them to 6 m lengths, leaving the logs in a pile on the ground.
2. An articulated tractor (forwarder) mounted with a knuckle-boom loader and log frame picks up the wood from the ground, puts it into the log frame, forwards it to roadside and unloads the logs in a pile.
3. A hydraulic knuckle-boom loader mounted on a truck base loads the logs onto a tractor-trailer.
4. Half time for a maintenance truck is included, which carries fuel and lubricants for the tractors and the driver is the field mechanic who does the routine machine maintenance.
5. A pickup truck is also included for transport of field personnel.

A cost sheet is made for each type of machine using an electronic spreadsheet. For this exercise, there will be eight spreadsheets for the eight machines (the hydraulic loader, the maintenance truck and the pickup truck are common to both methods).

Suppositions used for making the comparison calculations:

- This analysis is made in US$.
- The company owns a pulp mill with an annual capacity to consume 250,000 m3sub, or 5,200 m3sub/week. The mill also buys 200 m3sub/week from third parties.
- The wood production for the two methods is similar with a potential to harvest and deliver 1000 m3/week of solid wood underbark (m3sub). Thus, five sets of harvesting equipment would be required by the company to harvest and supply wood to the pulp mill.
- There are tropical eucalypt plantations with a mean annual increment (MAI) of 35 m3/ha/year with the harvesting being made at the end of the 6th year with a commercial volume of 210 m3sub/ha.

- The land is flat to slightly rolling which allows for the use of the machinery under study during the entire year. The work year is assumed to be 48 weeks (leaving four weeks for maintenance and repairs).
- Production costs are calculated for wood placed on trucks (FOB).
- Skilled labor is calculated based on daily wages plus benefits. Harvesting personnel are assumed to work 8 hours per day, 5 days per week.

The cost analysis for tree length logs is shown in Table 15-14 and the analysis for 6 m long logs is shown in Table 15-15. In this exercise, the 6 m length log alternative costs an additional US$1.56/m3 in comparison with the tree length log method. Thus the difference between the two methods is $1.56 x 200,000 m3 = $312,000/year.

Table 15-14
Tree-length harvesting method

Harvesting unit	US$/hour	Units	Personnel		Depreciation US$/year	Operating cost US$/year
No.	US$/day					
Feller-buncher	58	1	1	32	33,429	63,112
Grapple skidder	44	1	1	32	22,714	49,898
Knucklel-boom loader		1	1	32	21,549	45,280
Chainsaw	1	3	3	15	158	659
Maintenance truck	7	0.5	0.5	32	3,343	8,341
pickup truck	7	1	-		2,537	8,844
Labor	persons/week		6.5			
Work weeks/year		48				
Stumpage	m^3/ha		210			
Harvest unit capacity	m^3sub/week		1,000			
Machine depreciation	US$/week		1,716			
Machine operation	US$/week		3,610			
Labor	US$/week		788			
Harvesting cost	US$/week		6,115			
Harvesting cost	US$/$m^3$sub		,6,11			

Table 15-15
Cut-to-length 6 m wood harvest method

Harvesting unit	US$/hour	Units	Personnel		Depreciation US$/year	Operating cost US$/year
No.	US$/day					
Harvester	79	1	1	32	50,962	96,500
Forwarder	58	1	1	32	36,422	73,006
Knucklel-boom loader	27	1	1	32	21,549	45,280

Harvesting unit	US$/hour	Units	Personnel		Depreciation US$/year	Operating cost US$/year
No.	US$/day					
Maintenance truck	7	0.5	0.5	32	3,343	8,341
pickup truck	7	1			2,537	8,844
Labor	persons/week		3.5			
Work weeks/year		48				
Stumpage	m^3/ha		210			
Harvest unit capacity	m^3sub/week		1,000			
Machine depreciation	US$/week		2,357			
Machine operation	US$/week		4,746			
Labor	US$/week		563			
Harvesting cost	US$/week		7,666			
Harvesting cost	US$/$m^3$sub		7,67			

However, if there are variations in the field conditions or costs of equipment, the advantage of one method over the other may change. For example, if the company plans to work two shifts per day instead of one, the cut-to-length method has the advantage since there are no personnel with chainsaws working on the ground, a dangerous situation when working during night shifts. Another advantage is that the cut-to-length method allows the wood to be piled at roadside to leave it dry, while experience has shown that the tree-length method does not lend itself as well to piling at roadside. If the operation is to produce industrial charcoal, as is common in parts of Brazil, drying the wood at roadside is an alternative prior to moving the wood to the charcoal ovens. Transporting dried wood results in lower transport costs for long hauls and a lower delivered wood cost.

In the case of plantations that do not have large volumes of wood per hectare, the use of expensive machinery is anti-economical, because the yields of such equipment will be lower resulting in greater costs per cubic meter of wood produced. The advantage of the electronic spreadsheet model is that the different factors can be varied to determine how they affect the costs of a project with specific conditions of terrain, transport distance and other variables.

Financial analysis of a total forestry project

The determination of the real cost of a forestry project requires an analysis of investments made for more than just one rotation. This type of analysis can be made using an electronic spreadsheet when the user has the necessary skills of spreadsheet programming. The generation of such an analysis also requires a good understanding of finances, costs and production rates for forestry machinery and labor, along with an understanding of the silvicultural alternatives to be evaluated.

This section presents the variables that need to be considered when making an analysis of a typical forestry project in the tropics and how to organize the spreadsheets to determine financial values of NPV and IRR, based on total costs and revenues. When programming an electronic spreadsheet, it is always advantageous to design the program so that users of the program can change variables easily to determine the best combinations of options for a project and to make comparisons of the profitability of different management options.

For ease of use of a management program, it is best to place user entry boxes in the upper part of each spreadsheet, so that these can be seen when opening the program, without having to scroll down through the entire program to find user entry locations. A useful method for making user entry boxes easy to find is to place a frame around them and put a light shading in the box, such as the following:

Exchange rate for pesos to US$	10,7

When there are formulas needed for calculations but there is no need to show them, they can be hidden from view in that particular spreadsheet. To avoid having such locations deleted inadvertently, these boxes can be shaded to indicate that they are in use. In the example, 10% is written for the user to see, but this is then converted to a value of 0.10 for the computer calculations by dividing the user value by one hundred and placing the decimal value in an adjacent box as shown by the gray shading:

Non-commercial wood %	10%

Many spreadsheets will be required for a total project analysis and these are interconnected so that data can be freely moved among them. The programming sheets required in a typical program are shown in Figure 15-1.

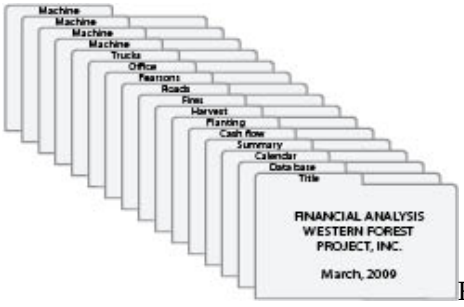


Figure 15-1. Files or spreadsheets included in a total financial analysis.

General data base

The general data base is a sheet where all common values are entered and can be accessed by other sheets in the program. By concentrating general values in

one single spreadsheet it is easier to find such information when programming the other spreadsheets and to make any changes in the data values when necessary. The following are examples of the types of information that may be included in the general data base, in this case for eucalypt plantations:

General conversions:

- National currency to US dollars
- Interest rate on loans for purchase of field equipment
- Interest rate on loans for purchase of trucks and other vehicles
- Land purchase price

Insurance

- Heavy off-road equipment
- Agricultural equipment
- Highway vehicles

Salaries and wages (Tables are included for hourly, daily, monthly and yearly rates, with net wages (direct pay) and gross wages (net pay plus benefits)

- Unskilled labor
- Field supervisors of labor
- Operator, wheel tractor (under 125 HP)
- Driver, pickup, small truck, bus
- Operator, heavy equipment
- Driver, logging truck

Contractor utility rates

- Plantation contractors %
- Road construction and maintenance contactors %
- Labor transport contractor %

Work schedules

- Weeks per month
- Work days per week
- Hours per shift
- Work days per month
- Work days per year
- Work weeks per year

General consumables and materials

- Gasoline (price per liter)
- Diesel fuel for highway use
- Diesel fuel for agricultural off-road use (if there is a different tax rate from that of highway fuels)
- Seedlings, price for 1000 trees in the nursery
- Seedlings, net number/ha, gross number/ha (includes replacement plants)
- Fertilizer: NPK price per ton
- Fertilizer rate: NPK, application in tons/ha
- Insecticide for leafcutter ants control, price/kg
- Insecticide for leafcutter ants application rate, kg/ha
- Herbicide, glyphosate, price/liter
- Herbicide, glyphosate, application rate, liters/treated ha

Wood harvesting conversions

- eucalypts, green tons/m3
- eucalypts, m3sub/stere meter (piled meter)
- eucalypts, delivered price for pulpwood at woodyard
- eucalypts, delivered price for sawlogs at woodyard
- eucalypts, percent of commercial volume for sawlogs

Harvest and wood transport

- Average diameter (DBH) of trees to harvest, cm
- Average total height of trees to harvest, m
- Average commercial volume per tree, m3sub, pulpwood
- Average commercial volume per tree m3sub, sawlogs
- Bark volume as percent of commercial log volume overbark, %
- Bark weight as percent of log weight with bark, %
- Wood losses during the first rotation, % of total volume
- Growth losses during successive coppice rotations, % of total volume
- Wood losses during harvesting operations, % of standing volume
- Average distance from stump to roadside, meters
- Average distance from forest properties to woodyard, km
- Average truck velocity with load of wood, km/hour
- Average truck velocity when empty, km/hr
- Average truck loading time, minutes
- Average truck unloading time in woodyard, minutes
- Truck stoppage time (for fueling, return to house at night, etc.)
- Average logging truck cycle time, hours
- Truck capacity, tons of wood

- Truck capacity, m3sub of wood

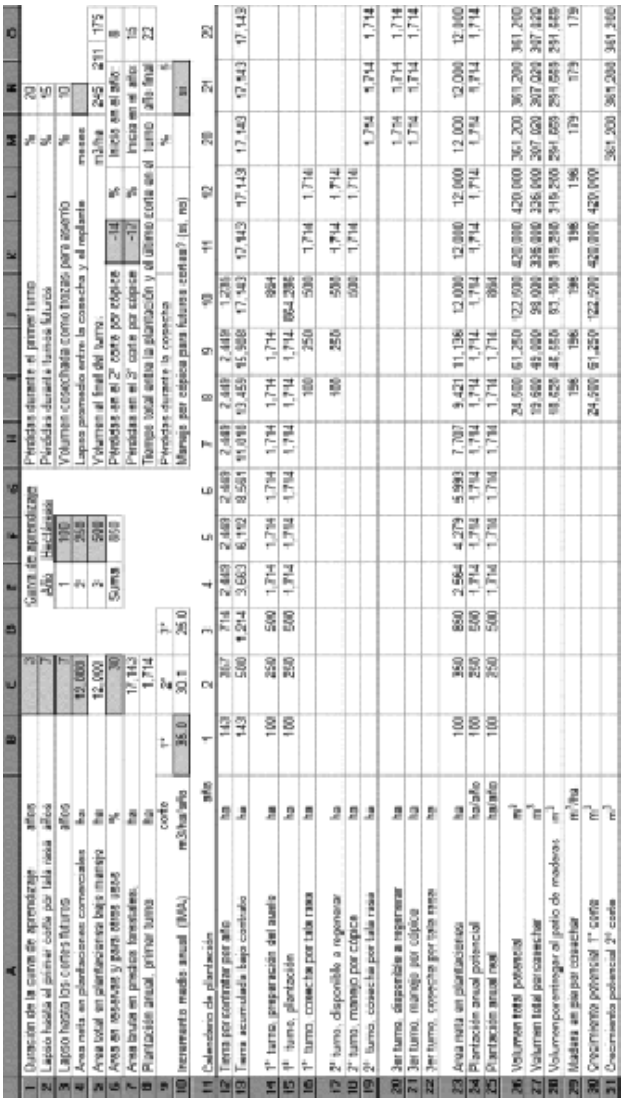
Calendar of activities

The activity calendar is a programming of land acquisition (purchase, rent or partnership), the planting and site preparation plan, the harvesting plan and projections of plantation productivity for each year (Table 15-16). All the other spreadsheets depend on the information defined in the calendar spreadsheet. In this example, there are eucalypt plantations which are managed by clear-cutting and management of the coppice sprouts for three cuts. The harvests are made after each 7-year growth period. Thus, the total rotation length is 7 + 7 + 7 + 1 = 22 years.

