Chapter 6
Tree Propagation and Planting

Much has been written about seed handling, propagation, and nursery practices for tropical trees. Significant contributions are included in appendix F and the bibliography. These processes are dynamic, changing with new species, materials, and ideas. Practices among projects or nurseries vary greatly because of different levels of ingenuity among nursery workers and, more particularly, because of lack of communication. Early planting efforts emphasized the use of bareroot stock. Excessive field mortality then led to the use of containers for eucalypts and pines. And now, because of the high cost of container use, there is an attempt to revert to bareroot planting, with more care given to the selection of weather conditions and to the planting technique.

This chapter is not intended to be a comprehensive guide to the propagation of the many potential timber species of the Tropics. Instead, the reader is referred to numerous excellent sources of information. Then, under each phase of the operation, typical or unusual findings are described as indicators of what to expect under local conditions (fig. 6–1).

Plantation Planning

Most countries in tropical America have already expressed interest in forests through preambles to legislation or national policy statements. These statements recognize the benefits natural forests and plantations offer: soil conservation, watershed protection, wildlife preservation, and wood production. The first step toward creating these forests, the assessment of resource potentials, and the decisions as to where, when, and how to achieve these potentials are the function of national resource planning.

Figure 6–1.—*Large-scale reforestation with industrial plantations, a long-term objective in southern Brazil.*

The Resource Planning Process. National planning rests heavily on the following kinds of information about the region's physical environment:

1. Planimetric maps of entire countries, accurate and up-to-date, and on a scale that is large enough to display major natural features in some detail

2. Topographic maps of countries on a scale and at contour interval adequate to locate watersheds and slope classes that indicate desirable limits of land-use intensity

3. Soil maps with adequate details and descriptions to distinguish, on the basis of soil stability, depth, and productivity potential, those areas most appropriate for food, forage, productive forest, and protective forest for soil, water, and biodiversity

4. Prospective water requirements and the location and extent of principal surface and subsurface water resources and reservoir sites

5. The location of present and potential flood hazard areas and the extent of foreseeable damage to irrigation works, prime croplands, and urban, commercial, and industrial infrastructures

6. Rainfall data, including long-term records and storm intensities

7. Recent aerial photographs with stereo overlap adequate for mapping forest cover and, if possible, major forest types, both commercial and noncommercial

8. Current and prospective national rates of timber drain, deforestation, and reforestation; imports and exports of forest products; and internal consumption trends

9. Productivity of existing forest plantations of different tree species on a variety of sites within the country or under similar conditions elsewhere.

In most areas of the region, enough of these resource data are available so that planning can proceed reliably.

In some areas, the information is stored in computerized geographic information systems (GIS). The following steps should lead to the selection of the land most in need of forest planting:

- A single map scale should be chosen to display and synthesize relevant aspects of site assessment and selection.
- Slope classes should be identified so as to tentatively delineate those areas that (1) are suited for mechanized agriculture, (2) may be clean-tilled continuously or periodically, (3) require permanent vegetative cover, (4) may be pastured continuously, (5) should be kept tree-covered, (6) may be logged feasibly, or (7) should be left unmodified to protect soil, water, or genetic resources.
- Information on soil groups or types may be added as more precise criteria become available for defining safe limits for land-use intensity within slope classes. Potential productivity of various agriculture and forestry activities is particularly important.
- Areas that provide critical water resources and their tributary watersheds can be located as a supplementary constraint on intensity of land use.
- These data can be synthesized to generate a provisional map of forest lands of the nation, showing all the areas that should be forested for any of the several resource values forest cover could contribute. Priorities for the maintenance of forest cover should be governed by slope, soil type, water resources, or unusual ecosystems.
- National (and possibly export) wood requirement target dates should be established far enough in the future to permit a realistic local production goal one tree rotation hence, predicted from current trends.
- Experience with forest and plantation productivity can be used to locate land areas able to meet production goals.
- Priority should be set for proposed forest plantations on the basis of the land's potential productivity and present land use (its availability, adequacy of vegetative cover, potential for adequate alternative natural regeneration, and ease of planting).

An analysis such as this commonly identifies more deforested, operable land than is needed to meet wood-production goals. The most productive sites should be selected for intensive management as either natural forests or timber plantations. The remainder can be allowed to reforest naturally, except where severe erosion or watershed problems may require rapid development of a protective cover.

Wood production may be less economically competitive than even intermittent food and forage production, partly because of the cost of transporting large volumes of bulky material. This problem, however, may be mitigated by concentrating wood production in areas where processing facilities either exist or can be established advantageously. Studies in Mexico led to the conclusion that no commercial timber plantation should be located more than 75 km from a processing plant (Gonzalez Navarro 1978a). Under these circumstances, a continuous source of wood, taken together with the value added in primary and secondary processing, may outstrip land values for agriculture, particularly those that are marginal.

The best sites for timber production may already be covered with natural forests. If inventories show these to be adequate for future crops, planting should be unnecessary. Otherwise, underplanting may be indicated, beginning with the best sites (or sites with the poorest stands, under the assumption that, in the meantime, stocking may become adequate naturally on sites where it is already better than the poorest stands).

A common problem is the lack of a clear distinction between good forest land and land that is considered marginal for agriculture, particularly pasturing. Where possible, clear distinctions should be made, and forest crops should be assigned to the best land that is clearly not suited for agriculture. On marginal land not designated as such, forest crops might at any time be destroyed by even ephemeral farming; therefore, their contribution to national wood requirements is doubtful. In these areas, a mixed practice—the production of food, forage, and fiber crops in some harmonious combination, either concurrently or sequentially—may seem most appropriate. How much wood such practices might supply beyond strictly local requirements will depend upon the number and the quality of the trees in the mixture. Based on these general principles, Lupatelli (1978) derived eight land-capability classes for Brazil (table 6–1).

Table 6–1.—Land capability classes for Brazil

Sustainable use	I	II	III	IV	V	VI	VII	VIII
	Appropriate land-capability class							
Cultivation unrestricted	X							
Cultivation with conservation practices								
Simple	X	X						
Complex	X	X	X					
Cultivation infrequent	X	X	X	X				
Forage unrestricted	X	X	X	X	X			
Forage with conservation practices								
Moderate	X	X	X	X	X	X		
Complex	X	X	X	X	X	X	X	
Production forests	X	X	X	X	X	X	X	
Natural vegetation, wildlife	X	X	X	X	X	X	X	X

Source: Lupatelli 1978.

Note: Roman numerals correspond to use classes; these classes are defined differently by different counties, with I being the most versatile class and VIII being the least.

For tropical Brazil (excluding Parana, Rio Grande do Sul, and Santa Catarina), occasional cultivation of crops is the maximum land-use intensity acceptable on 65 percent of the land area (table 6–2). Tree production is permissible on 98 percent of the land.

In combining classes V through VII, the summary does not distinguish between land for forage and land for fiber, suggesting a possible conflict. However, it should not be serious because Brazil's current wood requirements apparently could be met by well-managed plantations on less than 15 percent of the land in these three classes. The fact that most of Brazil, including much of the Amazon Basin, is classified for "occasional cultivated crops" indicates the prospective extent of shifting cultivation or possibly some form of agroforestry, yielding tree crops in combination with other crops.

This planning process may seem irrelevant to a forester instructed to plant some deforested mountainside. However, such instructions often lack a basis in sound planning and, therefore, may be wrong. Sites selected may be too poor for growing usable wood or too inaccessible to harvest it, or they may be capable of adequate natural

Table 6–2.—Land-use areas in tropical Brazil

Sustainable use limit	Capability class	Land area: Extent (thousand km^2)	Land area: Proportion (%)
Continuous cultivated crops	I–III	640	8
Occasional cultivated crops	IV	4,500	57
Forage or tree production	VII	2,650	33
Native vegetative cover	VIII	130	2

Source: Lupatelli 1978.

Note: Roman numerals correspond to use classes; these classes are defined differently by different counties, with I being the most versatile class and VIII being the least.

reforestation within an acceptable period. Planting instructions may also specify trees that are either not adapted to the site or are unsuitable for prospective markets. Even a superficial review of the planning considerations described may suggest important improvements. Planning is essential to successful planting.

Forest Plantings. Once a planting area has been selected, the rate of planting must be decided. If the purpose is solely to protect soil and water resources, the sooner the project is finished the better. If, on the other hand, sustained timber yields are desired or if techniques must be tested, planting may begin with small experiments and slowly approach the rate of 1/*n*th of the area per year (*"n"* being the number of years for the trees to mature). The result should be a sequence of age classes supporting a sustainable annual harvest at some later date.

The project area should be divided into compartments or "coupes," generally no larger than 1/*n*th of the total area, a single year's planting. To facilitate identification on the ground, compartments should be bounded by stable features, such as streams, ridges, site changes, and permanent roads. These boundaries will be irregular and produce compartments of various areas, but this inconvenience is minor compared to the advantages of boundary identification without the need for monuments or cleared lines.

A system of permanent access roads will be needed to bring crews and equipment to each compartment. This system can serve not only for planting but for later tending and harvesting. In parts of Mexico, such road systems are also the backbone of fire control (Gonzalez Navarro 1978a). Up to 1 km of road may be needed for each 20 ha of forest (Mathus Morales 1978b). Accessibility may be as significant as site quality in planning the different compartments.

Formal training of all planting personnel should benefit operations. All workers should be aware of the local, national, and future significance of the plantings and their products. They should understand how success depends on their personal performance, and they should know the reasons for each operation and the right and wrong ways of carrying it out. Safety measures and safety equipment should be accepted and used. Workers at all levels should participate in planning and setting standards for their work and be offered incentives for performance, including safety. These preliminaries are not frills, and they are as critical in small, remote projects as in any others.

Plantation programs in the Tropics commonly proceed without adequate advance pooling of outside expertise. As a result, practices may vary widely from place to place, even within a single country, for no apparent reason other than lack of communication. Some flexibility and variations are undoubtedly healthy, but the variations are commonly to the detriment of the least informed.

Planting Materials

Wilding Stock. The use of wildings—seedlings already present in existing forests—obviates the cost of both seed procurement and nursery propagation and permits precise coordination between planting-stock acquisition and the planting schedule. Nevertheless, it is not a common practice because wildings of most species are not sufficiently abundant or accessible for their acquisition to be easy. As tropical plantation areas expand, these problems may diminish, but using wildings greatly limits the possibilities of tree improvement through genetic selection, so their use may only be suitable for special conditions.

The lifting of wildings for use as planting material has proved possible with many species. In eastern Nigeria, for example, *Gmelina arborea* wildings were found to be as well suited for planting as for nursery stock, so the nurseries there were closed with a large saving in investment (Anon. 1958c). Wildings of *Tabebuia heterophylla,* an aggressive pioneer species, and of *Swietenia macrophylla* have been used extensively in Puerto Rico. Wildings of dipterocarps have also been used successfully for enrichment planting of hill forests in Malaysia (Gill 1970, Tang and Wadley 1976a).

Terminalia myriocarpa has been successfully regenerated by encouraging wilding production (Das 1937). Felling the forest around mother trees and plowing lines to receive the seeds resulted in a good crop of seedlings. When seedlings reached acceptable size, they were transplanted into gaps in the forest. This practice was considered less expensive than conventional artificial regeneration. Profuse seedling regeneration has also been produced by clearing beneath relic trees of *Cedrelinga catenaeformis* in Peru (Anon. 1985h).

The use of 1-month-old wildings of *Avicennia officinalis* on tidal sites in coastal Pakistan can be successful if lifting is done without root injury (Howlader 1971).

Seed Acquisition. Problems of seed procurement in the Tropics are international. Those described for Asia (Kamra 1973) also seem typical of tropical America. There is a need for large quantities of seeds, for an information system to channel requisitions to the best available sources, and for reliable testing and storage practices. Dependable seed-certification services and trained seed technicians are also needed.

The occurrence of "seed years" for tropical trees has long been recognized but, in most cases, has been neither well explained nor found predictable. As has already been pointed out, flowering and fruiting do not correlate well with weather in many species. Infrequent fruiting has been hypothesized as a response to seed predation by animals. The significance, however, is that for some species, seeds for more than one crop of seedlings may have to be accumulated when abundant seed crops occur.

The season of fruiting is more regular than the occurrence of seed years. The season is critical to collection, because few fruits or seeds are easily collectible after they fall or are viable for long periods thereafter. Mexican conifers illustrate this point (Hinds and Larsen 1961). Pines there are distributed through 12° of latitude, yet the seed collection season lasts only about 2 months.

The "Mysore hybrid" of *Eucalyptus tereticornis* in India flowers twice each year, in May and June and in October and November (Lohani 1978). Studies of *E. grandis* in Uganda (Kingston 1974) showed that flowering and fruiting were not confined to one period of the year. Some trees flowered and fruited far ahead of others.

Casuarina equisetifolia in Orissa and Bombay, India, flowers from February to April and from September to October; fruits ripen in May and June and in November and December (Kesarcodi 1951b, Sharma 1951). In Puerto Rico, this species fruits from January through April and from July through November. The best cone harvest of *Araucaria hunsteinii* in Papua New Guinea occurs during a short period from late September to early October (Havel 1965). In Yangambe, in what was formerly Zaire, some seeds of *Musanga smithii,* a species much like *Cecropia peltata,* are always available, but there the main seedfall occurs from July to September (Kesler 1950).

These are but a few illustrations of seasonal seed-production variability from place to place and by species. Because variation also occurs from year to year, cropping times for one locality are not reliable indicators for another. Therefore, phenological records must be compiled for each species and locality.

The need to select appropriate areas for seed collection was recognized early (Kesarcodi 1951b). Choosing an area with abundant seeds is, of course, one prerequisite. Mexican pine seeds, for example, were found to be more abundant in open, cutover forests than in virgin stands (Hinds and Larsen 1961). However, an equally important consideration is the variation in tree quality from place to place. Even those variations that may merely reflect better sites are of interest because they imply potentialities not ensured elsewhere. Good sites should be nearly free of unhealthy stock. On the other hand, if planting sites are especially adverse, it may be best to collect seeds from similarly adverse sites, because tolerance of such conditions may vary within species.

Selection of superior mother trees (female tree parents) has long been recommended because of the numerous inherited traits affecting the quality and yields of progeny (Kesarcodi 1951b, Tang and Wadley 1976a). For example, seedlings of *S. macrophylla* from plus-tree seeds were found to be superior to those from other parents in diameter, height, and dry weight at 10 months (Zabala 1978).

"Plus" stands have been selected for teak *(Tectona grandis)* seed collection in Papua New Guinea until adequate seed orchards become available (White and Cameron 1965). For a teak stand to be acceptable as plus, it has to be at least 8 years old and have a high percentage of well-formed, vigorous trees with log lengths exceeding 12 m. Where plus stands are not available, better-than-average stands have been thinned to 200 trees per hectare, or as a last resort, average stands are thinned to about 400 trees per hectare.

In Ghana, seeds from some *Cedrela odorata* trees germinated well before the peak of general seedlots (Jones, N., 1968). Therefore, identifying and selecting such mother trees could lead to earlier germination and more uniform seedling crops.

Selection of mother trees that are especially heavy seed bearers offers multiple advantages. Not only do they themselves constitute a good collection source, but if they are also of good quality, their progeny may likewise be both high in quality and prolific seed bearers.

Selection of mother trees for genetic tree improvement must be delayed for the time required for trees to reach the minimum age at which fertile seeds are produced. With the faster growing species, this period may be as short as 2 to 3 years for *Anthocephalus chinensis, Leucaena leucocephala,* and *E. deglupta,*3 to 4 years for *Ochroma lagopus* (Nair 1953), 5 years for *E. tereticornis* (Lohani 1978), and longer for *S. macrophylla.*

Determining the earliest time of seed maturity is critical to both plantation costs and seed quality. The earlier that seeds can be collected, the more likely the possibility of capitalizing on the economics of mass collection directly from the mother trees, establishing the certainty of parentage, and preventing losses to herbivores.

The earliest time for seed collection depends on individual characteristics of each species and thus must be determined locally. With *Cedrela odorata* in Ghana, seeds collected up to a month before the capsules opened had the best germination rate, up to 78 percent (Jones, N., 1968). *Cordia alliodora* seeds in Costa Rica showed good germination when collected 3 weeks before falling (Tschinkel 1967). In India, *O. lagopus* seed capsules have been gathered when they begin to open (Nair 1953).

Collecting seeds of selected quality has become a complex practice in tropical regions, requiring special climbing equipment, segregation of seeds from different mother trees, observance of safety measures, and trained personnel. Care must be taken to avoid damaging mother trees or removing too many branchlets to the detriment of future seed crops.

Seed Processing. The seed-cleaning process varies for each species or species group. The first step is usually separating the seeds from the fruits, followed by air-drying. With *Cedrela, Pinus,* and *Swietenia,* air-drying the cones or fruits releases the seeds without deterioration, provided insects and rodents are excluded. With *Casuarina equisetifolia,* one important problem may be loss of seeds to ants.

Bamboo seeds, because of immediate destruction by birds, rodents, insects, or fungi on the ground, should be shaken onto sheets and treated with pesticides before being dried (Hadfield 1958).

Cleaning very small seeds presents special problems. Seeds of *Eucalyptus* normally are removed from the dried capsules and left impure with fragments of the carpel walls. Small lots of the silky seeds of *O. lagopus* may be placed on a coarse screen over water and ignited to free the seeds (Holdridge 1940b). This practice also may increase germination. *Anthocephalus chinensis* seeds, with 17,000 per gram (Pollard 1969), are usually collected in Sabah as the fruits fall. The fruits are then allowed to soften and are macerated. To extract the seeds, the macerated fruits are rubbed through a coarse screen, pounded in a mortar, and then separated with a fine screen before being air-dried.

Grading of tree seeds in tropical America is in its infancy. Standards of purity and viability are obviously needed. However, there also may be other important criteria such as size. Although tests in India (Venkataramany 1960a) indicated no superiority for large teak seeds, tests in Mexico with *P. pseudostrobus* var. *oaxacana* have shown that seed size affected seedling height, hypocotyl diameter, and cotyledon length (Caballero Deloya and Toral Chacon 1967). These differences proved more pronounced after the second month.

The certification of seeds by a qualified authority is essential for responsible forest plantings. Such certification must specify the species, variety, and provenance, as well as any tree-selection standards used; the date and specific locality of collection; the purity percentage; the moisture content; the number of seeds per unit of weight; and the most recent germination record with date and technique. It must also specify that the seeds are free from diseases and insects, with time and type of any fumigation technique used.

A standard seed-testing procedure that has been used in Malaysia for *P. caribaea* is of general utility (Paul 1972). Five attributes are evaluated: (1) the proportion of apparently full seeds (purity percentage), (2) the number of pure seeds per kilogram (seed weight), (3) the proportion of seeds containing kernels (full seed percentage), (4) the moisture content of pure seeds, and (5) the proportion of seeds that germinates.

Germination tests may be made on blotting paper, absorbent cloth, or a substratum of pure quartz sand of pH 6.0 to 7.0 (Paul 1972). A common sample size is 400 seeds, divided into 4 subsamples of 100 each.

Seed Storage. Because of the variability and uncertainties of seed production, at least enough seeds for next year's planting should be kept in inventory, where possible. Consequently, seed viability must be maintained for at least that period of time. How can that be done? Trials throughout the Tropics have confirmed Temperate Zone findings that temperature and moisture control are crucial to extending seed viability for most species.

Seeds of some tropical trees are capable of long storage life. Records exist of *L. leucocephala* seeds germinating after 99 years, *Albizia lebbek* after 30 years, *O. lagopus* after 24 years (Dent 1942b). Nevertheless, most seeds (particularly those of the humid Tropics) may lose their germinative energy within months.

Evans (1992) made two general points about seed-storage temperatures: (1) near freezing temperature usually prolongs viability, and (2) temperature fluctuations are less favorable than constant temperatures. He quoted Turnbull (1972b) to the effect that naturally dry seeds can withstand high temperatures much better than seeds with high moisture contents. Evans pointed out that seeds of certain pines and eucalypts, dried to a moisture content of 4 to 8 percent, retain viability for many years at temperatures below freezing, but most seeds are stored at 2 to 5 °C.

Anthocephalus chinensis seeds in Sabah generally showed poor germination unless stored for 6 months (Pollard 1969). Seeds that were air-dried, sealed, and stored at 5 to 10 °C retained good viability for 2 years; seeds that were unsealed did not.

Araucaria hunsteinii seeds perished in less than 1 month in the open at ambient temperature (Anon. 1958a, Havel 1965). But when seeds were dried, sealed, and kept at 3 °C, viability of 50 percent persisted up to 12 months. These same storage conditions, plus the use of blotting paper to humidify the seeds, resulted in 50 percent germination after 18 months.

Seeds of *C. equisetifolia* stored in the open in India remained viable no longer than 12 months (Sharma 1951).

In Merida, Venezuela, seeds of *Cedrela odorata* stored at ambient temperature, began losing viability by the 4th month, and all viability was lost by the 10th month (Lamprecht 1956). With open storage at 5 °C, the decline did not begin until after 12 months. When seeds were sealed at ambient temperature, a decline began at 4 to 6 months and only 25 percent germinated after 14 months. Sealed seeds kept at 5 °C retained their initial germination rate up to 14 months. *Cordia alliodora* seeds sealed at 12 to 18 percent moisture content and stored at 5 °C remained 50 percent viable after a year (Tschinkel 1967).

The dipterocarps as a group have relatively perishable seeds. Seeds of two species of *Shorea,* which are normally viable for only 1 week, were stored successfully 3 to 4 weeks by reducing their moisture contents from 40 percent to 20 to 25 percent and by storing them at 16 °C (Tang 1971).

Tests in Nigeria showed that, by reducing temperature to near 0 °C, the viability of seeds of *Khaya grandifoliola* and *K. ivorensis* could be extended from 6 weeks to 3 years, the viability of *Entandrophragma angolense* from 6 weeks to 6 years, and the viability of *Triplochiton schleroxylon* from 4 weeks to 2 years (Olatoye 1967).

Ochroma lagopus seeds, tested in India, were effectively stored up to 18 months when sealed (Nair 1953). Seeds of *P. merkusii,* tested in the Philippines, deteriorated after 3 to 4 months at ambient temperature (Gordon and others 1972). Stored at 2 °C with 6 to 10 percent moisture contents, the seeds remained viable up to 3 years. Applying dry heat for 5 minutes to fresh seeds of *O. lagopus* resulted in the following germination rates: 30 °C, 3 percent; 55 °C, 19 percent; 76 °C, 70 percent; 96 °C, 78 percent; 115 °C, 42 percent; and 135 °C, 1 percent (Vazquez-Yanez 1974). Boiling the seeds of *O. lagopus* not only increased germination but gave better results after storage (table 6–3; Vazquez-Yanes 1974).

Seeds of *Swietenia macrophylla* typically remain viable for about 3 months in the open. At 5 °C, the seeds remain viable for about 1 year. A test in the Philippines showed possible benefits from sealed storage in the ground (Lopez 1938). At 24 days, the germination rate

Table 6–3.—Effects on viability of immersing *Ochroma lagopus* seeds in boiling water

Immersion (seconds)	Storage time (% germination) 1 yr.	2 yr.	3 yr.
0	2	6	3
15	84	80	67
120	78	71	64
240	60	64	56
480	57	65	56
960	25	44	38
1,920	5	6	2

Source: Vazquez-Yanes 1974.

was 90 percent, compared with 86 percent in open storage above ground. After 132 days, germination was 72 percent with ground storage versus 4 percent with open storage.

Using a 0.1-percent solution of hydrochloric acid to sterilize *P. caribaea* seeds did not harm seeds immersed up to 20 minutes (Hong and Ivory 1974). A dip of 5 minutes increased germination 6 months later by 20 percent.

Seed Germination Factors. Germination of the seeds of most tropical tree species poses no special problems. Germination begins within a few days after sowing and is soon completed (table 6–4; Barrett 1973). *Leucaena leucocephala* is an exception, however. Because of some hard seeds, germination may not be completed for 1 to 4 years, as indicated by experience in Hawaii (Akamine 1952). Fresh seeds of this species germinated at a 44- to 80-percent rate in 4 months and at 73 to 80 percent in 8 months.

Most *Anthocephalus chinensis* seeds germinate in 4 to 14 days (Pollard 1969). Because of their small size, they should be pressed into wet soil, protected from rain by glass covers, and watered frequently. *Swietenia macrophylla* seeds typically germinate 13 to 27 days after sowing (Araujo 1970). Germination of bamboo seeds generally takes 2 to 6 weeks (Hadfield 1958).

The germination "potential" for most tropical tree species is high, 85 percent or more (Araujo 1970). Nevertheless, mishandling seeds during collection or fumigation, or drying seeds too late can reduce germination

Table 6–4.—Seed germination periods for tree species in Zambia

Species	Germination (days from sowing)
Araucaria cunninghamii	7–19
Callitris spp.	21–57
Casuarina cunninghamiana	10–38
Cryptomeria japonica	20–83
Cunninghamia lanceolata	11–21
Cupressus lusitanica	21–63
Eucalyptus deglupta	19–117
E. grandis	7–54
Pinus elliottii	7–31
P. kesiya	9–46
P. patula	10–45
P. taeda	10–90
Tectona grandis	12–38

Source: Barrett 1973.

drastically. *Pinus merkusii* was reported to have typical seed germination of only about 10 percent (Anon. 1971b). However, improved handling increased this rate to more than 90 percent.

Seed dormancy must be understood if germination is to proceed as planned. The following three types of seed dormancy are recognized (Chapman and Allan 1978):

- Exogenous dormancy, related to seedcoat properties (mechanical, physical, or chemical)
- Endogenous dormancy, governed by the embryo or endosperm properties (morphological or physiological)
- Combined dormancy, caused by some combination of the other two.

After-ripening (continued maturation after the seeds leave the tree) is reported for some species. In what is now Sri Lanka, *Tectona grandis* seeds that were 9 months old germinated much sooner than fresh seeds (Fernando 1965); storage up to 18 months increased germination even more (Wood 1968). After-ripening of teak seeds was also reported from India (Gupta and Pattanath 1975). A water-soluble, germination inhibitor in the mesocarp was found to influence seed dormancy. Germination of *L. leucocephala* seeds 4 months after sowing has been as high as 80 percent with seeds 6 months old, compared with 50 percent for fresh seeds (Akamine 1952). However, by 12 months, the two seed groups had similar germination rates. Most other seeds, however, including those of *Cecropia negra* in Venezuela (Lamprecht 1955), can be sown promptly with satisfactory results.

Some shade-intolerant species do not germinate in the dark. One example is *Musanga smithii,* an African counterpart of *Cecropia,* which germinates up to 90 percent in the light (Ardkoesoema and Kamil 1955). Some other shade-intolerant species germinate well in the dark. One such species is *O. lagopus* (Vazquez-Yanes 1974). However, storage temperature is critical for this species. When seeds were subjected for 24 hours to constant temperatures of 16 °C, 26 °C, and 36 °C, *O. lagopus* germination did not exceed 4 percent, with or without light. With 20 hours at 25 °C and 4 hours at 45 °C, germination was 63 to 65 percent, regardless of light. In what is now Belize, observers concluded that, in nature, *O. lagopus* seeds germinate after fires (Stevenson 1940).

Seeds of *A. chinensis* in Costa Rica germinated better under an opaque metal roof than under a clear plastic roof (Gonzalez and Grijpma 1968). Light, temperature, and moisture were presumably all involved, but apparently light is not critical to germination of this species.

Presoaking seeds to stimulate germination is common in tropical areas. Soaking *P. caribaea bahamensis* seeds for 24 to 60 hours reportedly increases germinative energy (Anon. 1972c). Presoaking teak seeds for 48 hours has been practiced in India for a century or more (Laurie 1937). Another technique—daily soaking and drying for 3 weeks or more was also reported to give prompt, high germination (Bannerjee 1942). Another common practice is to soak the seeds 72 hours before sowing (Wood 1968).

Hot water stimulates the germination of some seeds. Germination of the seeds of *Prosopis juliflora* and several species of *Acacia,* for example, is increased by placing the seeds in boiling water and letting them cool to ambient temperature (Chapman and Allan 1978, Chatterji and Mohnot 1968). Soaking at 100 °C for more than an hour proved fatal. Soaking *Paraserianthes falcataria* seeds in water at 38 °C for 10 minutes raised the germination percentage from 36 to 72 (Valencia 1973). Seeds of *L. leucocephala* in India attained 85 percent germination when boiled briefly in water and then left to soak for 24 to 48 hours (Chaturvedi 1981).

Mechanical scarification (abrasion of the seedcoat) stimulates germination of some seeds. When *Prosopis juliflora* seeds, 40 percent of which are classified as hard, were shaken in a bottle two times per second for 15 minutes, their germination rate increased from 60 to 97 percent (Nambiar 1946). Shaking for 5 minutes produced prompt germination of 93 percent.

Tests with *T. grandis* in Thailand (Keiding and others 1966) showed that removal of the exocarps from the fruits by exposure to ants for 1 or 2 weeks accelerated germination. In a test in India, the endocarp was removed by splitting it on four axes with a sharp knife and then applying a fungicide; the result was rapid germination (Dabral 1976). Concurrent tests of nine mechanical treatments for teak seeds, however, gave such inconsistent results that more conclusive studies were recommended (Muttlah 1975).

An American tropical species, *Hernandia sonora,* normally has a germination rate of about 18 percent in 5 months (Anon. 1952l), but if the endocarps are perforated, germination may surpass 80 percent in 2 months.

Scarification with acid (usually concentrated sulfuric acid—H_2SO_4) accelerates germination of hard seeds. Tests with *L. leucocephala* in India gave good results after 20 to 40 minutes of soaking in concentrated sulfuric acid (Ramdeo 1971). Seeds of *Acrocarpus fraxinifolius,* normally with germination as low as 0.3 percent after 18 hours soaking in water, germinated at the rate of 90 percent after a 10-minute treatment in concentrated sulfuric acid (Rai 1976).

Direct Seeding. Sowing seeds directly, either broadcast or concentrated in spots, may cost only one-third to one-half as much as using nursery stock (Thomson 1968). With some species, including many with large seeds, this technique is also preferred because of seedling sensitivity to bareroot transplanting. Examples are *Calophyllum calaba, Hymenaea courbaril,* and *Manilkara bidentata.* Survival may be poor, however. Where seeds are scarce or expensive, broadcasting may be impractical because it tends to produce irregular stocking requiring early thinning of dense clumps.

Direct seeding is much less common than planting in the Tropics. The longer period of weeding required may make it more expensive than planting. Nevertheless, under some conditions, the technique is practical. Tests of *Eucalyptus saligna* in Australia have shown that direct seeding on burned land may produce abundant regeneration (Elliott 1956). Direct seeding of *Senna siamea* in India has been a standard method for establishing this species for fuel and fodder forests, particularly in the wet season (Guiscafre 1961, Prasad 1944b). This species is reputed to be capable of coming up through *Imperata* grass in Malaysia and killing it. *Imperata* grass has also been controlled in the Philippines by direct seeding of *L. leucocephala* (Buenaventura 1958). At the start of the rainy season, the grass has been burned to reduce the loss of tree seeds to rodents. The seeds were then broadcast either by hand or from the air or sown in cleared strips or spots. Brushing was done every 3 to 4 months for the first year and semiannually thereafter. Fire must be kept out for 2 years, after which the trees become fire resistant (Pendleton 1934). In one test of aerial sowing in heavy *Imperata* grass late in the season, 2.5 to 7 seedlings per square meter were found (San Buenaventura and Assidao 1957).

Direct seeding has been common in the arid regions of India. *Prosopis juliflora* has been sown in trenches to establish fuel and fodder plantations (Singh 1951); it has also been successfully established on shifting sands by sowing from the air (Singh 1954). Other species for which direct sowing has been successful include *Acacia auriculiformis, A. catechu, Anacardium occidentale, Azaderachta indica, Bauhinia* spp., and *G. arborea* (Goswami 1957). In a direct sowing of *G. arborea* involving the placing of 2 or 3 seeds on each of 5,200 mounded spots per hectare, survival after 1 year was 72 percent, despite a yearly rainfall of only 140 cm (Sabado and Asuncion 1970).