The learning curve refers to the initial or beginning plantations which are made on a lesser scale in order to train personnel and develop efficient operational procedures for all of the required tasks. During this period, the attention is concentrated on the quality of the plantation operations more so than on cost control.[15] This period can last between one and five years, depending on the experience of the professional personal, the work force and the size of the project that is being planned.

It is a good rule to begin a new project with a conservative growth projection. It is quite easy to reduce the length of a rotation once there is more information as to the site productivity, but it is much more difficult to increase the rotation length. For this reason, the program has two alternatives for the rotation length, that of the first rotation and that of successive rotations.

Table 15-16
Calendar of activities.



Los errores ortográficos que aparecen en esta imagen obedecen a la fuente original.

There is a time lapse between the harvest and replanting and this is a variable that is programmed into the calendar spreadsheet. In some locations there are long periods of dry season and the planting is only done during a short period of the year, whereas in others there is good rainfall throughout the year and planting can be carried out during all months of the year. Therefore, the average time between the date of harvest and the date of the next plantation may vary by several months per year. When working with the logistics of very large reforestation projects, it is common to have greater time delays between the harvest and the planting of the next plantation than for smaller projects. When managing coppice sprouts, the time lapse between harvest and sprouting is zero, by definition.

There will be some areas left in natural vegetation, some in roads and buildings and other non-productive lands. These also need to be taken into account as part of the total management area. As a general rule, a forestry company maintains 20% or more of its timberlands in natural forest or other natural vegetation.

Plantation productivity can also vary from one rotation to the next. In the case of coppice management, the second coppice of eucalypts will have less total wood production than the first. When forest research develops improved seed sources and then plus trees for its own lands, the site productivity can be increased. This variation in productivity from one rotation to the next is another factor that must be programmed into the calendar.

If there exists a market for sawtimber as well as for chip wood, the sawlog factor must also be programmed into the calendar.

The first consideration is the potential growth of the species to be planted. Deductions are made from this potential for losses during the life of the plantation and losses during the harvesting operation, in order to define the amount of wood that will be delivered to the woodyard.

With the information entered by the program user, the calendar is generated automatically by the spreadsheet. In the example, the information in the boxes shaded gray is entered by the program user, while all other information is generated by formulas embedded in the spreadsheet.

Cost and production rates for plantation establishment operations

This table has two parts. The first part (Table 15-17) is where individual functions are entered and costs are calculated on a per hectare basis. The second part (Table 15-18) calculates the costs per year, using the per hectare costs multiplied by the number of hectares (see the Calendar table).

Operational costs are separated in three parts: machinery, labor and materials. First, all operational functions that are required are listed in column A. For each function, the name of the machine to be employed is listed, along with its cost/hour (which comes from the machine spreadsheet), and its productivity (hours/ha). The productivity is determined using information from real operations with similar conditions or by estimating productivity. In some cases, all of the area is not given a specific treatment. For example, the plan is to push down some isolated or scattered trees in the tract (row four of Table 15-17), and the time required for this operation is listed per hectare. Then the average time for this operation is listed on a tract basis. For example, if there are 100 ha in a lot, but where isolated trees are to be pushed down on just 23 ha, and bulldozer time is 3 hr/treated ha F4, then the average bulldozer time for all of the tract is 3 * (23/100) = 0.69 or, 0.7 G4. In this example, the tractor operator cost is included in the

machine hourly operating cost[16] and the manual labor is calculated separately from the machine operations, these being persons who help with the tasks listed.

When several different site preparation methods are needed due to different land conditions, a section is generated in the table for each method to be used. Then, the proportion of land to be treated by each method is listed and a weighted average cost is calculated per ha.

If seedlings are produced in a company nursery, it will be necessary to generate another table showing nursery costs, where all the nursery functions are shown with machine costs, labor costs and materials. In this particular example, it is assumed that the seedlings are to be purchased from an independent tree nursery.

After the plantation has been established, the post-planting operations are listed for the life of the plantation. These include maintenance costs, such as weed and grass control, insect control (such as leaf-cutter ant), road maintenance and firebreak maintenance.

In this example, it is assumed that the eucalypts will be managed by coppice so that after a harvest the next stand comes from the stump sprouts. Thus, it is necessary to generate a section for costs for coppice management, as is shown in Table 15-17, rows 32 to 35. When there is no coppice management, this section is not needed.

In Table 15-18, the data from Table 15-17 is summarized by using the calculated plantation establishment costs per hectare and multiplying those values by the number of hectares treated per year (Table 15-16, Calendar). In this table, the information is listed separately for laborers, labor supervisors and machine operators. The labor field supervisors are those persons who control and supervise the activities of field laborers to make sure that the work is done correctly. The number of laborers that a supervisor can handle is listed in the table of basic information for each plantation operation. The number of field supervisor is determined by using this ratio multiplied by the number of field workers.

Annual costs are separated for hourly labor, materials costs, machine operating costs, machine capital costs and machine depreciation. This table also lists the number of laborers required (laborer, supervisors, machine operators) and the number and type of machines required and also the number of machines that will need to be purchased each year. The associated calculations are used to generate this information.

Table 15-17

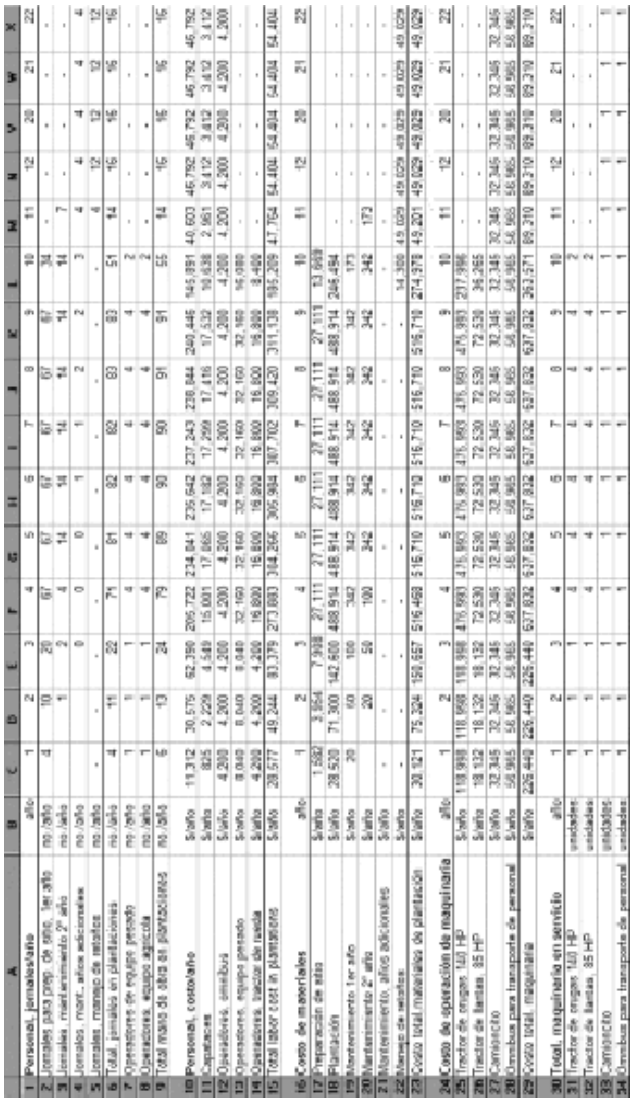
Costs and production rates for plantation establishment operations.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Costos del establecimiento de las plantaciones	Tarifa	Maquinaria					Mano de obra			Materiales				
2	Función														
3	Preparación de sitio	$/ha	Maquina	$/hr	hora/ha trabajo	hora/ha promedio	$/ha	Hombre trabajo	Hombre promedio	$/ha	Nombre	Unidad	unidad/ha	$/ha
4	Tumba de los árboles con un bulldozer		180 HP2	72	2.8	0.7	51							
5	Apilado de escombros		180 HP2	73	1.8	0.8	58	35.2	0.2	6				
6	Quema de las pilas de escombros							16.2	1.0	12	combustible			10
7	Arado		85 HP	18	2.4	1.1	39							
8	Subsolado, alineación de las líneas		140 HP	73		1.6	117	19.3	1.0	13				4
9	Control de las hormigas arrieras							9.6	1.0	10	insecticida, kg	3.63	0.55	2
10	Total, adecuación y preparación de la tierra	303					245		3.2	41				16
11														
12	Siembra										mil plántulas	2000	1.30	260
13	Trasplante de las plántulas							8.7	1.0	87				
14	Riego		85 HP	18	1.3	1.3	29	18.2	1.4	73				
15	Fertilización superficial							9.4	1.4	20	abono, ton	450	0.09	45
16	Total, plantación	429					29		3.8	120				288
17														
18	Mantenimiento, 1er año													
19	Control mecanizado de malezas y pastos	85 HP	18	1.3	1.3	29	9.8	1.3	17					
20	Mantenimiento de rompefuegos	140 HP2	73		0.4	29	22.2	1.0	22					
21	Control de las hormigas arrieras	85 HP	18	1.3	1.3		9.6	1.0	10	insecticida, kg	3.63	0.09	0
22	Mantenimiento de caminos		25				25.5	0.6	15				
23	Total, mantenimiento 1er año	patrol												
24		119				58		3.9	64					0
25	Mantenimiento, 2° año													
26	Control mecanizado de malezas y pastos	85 HP	18		1.3	29	9.8	1.3	17					
27	Control de las hormigas arrieras						22.2	1.0	22	insecticida, kg	3.63	0.09	0
28	Mantenimiento de caminos	patrol	25		0.2	5	9.8	0.1	1				
29	Total, mantenimiento 2° año	62				34		2.2	36					0
30														
31	Mantenimiento anomalo, años adicionales													
32	Mantenimiento de rompefuegos	180 HP2	73		0.4	29	13.2	0.1	1					
33	Mantenimiento de caminos	patrol	25		0.2	5	25.5	0.6	1					
34	Total, años adicionales de mantenimiento	98				34		0.1	1					
35														
36	Manejo de residuos													
37	Quema de los residuos						21.1	1.0	21					
38	Fertilización superficial del rastrojo						9.1	1.0	11	abono, ton	2000	0.11	23
39	Total, manejo de residuos	61				-		2.0	32					23

Los errores ortográficos que aparecen en esta imagen obedecen a la fuente original.