Direct seeding of *E. citriodora* and *E. saligna* is successful in Zambia only under certain conditions (Endean 1966). Seeding must be early in the rainy season, and a hot burn should precede sowing, followed by complete cultivation of seed spots. In Africa, *Cedrela odorata* produces adequate early height growth when direct seeded in cleared lines (Lamb 1969b).

In the Western Hemisphere, in addition to *Calophyllum* spp., *G. arborea* is direct seeded in Brazil and *O. lagopus* in Ecuador. In the latter case, seed spots are surrounded by plastic sheets for early weed control. Direct sowing of *Cupressus lusitanica* has also been successful on well-cleared, wet sites (Holdridge 1953). Direct sowings of *S. mahagoni* failed in dry forests of Puerto Rico because of extreme droughts that killed seedlings even in their second year. Direct seeding of *P. elliottii* in the southern United States requires burning the vegetation or disking the soil (Mann 1958). At Monte Dourado, Brazil, after years of planting *G. arborea* nursery stock on a large scale, the appearance of abundant natural regeneration from seedfall beneath the plantations led to direct seeding as a standard practice on all sites that had been burned (Woessner 1980a). By 1980, direct seeding had been successful on an area of 1,500 ha, with two seeds sown per spot.

The longer period of weeding generally required by direct seeding limits its use, even with species that otherwise are well suited for the technique. An example is seen in Colombia, where direct-seeded *C. lusitanica* and *P. patula* both survived well. But the cost of weeding made direct seeding more expensive than planting (Gutierrez and Ladrach 1978).

The future of direct seeding seems to depend on inexpensive control of competing vegetation and pests. As repellents are improved, direct seeding in the Tropics may be more widely practiced (Stuart Smith 1968).

Tree Nurseries. Where the use of neither wildings nor direct seeding is feasible, nurseries are required. These may vary from a few simple beds, used temporarily, to highly organized and technically advanced permanent operations. A few of the major considerations are detailed here. A technical guide for nursery management was published by Liegel and Venator (1988).

An ideal nursery site should (1) be near planting sites, (2) be accessible to both transportation and a labor supply, (3) have a continuous supply of good-quality water, and (4) have access to a well-drained, workable soil, either for direct rooting of stock or as a potting medium (fig. 6–2). The nursery site should be large enough to accommodate present and anticipated production. Within the nursery site, enough secure storage space for seeds, tools, and equipment is required. Generally, a partially shaded area protected from rainfall is needed for germination and early seedling development.

Timing is essential to tropical nursery management. Nursery operations must be scheduled to meet the dates when planting is proposed. If the planting season is

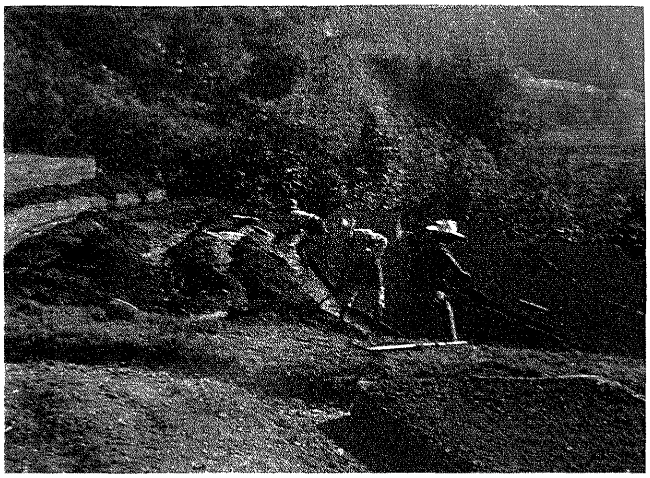

Figure 6–2.—*A typical small field nursery being prepared in Guatemala.*

several months long, a continuous flow of maturing stock will be needed throughout that period, requiring that all preceding steps be planned accordingly. Timing considerations in nursery operations include the following:

- The maximum length of the safe planting season for each tree species, scheduling planting according to when conditions may be favorable at different sites
- The period of production from sowing to lifting, together with variations possible through the use of stimulants such as pregermination seed treatment, the use of seedlings as substitutes for transplants, direct sowing in containers, soil enrichment, and the largest-to-smallest stock sizes that are safe
- Storage of seeds from seedfall to the sowing period
- Advance seed procurement, either from local or distant sources

Once these time-dependent steps are scheduled, less seasonal tasks, such as soil preparation and procurement of supplies and facilities, can be concentrated during slack periods. Timing also may be influenced by the seasonal availability of farm laborers.

Vegetative Propagation

The use of vegetative material rather than seeds for tree propagation is advantageous under some circumstances. In Ghana, it proved the only way to propagate *Triplochiton scleroxylon* during years of irregular seed crops (Nkansah-Kyere 1970). The height growth of cuttings rooted with hormones proved equal to the height growth of stumps or saplings during at least the first 4 years.

Vegetative propagation is relied on most commonly to control the genetic characteristics of propagules. Because the resemblance between ramets and ortets is likely to be greater than the resemblance between seedling progenies and parents, vegetative propagation increases the potential for genetic improvement of trees (Squillace 1970).

Because of this greater resemblance to the parents, trees produced from vegetative (nonsexual) propagation may differ from seedlings. For example, *P. radiata* from cuttings in Australia grew faster in height through 8 years than *P. radiata* from seeds (Fielding 1970). The cuttings also had thinner bark, less taper in the lower part of the bole, crowns that were less dense, and thicker and heavier roots. These differences were attributed to a carryover of the properties associated with the age of the parent tree or the developmental stage of the shoot. In the United States, 12-year-old *P. elliottii* trees produced from air layers did not differ significantly from trees grown from seedlings in terms of shoot growth and root surface area, but they lacked taproots (Schultz 1972).

Many tropical tree species have been reproduced vegetatively, providing great opportunities for genetic tree improvement. As early as 1953, 74 species were reported in India to reproduce by cuttings, 104 by root suckers, 11 by air layering (inducing root development on a plant's aerial portion), and 9 by budding and grafting (Rao 1953).

Under favorable conditions, vegetative propagation can be sufficiently successful for mass production of *Eucalyptus, Triplochiton,* and many other tropical genera (Heybroek 1978). All trees seem to have a juvenile stage during which they are easier to root than later. Clones of identical genetic characteristics have been developed as a result of large-scale vegetative propagation of eucalypts.

Leakey (1987) feared that clonal forestry could give rise to large, biologically uniform stands at risk to pests, diseases, and other hazards. He advocated retaining genetic diversity by using large numbers of clones to reduce risks. By continually producing new genotypes, diversity may in fact be more effectively maintained than in a seed stand/seed orchard. Leakey foresaw the selection of single-purpose clones of multipurpose, agroforestry species.

Stem and Root Cuttings. The first attempts to propagate trees vegetatively were usually by cuttings (sections of small branches) placed in the soil and kept well watered. Successful rooting of *Ceiba pentandra* by this method was reported early from the Philippines (Pacumbaba 1939–40). Roots of *Cedrela odorata* were struck from cuttings 5 to 15 cm in diameter driven into the ground (Castro 1951). Yet, tests in Ghana showed the rooting of cuttings from 9-year-old trees of this species to be unreliable even when the cuttings were treated with hormones (Britwum 1970). Tests in Taiwan with the related *C. sinensis* shed light on this variability in results (Huang 1967). Sprouting averaged 94 to 96 percent for cuttings taken in January and February, 90 percent for March cuttings, 82 percent for April cuttings, 31 percent for May cuttings, and 22 percent for June cuttings. It was concluded that sprouting was most vigorous before terminal growth started. Survival was similarly affected by the season the cuttings were set, being 35 percent in January, 55 percent in February, 32 percent in March and April, 20 percent in May, and 14 percent in June. The earlier cuttings also proved superior in height and diameter growth and root development. Cuttings from the base of the trees attained an 82-percent survival rate versus 65 percent for those from the terminals. The use of hormones improved the average survival from 63 to 72 percent.

Vegetative propagation of *Casuarina* has been reported. *Casuarina junghuhniana,* a Javanese species widely used in Thailand and introduced into India, was found to sprout from cuttings (Thirawat 1953).

Conifers are generally difficult to reproduce by cuttings. However, a test of branch cuttings of *Araucaria cunninghamii* in India produced roots on 50 percent and a 1-year survival rate of 17 percent (Dabral 1961).

The expense of cleaning *Prosopis juliflora* seeds in India led to tests with cuttings (Kaul 1956). Cuttings taken from natural seedlings about 1 m in height and 2 cm in diameter at the root collar sprouted and survived satisfactorily.

Eucalyptus deglupta cuttings can be easily rooted in water, and a 90-percent success rate has been reported (Davidson 1973c). However, rooting success greatly depends on the age of the ortet. Nearly all of the cuttings taken from the tops of trees up to 12 months old rooted, but none of those taken from 5-year-old trees did (Davidson 1974). It has been found that cuttings of most species of eucalypts will not strike roots once the plant is beyond the juvenile stage (Pryor 1978).

Stem cuttings of *Eucalyptus* have been used on a large scale at Aracruz, Brazil (Ikemori 1975, 1976). These cuttings have two pairs of leaves. The process has been successful with *E. grandis* and *E. urophylla.*

With many species, cuttings strike roots as readily with water alone as with hormone treatments. Topside branches of *Pinus caribaea* in Uganda performed as satisfactorily in water (24 to 26 percent) as with hormones (Tufuor 1973). Moreover, hormone treatments may vary in effectiveness with the chemical or its concentration. Tests normally compare more than one hormone and concentration. Yet, a test of indolebutyric and indoleproprionic acids with *P. caribaea hondurensis* in Brazil showed no difference in effectiveness at prescribed levels (Brandi and de Barros 1971).

In Costa Rica, *Acrocarpus fraxinifolius, Tabebuia rosea,* and *Toona ciliata australis* were rooted successfully with phytoregulators (Zanoni Mendiburu 1975). Failures included *Cordia alliodora* and *Swietenia macrophylla* (although rooted successfully elsewhere), *Cedrela odorata,* and *Simaruba amara.*

Root cuttings may prove superior to stem cuttings. The Temperate Zone species *Albizia julibrissin* reportedly has not been rooted from stem cuttings but has been rooted from root cuttings 2 cm in diameter and 8 cm long (Fordham 1968). The juvenile sprouts produced were, in turn, easy to root. The use of longer root sprouts (up to 30 cm) produced a larger number of sprouts. Greater rooting success with stump sprouts than with stem sprouts has also been reported for *Eucalyptus* (Pryor 1978).

In Papua New Guinea, a technique for reproducing *E. deglupta* by cuttings was 90 percent successful (Davidson 1973c). This and the stem practices used in Brazil can be expected to be applied more generally and to increase substantially the productivity of plantations of these species.

Air Layering. Where propagation by stem or root cutting is difficult, air layering has sometimes proved successful. In air layering, the outer bark of stems is severed, and the wounded area is moist-wrapped until rooting and separation can take place. Early efforts to air layer 42 species of tropical forest trees in India were successful (40 percent rooting or better) with *Casuarina equisetifolia, C. cunninghamiana, Chickrasia tabularis,* and *T. ciliata. Araucaria cunninghamii* and *Tectona grandis* rooted between 10 and 20 percent (Kadambi and Dabral 1954). The lower branches of *Casuarina junghuhniana* were also successfully air layered (Thirawat 1953).

The difference between young and old trees was found to be the same for air layering as for cuttings of *P. elliottii* (Hoekstra 1957). This difference was marked between trees 6 and 23 years old. With *P. roxburghii* in India, it was concluded that air layering should be done on the previous year's growth, just behind the apical bud (Chaudhuri 1960). This technique was found to be more successful if done when the apical buds were just opening in January. Rooting started in about 3 months and was adequate in 6. In another test in India, a 100-percent success rate was obtained in April and May for *P. roxburghii* and in June with *P. caribaea.* Two-year-old branches were found superior to 1-year-old branches (Kedharnath and Dhaundiyal 1963). Air-layering tests in Venezuela showed no problem using 8-year-old trees of *P. radiata* and 3-1/2-year-old trees of *P. oocarpa* (Melchior 1963). Use of indolebutyric acid accelerated root formation.

Grafting and Budding. Difficulty in propagating cuttings of many species has led to grafting and budding, the insertion of a bud or a terminal stem against the cambium layer of a rooted stock, as is commonly done with fruit and ornamental trees. A successful technique for budding *Ceiba pentandra* was reported early from the Philippines (Pacumbaba 1939–40).

Grafting of *P. radiata* with 8- and 3-1/2-year-old material of *P. oocarpa* was found to be easy in Venezuela (Melchior 1963). Field grafting of *P. caribaea* was developed by the use of plastic covering over top-cleft grafts (scion inserted within split terminal) (Nikles 1965). This technique improved the success rate from 66 to 91 percent. Use of the plastic enabled grafting to be done any time of the year. Plastic also made it possible to use dormant scions, which otherwise were 37 percent inferior to actively growing scions.

Top-cleft grafting was also successful in east Africa with *Araucaria,* an important finding because of the lack of local seeds (Willan and Salimu 1966). The scion must be from an apical leader to produce vertical growth. Decapitation was found to produce multiple leaders suitable for scions. Interspecific grafting of *Cupressus* was also developed (Dyson 1967).

Experience in Australia with *P. elliottii* showed grafting to be very satisfactory in view of the failure of cuttings (Slee 1967a). Under favorable conditions, top-cleft and whip grafting (side grafting at the terminal) proved satisfactory; bottle grafting (side grafting with the base of the scion retained in vessel of water) was better under difficult conditions. Protection from desiccation is important, and the summer months are to be avoided. However, young and old trees yielded the same results, and the use of auxins, basal wash, and antitranspirants showed no advantage.

Successful cleft grafting of eight species of *Eucalyptus* was reported from New Zealand in 1962 (Thulin and Faulds 1962). A root strike of 80 to 100 percent was attained. *Eucalyptus deglupta* was successfully bottle-grafted in Papua New Guinea shortly thereafter (Davidson 1968). Bottle and top-cleft grafts with this species were frequently found incompatible, a problem that was eliminated by the use of patch grafts (Davidson 1973a). Incompatibility remained a problem with many tropical species, however, requiring many replacements in seed orchards (Pryor 1978).

Grafting of *S. macrophylla* was tested in four seasons in Taiwan and found to be season sensitive; the best time for grafting there is the first 10 days of March (Liou 1969). Scions were soaked in one of three hormone solutions (50 ppm of indolebutyric acid, hapthalene, or indoleacetic acid) for 2 hours, on March 10 and March 30. Survival for all treatments was 80 percent or higher.

Teak budding on 1-year nursery stock showed promise as early as 1960 (Keiding and Boonkind 1960). Bud sprouts of teak from nursery stumps placed in a mist chamber gave an almost 100-percent rooting rate without hormones (Hussain and others 1976). The buds used had just put out two to three pairs of leaves when nipped off. Grafting of teak on 9-month-old plants achieved a 100-percent success rate in what is now Sri Lanka (Perera 1961).

Other Tree Propagation Practices. The use of tissue culture, growing and multiplying parenchyma in an artificial medium, shows great promise for large-scale vegetative propagation. It has been tested with several tree species in the Philippines (Crizaldo 1980), and promising results have been obtained with *Paraserianthes falcataria, G. arborea, P. caribaea,* and *P. kesiya.*

Skolmen (1985) points out that whereas tissue culture has the potential to produce enormous numbers of plants very quickly and efficiently, it has so far been successful only on species that can be readily propagated by conventional methods. Thus, it is not a method for overcoming propagation difficulties. In addition, the process is not simple or always successful. However, Skolmen anticipates that in the future it may be possible to outproduce conventional propagation methods at a greatly reduced cost by using tissue culture.

Bamboo is usually propagated vegetatively because of the infrequent periodicity of its flowering. Early experience with *Bambusa spinosa* in the Philippines showed that sprouting of vegetative material was most vigorous under direct sunlight (Mabbayag 1937). Also, it was observed that stem cuttings from the base of the culm grow faster early than do those from the middle or upper part of the culm.

Experience with bamboo propagation in Puerto Rico led to the recommendations that culms 2 to 3 years old be used, that all primary branches be pruned off, and that cuttings be buried in a furrow 15 to 20 cm deep (White 1948). *Bambusa vulgaris* cuttings 70 to 130 cm long often root when driven into the ground. For best results, the enlarged, congested nodes at the base of the culm were used. Similar recommendations have been made for *Dendrocalamus latifolius* in Taiwan (Lin 1962). Two-node cuttings were used, with the upper part of the culms avoided. Sprouting of this species in Taiwan proved best in March; April and May were the best alternatives.

Experience with *B. vulgaris* in the Sudan indicated that the best culm cuttings are three-node and from the middle third of the culm (Khan 1966b). Next are two-node cuttings from the same area. The third choice is three-node cuttings from other parts of the culm. The best month there for sprouting proved to be July. The cuttings were set in the ground on an angle, with one node buried. Sprouts appeared within 20 days. Two-year survival rate of the best type of cuttings was about 50 percent.

In the Philippines, young, 3-year-old seedling bamboos were divided to separate the 8 to 12 whippy shoots each had produced (Sunder 1970). These stood the shock well, and later each yielded more shoots. The practice in Bangladesh for thick-walled bamboos is to use culm bases, similar to offsets, about 50 cm long (Hasan and others 1976). When rooted, these develop good planting material in 20 to 24 months. This practice has been less effective with thin-walled bamboos.

Propagating Soil. Nursery practice throughout the world has produced a few axioms about soils used for propagation, whether it be by cuttings or by seeds. The soil should be light enough to provide free drainage and fairly easy lifting of stock without injuring the roots, yet heavy enough to hold water and nutrients and to cohere when containers are used. Once these conditions have been met, controlling the quality of the medium is chiefly a matter of chemistry, including regulating pH, ensuring the availability of existent nutrients, and correcting nutrient deficiencies.

As an example, river sand has been used as the basis for the potting medium in Nigeria (Lowe 1967b). Cocoa pod refuse, rice bran, and sawdust were added, primarily to assist in water retention. The addition of further organic matter proved undesirable because it reduced growth because of an adverse carbon (C)-to-nitrogen (N) ratio or increased mortality by disturbing the pH or nutrient balance. The use of relatively insoluble fertilizers was indicated.

Trials in Puerto Rico with *P. caribaea* showed sphagnum, if properly fertilized, to be better than sand and soil as a potting medium; the stock in sphagnum grew twice as rapidly as the stock in sand and soil (Marrero 1961). The best root development was in pots with a mixture of sphagnum, vermiculite, and loam.

The nutrient status of tropical tree nurseries must be diagnosed frequently (Swan 1969). Periodic foliar analyses are useful. Recognition of the need for phosphorus (P) and potassium (K) and other elements should prevent excessive attention to N alone, which may create or worsen an imbalance with other elements.

In some regions, filter-press cake from sugar mills has been a readily available organic supplement for nursery soils. Used as a bed dressing in Australia at the rate of

34 t/ha, it appeared beneficial, although 112 t/ha led to chlorosis (Anon. 1965g). In Puerto Rico, this treatment led to a pH increase to 8 or 9 from the Calcium (Ca) in the material, a threat of iron chlorosis.

South African practice recognizes a need to fertilize nursery stock well, even though the benefits may not continue after planting (Donald 1979). The use of organic additives for nursery soils is not practical everywhere in the Tropics. In parts of Brazil, where organic supplements are not readily available, inorganic fertilizers may produce a satisfactory medium (Simoes and others 1971). The application of N to nursery soil tends to shift blame for growth failure to some other factor. In Australia, neither N nor P alone commonly benefited propagation, but the two together may greatly stimulate growth (Simpson 1978). Studies of *E. saligna* nursery stock in Papua New Guinea showed stunted, purple-to-red seedlings resulting from a P deficiency (Reynolds and Lubres 1971). The condition was corrected by applying P, but high P fertilizer produced both a low root-to-shoot ratio and transplanting difficulties.

Seeds are usually covered with sand or a screened soil, although organic material such as peat moss is also used (Thomson 1968).

Symbiotic fungi that form mycorrhizae on plant roots and facilitate nutrient intake have proved crucial to the success of pine introduction in the Tropics. The fungi are generally introduced by inoculating nursery soils. Once established, their survival and future seem assured. Because their symbiosis is specific, they produce no environmental effect outside that of the pines themselves. The major danger is that of introducing unknown organisms in mycorrhizal soil.

Early attempts to introduce *P. merkusii* outside its natural range in Indonesia uniformly failed (Alphen de Veer 1954). Introduction of inoculated soil was unsuccessful. Then, small mother trees were planted at 1- by 1-m spacing, beneath which 6- to 8-week-old seedlings were transplanted. After 2 years, the beds had become uniformly inoculated, and the mother trees were no longer needed. The same technique was used for inoculating soils in Nigeria (Ekwebelam 1974). The addition of P appeared to stimulate the mycorrhizae.

Years were spent in Puerto Rico trying unsuccessfully to introduce conifers before the mycorrhizal fungi were introduced (Briscoe 1959, Hacskaylo and Vozzo 1967, Vozzo and Hacskaylo 1971). Introductions of fungi in culture initially failed. However, duff taken from pine forests elsewhere and worked into the soil around dying seedlings produced a spectacular response. Soil from inoculated plantations was then used to inoculate nursery stock. Subsequent use of inoculum of known fungi also proved successful. South African practice is to inoculate pines with ground sporophores or spores instead of infected forest soil (Donald 1979). The widespread occurrence of mycorrhizae in tropical forests is described by Janos (1975).

General Nursery Practices

Spacing of Stock. The spacing of seeds, transplants, or cuttings in the nursery is subject to few universal rules and generally must be determined for each species and local situation. A test of *G. arborea* spacing in India illustrates the main variables to be considered (table 6–5; Rajkhowa 1965). The number that survived and were usable increased with the number of seeds sown. The closest spacing may be considered best if there are plenty of seeds and the nursery area is limited. Wider spacing is better where seeds are scarce or expensive.

In Africa, pine sowings for later transplanting generally have aimed at a density of 2,000 to 6,000 seedings per m^2 (Allan and Endean 1966, Donald 1965). For *Eucalyptus*, a density of about 1,500 per m^2 is common.

Sowing directly in containers has many advantages, including faster growth and less danger of widespread

Table 6–5.—Effects of spacing on survival and yields of *Gmelina arborea* in India

Initial spacing (cm)	No. of seeds[a]	No. of survivors	No. of usable stumps[a]	No. of trees lost[a]
5 by 5	400	160	56	344
5 by 10	200	104	45	155
10 by 10	100	62	22	78
10 by 15	67	42	18	49
15 by 15	44	31	14	30

Source: Rajkhowa 1965.
[a]Per square meter.

damping off. But more seeds may be needed, because it is necessary to sow more than one seed per container and then thin out.

Transplanting. Transplanting nursery seedlings to prepared beds or to containers permits foresters to select a uniform crop of the most vigorous seedlings and to place them at their final spacing in the nursery. Pines were formerly transplanted several weeks after germination but are more commonly transplanted after only 2 to 4 weeks (Griffith and others 1962, Leuchars 1960). The advantages are higher survival rates and less post-transplant shock. *Eucalyptus* has been generally transplanted after the seedlings have three to four leaves (Anon. 1963c). In Malaysia, *P. caribaea* has been transplanted 4 to 6 days after germination (Paul 1972).

Shade. Shade over seedlings was once thought optimum for nursery stock because most forest species tolerate shade in nature. More recently, however, stock is shaded only when sensitive to high temperatures and desiccation, such as during germination and rooting of cuttings and transplants. Even species as shade tolerant as *Araucaria hunsteinii* have received half shade for only 6 weeks, about 10 percent of their time in the nursery (Havel 1965). At the other extreme, *Anthocephalus chinensis,* a very intolerant species, is at first lightly shaded because of its extremely delicate seedlings, but it soon bends toward the light it needs (Pollard 1969). *E. tereticornis* and most other *Eucalyptus* species only need about 2 weeks of shade (Lohani 1978). Well-established seedlings generally grow more rapidly and become more robust and woody under full light than under shade. Full light is desirable even for stock that is to be underplanted.

Root Pruning. Severing the deep roots of planting stock during growth in the nursery increases the compactness and density of the root system. Shorter taproot and increased fibrous roots reduce later planting shock and increase survival and early growth. This has long been standard practice. Common in small nurseries in the Tropics, such pruning may be done by pulling a wire stretched beneath the side boards under the beds. Experience with *S. macrophylla* in the Philippines recommended pruning at 60 days (Asiddao and Jacalne 1958). In what is now Zimbabwe, this has been considered an important advantage for pine and eucalypt stock to be used on grassy sites (Stubbings 1958).

Types of Planting Stock

As planting stock selection advances from species to provenance and then to progeny, intensification of investment in planting-stock quality becomes warranted. The production of seedling and transplant stock merits more study, not only to reduce planting costs and mortality but also to enhance the capacity of planted trees to adjust to field conditions and weed competition.

Bareroot Stock. Bareroot stock may die if the roots are exposed between lifting and planting. Even brief exposure to the wind or sun may preclude planting success, so moist packing material must be kept around the roots. Desiccation may also be reduced by stripping some or all of the leaves at the time of lifting.

In southern Brazil, *P. elliottii* and *P. taeda* have been planted bareroot only where rains are well distributed throughout the year (Simoes and others 1976). In Puerto Rico, bareroot planting of *P. caribaea* was discontinued partly because the rains were unreliable but also because of the long recovery period from planting shock, extending weeding by as much as 1 year.

Bareroot stock has been tested everywhere direct seeding, an initially cheaper alternative, has proved unsuccessful. Erosion-control plantings on poor soils in India have been done with bareroot transplants of *Albizia amara, A. lebbek, A. procera, Azaderachta indica, Dalbergia sissoo, Eucalyptus* spp., and *G. arborea* (Goswami 1957). On irrigated dry sites, *Casuarina equisetifolia* is planted bareroot (Venkatesan 1973).

In moist climates, bareroot planting is successful with many species. In Malaysia, the abundance of wilding stock made containerized trees too expensive (Gill 1970). *Cupressus lusitanica* has been successfully established bareroot in Guatemala when special care was taken to protect the roots (Holdridge 1953). *Virola surinamensis,* one of the trees with good potential in the moist forests of northern South America, has generally been bareroot planted (Schulz and Rodriguez 1966).

Swietenia macrophylla has been bareroot planted successfully in the Philippines (Santos and Rimando 1952). A test of *Terminalia ivorensis* in Nigeria, comparing potted stock with stumps, showed that during the 3- to 5-month rainy periods there was no need to use pots (Lowe and Dobson 1966). In Puerto Rico, *Casuarina* *equisetifolia, Cordia alliodora, Hibiscus elatus,* and *Swietenia* spp. have traditionally been bareroot planted. Both *Eucalyptus* spp. and *P. caribaea* have been bareroot planted experimentally, and there seems some prospect that this will continue under favorable conditions.

A planting of *P. caribaea,* both bareroot and in polyethylene containers, gave a survival rate of 99 percent for both methods at 30 days. After a subsequent 7-week drought, survival dropped to 88 percent for the bagged stock and to 45 percent for the bareroot stock. Yet, if all costs are included, it might commonly prove cheaper to replant than to use containers (Briscoe 1960).

A test in Florida with *Eucalyptus* seedlings raised in plastic bags showed no decline in the survival rate after soil was washed off before planting (Meskimen 1973). The treatment retarded growth during the first month, but transportation was simplified, and mechanical planting was made possible. The experiment also showed better results with woody than succulent stock.

Size of Stock. The size of planting stock has been standardized based on local conditions in tropical countries. This has led to the rejection of trees considered substandard, generally with little understanding of the significant criteria involved. The best seedling size for *Araucaria hunsteinii* in Papua New Guinea proved to be no taller than 18 cm (Havel 1965). In the Philippines, stock age was the criterion used. Eleven-month-old *Pinus kesiya* nursery stock grew much faster in height after planting than did stock that was 6 months old (Zamora and Agpaoa 1976). For planting of pines and eucalypts on grassy sites in what is now Zimbabwe, large bareroot stock 40 to 50 cm tall has been preferred (Stubbings 1958).

Size differences in nursery-produced planting stock are commonplace, yet whether there is genetic gain from taking the largest nursery stock to the field is questionable. For example, on the edge of a bed of polyethylene-bagged stock, shorter pines are common. However, this effect may be due to inhibition of mycorrhizae by lateral exposure to the sun, a phenomenon totally unrelated to the genetic potential of these trees (Jackson 1974). In fact, Sweet and Wareing (1966) concluded that size variations in nursery stock less than 1 year old are due almost entirely to small site differences occurring at (or soon after) the time of germination and are independent of genetic differences.

Selection of dominants thus may not guarantee genetic superiority.

Isolated experiments would appear to support this conclusion. In Brazil, of the 9-month-old *P. elliottii* tree stems that grew best and appeared strongest, only 1 stem per 3,500 was chosen (Shimizu and others 1977). At the time of planting, the selected trees were 34 percent taller than the others. After 1 year, the difference was 46 percent. At the end of the second year, it had dropped to 31 percent, and by the end of the third to 12 percent, meaning that the benefit from selection had largely disappeared. In another case, tests of *P. taeda* in the United States disclosed genetic variation in the capacity of the trees to withstand transplanting shock (Beineke 1967). Tall trees were consistently the poorer survivors. These examples do not necessarily argue against nursery stock standards and selection, but they do suggest that stock that looks inferior may not really be so.

There is no reason, however, to reject seedling selection as a logical process for recognizing phenotypic vigor. A study of 45-year-old pines in the southern United States showed that trees from first-grade seedlings significantly outperformed those from third-grade seedlings (Wakeley 1969). The initial indications were vindicated by later performance.

Nursery workers commonly must decide whether to discard or hold over excess stock at the end of a planting season. Such stock normally will be larger and costlier to plant and perhaps less likely to survive. Probably not all such stock deserves to be saved, but results in Puerto Rico indicated that the capacity of *S. macrophylla* trees to survive planting need not decline over a few months (Marrero 1942). Overgrown stock 1 to 2 m tall cut back to 10 cm in height can survive well in the field. Small teak plants left over from a previous year are not necessarily inferior as planting stock (Venkataramany 1960a).

Stump Plants and Striplings. Large planting stock is ordinarily used in underplanting because it appears to have a head start on competitors. However, the other extreme, use of trees 1 to 2 m tall cut back to "stump plants," is also widely practiced. Stumping is probably most common with teak; the practice arose because many trees that were not cut back died back anyway after planting or sprouted at a point thought less desirable than the base of the stem. Teak stumps are cut back to about 2 cm above the root collar and usually have 15 cm of taproot below, with no lateral roots (Wood 1968). In a test in India, 2-year survival and height growth of teak increased with stump size (table 6–6; Anon. 1944, 1947a).

Stumps store well. A test in what is now Myanmar (Anon. 1947a) showed that *Toona ciliata* stumps left in the open air indoors had a 75-percent survival rate after 5 days of exposure, but none survived after 10 days. However, when stumps were stored in moist sacks, the survival rate was 90 percent after 25 days and 28 percent after 45 days. Oversized stumps may be halved by splitting without much loss, but if quartered, survival is lowered (Venkataramany 1960a).

On large projects, stumping offers such advantages that it will probably be used with more tropical species in the future. It has been used widely with *G. arborea* and on a large scale in Brazil (Woessner 1980a). The *G. arborea* stumps used are 4 to 6 months old and about 2 cm in diameter at the root collar. They are cut off about 4 cm above the root collar and have a taproot about 10 cm long. In India, stumps have been used under dry conditions with *Albizia lebbek, Bauhinia* spp., and *D. sissoo* (Singh 1951). A study of root systems in Ivory Coast indicated that stumping should be successful with *Tarrietia utilis, Terminalia ivorensis,* and, under favorable conditions, with *Entandrophragma utile* (Bonnet-Masimbert 1972). *Triplochiton scleroxylon* proved unsuited because it needs its entire fragile root system for survival. Stumps are not recommended for underplantings because of the need for maximum early height growth (Lamb 1969a).