Table 15-18

Cost and productivity of the plantation establishment activities (continuation).



Los errores ortográficos que aparecen en esta imagen obedecen a la fuente original.

Cost and productivity of wood harvesting and transport

Usually, a company defines the productivity of a combination of machinery and personnel by the hour or by the day. The number of shifts per day when machinery is working must also be noted. With this information, it is possible to calculate machine productivity as m3/year. Total machine cost per year (from the machine spreadsheet) is divided by its yearly productivity to obtain the production cost per cubic meter of wood (Table 15-19). Within the harvesting units it is important to include the support elements, such as the fuel and lubricant truck and the maintenance truck. These units may be used exclusively by one harvesting unit or they may be shared by two or more units, depending on the size of the operation.

Having this annual productivity information, it is possible to calculate the number of harvesting units required per year. Then the annual costs of harvesting and transport can be calculated. Other annual values are also calculated, including materials, capital costs, depreciation and salaries.

Forest road construction and maintenance

Road construction and maintenance is related to the conditions of the management area. First, the road specifications must be defined according to the particular needs, as is shown in the example in Table 15-20. Information regarding the kilometers of road required for each road class must be developed through studies of the topography of the potential forest land base in the region where the forestry project is to be located. Machine productivity for the construction and maintenance of roads can be obtained from other, similar projects, or from contractors who have worked with public road construction in the region. The information regarding machine costs per hour comes from the cost spreadsheet for each type of machine used in road construction or maintenance.

Once the road costs per kilometer have been defined, along with the ratios of the kilometers of road to the hectares of forest property, it is possible to calculate the annual road costs using the information presented in the “Calendar” spreadsheet.

Table 15-19

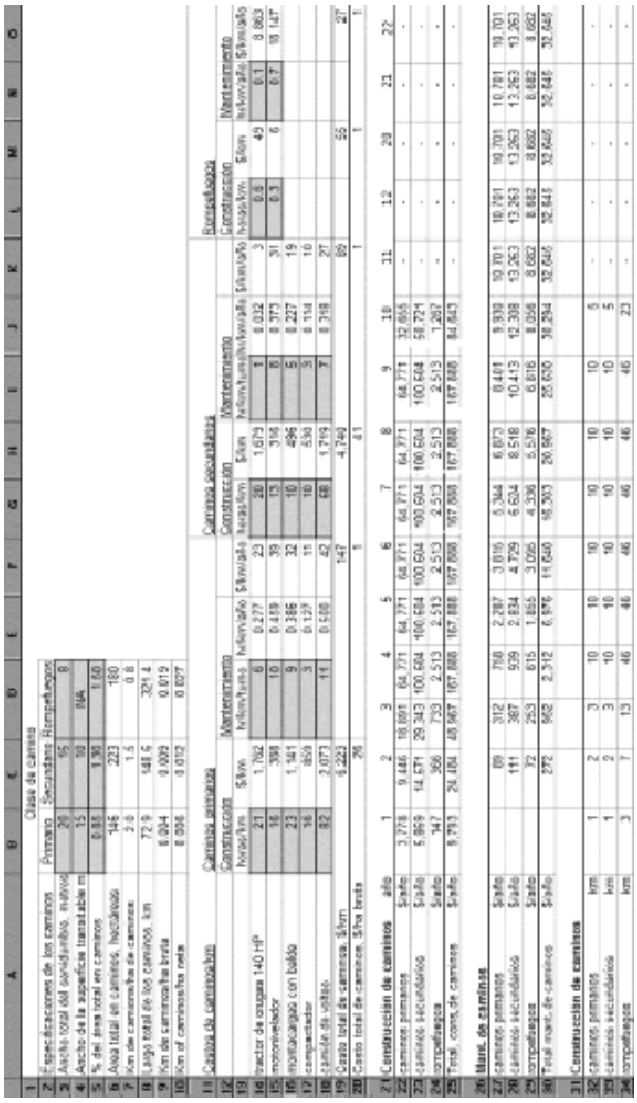
Costs and productivity of wood harvest and transport activities.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Cosecha y transporte de madera de 6 metros de largo											
2							productividad					
3		productividad			máquinas operadoras		potencial	nominal				
4	Unidad de cosecha	m³/hora	turnos/día	m³/día	/equipo	/equipo	m³/año	m³/año	$/hora	$/m³		
5	tractor articulado con cabezal cosechador	35.0	2	462	1.0	2.0	138,600		77.85	2.22		
6	tractor articulado porta trozas	28.0	2	384	1.0	2.0	109,200		55.33	1.98		
7	camioncito de combustible y lubricantes	NA	1	NA	0.2	0.2			5.18			
8	camión de mantenimiento	NA	2	NA	0.3	0.3			5.18			
9	Total cosecha				2.6	4.6		109,200		4.20		
10	Unidad de transporte											
11	grua hidráulica	45.0	1.6	594	1.0	2.0	166,729		35.30	0.79		
12	camión, cabezal 350 HP y semi-remolque	9.3	2.2	163	4.0	2.2	169,586		18.18	1.96		
13	Total transporte				5.0	4.2		166,729		2.74		
14	Costo total cosecha y transporte									6.94		
15	Unidades requeridas	año	6	7	8	9	10	11	12	20	21	22
16	equipos de cosecha	#/año	-	-	-	1	1	4	4	3	3	3
17	equipos de transporte	#/año	-	-	-	-	1	3	3	2	2	2
18	Personal requerido											
19	Cosecha	#/año	-	-	-	4	4	18	18	13	13	13
20	Transporte	#/año	-	-	-	-	4	13	13	8	8	8
21	Total mano de obra	#/año	-	-	-	4	9	30	30	22	22	22
22	Costos de mano de obra											
23	Cosecha	$/año	-	-	-	35,778	35,778	141,112	141,112	107,334	107,334	107,334
24	Transporte	$/año	-	-	-	-	33,768	101,304	101,304	67,536	67,536	67,536
25	Total, cosecha y transporte	$/año	-	-	-	35,778	69,546	244,416	244,416	174,870	174,870	174,870
26	Costo de operación de maquinaria											
27	Cosecha	$	-	-	-	328,313	328,313	1,313,252	1,313,252	984,939	984,939	984,939
28	Transporte	$	-	-	-	-	377,286	1,131,858	1,131,858	754,572	754,572	754,572
29	Total, cosecha y transporte	$	-	-	-	328,313	705,599	2,445,110	2,445,110	1,739,511	1,739,511	1,739,511

Los errores ortográficos que aparecen en esta imagen obedecen a la fuente original.

Table 15-20

Construction and maintenance of forest roads.



Los errores ortográficos que aparecen en esta imagen obedecen a la fuente original.

Protection against wildfires

The fire protection spreadsheet is made separately because there is no direct relationship of fire control to the planted area nor to machine productivity. In small operations, the fire protection group may be simply crews of fire combat personnel with their hand tools and vehicles for emergency transport of personnel to the site of a wildfire. In larger projects, there can be watchtowers for fire detection. The number of watchtowers required depends on the terrain and the plantation conditions (Table 15-21).

Where there are distinct rainy and dry seasons, the fire protection group may maintain fire protection personnel in the watchtowers during the dry season, using these people in other functions or in other areas of the company during the rainy

season. A tanker truck or crawler tractor and fire plow are units that operate less hours per year than similar machinery working in plantation production jobs. Thus, the machine life of a fire tanker truck is normally longer than for a truck used daily during all of the year and the operational amortization of such fire protection vehicles is often longer. For example, if it is normal to amortize a truck working in reforestation activities for five years, a similar fire tanker truck may be amortized over a 10-year period due to the reduced annual utilization.

Fire combat personnel may work only a short time within the fire protection group and can be assigned to other functions during the low fire danger periods. For example, if there are ten persons in a fire combat crew and if they work 20% of their time in fire protection, there are just 10 * 0.2 = 2 effective man-years. The tanker truck operator may be assigned to a truck all year, because it can be used for other functions, such as supplying water to irrigation trailers, for filling water emergency tanks placed in strategic locations within the plantations, or for other similar functions.

Cash flow

Table 15-22 is a cash flow spreadsheet. Reference data are noted in the upper section of the spreadsheet as a courtesy to the reader, including the total and net plantation areas, the harvest plan and wood production data. There are no wood deliveries until year eight, since the rotation length is seven years and the first harvest is made in year eight. The first harvest at year eight is small since the initial planting was just 100 ha, following the learning curve.

Expenses include all the cash or capital required as operational costs as well as any contract costs; for example, when the road construction and maintenance is by contract to third party contractors. Administrative costs are also included.

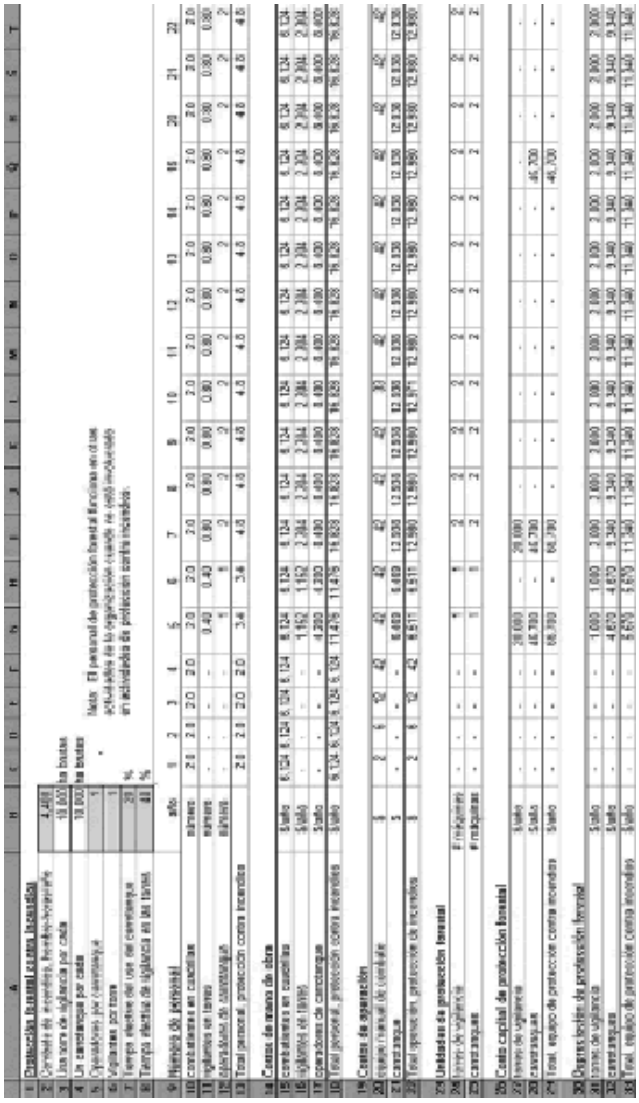
There are two sources of income: the sale of sawlogs and the sale of pulpwood or chip wood.

The annual cash balance (row 38) is the difference between the costs and incomes during each year. The accumulated cash balance (row 39) is for the life of the project. The year in which the accumulated balance becomes positive is defined as the payout year.