Table 6–6.—Teak, *Tectona grandis,* stump diameter versus survival and early height growth in India

Root-collar diameter (cm)	1-yr. survival (%)	2-yr. height (m)
0.8–1.0	64	0.9
1.0–1.3	81	1.3
1.3–1.5	88	1.5
1.5–2.0	92	1.5

Source: Anon. 1944, 1947a.

At the other extreme are striplings, nursery stock 2 to 3 m tall stripped of most leaves but otherwise intact. These are used in areas where animal damage would otherwise be excessive, with species subject to stem pests, and in underplantings where weeding must be minimized (Parry 1956). Striplings have been used with *Gmelina* and the Meliaceae, chiefly in Africa, but also with *Swietenia* in Central America. Their usefulness depends almost entirely on local conditions. At best, the extra costs of longer production in the nursery and of planting can be recovered by an earlier "getaway" for the plantation.

Containerized Stock. The use of containers for forest planting stock has been much more common in the Tropics than in the Temperate Zone. The chief reasons are the lack of a dormant season during which transplanting shock would be minor and the need to facilitate early domination of planted trees over competing vegetation, particularly in underplantings (Lamb 1969a). Many tropical plantation failures have been blamed on rooting damage resulting from bareroot planting (Touzet 1972). Containers offer other benefits under special circumstances, such as a need to store the stock near the planting site.

Experiments in Puerto Rico compared the production and performance of *P. caribaea* stock in polyethylene bag containers, ball-rooted stock placed in bags the day before planting, and bareroot stock (Briscoe 1962). Both types of bagged stock required more space, more equipment, and more labor to produce than bareroot stock but were considered superior because of a higher survival rate and more rapid early growth.

The use of containers may require a large investment. Rooting media are expended with the planting and so must be procured continuously. In addition, the greater weight and bulk complicate transport. The containers themselves are generally expendable and costly, if filled by hand (as is usual). Large holes are required for planting, and planting machines are not widely used with container stock.

Containers have been made of bamboo, used tin cans, tarpaper, wastepaper tubes, milk cartons, specially made waxed-paper cartons, perforated polythene bags, and rigid plastic tubes (fig. 6–3). The most widely used container in the Tropics is the clear polyethylene bag, about 6 cm in diameter and 12 cm deep.

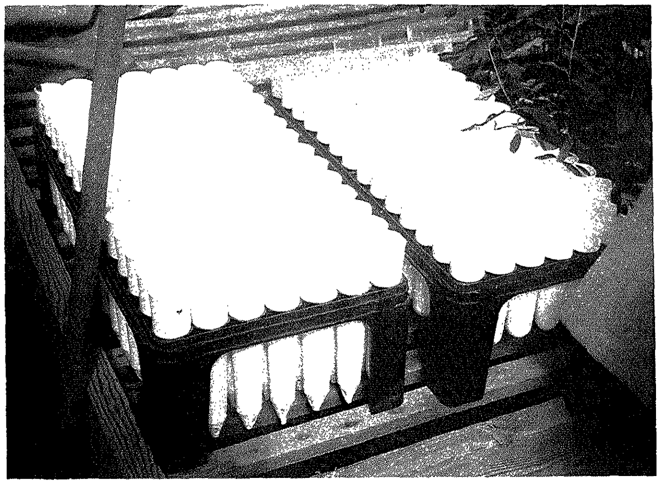

Figure 6–3.— *Reusable plastic containers have proved practical in some nurseries.*

For severely drifting sand in Madras, India, seedlings of *Prosopis juliflora* were produced in pots 7 cm in diameter and 15 cm deep to avoid field watering after planting (Rao 1951). *Casuarina equisetifolia* has also been potted in Orissa, India, for extremely dry, sandy sites where, even with potted stock and weekly watering for 2 years, casualties may be as high as 50 percent (Sharma 1951).

Rapid early growth of containerized *G. arborea* in low-rainfall areas in what is now Malawi replaced the use of stump plants (McEwan 1961). Tests in Tanzania (Wood 1966) with *Pinus caribaea* showed that containerized plants had significantly higher survival rates than bareroot stock. There was no difference in survival between 10- and 15-cm tubes, but at 1 year, the trees from the larger tubes were significantly taller, a difference of 1.4 versus 1.1 m. In Cuba, similar results were found (Acosta and others 1975). On one site, trees from containerized stock at 19.5 months averaged 88 cm tall compared with 59 cm for bareroot stock. In spite of the greater height growth, however, there was some question as to which practice yielded the most benefit for the investment. In Venezuela, some of the extensive pine plantings in the lower Orinoco have been established with bottomless tarpaper cylinders 6 cm in diameter (Lama Gutierrez 1976).

Eucalyptus planting in tropical America is generally containerized. Tests at Vicosa, Brazil, with seven species showed the planting survival rate with bareroot seedlings never to be above 29 percent (Brandi and de Barros 1970).

Soft plastic bags are difficult to fill rapidly and economically. Devices to facilitate filling them have been developed in Brazil, Venezuela, Puerto Rico, and elsewhere. The simplest of these is an appropriately dimensioned, metal funnel. Performed by hand, this process is still time consuming and, where labor is expensive or scarce, the cost may be prohibitive. A good mechanical bag filler has been used in Australia (Evans and Duyker 1965). The process requires bone-dry, fully pulverized soil.

Direct sowing of seeds into bags is much less expensive than transplanting. In Papua New Guinea, direct sowing of *P. caribaea* reduced growing time 28 percent and seedling cost 93 percent and produced a mean tree height advantage of 42 percent (Howcraft 1973). An alcohol-flotation technique was used to eliminate nonviable seeds. Two seeds were sown per bag.

Bag-filling problems, together with the expense of bringing large volumes of potting soil to nurseries and transporting the soil to the field, have recently led to the use of rigid containers, either disposable or reusable. Bottomless tarpaper pots, long used in Argentina, Venezuela, and elsewhere, can be filled rapidly. These pots stand upright in tight arrangement between bed sideboards and are filled collectively and quickly with a shovel.

Rigid plastic tubes no more than 3 cm in diameter and 15 cm deep with a conical, perforated bottom are being used in Florida and Hawaii and are being tested elsewhere. Typically, an artificial potting medium such as vermiculite or perlite is used. Therefore, there is no need to transport tonnes of potting soil each year. Moreover, the tubes can be placed in light frames for easy transport. They are reusable and can be removed and kept at the nursery if the medium is sufficiently cohesive to withstand rolling in burlap for the field.

Because desiccation kills many recently planted seedlings, chemical transpiration retardants have been tested as a preventive. However, in Hawaii, a test of *E. saligna* utilizing a captan-malathion solution and comparing dipping and spraying showed no superiority in either the survival or 1-year growth rate in the field (Walters 1971).

Insects and Diseases
The collection, storage, and production of propagating materials for tropical forest trees are not without insect and disease problems. These problems are diverse, usually local, and subject to rapid change. Some of the problems encountered are described here, but a detailed review of pest behavior and treatment recommendations is not attempted. The reader is referred to specialized reports on forest entomology and pathology for more information, some of which are cited in the bibliography. There is no comprehensive reference on forest insects of the Tropics.

An important category of nursery problems is termed "deficiency diseases," where stock has too little (or too much) of some abiotic component essential to its environment, such as moisture or nutrients. Excellent information now exists on these problems for agricultural crop plants, fruit trees, and ornamentals. This information is useful in diagnosing and correcting similar problems affecting forest tree, nursery stock. Specialists in entomology and plant pathology should also be consulted.

Most insect and fungal pests are host selective. Trees grown outside their native ranges may be spared from the pests of their home environments but may become new hosts for pests in their new locations. Making sure that the young trees introduced are kept healthy reduces the danger of pest attacks or infection (Chapman and Allan 1978). Control may be silvicultural, biological, mechanical, or chemical.

Silvicultural measures include control of tree spacing and the use of mixed plantings. Biological control involves coaction between two or more organisms favoring the desired crop. Mechanical control usually calls for removing infested material, including alternate hosts. Chemical control relies on insecticides and fungicides (Chapman and Allan 1978).

In the Tropics, the need to reduce or eliminate unwanted organisms from soil used for tree propagation is almost universal. Repeated cropping tends to attract such problems. An intensive practice in nurseries is to expose well-loosened soil to methyl bromide, a highly toxic (and dangerous) gas. This substance has been utilized for decades in *Eucalyptus* propagation. Methyl bromide's excellent properties as a sterilant, including the fact that it does not necessarily kill all organisms in the soil, were demonstrated in 1954 (Guimaraes and others 1954). The compound has been widely used in Brazil ever since. Its use became standard practice in *Eucalyptus* production in South Africa (Knuffel 1967), where it increased the number of plants by about 50 percent.

Insect problems may also be significantly reduced by treating nursery soil with insecticides. This is a standard practice with *E. tereticornis* in India (Lohani 1978). Ideally, treatment should be tried on a small scale to minimize unknowns before larger scale operations are undertaken.

The isolated locations of many forest nurseries in the Tropics means that common insect and disease problems can be handled only with common sense. An example is seen in a nursery of *Cedrela odorata* and *S. macrophylla* in Fiji (Anon. 1954d). An unknown Scolytid beetle attacked the seedlings of both species, boring into the stems near the root collars and laying eggs. The infested seedlings were quickly removed and burned, and the problem was essentially controlled. Such situations call for similar solutions because of lack of either precedent or access to specialists. Common-sense practices must continue, but because these generally neither identify the cause nor provide a scientific solution, the more serious or frequent problems of this nature sooner or later demand careful research. Biological controls are in many cases a research objective not yet attained.

Planting Techniques
Planting techniques in the Tropics vary so widely, and correctly so, that no practice is applicable everywhere. Standard manuals should serve merely as guides, being modified to suit the needs of each situation. Several compendia of planting experiences within the Tropics have been published that are useful for selecting planting practices. An excellent example by Chapman and Allan (1978) deals in detail with plantation planning; site preparation; direct seeding; planting and tending; special techniques for soil and water conservation, irrigation, sand dunes, wet or interlogged sites, and mine spoils; and protection of plantations from weather, insects and fungi, and fire.

The importance of site preparation where a tree is planted outside its natural range is shown by experience in Kenya (Schonau 1975). There, establishment techniques influenced the early growth rate of *E. grandis* more than did site quality. Where rainfall is limiting, complete site preparation, including plowing, fallowing, and harrowing, may be needed. The superiority of growth on sites so prepared was still apparent at age 7. The use of fertilizers, particularly P, may yield a financial return of 25 percent per year. A main need is for P, but the need for N increases with less site preparation.

Planting Season. Nearly all planting sites in tropical America are subject to seasonal rainfall variations. Rainfall occurring immediately before and after planting is critical to the survival of most tree species. Planting should begin at the onset of the normal wet season when maximum duration of adequate soil moisture is expected. Teak planted in India at the beginning of the rainy season invariably does better than if planted later (Laurie 1941g). Land preparation and digging of holes may be done months in advance to shorten the period required for planting (Lohani 1978). In west Africa, trees have been generally planted a full 6 months before the dry season (Groulez 1961a). For *E. deglupta,* a species that needs almost constant moisture, planting should not be done less than 1 month before a normally dry season (Dalton and Davidson 1974).

In Puerto Rico, the ideal times for planting seem to be months that average at least 15 cm of rainfall, preceded and followed by months averaging at least 10 cm (Marrero and Wadsworth 1958). In India, on sites where rainfall is less than 100 cm annually, direct seeding of *A. lebbek, Azadirachta indica,* and *Cassia fistula* may be done every month (Laurie 1941b). The seeds persist on the soil until the advent of the unpredictable rains.

Site Preparation. The preparation of the land is usually crucial to planting success. It may facilitate the planting job itself, but its primary purpose is to give the planted trees a head start over the natural vegetation and thus minimize weeding.

The general considerations in site preparation have been well described by Chapman and Allan (1978). Where vegetative cover can prevent successful plantation establishment, methods must be developed to eliminate or reduce such competition. Site preparation often constitutes a major proportion of total establishment costs. Therefore, efficient and economical methods that avoid undesirable ecological changes are required. Under favorable circumstances, little vegetation may need to be removed, and the soil may be left undisturbed. At the other extreme are rain forests with heavy residual vegetation and fragile soils.

Site-preparation costs are a major obstacle for planting on nonforested areas. Even on the grasslands of the lower Orinoco in Venezuela, land preparation has accounted for more than a quarter of the field cost of plantation establishment (Gutierrez 1970).

Land preparation is a twofold process: the elimination of competing vegetation and the preparation of the soil. Competing vegetation has been reduced on many sites by shifting cultivation. Remaining trees may be felled or, if large, girdled or poisoned. In dry areas, it is essential to prevent the consumption of scarce water by vegetation other than the planted trees (Cooling 1960). In a test in the miombo woodlands of Zambia, complete elimination of weeds resulted in a 14-month plantation survival rate of 95 percent compared with less than 30 percent where only spot weeding was done (Endean and Jones 1972).

Much of the land needing reforestation in the Tropics is poorly suited to mechanized site preparation because of steep or irregular terrain. Costs of personnel training, equipment maintenance, and parts and fuel inventories in remote locations may well exceed expectations. Even where mechanized techniques are feasible or less costly than hand methods, the social benefit of employment that using hand methods would provide should be weighed carefully before mechanization is considered.

Site preparation may not be required on eroding slopes, active dunes, and recently abandoned, cultivated fields. The less soil disturbance in such areas the better. What little weeding might be desirable can generally be done easily and by hand.

The contracting of shifting cultivators to prepare sites for forest planting and the initial sharing of the land by food and forest crops—the taungya system—has been and may in some places (such as Trinidad) (Lackhan 1976) remain a practical way to convert cutover forests to timber plantations where public control of forest land is adequate. At Monte Dourado, Brazil, where forests had recently been felled and burned, cultivation was contracted on a large scale to produce food crops and incidentally to weed planted trees. Site preparation by this method often left large, standing relics that later had to be felled with some damage to the plantation.

Where the taungya system is impractical, the removal of brush, low secondary forests, or recently logged stands is commonly done by hand with machetes, axes, and chain saws. Clearing high forests for planting is generally impractical by hand methods. At Monte Dourado (Jari), Brazil, high forests are felled, and up to 80 percent of the volume may be used for lumber and pulpwood. Most of the rest is used to fuel a pulpmill and generate electricity (Woessner 1980a). The harvest leaves chiefly branchwood to be burned in preparation for planting. This material is usually adequate to support a clean burn, allowing planting in the ashes immediately thereafter.

The use of fire for final site preparation is common in the Tropics. Where large volumes of debris cover the site and mechanical windrowing is impractical, using fire is the only way to provide the planters easy access. Where fire is not required for this purpose, however, it should be avoided, particularly on slopes, because burning releases nutrients (fig. 6–4). The N in the biomass is lost, and those nutrients remaining in the ashes may be lost to erosion. Allowing slash to decay in place, on the contrary, releases these nutrients to the soil at a rate roughly as fast as the new crop takes them up.

A less drastic method of converting secondary forests to plantations in the Tropics is by strip clearing and underplanting, a practice used widely in Africa but sparingly so far in America (see chapter 5). It was assumed that clearing lines about as wide as the crown diameters of mature trees would greatly reduce the site-preparation task, that species requiring early partial shade would be provided an environment similar to the natural one, and that most of the native forest might never need to be felled because the planted trees would soon dominate it. The technique proved to have merit, but it has not been as simple or effective as hoped. The shade left was initially too heavy, and planted species of slow-to-medium growth rates have required many years of tending, including liberation cutting, before their crowns were free. Subsequent emphasis has been on the use of fast-growing, intolerant species, requiring removal of the overstory (Lamb 1960). Thus, site preparation, even though the strips may initially be only 1.8 m wide (Lamb 1960), may be only slightly less costly than conventional plantings.

Figure 6–4.—*Site preparation by widespread burning 3 months after felling of the primary forest, an early practice at Jari, Brazil.*

Mechanized Site Preparation. Either manual or mechanized site-preparation methods may be used. On large planting projects in Brazil, land preparation has been generally mechanized (Simoes and others 1976). A thorough study of the relative social as well as economic advantages of manual and mechanized methods should precede any large planting project (Chapman and Allan 1978).

On flat land and slopes up to 30 percent that are free of surface irregularities or obstructions (the best sites available), machines may be used to topple trees, windrow debris, and plow and cultivate the soil for tree planting. Where labor is scarce or the planting season short, mechanization may be the only practical site-preparation option. The greater capability of machine operations may also provide employment opportunities that otherwise would not be available.

Mechanical removal of vegetation can damage the site, however. A study in Suriname revealed serious impacts on physical and chemical soil properties (van der Weert 1974). Heavy equipment may be detrimental to soil structure and may remove topsoil. Soil compaction may cause shallow and small root systems. Compaction is greatest when soil is wet, so clearing should be done during the dry season. To minimize repeated traversal of the land by machines, windrows should be closely spaced, at about twice the distance between the rows of the plantation.

Machines are commonly used for site preparation on the relatively level areas of cerrado forest being planted in Brazil (Brandi and others 1971). Small trees may be uprooted by chains drawn between heavy tractors, and the soil is usually thoroughly plowed and disked, not only for weed control but also to conserve soil water for the trees. Control of leafcutting ants with pesticides is an integral part of site preparation in Brazil. Plowing and disking on the altiplanos in Colombia produced faster growth of *E. grandis, P. kesiya, P. oocarpa,* and *P. patula* throughout their first 5 years (Cannon 1980; Ladrach 1978a, 1978b).

In the Tropics, site-preparation operations using mechanical equipment include the following:

Felling—Felling is usually done during the rainy season. In high or secondary forests, felling may be done with chain saws or cutting blades mounted on crawler tractors. Where trees are small, chaining with tractors in tandem may be done. In light brush, heavy, rolling choppers drawn behind crawler tractors may be used.

Windrowing—Windrowing is normally done shortly after the end of the rainy season. Heavy bulldozers or tractors with front rake blades are commonly used. Complete stump removal is necessary if the plantation is later to be machine tended. Large stumps that cannot be uprooted are surrounded with debris and burned.

Burning—Burning is done before the end of the dry season. Peripheral firelines are cleared with bulldozers, with workers standing by during the burning to consolidate incompletely burned material. Crews trained to control fires must be on hand.

Cultivation—Cultivation must be done immediately after burning. Soil is tilled only where heavy vegetative cover or a dry climate otherwise precludes successful plantation development. Heavy plows and disk harrows are drawn behind tractors.

Use of Herbicides. The use of chemicals involves hazards both to those who apply them and to the natural environment. It is necessary to remain informed of rapidly changing assessments of specific pesticides to avoid applying any that may unnecessarily harm the environment. The safety of workers exposed to these agents is of equal concern. Herbicide use calls for a number of important precautions. The manufacturer's safety instructions should be followed precisely. Many herbicides are irritating or toxic to mammals and may be absorbed through the nasal passages or the skin. Where sprays are used, protective clothing, including gloves and face shields, must be worn. Additional dangers arise from herbicides after application. Those that persist or that decompose into other dangerous or little-known chemicals must be kept from watercourses. This may call for minimum applications, avoidance of rainy weather, and tree injection in place of surface application.

Chemicals that kill plants are useful in preparing sites for planting under some conditions. Because they may kill grasses, weeds, and woody plants outright without the need for uprooting, herbicides can be superior to mechanical methods where site clearing is required. In areas with only grasses or weeds, herbicide treatment alone may be adequate. Where tree stumps remain, herbicides may be applied to prevent them from sprouting. Some herbicides kill vegetation upon contact; others must be translocated within the plant before they become effective; still others kill seeds in the soil. Herbicides are most effective when used in clear weather.

A few of the herbicides that have proved useful for tropical site preparation are listed below. The use of proprietary names is for clarity and conveys no greater endorsement than applies to any equivalents on the market.

1. Against grasses:
   a. Dalapon is a translocated herbicide affecting only monocotyledons. It is not known to endanger aquatic life.
   b. Paraquat is a translocated herbicide of extremely rapid action against grasses and fibrous-rooted or stoloniferous species. It defoliates (but rarely kills) woody species.

2. Against broadleaf, herbaceous weeds:
   2, 4-D (2, 4-dichlorohenoxyacetic acid) is a translocation herbicide applied as a foliar spray.

3. Against woody species:
   a. Picloram is a translocated herbicide that is extremely effective against woody plants and particularly useful in preventing coppice growth. Most grasses are tolerant.
   b. Ammonium sulphamate is a soluble, crystalline chemical that is applied to stumps in liquid or crystalline form to prevent sprouting.

4. Against seeds in the soil:
   Atrazine is an effective soil sterilant. It may be applied to low vegetation by manual or machine-powered, backpack sprayers or mistblowers. Trees may be treated by using basal spray (a mere wetting

of the bark around the stem), by wetting frill girdles, or by using injectors. Injectors deteriorate rapidly in wet climates and with the use of corrosive herbicides.

A combination of traditional methods for vegetation removal and chemical arboricides is found effective where low, dense, woody growth must be removed. Control of the introduced, leguminous, shrub marabu *(Dichrostachys glomerata)* in Cuba, found impractical by mechanical methods, has been successful with arboricide spraying at the beginning of the dry season and again during moist weather (Kudela 1978).

Special Site-Preparation Considerations. On soils susceptible to serious erosion because of texture, slope, or rainfall intensity, less complete site preparation may be appropriate. It is particularly important that the natural protective cover on such sites be preserved to the degree compatible with successful plantation establishment. This could mean leaving natural grasses, herbaceous cover, or low, woody growth between trees in contour rows. Sites must also be protected from damage by fires, grazing, and cultivation.

Large areas in tropical America that are unsuited to agriculture are poorly drained and may be low in timber productivity as well. At least some of these areas, and possibly all mangroves, have important water-conservation or wildlife-habitat values that may preempt their use for wood production.

In dry climates, the use of contour structures to trap needed rainwater, as is common in the Eastern Tropics, deserves further testing in America. Trenches with cross barriers apparently can be effective in such climates. Several of these traps have been tested in Mexico. The survival rate of *Chilopsis linearis* was increased in Coahuila from 20 to 100 percent by using such trenches (Zapien Barrogan and others 1978). Outlets must be carefully engineered, because a breakthrough may so concentrate waterflow that an entire slope is damaged. Under extreme conditions, the setting of wide, wooden sticks 30 cm long into the ground at the base of recently planted trees and slanting them perpendicular to the prevailing rains directs added rainwater to the trees.

Preparing sand dunes for fixation is a special case. Unstable, sharp, sand particles may be blown at high speed along the land surface, presenting a particularly adverse environment for the establishing plant cover. The nature of the substrate on these sites is also adverse, with low moisture retention and nutrient levels. Any natural vegetation present is usually desirable and should be left. Where sand movement is greatest, physical barriers of wood or other material can be used to slow the movement and build up the surface level. It may be necessary to increase the height of such barriers progressively as they become covered. This can be followed by planting shrubs or trees. Trees such as *Acacia* and *Pinus* are preferred for their crown densities near the ground. *Casuarina* proved successful near Veracruz, Mexico. Complete protection of exposed dune areas from grazing and fire is essential.

In much of tropical America, chemical treatment against leafcutting ants is also crucial to plantation success. In *Eucalyptus* plantations in Minas Gerais, Brazil, ants can reduce survival rates by as much as 15 percent (Simoes and others 1976). Treatment must extend to major ant colonies some distance from the planted area.

Vegetation that has been killed may also have to be removed in preparation for planting. The most common method has been burning. Many years ago in India, it was recognized that light burns do not necessarily destroy organic components of the soil (Griffith 1946). Burning was also found to reduce the acidity of the topsoil and to release significant amounts of nitrates. In fact, burning alone significantly increased the early height growth of planted trees, even into the second year. Burning has been a traditional site-preparation practice for *Eucalyptus* plantings in India (Lohani 1978).

General burning after tree harvesting in the miombo woodlands of what is now Zambia favors aggressive grasses (Cooling 1962a). For land preparation, it has proved better to uproot the large trees with tractors, dig out the smaller ones, and let charcoal burners clean up. The land is then plowed and harrowed at the end of the rainy season and fallowed over the dry season to prevent depletion of soil moisture.

The study of burning in preparing planting sites has shed more light on its effects (Anon. 1949a). Burning destroys organic acids and liberates bases, tending to neutralize acid soils, thus possibly improving conditions for plant growth. Burning has been seen as favoring bacteria rather than fungi, thereby changing the balance of nutrients available to plants. Burning also increases the soluble mineral nutrients in the soil for a protracted period after the burn. However, burning may destroy some of the organic matter in the immediate surface soil and can destroy all surface seeds. The released nutrients tend to be concentrated in the ash, so regeneration may do best where ash is concentrated. One of the benefits of burning may be the replacement of Ca in the ash.

The adverse effects of burning may show up in crop performance. In Papua New Guinea, burning of moist forests after logging depressed early height growth of a subsequent plantation of *E. deglupta* (Lamb 1976). Planted trees in unburned areas had an average height superiority of 2.6 m at 9 months and of 2.9 m at 15 months; the differences were significant at the 5-percent level. Foliar nutrient concentrations, including manganese (Mn) and boron (B) but excluding P and K, were up to 24 percent higher in the unburned area, the differences being highly significant. Phosphorus and K were significantly lower (at the 5-percent level). Growth inferiority in burned areas was blamed on the loss of N through fire, followed by only gradual recovery.

Once vegetation has been treated, the soil may also be prepared to conserve moisture, eliminate competitors, and improve texture for root penetration. In a planting in the savanna areas of northern Nigeria on land devastated by tin mining, the application of subsoilers to loosen the surface soil was important to the success of *E. camaldulensis* (Wimbush 1963). The soil was disked to control weeds. Tractors and subsoilers have been used also for *P. patula* plantings on the mountain grasslands of Madagascar (Vignal 1956). Disking for a plantation of *P. elliottii* in the Southeastern United States doubled the root surface at a 30- to 45-cm depth in the soil at 4 to 6 months in comparison with sites where no disking was done (Schultz 1972).

The use of machinery in soil preparation is advantageous only on good terrain and large planting areas (Letourneux 1960). The technology used must be justified not only financially but also socially, in view of trade balance and employment needs. It must also be recognized, however, that on many sites intensive soil treatment may greatly increase productivity. In the cerrado of Brazil, brush cutting with a heavy roller knife resulted in *E. saligna* plantations with 50 percent more early height growth than sites that were only plowed and harrowed (Mello and Rodriguez 1966). Even underplantings responded significantly to thorough ground preparation (Danso 1966).

In dry areas, soil preparation may be done chiefly to reduce water loss through runoff and evaporation. In areas of India with annual rainfall of less than 100 cm, the soil may be worked to a depth of 15 cm along planting lines, and rockwork bunds (ridges) may be constructed for erosion control (Laurie 1941a). Trenches about 4 to 6 m long, 60 cm wide, and 45 cm deep were dug in red soils, and the dirt was heaped to form a mound (Muthanna 1941). The seeds were then sown on the mounds. In a test with *A. arabica*, the use of contour bunds almost doubled the early height growth (Ahmad 1957). Elsewhere, the trenches have been refilled with the loose earth where the sowing is then done (Singh 1951). On barren areas planted with *Anacardium occidentale*, pits 50 by 50 cm were dug, and the soil was exposed a month before being replaced for planting (Iyppu 1957). Complete land clearing and deep plowing in advance of tree planting in India have long been done to prevent water loss (Shetty 1973). Full soil preparation, with disking, is done in the cerrados of Brazil for the same reason (Ayling and Martins 1981, Simoes and others 1976). In India, where the annual rainfall is less than 50 cm, taungya farming may begin 3 years before tree planting (Sweet 1946).

Under extremely dry conditions, pits to capture water may be dug well in advance of planting to take advantage of short moist periods. In India, ditches have been dug 30 to 40 cm deep before the rainy season either on the contour or spaced about 3 m apart (Sahai 1945). Seeds of *Acacia, Dalbergia,* or *Prosopis* were sown, and the earth was replaced loosely at the beginning of the rains (Krishnaswamy 1960).

Spacing of Planted Trees. Tree spacing affects planting costs, the need for later silvicultural treatment, and ultimate yields. Chapman and Allan (1978) listed factors influencing the choice of spacing in tropical plantations:

- Growth rate (the closer the spacing, the slower the rate)
- Tree form, crown shape, and degree of self-pruning
- Weed hazard and need for mechanized weeding, side shade from natural intergrowth, and taungya weeding
- Prospective rooting depth (wider spacing is needed where rooting depth is shallow)
- Marketability of early thinnings, and final d.b.h.
- Costs of culture and of carrying investments.

Evans (1992) listed some of the effects (good and bad) of wide spacing, including: cheaper ground preparation, fewer trees required, higher survival rates, mechanization of planting and tending favored, longer tending and fire-hazard period before stand closure, thicker and more persistent branches to prune, less need for precommercial thinning, and fewer trees to harvest per volume unit.

For field planting, the spacing most commonly used ranges from 1.8 by 1.8 to 2.5 by 2.5 m, but there are many exceptions. In one area of Madras, India, spacings of *Casuarina* as close as 1 by 1 m have been used for fuelwood production; yields were 200 to 250 t/ha of dry wood after 4 years (Kaul and Gurumurti 1981). Even closer spacings (0.9 by 0.9 m) have been used with *Sesbania grandiflora* for 3-year fuelwood rotations. On favorable sites, the trees reach 8 m in height and an average d.b.h. of 10 cm with yields to 40 t/ha/yr air-dry (Bhat and others 1971).

In southern Brazil, *Eucalyptus* for cellulose has been commonly spaced at 2.5 by 2.5 m or 2 by 3 m and *Pinus* at 2 by 2 m for pulpwood or 2.0 by 2.5 m for sawtimber (Simoes and others 1976). For *P. caribaea* in Venezuela, a common spacing has been 2.5 by 2.7 m (Lama Gutierrez 1976). Plantings of *Cupressus lusitanica* in Costa Rica have been spaced at 1.5 by 1.5 m to foster natural pruning (Holdridge 1953).

In the Amazon plantings at Monte Dourado, Brazil, *G. arborea* has been spaced 3.5 by 3.5 m and *P. caribaea* at 4.0 by 2.5 m to provide access to the trees (Woessner 1980a). Spacing for *Anacardium occidentale* on barren areas in India may be as wide as 10 by 10 m (Iyppu 1957).

Studies of *P. elliottii* in southern Queensland, Australia, over a 20-year period show the greater value of wide spacing for the long rotation, despite the lower yield, a reflection of the importance of tree diameter (table 6–7; Anon. 1972a).

Studies of *P. elliottii* grown for sawtimber in southern Brazil show that at spacings as wide a 2.8 by 2.8 m too few well-formed trees were available for final crop selection (Fishwick 1976). In addition, the number without growth defects increased with closer spacings.

Plantations of *O. lagopus,* a tree requiring very wide spacing, were tested in what is now Sri Lanka at 3 by 3 m and 4.6 by 4.6 m; the latter proved better (Parsons

Table 6–7.—Spacing effects on *Pinus elliottii* in Queensland, Australia

Spacing (m)	Productivity (m^3/ha/yr) Age 12	Productivity (m^3/ha/yr) Age 20	Relative value per yr.[a] (%) Age 12	Relative value per yr.[a] (%) Age 20
2.1 by 2.1	13.7	19.5	41	92
3.0 by 3.0	11.1	16.3	39	100

Source: Anon. 1972b.

[a]As a percentage of the relative value of the 3.0- by 3.0-m spacing at age 20.

1943, 1944). In India, balsa spacing has varied with the site, from 3.7 by 3.7 m to 4.6 by 4.6 m on poor sites to 5.2 by 5.2 m on good sites (Nair 1953). In Papua New Guinea, initial spacing has been at 2.1 by 2.1 m, but thinning has been done after 1.5 years to an average spacing of 3.9 by 3.9 m (White and Cameron 1965).

Wardle (1967a) has shown that in England tree spacing can be prescribed on an economic basis with some certainty and that a range of spacings from close to wide may affect total volume production by less than 10 percent. There, 2.4-m spacings were at one time found to yield about 95 percent of the maximum in net discounted revenue. Closer spacing increased volume but sharply diminished monetary returns. Wardle points out that physical production in the narrow sense is generally just one objective of a spacing decision. Others may be the value at the time of harvest, the net discounted value, or the risk of loss.