The net present value (NPV) varies according to the discount rate used to calculate the value of the annual balance carried back to year 1. In line 43 of Table 15-22, it can be see that with a discount rate of 6% the NPV is negative, but with a discount rate of 4% it is positive. This means that the internal rate of return is between 4% and 6%, because it is the point where the NPV = 0. In the example, the IRR is 4.8% with a 22-year base. If the IRR is calculated for another rotation length, for example,18 years, the IRR may vary, since it is calculated for an 18-year project instead of a 22-year project. Therefore, it is important to define the length of time used for calculating the IRR.

Table 15-21

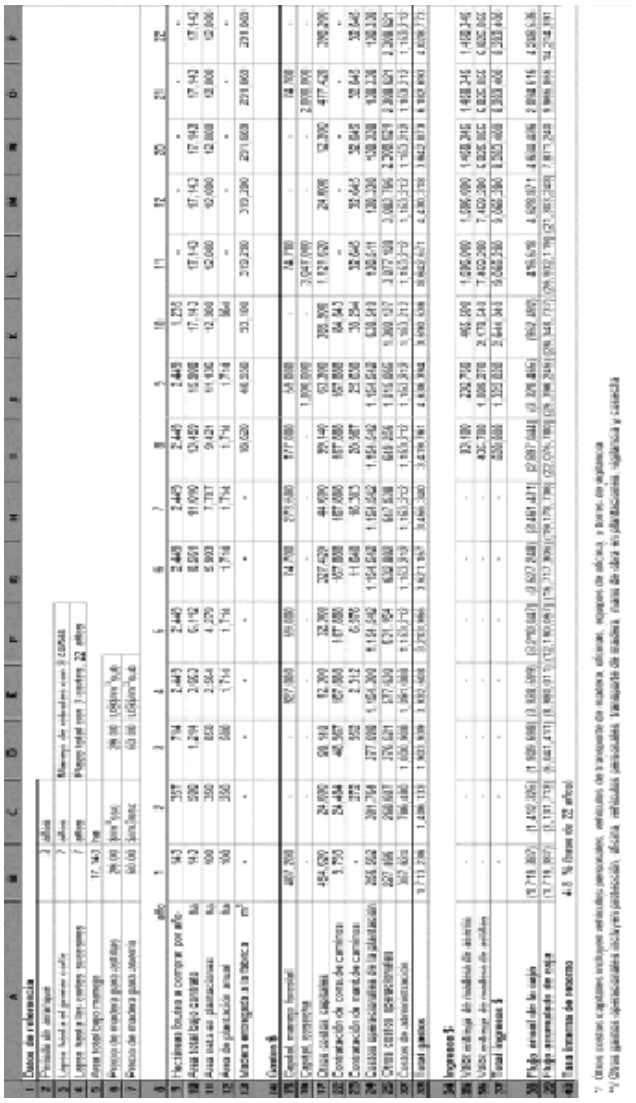
Forest protection against wildfires.



Los errores ortográficos que aparecen en esta imagen obedecen a la fuente original.

Table 15-22

Cash flow.



Los errores ortográficos que aparecen en esta imagen obedecen a la fuente original.

Summary of the financial analysis

Table 15-23 is a financial summary of the forestry project. The operational expenses, capital expenditures and administrative expenses are listed separately. The summary also includes a listing of the total forest property, the area available for planting each year, the volume of wood to be delivered to the woodyard and the income expected from wood sales. Listing these data in this spreadsheet provides points of reference to readers (investors), without their having to go back to other tables to obtain this information.

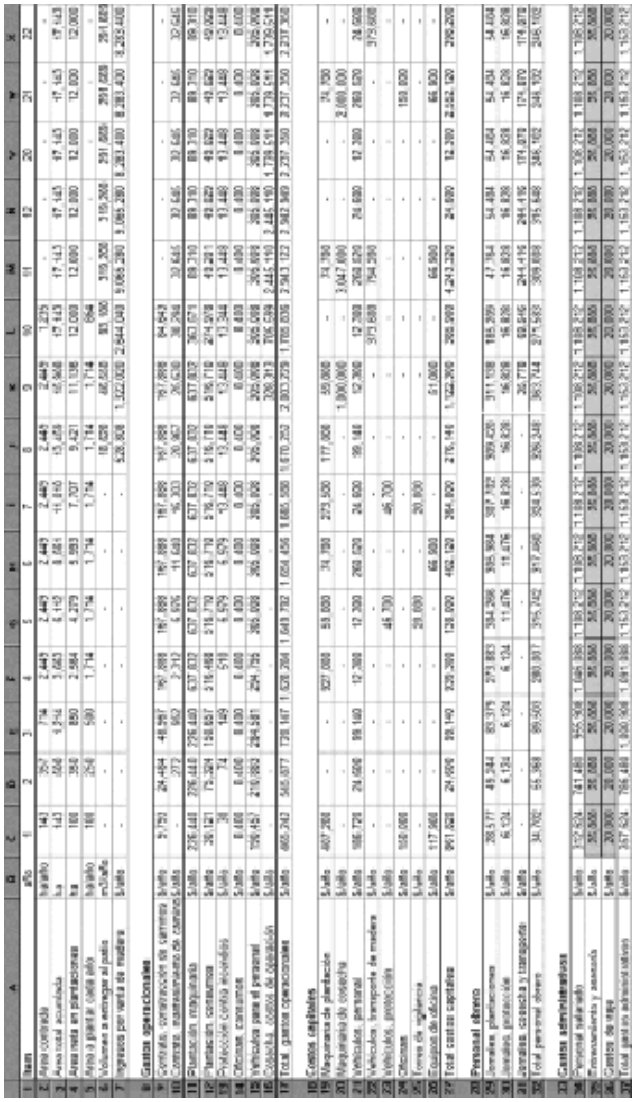
It is also very useful to include a list of all personnel employed in the project. Some of the administrative expenses that are not included in the other tables include employee training and expenses for consultants (line 35), along with the

expenses for travel outside of the project area, such as to meetings with banks, with government officials, as well as attending symposia, training courses or other business travel (line 36).

When the financial analysis is made in terms of a national currency, the summary is also made using the same currency, but in an additional spreadsheet it is useful to include these values converted to an international currency as a point of reference for investors. This is especially important for those countries where there is a high rate of inflation and/or devaluation of the national currency. The financial analysis may be made for a given year, but if it is in an international currency, it can also be used as a reference for evaluations by investors in future years.

Table 15-23

Summary of fi~nancial analysis.



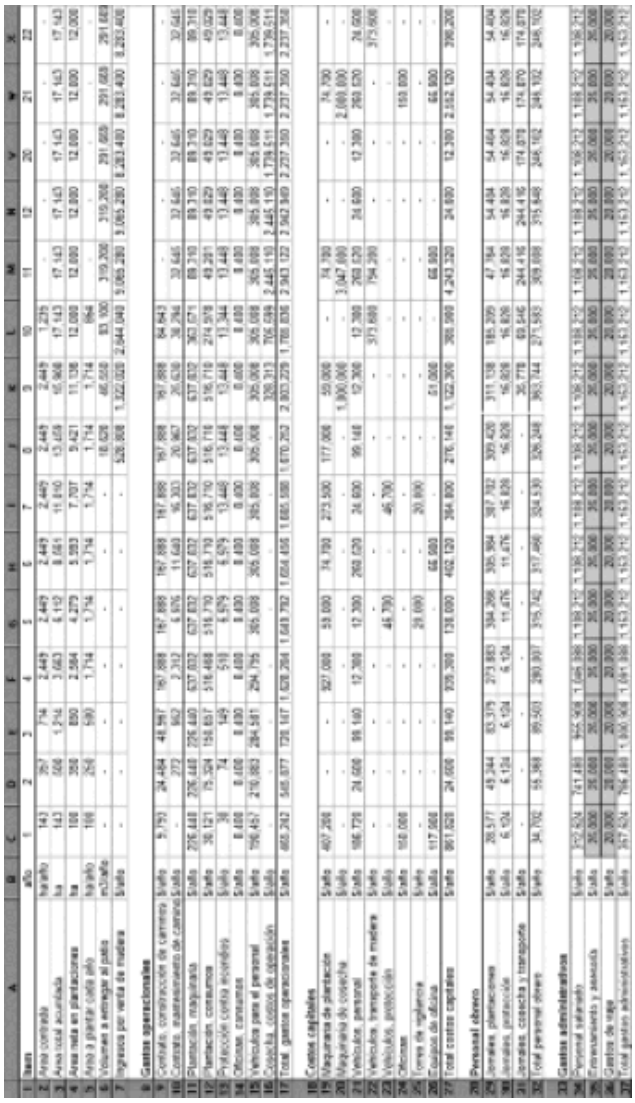
Los errores ortográficos que aparecen en esta imagen obedecen a la fuente original.

Cost basis calculations

When contemplating a reforestation project, it is important to be able to compare the model or project cost of wood delivered to a woodyard with the cost of wood obtained from economic reports or publications and also to be able to compare the stumpage price of wood in the model with that of other forestry projects. The objective of the cost basis analysis is to define these values. The cost basis spreadsheet is similar to that of the cash flow, but with the difference being that the cost basis spreadsheet uses the depreciation values for equipment instead of their capital costs.

The costs for a given year are compared to the production rates obtained that correspond to those same costs. For example, if the rotation age is six years, as in Table 15-24, the cost/m3 of wood is obtained by dividing the plantation establishment costs for year one by the volume of wood produced in year seven, which is $15.52/m3 in line H28. The unit costs of road construction and maintenance ($0.73/m3) H29 and the general costs ($10.45/ m3) H30 are determined similarly. The cost of harvesting and wood transport are generated in the same year as the income from the wood harvest, i.e., year seven; thus the harvest cost in year seven is divided by the income generated the same year, which is ($18.23/m3) H30. The value of stumpage is the difference between the price of wood H33 and the wood production costs H32. In Table 15-24 it can be seen that stumpage values have considerable fluctuations during the first years of the project, due to the lesser production during the years of the learning curve, but that stumpage values tend to level out afterwards. After the initial years, the average value on line 34 is the expected value for stumpage in the project.

Table 15-24
Cost basis for calculating stumpage value.



Los errores ortográficos que aparecen en esta imagen obedecen a la fuente original.

How to make the decision to invest in forest tree plantations

The financial analysis is the basis for making decisions for forestry investments. The internal rate of return represents the potential for making profits on the investment. Besides the financial analysis, there are other important considerations to take into account.

Among the most important of these is the potential market for wood produced in tree plantations. The evaluation of existing and potential markets is a necessary and integral part of the decision making process for plantation investments. An evaluation of markets for wood products is beyond the scope of this text, but it is of vital importance for investors. Where there exist well-established markets for the purchase of different classes of round wood, the investor can consider

investments in plantations and the sale of round wood at a woodyard. Unfortunately, such situations of free market buying and selling of wood are, at best, scarce. There are markets in Southeastern United States where there can be several pulp mills that have woodyards within a reasonable distance of individual timberlands and there are also markets in other sites, such as in Paraná State, Brazil, where there are buyers for pulpwood and also sawmills that will buy plantation sawlogs. Unfortunately, these are, at best, the exceptions. Where there are limited markets for round wood, investors must also consider the possibility of an integrated approach which includes wood manufacturing and marketing of processed wood, with plantations supplying the raw material for such industries.

Within the context of markets, it is important to look beyond local or even national production. International competition can be of great importance to the decision-making process. The investor must observe the potential for such competition. For example, in international markets there exist wood products manufactured from rubber wood obtained from rubber tree plantations in Indonesia and Malaysia, including such products as kitchen utensils, tables, folding chairs and even office desks. In North America many stores sell numerous products made of poplar wood from China. The wood of radiata pine from Chile and New Zealand can be found in markets in North America and Europe in the form of window and door frames, tables, closet doors, molding and other items.

Any investment made in tropical or subtropical tree plantations must be framed within the context of producing wood products that may have international competition and that have the ability to compete successfully with such imported wood products that may find their way into local markets or as export products in the international arena.

Another important factor is the duration of any fiscal incentives offered by the government. Incentives are key to initiating successful reforestation projects as well as wood manufacturing industries, particularly so in the tropics and subtropics. Notable among the most successful incentives were those in Brazil and Chile during the later part of the Twentieth Century. On the other hand, some countries began to offer good incentives, but ran out of funds to continue them after just a few years. In Colombia, the Twentieth Law of 1979 offered incentives that substantially increased the rate of reforestation from 1980 to 1984. However, with changes in the government and changes in the political direction, those incentives lost governmental financing and, as a consequence, reforestation programs essentially stopped, except for a few traditional wood-using industries that continued their reforestation efforts without incentives.

If the forestry project is to be based on fiscal incentives, the investors must evaluate the risks and calculate the viability of the investment with and without the incentives. It is also necessary to understand when and how incentive

payments are made. If the payments are made up front, that money can be used for the investment, but if partial payments are made over an extended period of time or at the end of the rotation, there exists the risk that the government may not make good on the initial promises of payments. At the same time, the long-term political stability of the country needs to be taken into account when planning for long-term investments and how this may affect the investment decision. If the country has a history of reversals of policy towards agro-industries or forest industries when there are changes in the government administration, these must also be considered. For example, there may be significant changes in real estate taxes or new legislation that limits the use of land for different types of crops based on soil classifications. There have been cases where certain classes of soils that were initially approved for plantation forestry by one administration were reclassified by a later administration and thus could not be replanted to trees for timber production.

If there are indigenous communities in the region, reforestation may be seen as an opportunity for them to improve their economic well-being, or, to the contrary, it could be seen as a threat to their traditional way of life. If such communities perceive that land acquisition deals were made between the central government and foreign companies without consulting them, and that this represents an invasion of lands that have traditionally been under their control, such local populations could actively resist long-term plantation forestry projects. Such resistance has occurred in more than one case, where the problem was not even considered to exist by government officials prior to promoting major plantation forestry programs.

It is also critical to consider the quality of the education within a country or region and the availability of technical personnel to carry out the operational duties of a forestry project. If there has not been a history of plantation forestry within a country nor experience with tree planting and forest management, there can be significant difficulties when developing a qualified professional work force of employees and managers for the proposed forestry project. As a general rule, if the available technical workforce has been employed primarily within government forestry organizations for the protection of natural forests, rather than for plantation management in the private sector, it will be necessary to invest in extensive training with relation to the basic concepts of how private industry works, the organization processes involved, the chain of command and the overall management of tree plantations for profit.

[1]Some years ago, a forestry company contracted a forestry professor from a well-known university to program an analysis of a series of long-term tree growth plots. The forest manager didn‘t have much faith in the new computers which turned out large volumes of printed green and white banded pages and,

when the first invoice for fees arrived from the programmer with a date of "*August 34"*, it confirmed his suspicions!

[2]In a forestry company that the author visited in Brazil, the monthly production reports were on the manager's desk three days after the close of each month.

[3]*Schizolobium parahyba* or *S. parahybum* (family Caesalpiniaceae) has a natural distribution from Mexico to Brazil and it has many common names including the following: Ecuador: pachaco, Costa Rica: gallinazo, Guatemala: copté, Bolivia: serebo o sombrerillo, Venezuela: bacurubú, Brazil: ficheiro, guapuruvú, Colombia: tambor, Belice: quamwood. It is also known as palo de picho, parica, birosca and *Brazilian fern tree.*

[4]The value of IRR in the reference publication was calculated based on sucres, the national currency, and this exercise was calculated in US$. The values between the two versions vary slightly.

[5] It is common for forestry companies to carry the original land cost as an asset without adjusting the land value with time. This has the advantage of showing better ratios of profit to capital assets in annual company reports. However, this practice has a downside, since the land asset value of neighboring lands may be increasing and the company land value becomes significantly lower than the real market value. As a result, such companies can become targets for takeover by speculators who can acquire an undervalued company and then sell off the land for a quick profit.

[6]When a company in South America began buying lands for a forestry project, the prices were quite reasonable; there was little competition for land in the region. The company needed to buy a minimum land quota each year to plant and produce sufficient wood furnish for its mill. Land prices began to increase each year at rates that were greater than the overall inflation rate. After eight years of land buying, the land prices had become extremely high, and the company made the decision to not acquire more land unless the value was within normal inflation rates. After abandoning the policy of acquiring a minimum annual land quota, and becoming more selective in its purchases, land prices dropped dramatically and the company was able to acquire land at prices that were less than half of those just six months previously. What really happened, without realizing it, was that the company had created an elevated market due to its requirement of obtaining an annual land quota for its forestry plantations.

[7]Land improvements include brush removal, drainage, internal road construction, soil analysis, soil-site production studies, the development of the correct species and seed sources for the particular sites as well as training of a work force in the region for forest management.

[8]Even were there may be a rental agreement between a reforestation contractor and a landowner that requires that the land be returned to the landowner in its original condition, such agreements are often ignored and small landowners seldom have the financial resources to contract a lawyer and take a breach of contract case to court. A Venezuelan landowner once told me that if there is a problem of cattle stealing, the police or even the army can be called upon to help the landowner to quickly find the cattle rustlers, but if there are other land disputes, there is seldom interest by the authorities to pursuing the offending party.

[9] During the years after the Second World War, many countries created legislation that prohibited the export of round wood, with the hope of promoting a local forest products industry. The effect was just the opposite: sawmills did not increase their output significantly, but what happened was that they could buy better quality logs at the same or a lesser price, with the result of a greater waste of logs left in the forest to rot. According to Dr. Rigoberto Stewart, Costa Rican economist, export restrictions on round wood resulted in the devaluation of the wood in Costa Rica, Ecuador and Bolivia because the inefficient sawmills converted high value round wood into low value sawn lumber (Stewart, 1994; Howard, 1995). As a consequence of such legislation, it was more to the advantage of landowners to eliminate the forests on their land and plant beans and other subsistence crops. Fortunately for Costa Rica, with the Forestry Law No. 7575 of 1996, incentives were created in the form of a forestry bank called FONAFIFO (*Fondo Nacional de Financiamiento Forestal*), which had the positive effect of increasing reforestation and the conservation of the natural forests. Costa Rica is now increasing its forest area by establishing tree plantations and conserving the natural forests at a rate that is among the highest in the world.

[10]In 1989 there were three different bills in circulation in Brazil at the same time: the *cruzeiro*, the *cruzado*, and the *novo cruzado*. The cruzeiro was devalued one thousand points in 1986 (1000 cruzeiros = 1 cruzado) and the cruzado was devalued one thousand points in 1989 (1000 cruzados = 1 novo cruzado).

Later, in 1993, the *novo* cruzado was devaluated one thousand points (1000 novo cruzados = 1 real). The *real* is the currency of Brazil today.

[11]LIBOR is the abbreviation for the "*London Inter-Bank Offer Rate*" and is a rate fixed daily for operations among the most important banks in Europe and the London currency exchange. The LIBOR rate reflects the cost incurred by banks to finance resources in US dollars in European financial markets. Normally the rate is less than the prime rate in the United States. The LIBOR is calculated daily for averages of 1, 2, and six months.

[12]Example: Caterpillar brand tractors of the models D5, D7 and D9 are commonly used for road construction, whereas the models D4, D6 and D8 are more commonly used by forestry companies. If the local dealer sells D5 and D7 models, but not D4 and D6 models, it may be better to buy the available models where there is more experience in their repair and maintenance and where the dealer may have a better supply of spare parts.

[13]There are cases when it is a better business decision to sell a machine prior to the end of the expected useful life. For example, if there exists a local market for used equipment in good condition and with few kilometers or hours, it may be more profitable to sell the equipment prior to the end of the calculated useful life.

[14]This method is also called cut-to-length harvesting.

[15]It is not reasonable to try to control costs before developing the procedures and developing efficient production methods. What is the purpose of trying to reduce costs if the plantation is poorly established?

[16]Another option is to record the machine operators in a separate column (or spreadsheet) depending on the preference of a particular company.

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Anexes

Forestry conversions

This section presents some of the conversion factors used for land management and wood marketing. The forestry conversions presented are the most common. However, in some countries the measurement standards can vary from those presented. There are also included conversions used between the metric system and the English system, which is still used in the United States and in other countries with a tradition of English wood measurements.

General Forestry Conversions

1 foot2/acre	0.23	meters2/hectare
1 meter2/hectare	4.36	feet2/acre
1 foot3/acre	0.07	meters3/hectare
1 meter3/hectare	14.29	feet3/acre
1 board foot	144	cubic inches
1 meter3 of sawn lumber	424	board feet of sawn lumber
1000 board feet (mbf) of lumber	2.359	m3 of lumber
1000 feet2 of plywood	0.295	m3 of plywood (1/8” thickness)
1 m3 piled round wood	1.0	stere meter of round wood
1 m3 solid wood	1.6	stere meter of round wood
1 m3 round wood	221	board feet of sawn lumber
1 mbf sawn lumber	4.53	m3 round wood
1 mbf/acre	11.2	m3/ha sawlogs (6.25 board feet lumber/feet3 sawlogs)
1 cunit (100 feet3)	2.832	m3 round wood
1 m3 round wood	0.353	cunit
1 m3/ha	0.2	cords/acre
1 lb (avr)/acre	1.12	kg/ha (avr = avoirdupois, English system)
1 kg/ha	0.89	lb (avr)/acre
1 ppm (parts per million)	2	lb/acre (for fertilizer applications)
100 trees/acre	247	trees/ha
100 trees/ha	40	trees/acre

Common conversions for pine used in Southern United States

1 cord	1.96	m3 round wood *
1 cord/acre	4.9	m3/ha solid round wood*

1 cord	2.55	m3 round wood **
1 cord/acre	6.2	m3/ha solid round wood**
1 short cord of round wood	5400	lb = 2.45 metric tons (green wood)
1 cord tree length logs	5500	lb = 2.50 metric tons (green wood)
1 cord of debarked chips	4800	lb = 2.18 metric tons chips (green wood)
1 BDU (bone dry unit)	2400	lb chips = 1.091 metric tons of oven-dry chips
(1 BDU is calculated at 0% wood moisture and is used for international marketing of chips)		
100 m3 chips	72	m3 solid round wood
1 mbf Scribner rule	5.9 – 7.3	metric tons of green round wood