Comparisons of four species of *Eucalyptus* near Sao Paulo, Brazil, showed that a spacing of 1.5 by 3.0 m yielded more stacked wood (and bark) for particleboard at 5 years than a spacing of 2 by 3 m, but the mean diameter was significantly smaller (Simoes and others 1976). For paper manufacture, the wider spacing yielded the greater volume of usable wood.

Evans (1992) concluded that for field plantings, three ranges of spacings are desirable: (1) for fuelwood with maximum yield per year and no small-size limit, 1 to 2 m; (2) for pulpwood logs from 10 to 40 cm in diameter, 2 to 3 m; and (3) for sawtimber and veneer requiring logs 30 cm or more in diameter from trees selected by thinnings, 2.5 to 4.5 cm.

The effects of extremely close spacing of plantations of *L. leucocephala* are apparent in a Taiwan study by Wang and others (1984). The "Salvadorian type" of *L. leucocephala* was used, and density ranged from 2,500 to 40,000 trees per hectare. The yield at 4 years is shown in table 6–8. The high biomass production shown for the 40,000-per-hectare spacing is deceptive. Mortality eliminated 12,000 trees per hectare, and 74 percent of the survivors were less than 4 cm in d.b.h. and so could not be used for pulpwood, reducing the ultimate size of the crop to 7,000 trees per hectare.

A similar experiment with *S. sesban,* conducted in India, showed that the d.b.h. decreased with closer spacing but yield increased (table 6–9; Dutt and Pathania 1986). Although the last column in table 6–9 may exaggerate the results because it does not include mortality, it suggests an inevitable contrast between tree size, which is significant not only to utilization but also to the cost of handling.

In taungya plantings, where trees are interplanted with food crops, tree spacing has been wide to ensure a cropping period long enough to reward the cultivator for land preparation. Thus, in India, taungya plantings of *Acacia arabica* and *D. sissoo* have been at 3.7 by 4.6–m spacings (Sahai 1945). In what was formerly Zaire, where *Terminalia superba* has been interplanted with bananas, the tree spacing ranged from 3.7 to 5.5 m (Baur 1964a). At Monte Dourado, Brazil, plantings of *Eucalyptus, Gmelina,* and *Pinus* have been spaced 2.25 by 4.00 m to prolong forage production where grazing is planned (Woessner 1980a). *Pinus caribaea* taungyas in Trinidad have been planted at a spacing of 2.7 by 2.7 m (Lackhan 1976).

Table 6–8.—Spacing effects at 4 years on *Leucaena leucocephala* biomass yields in plantations in Taiwan

Tree component	Biomass of trees planted (t/ha) *N* = 2,500	*N* = 10,000	*N* = 40,000
Stems	36	50	83
Branches	8	6	11
Leaves	3	3	6
Roots	11	13	24
Total	**58**	**72**	**124**

Source: Wang and others 1984.

Table 6–9.—Spacing effects on tree volume at 30 months for *Sesbania sesban* in India

Spacing (trees per ha)	Mean d.b.h. (cm)	Yield (m^3/ha/yr)	No. of trees per cubic meter[a]
2,500	7.7	21	48
5,000	6.5	29	69
10,000	5.3	39	103
20,000	4.0	41	195
40,000	3.1	45	356

Source: Dutt and Pathania 1986.
[a]No mortality assumed.

Spacing of underplantings has been wider still. In fact, the need for few trees per unit of area has been an important argument for the practice. Because the natural forest is left between the rows, close spacing is not required to ensure good tree form. In the Central African Republic, spacing of *T. superba,* has been 12 by 12 m, compared with francophone Africa, where spacing has ranged from 5 to 20 m between lines and from 3 to 7 m within the lines (Aubreville 1958; Baur 1964a; Catinot 1965, 1969a).

Underplantings in Malaysia have been spaced at 2 m in lines 10 to 12 m apart (Tang and Wadley 1976a, 1976b). In Fiji, underplantings of *Swietenia macrophylla* have been spaced about 3 by 12 m (Busby 1967). In Papua New Guinea, *Araucaria hunsteinii* has been underplanted at a spacing of 3 by 7 m (Godlee and White 1976).

Spacing for underplanting may be a function of the crown diameter of the trees at maturity. In Africa, it is recommended that spacing between lines be at least equal to final crown diameter or slightly wider to permit persistence of natural trees (Dawkins, cited by Lamb 1969a). Within the lines, the trees have been spaced about one-fifth of the distance between the lines, providing for a good selection of final trees.

Final crown width has been measured on uncrowded trees. As an example, in Malaysian lowland dipterocarp forests, *Dyera costadata* has a crown-diameter-to-bole-diameter ratio of about 17, considered remarkably low for a fast-growing tree (Wong 1966a). The distance between the lines for this species at 60 cm in d.b.h. at maturity, using triangular spacing, becomes 0.60 × 171/155 = 8.8 m. Other Malaysian trees have a crown diameter-to-d.b.h. ratio ranging from 16.5 to 25 (10 to 15 m for trees 60 cm in d.b.h.), and line spacing is frequently calculated at 1.5 times this amount, with initial spacing within the lines at 1.8 m (Tang and Wadley 1976b).

Widely spaced, group plantings have been tested extensively in the Tropics. They are frequently associated with the name Anderson because of his description of early group plantings in Scotland and northern England (Anderson 1953). The Anderson concept is that a group of trees, rather than a single tree, is the planting unit and that the units are spaced widely enough that much of the area between the units remains unstocked until the planted trees mature. There are variations in the initial number of trees per unit, the composition of the unit, the spacing within the unit, the spacing between units, and the species mixture. The number of trees per unit has ranged from 3 to 25, spaced 1 m or less apart; inferior trees are thinned out early to favor the best. Species mixtures may be alternated within or between groups. Spacing within units has varied from 30 to 150 cm and between units from 2.8 to 7.5 m. In Uganda, the method has been used successfully with 5- by 5-tree squares with internal spacing of 1 m (Lawton 1976).

Advantages attributed to the Anderson pattern are facility in relocation for weeding, thinning, and harvesting; relative freedom from branches on interior trees; and wind stability. There is a tendency for the outer trees to dominate, but this may not be an important drawback because early thinning can favor the best trees. In Brazil, it was noted that damage from Meliaceae shootborers was seldom spread throughout each unit; in other words, some trees in each group tended to escape attack.

An adaptation of the Anderson pattern has been tested in Suriname with *Cordia alliodora* (Vega 1977). There, trees are planted 1 m apart in triangular spacings in secondary forests at the time of overstory poisoning. The units are spaced 5 by 10 m apart, or 200 per hectare, with an expected harvest of 130 to 150 trees. Tests in Brazil are using closer spacings within the unit, but the units are separated by 20 m.

Spacing involves much more than the number of trees required and the ease of early tending. Equally important are its effects on stem straightness, natural and artificial pruning, stem taper, diameter growth, and the size of the trees when a first thinning might be required.

Studies of these relations have been made under tropical conditions or where conclusions may be applicable to the Tropics. An early fuelwood production experiment with *E. saligna* in Sao Paulo, Brazil, illustrates the results of different spacings (table 6–10; Guimaraes 1957, Navarro de Andrade 1939). The return on the investment probably favored the wide spacing even more than is shown because a constant value per cubic meter was used, without taking into account the probable lower cost of handling the fewer, larger pieces yielded by the wider spacing.

A spacing test in Kenya with exotic softwoods compared 10-year growth at 1.8- by 1.8-m, 2.1- by 2.1-m, 2.4- by 2.4-m, and 2.7- by 2.7-m spacings (Anon. 1962a). Mean branch size and the mean height of all trees was depressed by close spacing, but for the 250 largest trees per hectare, mean height was slightly greater at close spacing than at the wider spacings. The diameter of the largest 250 trees per hectare was about the same regardless of spacing. The widest spacing produced many poorly formed trees, some of them large; therefore, thinning them out left the mean diameter of the remaining crop smaller than the mean diameters of the two intermediate spacings.

In a study of *E. saligna* in Hawaii, the diameter-growth rate of dominant and codominant trees was less affected by spacing than that of the entire stand (table 6–11; Walters 1973, Walters and Schubert 1969). Dominance continued to benefit growth to the 10th year.

Another study in Hawaii involved *P. taeda* (Whitesell 1974). Crown closure occurred by the 4th year for the 1.8- by 1.8-m spacing, by the 7th year for the 2.4- by 2.4- and 3.0- by 3.0-m spacings, and by the 11th year for the 3.7- by 3.7-m spacing (table 6–12). The progressive effects of spacings are again apparent. The benefits of wide spacing on diameter growth continue to increase with time. The decline in basal-area growth at close spacing is indicated by the relative increase in the basal area at the wider spacings.

A study of the same species, *P. taeda,* in the Southeastern United States shows the influence of spacing on harvestable volume (Balmer and others 1978). The age of the plantation (15 years) is not indicative for the

Table 6–10.—Spacing effects on tree yields at 8 years for *Eucalyptus saligna* in Sao Paulo

Spacing (m)	Trees per hectare (thousand)	Mean d.b.h. (cm)	Yield (m^3/ha/yr)	Return on investment (%)
1 by 1	10.2	7.2	33.4	–3.7
1 by 2	5.2	8.6	33.2	3.4
2 by 2	2.6	11.8	30.8	15.8
2 by 3	1.7	12.5	25.8	20.4

Source: Guimaraes 1957, Navarro de Andrade 1939.

Tropics, but the relationships are (table 6–13). The 3.0- by 3.0-m spacing yielded more than three times as many trees larger than 20.3 cm in d.b.h. than the 1.8- by 1.8-m spacing.

Triangular spacing has its proponents who see it as a way to distribute space more uniformly among planted trees. Each tree is placed at the center of a hexagon of six other trees and thus equidistant from each of its neighbors. Triangular spacing allows 15 percent more trees per unit of area than square spacing, or a 7.5-percent greater minimal distance between trees (Wakeley 1954). Triangular spacing is of special interest in experimental studies of spacing, but requires more care in alignment than may be justifiable in large-scale plantings.

Looking to the future, Lewis (1968) concluded that the advantages of a small core of juvenile wood and perhaps smaller branches, which have long been reasons for close spacing, will probably have to be foregone in an era when quantity will be more important than quality.

Planting Guidance. The layout of plantings requires forethought and planning. Access to the area must be provided, and protection from fire and animal damage may be needed from the outset. Tree alignment is important on all but the roughest terrain. Straight rows make row thinning possible (Brown 1965) and facilitate the use of mechanical equipment for culture and harvesting. They also foster uniform spacing and, therefore, fullest use of the site. Plantings have been commonly laid out by means of two long tapes marked with the planting distance. The tapes are laid out at right angles to each other and moved progressively over the terrain for staking each planting spot. This task should be completed before good planting weather arrives. In rough terrain in Mexico, the edge of the plantation has been marked, allowing the planters to use the spacing of the first row as a guide for spacing the trees in each subsequent row (Martinez McNaught 1978). Use of a single tape is normally adequate for mechanized planting.

Planting on all but the most favorable sites in the Tropics is done by hand. The large project at Monte Dourado,

Table 6–11.—Spacing effects and tree growth at 5 years for *Eucalyptus saligna* in Hawaii

Spacing (m)	Mean d.b.h. (cm)		Basal area (m^2/ha)	Comparative 5–10/0–5yr. basal area growth per tree[a] (%)	
	Dominants and codominants	All trees		Dominants and codominants	All trees
2.4	19.0	15.7	33.6	0.98	0.51
3.0	21.3	17.8	27.6	1.01	0.54
3.7	21.8	18.8	20.3	1.05	0.64

Source: Walters 1973, Walters and Schubert 1969.
[a]Basal area growth between the 5th to 10th year as a percentage of the growth for the first 5 years.

Table 6–12.—Influence of spacing on growth of *Pinus taeda* in Hawaii

Spacing (m)	Comparative plantation development[a] (%)					
	Stem diameter			Basal area per hectare		
	4 yr.	7 yr.	11 yr.	4 yr.	7 yr.	11 yr.
1.8	100	100	100	100	100	100
2.4	107	117	119	62	72	79
3.0	107	128	136	43	59	67
3.7	117	143	153	35	51	60

Source: Whitesell 1974.
[a]Relative to 100 for 1.8-m spacings.

Brazil, at least until 1980, has been planted entirely by hand (Woessner 1980a, 1980b). Most tropical sites appropriate for forest plantations do not favor the use of machinery nor do conventional types of containerized planting stock. The trees are carried along the planting lines in trays with wet packing or other containers to protect roots from exposure. Holes are opened in the soil of a size and shape to accommodate the root systems of the trees in a natural position. For bareroot stock, the hole may be made with a bar with a narrow, spadelike blade or with a conventional spade. A danger here is that in an effort to minimize the work, too small an opening is made, and the roots are cramped when the hole is tamped closed. Whatever tool is used, the tree should be set at about the same depth as in the nursery (the root collar at the surface level).

Tamping of planted trees is normally done with the heel of the planter's shoe, firmly on at least two sides. Air pockets must not be allowed to remain in the soil near the roots. Hard-packed, tamped, clay, surface soil should be mulched around the trees with litter to prevent high surface temperature and rapid evaporation.

Table 6–13.—Spacing and yield at 15 years for *Pinus taeda* in the Southeastern United States

Spacing (m)	Trees per hectare	
	D.b.h. > 15.2 cm	D.b.h. > 20.3 cm
1.8	1,373	111
2.4	1,388	496
3.0	1,008	652
3.7	699	642

Source: Balmer and others 1978.

Except when it is in small, rigid tubes, containerized stock requires larger planting holes than bareroot stock. These holes are commonly made with a pick-mattock. This process tends to mix both surface and subsoil and may expose hard clods. When the containers have been carefully opened or removed, it is best to place topsoil against the root mass and then fill the rest of the hole with subsoil, breaking up any large clods. Tamping should be done gently near the root mass, but repeatedly as the planting hole is filled. In dry areas of the Tropics, the holes are sometimes opened early in the wet season to capture moisture before planting (Mathus Morales 1978b).

A major advantage of small, tubular containers is that they require only small, cylindrical holes for planting, which can be made with a pointed metal bar. Special care is needed to ensure that the depth is correct and that tamping eliminates air pockets.

Newly planted trees must be easily identified so the site can be weeded. The use of large planting stock may make this easier, but placing a stake next to smaller trees may be advisable. Ease of relocating trees is a major reason for planting in straight rows.

The use of planting machines has greatly accelerated planting rates on suitable sites. Machine use is limited to large, relatively flat sites that are neither swampy nor rocky and in climates where bareroot seedlings can be expected to survive. Machines use a vertical blade to cut the soil to a desired planting depth. Then, a wedge-shaped blade opens the slit wide enough to allow manual placing of tree roots in the opening. The slit is closed by pressure from two rubber-tired wheels mounted side by side, forming a "V." Two lines may be planted behind a single tractor. As many as 12,000 trees may be planted per machine per day (Chapman and Allan 1978). Machines have been utilized effectively in eastern Venezuela and southern Brazil. The largest mechanized-planting project in the region may be one that involves *P. caribaea* planted on savannas in Venezuela's lower Orinoco basin. Some planted bareroot stock has been lost as a result of unexpectedly dry weather, but subsequent replanting has also been done by machine because of the large scale of the operation.

In Malaysian mangroves, *Rhizophora mucronata* is planted by manually pushing the already germinated hypocotyls deeply into soft mud (Walker 1938).

Some foresters have assumed that under dry conditions, planting stock should be set deeper than in the nursery. But tests in the Sudan with *Azadirachta indica* indicate that on dry sites trees should be planted at the same depth as in the nursery, that is, with the root collar at the surface (Reynders 1965). Also, the desirability of removing the plastic bags from the roots under such conditions has been questioned. Test results with *E. microtheca* in the Sudan suggest that leaving the bags on seriously delays root development and lowers drought and wind resistance of the trees (Wunder 1966). On the other hand, in the miombo woodland region of what is now Zambia, *Eucalyptus* stock has been successfully established leaving the bottomless, black, polyethylene tubes about 9 cm in diameter and 15 cm deep attached around the roots (Cooling 1962a).