*/ young trees with 70 feet3/cord

**/ mature trees with 90 feet3/cord

Conversion factors by country

1 ha	1.431	*manzanas* or squares (Costa Rica)
1 *manzana* (Costa Rica)	0.6987	ha
1 m3 round wood (Costa Rica)	325	Tica market inches (*pulgadas mecates ticas* or pmt)
1 load or *tarea* (Costa Rica)	1 x 1 x 2	varas (1 vara or yard = 84 cm= 33 in)
1 cord (Costa Rica)	1 x 1 x 2	meters
1 *quintal* (weight measure Costa Rica)	50	kg
2 *quintales* (Costa Rica	1	*carga* (a pack animal load or 100 kg)
1 *brasa*	2.2	m (Brazil)
1 *alquiere* (São Paulo State)	2.42	ha (Brazil)
1 *alquiere* (Minas Gerais & Goiás)	4.84	ha (Brazil)
1 *alquiere* (Bahia State)	9.69	ha (Brazil)
1 *alquiere* northern states	2.72	ha (Brazil)
10 liters (area measurement)	1	*cuarta* or fourth = 6,000 m2 (Brazil)
40 litros (area measurement)	1	*alquiere* (Brazil)
1 *colonia*	10	*alquieres paulistas* = 24,5 ha (Brazil)
1 rai (Tailandia)	0.16	ha
1 ha	6.25	rai (Tailandia)
1 ha	150	mu (China)
1 *hoppus foot* (Guyana)	.27	cubic feet
1 m3 (Guyana)	.74	*hoppus feet*, round wood
1 hoppus ton (Myanmar)	50	cubic feet round wood (see Glossary for explanation of hoppus measure)
1 *leño* (Honduras)	60 cm x 5 to 8	cm diam. (a stick of firewood)

1 *carga* or load (Honduras)	50	*leños* (pack animal load)
1 *caballería* (Guatemala)	45	ha
1 *metro ruma* (Chile)		2.44 m x 1 m x 1 m
1 stere meter (1 x 1 x 1)		piled cubic meter
1 stere meter	0.7	m3 solid eucalypt wood (Argentina)
1 stere meter	0.6	m3 solid pine (Argentina)
1 green ton of eucalypt wood	150	board feet (Argentina)
1 *pieza colombiana* (Colombian stick)	3	m x 10 cm x 10 cm = 0.03 m3
1 *manzana, plaza o fanegada*	0.64	ha (Colombia)
1 *vara* (Chile)	63	cm (25 inches long)
1 *vara* (Colombia)	80	cm (30 inches long)
1 *vara* (Costa Rica)	84	cm (33 inches long)
1 *vara* (Spain)	91	cm = 1 English yard (36 inches long)

Glossary

The following are terms used in this text along with their definitions for forestry use.

additive traits: Traits of an organism that are transmitted sexually to progeny in a predictable manner.

AFOCEL: *Association Forêt-Cellulose*, is the French organization of the pulp and paper industry that works internationally, especially in Africa.

agroforestry: Management of trees in combination with agricultural crops.

air dry wood: Wood cut and allowed to dry for several months until the wood moisture level drops and adjusts to the humidity level of the environment.

allelopathy: Natural mechanism used by some plants to compete within their environment by exuding toxic substances that inhibit or reduce the germination or growth of other adjacent plants.

altimeter: Apparatus used to determine the altitude above sea level; apparatus used to measure the height of objects such as trees.

amine formulation: Herbicide or other chemical with a formulation that is soluble in water.

Angiospermae: Major plant group that has flowers and produces seeds within a protective covering (fruit). Included are the Dicotyledons, species that form two initial leaves when germinating; it includes all broadleaf species of trees.

ANOVA, analysis of variance: Term which refers to mathematical calculations of the variation among measurements of different treatments in a statistically designed study.

arboretum: Experimental plantation established to demonstrate variations among tree species

articulated tractor: Tractor with a central vertical hinge in the body that is used for turning by means of hydraulic cylinders, rather than to turn by moving the wheels as in a conventional wheel tractor or vehicle.

backfire: Term for indirect fire combat where a fire is started along a firebreak and allowed to burn the fuel between the firebreak and the wildfire.

backhoe: Crawler or wheel tractor base with a hydraulic arm that has a bucket attached for excavating soil. Some track-based units are modified for use with a harvester head to fell, delimb and cut trees into logs.

bark: The protective covering of tree trunks, branches and roots that is formed from dead phloem cells.

BDU or bone dry unit: Measurement of wood chips where 1 BDU = 1.091 metric tons of oven-dry chips; a measure commonly used to buy and sell wood chips in international markets.

bedding harrow: Implement used to form beds during site preparation for planting and that is normally pulled by a crawler or articulated wheel tractor.

beds: Soil pulled into raised rows that are generally 2.5 m wide and 40 to 50 cm high, with trees being planted on top of the raised rows.

biotechnology: General term that refers to the application scientific methods to the production of vegetative material.

bitrain: Truck configuration where there is a truck-tractor, a semi-trailer and a trailer, with 5th wheel connections between truck units, normally with a total of 7 axles.

bluestain: Fungus that attack the cells of fresh, recently cut wood causing its discoloration.

bole: Trunk or stem of a tree.

broadleaf species: Species within the group of Dicotyledons that generally have flat, broad foliage.

cable bell: Forged iron device used to connect a choker cable around logs and/or to connect logs to a winch cable quickly and without the use of cable hooks.

calipers: Tool used to measure the diameter of trees and logs.

cambium: Thin sheath of living parenchyma cells under the bark of trees which generate the specialized wood cells of phloem (bark) and xylem (wood).

CAMCORE: International Tree Conservation and Domestication Cooperative located at North Carolina State University. It has members in governments and private companies in several countries of America, Africa and Asia.

canker fungi: Causal agents of diseases that produce wounds or cankers in the bark of live trees.

carriage for wood extraction: Device with pulleys that is hung on a skyline cable and used to pull logs to roadside along a main line cable.

cash flow: Financial term referring to the money required for the current operation of a company or project.

CCA: Wood immunization process. After the wood is dried, it is placed in a vacuum/pressure chamber. A vacuum is first drawn to remove air in the cells of the wood and then a solution of water soluble salts is forced into the wood under pressure. These chemicals bind chemically to the cells in the wood and make it resistant to rot and insect attack for many years. The most commonly used chemicals are chromium trioxide, (CrO_3), cupric oxide (CuO) and arsenic pentoxide(As_2O_5).

cellulose: Chemical component that gives structure to wood fibers; common name for wood pulp used for paper production.

charcoal: Product produced by burning wood with insufficient oxygen where the wood is carbonized.

check plot: Research treatment that includes a base of comparison in tests of several different treatments; it may be a minimum check, a commercial check or an optimum check.

chemical pulp: Separation of wood fibers by dissolving the lignin between woody cells.

chip-n-saw: Sawmill design which uses multiple chipper heads to form squared cants from logs. This type of sawmill is generally used when cutting small sawlogs. It produces wood chips instead of sawdust that can then be sold to a pulp mill or other facility that uses wood chips as raw material. The cants formed are cut into boards or dimension stock by resaws.

chips: Small wood pieces produced by a chipper; wood used to produce pulp or particle board

chokers: Wood harvesting term for a cable fitted around a log that is used to drag it either by a cable logging system or by a skidding tractor.

clambunk: Large, articulated tractor that has a pair of hydraulically operated overhead grapples that open to receive tree length logs and then close so that the logs can be skidded to roadside.

clear-cut: Total harvest of the commercial standing forest.

clinometer: Device used to measure tree height by employing the concept of right triangles.

clonal garden: Area planted with genetically improved trees and used to produce cuttings for vegetative propagation.

clonal production: Vegetative production of a clone where all individuals are genetically identical.

clonal seed orchard: Seed orchard composed of genetically improved trees produced by grafts or other means of vegetative reproduction, such as by rooted cuttings.

clone: A group of trees that are genetically identical and which have been produced asexually by vegetative propagation.

commercial thinning: Partial elimination of some trees in a stand where the resulting logs of the trees removed have commercial value.

commercial volume: Wood volume calculated for tree boles or logs that have useable diameters for commercial wood products.

conifers: Species in the plant order Coniferales, of the Gimnospermae great group; the fruits are often called “cones” and the foliage is usually perennial.

conservation bank: A site where examples of select trees are grown and cared for; normally refers to clonal material that has been obtained from select trees or plus trees by vegetative reproduction

control-pollinated progeny: Offspring of seed collected from fruits that were manually pollinated and where both the mother tree (flower) and the father tree (pollen source) are known.

coppice: The mass of sprouts that grow from a stump after a tree is cut. Coppice management refers to sprout management to produce a future wood crop from the stumps without the need to replant.

cord: Measurement of piled volume of round wood commonly used for small pulpwood sized logs in the United States. A standard cord is 4’ x 4’ x 8’ = 128 cubic feet (3.62 m3).

crown: Combined branchy tops of trees in a stand

CSIRO: Commonwealth Scientific and Industrial Research Organization, for scientific forestry research of the Australian government which has collected many seeds of native tree species such as eucalypts and acacias along with documentation at to the specific locations where the seed was collected. CSIRO makes small seed samples available for sale at a modest price to international agencies for purposes of forest research.

cubic meter: Solid measure of a cube of wood 1 x 1 x 1 meter.

current annual increment (CAI): Absolute growth of plantation forests between two specific dates, for example, between years six and seven, normally expressed in terms of cubic meters per hectare per year.

DANIDA: Danish International Development Agency is a government institute that participates in the collection and distribution of forest tree seed for research purposes.

DBH: Diameter at breast height in a tree, specifically the diameter at 1.3 m (4.5') above ground level..

debarking: Removal of the bark from logs by hand or with machinery.

degrees of freedom: Statistical term which is a value based on the number of observations in an analysis of variance.

delimbing gate: Device constructed with iron pipe or tubes in the form of a heavy gate that is chained between two trees at a tree length harvesting operation. A grapple skidder moves with its load in front of the gate and then backs the load into it, tree tops first, in order to break off branches as the tree tops pass between the rails of the gate. It is an effective delimbing method for tree length pine harvesting.

deciduous species: Tree species that drop their foliage at the beginning of the dry season and sprout new foliage at the beginning of the rainy season.

desprouting: Action of eliminating some sprouts from a stump in order to promote better growth of the remaining sprout or sprouts during coppice stand management.

diameter tape: Forestry measurement device that is placed around a tree or log and which gives a direct reading of diameter in centimeters or inches.

direct attack: Fire combat term where fire crew personnel try to put out a fire using tools designed for close encounter with the flames.

direct seeding: Sowing tree seed directly in the field, without germinating it first in a tree nursery.

drip torch: Tool for starting a backfire during fire control activities or for making controlled burns.

drum chopper: Rolling drum with horizontal blades that is pulled with a tractor and used to flatten brush and vegetation to the ground so that it dries out. After the vegetation is dried out, it is often burned to remove it from the site as a preparation for tree planting.

early wood (spring wood): Wood produced at the beginning of the rainy season or in the spring which has cells of greater diameter but with thinner cell walls than those of latewood or summer wood.

ectomycorrhizae: Mycorrhizal associations between plants and fungi where the hyphae of the fungi form sheaths around the root hairs of the plant or tree.

endomycorrhizae: Mycorrhizal associations between plants and fungi where the hyphae of the fungi penetrate the cells of the root hairs of the plant or tree.

ester formulation: Herbicide or other chemical with a formulation derived from petroleum.

evapotranspiration: Sum total of the loss of moisture from within plant leaves in combination with the evaporation of moisture from the environment around the plant.

exotic or introduced species: Species planted or established outside of their natural range or distribution.