Tests of direct seeding in Kenya with *Cupressus lusitanica, P. patula,* and *P. radiata* proved the efficacy of using bamboo slats to direct rainwater to the tree (Howland and Hosegood 1965). Slats 1 m long and 2.5 cm wide were placed in the soil so that each slat stood up at an angle perpendicular to the usual slant of the rainfall; each tree was also surrounded on its lower side by a sleeve of bamboo to retain surface water. The sticks and sleeves proved vital for survival, providing 60 percent more water to the trees.

The cost and quality of the planting job depend on the expertise of the planters. For hand planting, a supervisor is generally needed for every 10 to 16 workers. Worker time must be judiciously balanced between transporting and planting. "Lining out" (the location of tree sites to be planted), if it is to be done at the same time, is better organized as an independent operation, ahead of the planters. Trays that shelter the stock from sun and wind may be carried by the planters themselves, each planter making the planting hole, planting the seedling, and covering the roots. On difficult terrain, one worker makes holes and a partner plants seedlings. The supervisor should check not only for tightness of the soil but also for planting depth and root-system spread.

In tropical America, most trees have been planted by unskilled rural workers. The assumption is that those who plant other crops know what to do, an assumption close enough to the truth to have yielded many successful plantations. One result of such an assumption, however, is unexpected losses from improper care in planting. Initial training should include indoctrination in the purposes and importance of the work, demonstration of each practice, and close observation of initial performance. Instruction in accident prevention and first-aid is also essential. Minimum safety equipment includes special footwear, shinguards, gloves, headgear, and first-aid kits.

Crew training for mechanized planting must be more intensive, involving the use, care, and maintenance of mechanical equipment; inherent and avoidable hazards; accident prevention; and response in case of accidents. Access to safety equipment and first-aid materials is particularly important.

Soil Additives. Trees, like any other crop, require a balanced intake of 13 essential elements for satisfactory growth (Swan 1968). These include the macronutrients—N, P, K, Ca, magnesium (Mg), and sulphur (S)—and the micronutrients or trace elements—B, copper (Cu), iron (Fe), zinc (Zn), Mn, molybdenum (Mo), and chlorine (Cl) (Chapman and Allan 1978). Nutrient deficiencies are common in the marginal soils planted to trees. Tropical forests commonly grow on nutrient-deficient, siliceous sands or highly leached clays. After deforestation, these natural soil deficiencies can be ameliorated only by fertilizing.

Fertilizer use in forest plantations has been much less general in America than elsewhere in the Tropics, although its benefits have in some instances been impressive. Fertilizers have proved capable of increasing the site adaptation of different tree species as well as improving their resistance to pests and diseases (Baule 1979). A worldwide Food and Agriculture Organization (FAO) study of 13,000 fertilizer trials showed an average increase in growth of 73 percent with the application of fertilizer and an increased value-to-cost ratio (Phillips 1972).

Adding nutrients to the soil may spectacularly accelerate tree and stand growth in tropical forests, and the response may last for many years (Swan 1968). The potential gains to be realized by the correction of forest-soil deficiencies in the Tropics are more immediate and substantial than gains produced by other forms of intensive silviculture (Assman 1970). For most end uses, wood produced by trees receiving supplemental nutrients is little, if at all, inferior in quality to wood produced by trees not so favored.

The process of preparing for forest planting accentuates the prospects for nutrient deficiencies. Wholetree logging, clearing, and burning drain nutrients from the site and cause deficiencies just when the new trees most need nutrients—immediately following tree planting (Waring 1972). Studies in Kenya show that planted trees of *E. saligna* begin downward root growth into the moist lower soil layers within 2 weeks of planting (Griffith and Howland 1962). The response of newly planted trees to soil additives has confirmed their almost immediate need for nutrients (fig. 6–5).

Weed control and nutrient supply are the keys to early tree growth in the Tropics. The production gain is permanent, and the full growth potential of the site is directed to the tree at the earliest time (Waring 1972). Increased nutrient levels can also increase the number of tree species or provenances that can be grown as well as their resistance to pests and diseases (Baule 1979). Rational use of mineral fertilizer, selection of appropriate geographic provenances, and procurement of good-quality seeds are considered Brazil's three most important silvicultural requirements (Golfari 1977). Notwithstanding these many benefits, only a negligible area of the land planted to trees in the Tropics has been fertilized (Baule 1979).

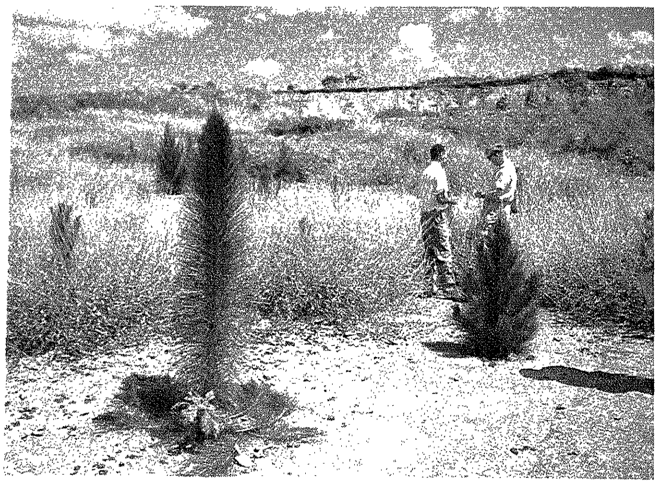

Figure 6–5.—*First-year growth of* Pinus caribaea *was induced by placing fertilizer in the bottom of the planting hole at the time of planting on a poor site in Jamaica.*

The best time for fertilizing is at planting. Fertilizer should be placed in the bottom of the planting hole beneath the reach of the roots of most weeds. Mixing the fertilizer with a small amount of soil may be desirable to avoid "burning" the tree roots. The amount and mix of nutrients or fertilizers should not be haphazard. One source of guidance is local agricultural practice. Another possible source is soil analysis. Yet another is to test in representative areas the early growth responses of trees to different amounts of each nutrient and nutrient combination, with unfertilized trees as controls.

Chemical fertilizers represent but one source of plant nutrients. For centuries farmers have been applying organic residues to their crops. Trees benefit from any residue left from previous forests or crops.

Attention to soil nutrients began early in India, where leguminous *Ipomaea* vines were interplanted in *Casuarina equisetifolia* plantations on beach sands to supply N (Sharma 1951). This practice was later found to be of no significant benefit, evidently because *C. equisitifolia* fixes much of its own N.

On land devastated by tin mining in northern Nigeria, reforestation with *E. camaldulensis* on bare subsoil was tried; a half shovel of compost and about 90 g of ammonium sulphate were added to each tree (Wimbush 1963). The trees grew to 3 to 4 m in height the first year. Without compost application, height growth was half as great.

The use of green manure or plant nutrients in tropical plantations began early with teak in Java (Alphen de Veer 1958b, Sieverts 1958). Teak was growing unsatisfactorily on poor soils. *Leucaena leucocephala,* considered a purveyor of N, was interplanted about 1 month after the teak was planted. But the *L. leucocephala* tended to compete with the teak at the latter's expense. However, heavily pruning back the *L. leucocephala* three times each year and placing the branches around the teak proved a very effective stimulus to the teak (Alphen de Veer 1958b).

Putting mixed, inorganic fertilizers in the planting holes at the time of planting has generally accelerated initial height growth. *Eucalyptus* planted in tubes on poor sites in Hong Kong attained high survival rates, but early growth was slow (Anon. 1954f). The addition of 15 to 30 g of ammonium sulphate per tree at planting time increased height growth by a meter or more within a few months.

In Colombia, poor growth of *Cupressus lusitanica* was found to be due to deficiencies in P and N (Tschinkel 1972b). Application of P fertilizer alone increased stand volume growth by 53 percent. Addition of N alone increased it 58 percent. Applied together, they increased stand volume growth by 230 percent. In the Philippines, application of 12-12-12 and 16-20-0 fertilizer to *E. deglupta* increased tree height by 2 m at 6 months; there was no marked difference between the responses to the two fertilizer mixes (Tagudar and Gianan 1970). In Brazil, the application of NPK greatly increased 1-year *Eucalyptus* height growth, and a difference of as little as 1 m repaid the fertilizer cost (Foot 1968a).

A test treatment of *E. saligna* in the savannas of Minas Gerais, Brazil, showed significant returns from applying 60 g of N, 80 g of P, and 20 g of K to each tree (Knudson and others 1970). Two-year heights for the treated trees averaged 7.2 m compared with 4.2 m for untreated trees. Adding small quantities of B and Zn further raised the mean height of treated trees to 9.1 m. In another experiment with *E. saligna* in the state of Sao Paulo, Brazil, the initial application of 5-17-3 fertilizer yielded, at 5 years, 266 stacked cubic meters per hectare versus 150 for the untreated controls (Simoes and others 1976). Fertilizers increased mean yields of eucalypts in Brazil to 35 m^3/ha/yr (Golfari 1977).

Fertilizer-growth acceleration with *P. caribaea* and *P. patula* in Uganda was limited to trees on sandy and highly leached red soils (Karani 1976b). Fertilizer was no substitute for clean weeding in terms of survival and initial growth. Pines, particularly, have responded unpredictably to fertilizer under many conditions. In Uganda, *P. caribaea* and *P. patula* responded to various fertilizers only on the poorest sands and leached clays (Karani 1976b). On one site, highly significant growth responses were attributed to Mg and K.

The use of slow-release fertilizers has recently been tested as a method of prolonging the stimulus to early growth. Placing such fertilizer about 8 cm from the tree roots in the planting hole at the time of planting resulted in a significant growth difference at the end of the first year for *Toona ciliata* grown in Hawaii (Walters 1975). This test was made in heavy grass, which also grew better because of the treatment, but the tree seedlings outgrew the grass.

Nitrogen has proved to be a key element in most fertilizer trials in the Tropics. The main effect of N is to increase the leaf area (Helms 1976). In a test with *E. deglupta* in Papua New Guinea, height growth increased with foliar N (Lamb 1977). In fact, foliar N accounted for 72 percent of the height variation at 15 months.

Nitrogen usually stimulates growth more than other minerals. Width of growth rings of pines in the Temperate Zone increases with the N content of the needles (Assman 1970). A test with *E. camaldulensis* in the Philippines, using N, P, and K, showed a growth response only to N (Mendoza and Glori 1974).

Light application of N fertilizer (34 kg/ha) at the time of sowing *L. leucocephala* in Papua New Guinea aided growth without inhibiting nodulation (table 6–14; Hill 1970). Note that N applications aided the *L. leucocephala* whether or not plots were weeded, but the higher fertilizer level was no more beneficial in the weeded plots than the lower level.

The scarcity of N in nature may limit the natural occurrence of some tree species. On the coastal lowlands of Queensland, Australia, hoop pine, *Araucaria cunninghamii,* does not occur naturally (Richards 1962). On lateritic and podzolic soils, plantings of this species failed and were replaced with *P. taeda*. After the latter became established, the surviving hoop pines improved. Apparently, hoop pines need N that the *P. taeda*

Table 6–14.—Nitrogen application and weeding benefits to *Leucaena leucocephala* in Papua New Guinea (kg/ha)

Nitrogen application	9-week green wt. of forage	
	Unweeded	Weeded
0	750	960
34	830	1,650
68	1,090	1,650

Source: Hill 1970.

somehow supplies (Richards 1962). This theory is supported by the fact that pure plantings of hoop pines do better with applications of 120 kg/ha/yr of fertilizer (Richards 1967). However, N fixation by pines, although claimed by some, is unsubstantiated. The N might come from other organisms favored by the pines. Native legumes do not supply enough N for hoop pines. Pine litter does not appear to be the source of this N because the hoop pines do well in openings in sparse pine stands that are beyond the littered area but not beyond the root spread. It was postulated that the *P. taeda* might also repress some organisms antagonistic to the hoop pines (Richards 1962). Site "preparation" by the *P. taeda* takes 5 to 6 years. Underplanting *P. taeda* with hoop pines gives promise of success.

Nitrogen-only applications can be chancy (Swan 1969). Many experiments have shown varied results of such treatments, and the equal importance of P and K has repeatedly been demonstrated. Research is needed to clearly distinguish causes of problems.

Growth of *P. caribaea* plantings on coastal sands in Tanzania decreased where N fertilizer was applied without P (Dick 1969). The cause was concluded to be a serious P deficiency. A similarly weak growth response was reported from a controlled experiment of *P. caribaea* in Queensland, Australia (Cameron and others 1981). Application of N plus trace elements led to reduced dry weight after 238 days. These same additives stimulated growth in the presence of P.

A more elaborate study with *P. radiata* in Australia shed additional light on the interaction between N and P (Waring 1968). Applications were made five times during the first 4 years of a plantation's life. Nitrogen, in the form of urea, was applied at the rate of 50 g per tree, or 600 kg/ha. Phosphorus (dicalcium phosphate) was applied at the rate of 20 g per tree, or 235 kg/ha. Nitrogen and P together produced about three times the height growth and five times the basal area growth of the controls. Phosphorus alone almost doubled the N uptake from the soil over that of the controls. Trees receiving both N and P took up more than six times as much N as the controls, or about 25 percent of the applied N. The trees receiving N and P took up 18 percent of the applied P compared with only 3 percent for trees receiving the same quantity of P without N. The addition of P raised N intake by 50 percent, apparently because of an increase of N mineralization or better exploitation of the soil by stimulated root growth. Phosphorus uptake with added N (but no added P) was only 60 percent of what it was without added N, indicating an increased P deficiency in the presence of N.

An Australia-wide test of N, P, and K application at the time of planting showed *E. globulus,* one of the species most planted in western tropical America, to be more responsive to fertilizer than several other *Eucalyptus* species (Cromer and others 1981). The application of N and P greatly affected the N-to-P ratio of the leaves. A ratio of about 15:1 seemed right for *E. globulus* because above that level the response was to P application, below it, the response was to N.

Although foliar analysis has been useful for measuring nutrient deficiencies in the Tropics, Evans (1992) cites data collected from *G. arborea* that indicate a great need for standardizing procedures in collecting leaf samples for comparative analysis (table 6–15).

A test with *P. caribaea bahamensis* on a cerrado site with poor, acid soil in the State of Sao Paulo, Brazil, showed a 1-year height growth of 1.3 m versus 0.8 m for the control; apparently, the difference was due chiefly to the addition of P and Ca (Simoes and others 1976). Experience in Colombia appears to confirm the importance of these two nutrients (Ladrach 1974). *Cupressus* was similarly stimulated by Ca. Tests with *E. grandis* have shown a need for B (Chapman and Allan 1978). Without it, no salable wood yields were produced, but with it, yields reached a mean annual growth of 25 m^3/ha. Studies in

Table 6–15.—Foliar nutrient variation in the leaves of a single *Gmelina arborea* tree

Location	Nutrient (% oven-dry wt.)			
of leaves	N	P	K	Ca
Upper crown				
Topmost	2.10	0.11	1.5	1.0
Outer	1.86	.11	1.6	1.0
Inside	1.69	.10	1.1	1.8
Lower crown				
Outer	1.79	.11	1.5	1.5
Inside	1.39	.08	1.6	1.7

Source: Evans 1992.
Note: N = Nitrogen. K = Potassium.
P = Phosphorus. Ca = Calcium.

Colombia have also shown benefits from B applied to *E. grandis* (Cannon 1981).

In Australia, where the productivity of successive crops of *P. radiata* has been under intensive study, the use of fertilizers has become a necessity. It has been concluded that any decline in soil fertility can be arrested by judicious use of legumes and N fertilizers (Waring 1968).

Irrigation of fuelwood plantations is not uncommon in dry areas throughout the Tropics. At Changa Manga, Pakistan, plantations of *D. sissoo* have received about four times the amount of water used locally for agriculture (Tahir and Ali 1974). After a century of fuelwood production, surface soil had four times the organic matter content of virgin soil and five times its N content. Both P and K content, however, were less than in the virgin soil.

This chapter has presented a variety of experiences with nutrient requirements for planted trees, some with apparently conflicting results. What is illustrated is the great variation in conditions and corresponding needs. Application of inorganic fertilizers should normally be considered only as a supplement to the natural level of nutrients. To the degree that these are unknown, the application of fertilizers can be expected to produce unexpected results, either positive or negative. Trial-and-error at an experimental scale has been the basis for many findings in the past. In the future, fertilizer applications must be based more on prior soil studies.