FAO: Food and Agricultural Organization of the United Nations with headquarters in Rome.

fell: Cut trees leaving a stump.

feller-buncher: Tractor mounted with a harvesting head that can cut off several trees, hold them upright and drop them in a pile or bunch, using a shear head or a hydraulic saw head for severing the trees.

felling wedge: Soft metallic or plastic wedge that is hammered into a cut during a tree felling operation to make the tree fall in a desired direction.

fibers: Cells of broad leaf species that provide physical structure to the wood.

fire plow: Apparatus that opens a shallow trench to mineral soil during a wildfire emergency as part of an indirect fire combat tactic. It is generally pulled by a crawler tractor.

fire rake: Fire combat tool with triangular teeth from an agricultural reciprocating mower which are fasten to a handle.

fire swatter: Fire combat tool which has a rubber square pad approximately 30 cm x 40 cm and 5 to 8 mm thick, and which is fixed to a long handle. The user can swat the flames of the fire with the rubber pad or drag the pad over the flames to put out the fire.

firebreak: Permanent, wide strip of land maintained free of vegetation or organic fuel to act as a barrier to the advance of fire.

fire line: Term for indirect fire combat where a path or ditch is cleared to mineral soil. A backfire is then started alongside of the fire line and allowed to burn back towards the wildfire with the purpose of eliminating the available fuel between the backfire and the wildfire.

forest inventory: Measurement of trees in a forest stand in order to determine the volume (or weight) of wood in the stand. In the practice, a sample of the total area is measured using a systematic or random sampling design and calculating the total volume based on the percent of the total area measured.

forest sampling: Forest inventory technique where a portion of the forest is measured using systematic or random plot locations in order to calculate the total volume of wood in a given lot or area.

forestry cooperative: Association where several companies and/or public institutes come together with the forestry faculty at a university to carry out forest research for the benefit of all the members.

formation pruning (singling): Removal of forked stems on a tree, leaving just one stem to become the tree bole.

forwarder: Articulated tractor with a hydraulic grapple which loads long wood into a frame on the back of the vehicle; used to collect cut-to-length logs in the field and forward them to roadside.

frustum: Section of a geometric figure. The frustum of a cone is a truncated part, without the point.

geotextile: Woven or unwoven cloth used as a sub-base for road construction, normally made of synthetic fibers.

GIS or geographic information system: Computer program for making maps and creating a complementary data base.

GPS or global positioning system: A GPS network is formed using a series of satellites that transmit signals to a GPS receiver on the earth’s surface to define the location of the receiver.

graft: Vegetative reproduction where a branch or shoot is placed in a donor plant of the same species, so that the cambium or growing regions of both plants are adjacent and fuse together.

green wood: Wood with natural humidity in standing, live trees.

Gymnospermae (Latin for naked seed): Great plant group that includes the Coniferales order.

hardening off or lignification: The process of promoting woody stem formation in nursery tree seedlings prior to their being outplanted.

heartwood: Interior dead wood in a tree or log. In many species the heartwood has a darker color than the outside or sapwood due to mineral or other chemical deposits that can provide some added resistance to wood rot fungi.

hemicellulose: Chemical compound found in wood, but as a lesser portion of the total cellulose content.

heritability: Statistical term used for progeny tests; it is a mathematical expression of the observed variation in traits observed within test families.

high-lead cable: Single cable loop used to forward wood to roadside. With a highlead the butt of the log is dragged along the ground to roadside. There is normally a main mast at roadside which lifts the high-lead cable and the log butts as they approach the road.

hoppus log measure: Imperial British or hoppus log measure continues to be used in Myanmar (Burma) for marketing of teak logs. The hoppus volume of a log is calculated by dividing the mean circumference of a log into 4 equal lengths and assuming that these represent 4 sides of a square. Hoppus volume is thus the volume of a cuboid which has the area of this hypothetical square multiplied by the length of the log. Example: For a 20 foot log with a mean circumference of 4 feet, the log mean diameter = 1.27 feet. The hoppus volume = 1 x 1 x 20 = 20 feet3.. The volume of a cylinder with the same dimensions = (1.27/2)2 x *Pi* x 20 = 25.3 feet3, which is 26% greater than that of the hoppus volume.

Example: For a 24 foot log with a mean circumference of 6 feet, the mean diameter of the log is 6/*Pi* = 1.9 ft. The hoppus volume = 1.5 x 1.5 x 24 = 54 feet3 The volume of a cylinder with the same dimensions is: (1.9/2)2 x *Pi* x 24 = 71.6 ft3 which is 33% greater volume than hoppus volume. Thus, the difference between hoppus volume and cylindrical volume increases as the log diameter increases.

Initially, the hoppus ton was only used for log measurements, but it is now applied to sawn lumber as well: 50 foot3 = 1 cubic hoppus ton of sawn lumber. (1 foot3 = 0.02832 m3 and 50 foot3 = 1.416 m3)

hybrid: Plant produced by crossing two species, either by natural or artificial methods. May also refer to crosses made between two different strains or genetic lines of plants within the same species.

hypsometer: Tool for measuring the heights of trees. Alternative name for an altimeter.

improved seed: Seed that is produced by genetically improved trees in a seed orchard.

increment borer: Metal, hollow tool used to drill into a standing tree to remove a wood tube, called a core sample, to be used for study; the cores are normally 5 mm or 12 mm in diameter.

indirect attack: Fire combat term where a backfire is started along a fire line, leaving that fire to burn and remove the fuel between the fire line and the wildfire

IRR, internal rate of return: Financial term that is the discount rate which provides for a net present value (NPV) of zero.

juvenile wood: Wood produced nearest to the center (pith) of the tree. In many species the wood is of lower density and the fibers are shorter than wood produced towards the outside of the same

tree.

Kalimantan: Southern portion of the Island of Borneo that belongs to the Republic of Indonesia, and is divided into four provinces (West, Central, South and East).

kapur: commercial name of tree species in the genus *Dyrobalanops*, in the *Dipterocarpaceae* family that occur in the Philippines, Malaysia and Indonesia. The wood is used for general construction.

keruing: commercial name of species in the genus *Dipterocarpus*, in the *Dipterocarpaceae* family that occur in the Philippines, Malaysia and Indonesia. The wood is hard and heavy and is used for posts, pilings and foundations in construction.

land race: Trees tested and found well adapted to local planting conditions and which are then used to propagate seed or cuttings for making future plantations within the same region.

late wood (summer wood): Wood produced during the dry season or the summer which has cells of lesser diameters but with thicker cell walls than early wood or spring wood.

Latin square: Statistical design in a square where there are the same number of treatments and replications and with each treatment occurring in each row and each column of the square.

LD50: Term for the toxicity of chemicals, equivalent to the dosis of an ingested chemical necessary to kill laboratory rats, expressed in mg of chemical per kg of animal weight.

leaf-cutter ants: Species of ants, commonly in the genera *Atta* or *Acromyrmex* that cut foliage in trees and bushes into small pieces and then carry it to their den to be used as a host material for growing fungi which are used as food by the ants within the colony

learning curve: Time period necessary for developing operational processes at a smaller scale than that of the planned operations. In the case of forest plantations it is normally a period of between one and five years.

lignification: Process of stiffening of the stems of nursery plants as they begin to form woody tissue.

lignin: Chemical in the wood that acts as glue between woody cells. During the chemical pulping process the lignin is dissolved to separate the cellulosic fibers.

linear regression: Regression where there is one independent variable and one dependent variable.

loam: Soils term for a medium texture composed of particles of clay, silt and sand.

log deck: Temporary location where harvested wood is accumulated, normally located at roadside, also called a concentration yard.

long fiber: Commercial term for cells of wood of conifer species whose technical name is tracheids, which normally measure between 2.5 and 4.5 mm in length.

long wood: Logs that are cut into lengths of between 4 and 6 meters.

lumen: The interior cavity of a plant cell which contains the living plasma and cell nucleus.

map file: Special cabinet with many drawers designed to hold originals of maps in a flat position.

matrix map: Base map of a tract, including legal limits, roads, sources of water and permanent constructions. Additional maps are drawn over this base map to indicate forest management activities.

mature wood: Wood produced towards the outside of the tree after several years of tree life. In many species it has higher density and longer fibers than the wood grown towards the center of the same tree.

McLeod or combi tool: Fire combat tool that can be used for two functions, one side being a hoe-type blade and the other a fire rake.

MDF: Medium density fiberboard, a construction board produced from mechanical wood pulp that is impregnated with glue and pressed under heat to form a solid panel of medium density.

mean annual increment (MAI): Average growth between the beginning of the plantation and the date of termination, normally expressed in terms of cubic meters per hectare per year.

mechanical pulp: Separation of wood fibers by grinding logs against stone cylinders or by rubbing chips between platens of hard or stone-like materials.

mensuration: The science of measuring and quantifying the timber in a forest.

meranti: Commercial name of wood in the genus *Shorea* of the *Dipterocarpaceae* family, which contains more than one hundred species that occur in Malaysia, Indonesia and the Philippines and that are sold in international markets for the manufacture of plywood and lumber. Also known in the Philippines as lauan.

monsoon: Climate where there are distinct dry and rainy seasons.

mother tree: A tree selected for its good physical traits and used to produce seed

multiple regression: Linear regression where several independent variables are used to calculate the value of a dependent variable.

mycorrhizae: Symbiotic relationships between plants and fungi where the plant supplies food to the fungus which attaches itself to the plant roots and provides for greater absorption of water and nutrients to the plant roots.

nematodes: Microscopic roundworms; some species can cause diseases in some plants and animals.

non-additive traits: Traits of an organism that do not pass to progeny in a predictable manner during sexual reproduction.

non-linear regression: Advanced mathematical regression without an intercept coefficient for the vertical or “Y” axis of a graph.

NPV or net present value: Financial term. The value of the costs and incomes of a project carried to the present using a discount value.

nursery: Site where tree seed is germinated and seedlings are grown for their eventual transplanting to a field location.

nursery beds: Raised strips of soil used to produce tree seedlings which are then outplanted in the field

open-pollinated progeny: Offspring from seed collected from mother trees, but where the source of the pollen (father) is not known.

oven dry wood (OD wood): Wood with zero humidity in samples placed in an oven to dry at 105° C for several hours or days, depending on the size of the laboratory sample.

oven dry wood density: Wood density after drying a sample in a laboratory oven at 105° C until there is 0% humidity in the wood.

Papua New Guinea: Nation located in the eastern portion of the Island of New Guinea that is part of the British Commonwealth. The western portion of the island is a province of Indonesia.

parenchyma: Initials or stem cells of plants that can diversify into other specialized cells. Cells in the tree cambium are parenchyma cells, as are those of callous tissue.

pH: Laboratory scale that represents the acidity (or alkalinity) of water or other liquids or the acidity on soil and refers to the number of hydrogen atoms available in the solution. The scale is exponential: pH = log10 (aH+) where log10 is the logarithm, base 10, and aH+ represents the number of hydrogen atoms in solution. A pH value of 7 = 0, or neutral. Values greater than 7 represent alkalinity and values less than 7 represent acidity. Agricultural and forest soils normally have pH values between 4.0 and 8.0.

phloem: Cells produced towards the outside of the tree cambium whose function is to conduct sugars downwards in the tree from the leaves towards the roots. Upon dying, the phloem cells become tree bark.

pioneer species: Species that have the ability to grow and develop successfully in marginal soils and soils with nutrient deficiencies as well as those that have the capacity to quickly recycle nutrients between the tree, the leaf fall or litter layer and the soil.

planimeter: Mechanical instrument used to measure areas on maps.

planting hole: Hole made with a hoe or other tool for transplanting tree seedlings.

plug or root plug: Planting substrate in which the roots of seedlings grow in a tree nursery.

plus tree: Tree with proven genetic superiority for selected and desirable traits.

Poplar: General term for species of cottonwood and aspen in the genus *Populus.* Cottonwood row plantings are used for windbreaks and the wood is often used for making matchsticks as well as boxes for shipping fruits and vegetables.

pre-commercial thinning: Partial elimination of trees in a stand before the wood removed has commercial value.

pre-emergent herbicide: Chemical that kills weed and grass seeds as they germinate.

progeny test: Research where seedlings grown from seed of individual mother trees are planted in plots to evaluate differences in growth and development among the various test seeds. Method for evaluating the comparative genetic worth of the mother trees through the growth and development of the progeny.

progeny: Sexual offspring from seed.

provenance: Origen of a species. If seed of *Acacia mangium* is originally from Papua New Guinea but was obtained from trees growing in Pará State, Brazil, then the provenance is Papua New Guinea and the seed source is Pará Brazil. If the origin of the species is unknown, only the seed source is noted, not the provenance.

provenance test: Research where different seed sources of trees are planted in plots for the purpose of analyzing the difference in the growth and development among sources.

prune: Removal of branches from a standing tree or from logs being harvested.

pruning for quality: Removal of branches on the tree bole with a pruning saw or other device to produce clear, knot-free wood at time of harvest which can be sold at a higher price than wood with knots.

pseudoestaca or seedling stump: A nursery plant which has had the top and roots pruned leaving a rooted stem for transplanting in the field. It is a method used for certain broad leaf species such as *Gmelina*, teak and species of the genus *Tabebuia*.

pulp: cellulose fibers of wood that have been separated for use in paper and fiber board manufacture.

ramet: Individual within a clone of identical plants or trees.

randomized complete blocks: Statistical design used to establish research studies where there are several replications (blocks) with equal treatments within each replication and with the treatment plots placed at random within each block.

rays: Wood physiology term for cells that transport liquids transversally through the tree between the outside and inside of the stem or branch. They are cells similar to parenchyma cells.

regression: Mathematical term for a formula that allows the user to calculate an unknown variable based on other known, independent variables.

Rhizobium: Genus of bacterium that forms symbiotic relationship with trees in the genus *Acacia* and fix nitrogen in root nodules.

root collar: The base of a seedling at ground level where the stem becomes root.

root pruning: Process of cutting off roots in a plug or roots that extend out the bottom of a tubette in the tree nursery.

rooting: Process of forming roots on a live cutting of a plant part (root, leaf, stem, bud) for the process of producing additional identical plants through vegetative reproduction.

rotation: Time of tree growth between plantation establishment and harvest.

round wood: Round logs.

rubber tree: (*Hevea brasilensis*) *Moraceae* family, a tree species originally from Brazil. Although there are multiple tree species that produce latex, *Hevea brasilensis* is the primary species used for this purpose. For latex production, a root stock is planted that is resistant to root rot, a high latex producing stem is grafted onto the rootstock and, in Southeast Asia, a crown is grafted onto the stem that is resistant to leaf rusts.

Sabah: State of Malaysia in Northeast Borneo.

salvage thinning: Partial elimination of trees in a stand to recover wood that would otherwise be lost due to attacks by insects, disease or other causes.

sapling stand: Secondary natural regeneration of a forest where the trees are small, usually less than 10 m in height.

sapwood: the living exterior wood in a tree, normally with a white or light color.

Sarawak: State of Malaysia in Northwest Borneo.

sawdust: Fine woody material produced by a sawmill during the process of producing boards from a log.

sawlogs: Round wood or logs destined to be used to produce lumber in a sawmill

seed orchard: Plantation of trees selected for their high quality and allowed to freely pollinate among themselves in order to produce abundant and continuous crops of seed.

seed production area (SPA): A good quality stand of trees that has been heavily thinned from below, leaving the best trees standing as seed producers.

seed stand: see seed production area.

seedling seed orchard: Seed orchard composed of select trees produced from seed.

serotinous cone: A woody fruit produced by some species of pines where the cone remains on the tree and the seed scales remain closed even after the seeds have matured. The cone opens after there has been a forest fire, where the heat of the fire softens a spot of resin has held the scale closed, allowing the seed to drop to the ground and germinate after the fire.

shade house: Structure for producing nursery plants, covered with plastic cloth to provide a partial shade, usually between 40 and 50%.

shade leaves: Plant leaves that develop in shade, having a thin surface layer and more stomates on the underside than do sun leaves. They are generally larger than sun leaves on the same or plant or tree. Such leaves can be damaged by long exposure to full sunlight.

shear: Tree harvesting device that employs two scissor-like blades that snip off a tree at ground level using hydraulic pressure. It is an integral part of a feller-buncher head which is mounted on the front of a tractor.

shoot: Terminal sprout on a tree branch.

short fiber: Commercial term for the cells of wood of broad leaf species, normally being between 0.7 and 1.5 mm in length.

short wood: Harvesting term for wood cut to lengths of between 1.5 and 2.4 m, sizes which allow for wood transport on the shoulder of laborers.

site capacity: Maximum productive potential biomass production of crops or forests on a given site, according to soil quality, rainfall and available sunlight.

site preparation: General preparation of the land prior to tree planting, which can include such activities as piling debris from a previous harvest, burning piled material, making drainages, forming beds or subsoiling.

skidder with an arch and winch: Articulated tractor with a rear winch and cable that passes through a logging arch to lift the butt end of a log. This configuration is used for skidding large logs that have not been bunched.

skidder with hydraulic grapple: Articulated tractor which a hydraulic grapple used to lift the butt end of logs. Commonly used with bunched logs in combination with a feller-buncher.

skyline: A cable suspended between two masts that is used in cable forwarding of wood to roadside. With the skyline cable method, the butt of the log (or the whole log) is lifted off the ground to facilitate log movement to roadside. The skyline cable method utilizes two cables: the skyline cable on which a carriage runs to and fro and the main line cable which is threaded through the carriage and is used to lift the logs and haul them to roadside.

slabs: Wood and bark pieces that are removed when a log is passed through a saw.

soil texture: clay, sand, loam, silt: Texture refers to the size of particulates that compose the soil. The largest particles are sand and the smallest are clay. Silt is an intermediate size. Loam is a soil which contains a combination of the three soil particulate sizes.

solid overbark, sob (solid outside bark): Terminology for round wood measure of wood with bark.

solid underbark, sub (solid inside bark): Terminology for round wood measure of wood only, without bark.

solid wood products: Products manufactured in the form of sawn lumber, veneer, plywood and particle board. It does not include fibers such as cellulose or paper products.

somatic embryogenesis: Vegetative reproductive process of plants and trees where the stem cells of embryonic tissue is separated in the laboratory and used to make genetically identical plants through tissue culture techniques.

specific gravity: Oven dry weight of wood divided by the green volume

spiraled roots: Defective formation of tree roots in containers in the nursery where the roots spiral around the inside of the container.

sprouts: Stems that emerge from the stump of a tree.

stain fungi: Fungi that attack fresh wood of recently cut trees and result in wood discoloration, but which do not cause structural damage to the wood. They are more common in pine wood than in the wood of broadleaf species.

stand density: Number of trees per hectare.

stand: Group of trees.

stere meter: Piled measure of wood, including the spaces among the logs in a block that measures 1 x 1 x 1 meter. The solid volume of wood in a stere meter is around 0.7 m3.

stomates: Microscopic openings on the undersides of leaves that allow for the movement of air and humidity in and out of the leaf. During dry periods the stomates close to conserve moisture within the leaves. During rainy periods, the stomates open to allow for evaporation of the leaf moisture so as to facilitate the movement of moisture and minerals from the roots up to the leaves. Stomates also allow for the transfer of CO2 and O2 between the environment and the leaves.

stump: Base of a tree left in the ground after felling the tree.

stumpage: measurable volume of standing trees; wood in live, uncut trees.

subsoil: Soil horizon that is found below the surface soil layer where finer soil particles tend to accumulate.

subsoiling: Forming a cut or slit in the soil as a method of site preparation for tree planting.

subtropic: Cooler regions in the tropics at higher altitudes where tree species from more temperate origins can be planted. Regions or latitudes greater than 23° N or S with mild climates where tropical species can be planted.

sun leaves: Plant leaves that develop in sunlight and that have a thick surface layer on the upper side and few stomates on the underside. They are normally smaller than shade leaves of the same plant or tree.

sun scald: Damage to shade leaves of plants recently transplanted to the field. Sunlight damage to succulent tissues of young trees.

systemic herbicide: Chemical that is translocated within the plant down into the roots and the kills all of the plant.

tandem truck: Truck with two rear axles in a tandem configuration.

thinning from below: Partial elimination of trees in a stand, removing those trees of inferior quality, such as small trees, forked trees, crooked trees or bent trees, leaving the best trees in the residual stand.

thinning: Partial removal of some trees in a stand.

topping: Removing the top stem of a tree that is being cut into logs, usually at the minimum diameter limit.

total height: Tree height from its base (soil) to the highest point of foliage.

total volume: Volume of all wood in a tree bole, including commercial and non-commercial portions.

tracheids: Principal cells in conifer wood. Known as “long fiber” in the pulp and paper industry.

tree improvement: Science of selection of the best individual trees (best phenotypes), their testing in progeny tests (best genotypes) and their use for producing genetically improved trees for future plantations.

tree length logs: Tree that is felled, delimbed, topped, and skidded to the log deck as a single log without cutting it into pieces.

tritrain: Truck configuration where there is a truck-tractor, a semi-trailer and two trailers, with 5th wheel connections between truck units, normally with a total of 9 axles.

tropics: Region between latitudes 23° North and South, i.e., between the Tropic of Cancer and the Tropic of Capricorn. Warm sites free of frost during the entire year.

tubette: Plastic tube used as a container for producing trees in the nursery.

variance: Statistical term that mathematically represents the variation among individuals within a given population.

vegetative propagation: Any asexual reproductive method of plants.

vermiculite: Expanded mineral (mica) used in tree nurseries to improve the moisture retention in a growing medium or substrate.

vessel cells: Wood cells found in broadleaf species that form tubes for moving water from the roots upwards to the tree crown.

weed killer: Chemical herbicide that kills the foliage that it touches.

wood boring insect: An insect that lays its eggs in or on a tree and the hatched larvae live in the wood, emerging to fly away as adults after leaving the pulpal state. Normally considered to be insects that damage the wood quality for sawtimber since the larvae make tunnels and can also carry fungi that cause further damage to trees.

wood processer head: Device mounted on a track or articulated tractor base that is used for felling, delimbing and bucking trees into uniform length logs.

woodyard: Permanent location for the storage of logs at a mill site.

xylem: Wood cells in a tree that transport wood from the roots to the tree crowns.

About the author

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