Chapter 9

Forestry Technologies for Disturbed Forests

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HIGHLIGHTS

Management of Secondary Forests

- About 400 million hectares (ha) of potentially productive closed secondary forests exist in tropical nations. If managed properly, secondary forests could satisfy the growing wood needs in the tropical nations that have substantial closed forests.
- Technologies to manage secondary forests are not yet adequate to assure suitable returns on investment. Technologies are needed to reduce costs and increase yields.

Reforestation of Degraded Lands

- Approximately 2 billion ha of tropical lands are in various stages of degradation. Opportunities exist to increase productivity of these extensive areas and, at the same time, meet the growing need for forest products and environmental services.
- Plantation management, like secondary forest management, is constrained by a lack of investment. Again, the solution seems to lie in reducing costs and increasing benefits.

INTRODUCTION

Growing populations and increasing needs for fuel, food, fodder, building materials, and work opportunities have caused selective logging and tropical deforestation. When cleared forest land cannot sustain the new land use, the consequences include land degradation, abandonment, and varying degrees of recovery. After either logging or agricultural clearing, the type of vegetation that returns generally depends on the intensity of land use and degree of degradation that have occurred and on whether the site has been grazed or burned. Usually, second growth forests appear; sometimes grasses invade, sometimes only barren wasteland is left.

The selection and application of forestry technologies on these lands will vary depending on the vegetation. If enough valuable trees exist in the secondary forest and the site is not too degraded, some form of canopy or understory manipulation can be applied. If the site is severely degraded and natural tree regeneration is difficult, complete clearing foIlowed by site preparation and field planting may be more appropriate. The following describes various forestry technology options according to vegetative cover.

MANAGEMENT OF SECONDARY FORESTS

Background

Where tropical forests have been exploited by wood harvesting and/or by shifting cultivation, the land is commonly "returned to nature" and secondary forests are allowed to develop. Secondary forests, for the purpose of this report, include both residual forest that has been cut once or several times during the past 60 to 80 years and second growth forests that invade after periodic cultivation. This includes the "logged" and "forest fallow" categories discussed in chapter 3.

In the past, foresters considered tropical secondary forest trees of little use because the trees were perceived as having poor form, being inferior species, or simply too small. Most of these trees are not used except as poles or fuel. Unless an especially good market for fiber or fuelwood exists, secondary forest land usually is left idle or converted to marginal croplands.

These reasons for not investing in secondary forest management technologies are being dispelled as knowledge of secondary forest species improves. Secondary forests often are more homogeneous than mature forests because the vegetation that grows after a site has been cleared usually is dominated by a few pioneer tree species. This can simplify management, harvest, and use of the secondary forest. Furthermore, pioneer tree species are fast-growing, their wood is uniform and light, and their stems tend to be straight and dominated by a single leading shoot. Such characteristics can make these species marketable. Since the leaves of these species usually are large and thin, adequate light can reach the understory to permit development of dense undergrowth. This understory frequently includes late successional hardwood species that are valuable for timber–e,g., ***Meliaceae.*** Finally, the wood of the secondary pioneer species usually lacks resins and silica and this facilitates wood processing, although it makes the trees vulnerable to damage (19).

Technologies

Desription

There are several technologies that could be used to improve the productivity of secondary forests. These technologies vary in intensity of treatment. The choice depends on the quality and quantity of tree species found in the forests as well as the management objectives. The following technologies are presented from least to most intensive:

- No ***Treatment—No*** silvicultural treatment is applied. The success of regrowth is dictated by the duration and severity of past forest modifications and by soil quality, moisture availability, and access to the area by missing components of the former forest, including tree seeds and animal life.
- Refining-This is also known as improvement felling and timber stand improvement. Some trees are removed to give more growing space to other, more desirable trees. The underlying premise is that potentially valuable trees, unless tended, will be constrained by competition with less valuable trees for light, moisture, or nutrients. It is justified only in forest stands that already contain enough valuable trees to promise an economic crop.
- Tropical shelterwood—This treatment consists of removing the upper layer of canopy in one or more cuttings to promote either germination or the growth of existing understory seedlings or saplings. Periodic weeding is necessary.
- Underplanting—Trees are planted under some living portion of the former forest to ensure a rapid-growing new crop of acceptable tree species.

Assesment

Each of these secondary forest management technologies has certain technical, environmental, economic, and sociopolitical constraints.

No Treatment.—Untreated secondary forests are low-input/low-output. The attractiveness of no treatment, with its lack of initial expense and investment, is offset by low harvestable yields (61). For instance, a 20-year record from unmanaged residual forests in Puerto Rico showed an annual yield less than 5 cubic meters per hectare (m_3/ha) (5). This calculation is based on merchantable timber. Thus, yields might be increased by expanding the market for the materials produced.

Repeated harvesting may cause an eventual decline in site productivity due to nutrient losses. Harvesting all the stemwood from a moist tropical forest can remove 10 percent of the ecosystem's nitrogen, 39 percent of the phosphorus, 38 percent of the potassium, 20 percent of the calcium, and 57 percent of the magnesium (20). However, development of harvesting systems that leave forest structure* and its nutrient-cycling mechanisms intact is constrained by financial considerations. For instance, although small-scale clearings recover more quickly than large disturbed areas, this approach often is not suitable for commercial forestry because of higher costs incurred in the transportation of labor and machinery.

Nevertheless, harvesting systems are being designed to reduce nutrient loss. A harvesting method used with some success in the United States has been proposed for adaptation to the Amazon forests (34). In this scheme, a strip of forest is harvested on the contour of a slope. A haulage road is built along the upper edge of the strip. After harvesting, the area is left alone until saplings appear. Then a second strip is cut above the road. Nutrients washed downslope from the freshly cut second strip can be captured and used by the new trees in the original strip. The remaining mature forest can provide seeds for regeneration. Once a network of roots is reestablished in a strip, another strip farther up the slope can be cut, the timber used, and the newly cut strip then regenerates naturally (fig. 27).

*Forest structure: distribution and arrangement of trees in a forest stand.

Strip logging, like clear-cutting, has economic problems because many of the tree species cut do not have well-developed markets.

Refining. —Forest refinement has advantages and disadvantages. Few good trees are needed for this treatment. As few as 100 saplings per hectare, if refined, could produce a fully stocked crop of mature trees (11). But logging damage and post-logging mortality can limit the use of this treatment (49,55). The application of logging controls throughout the Tropics might greatly increase the area of forest meriting refinement. For instance, successful control of logging damage in the Philippines has enabled the use of refining in large areas (22).

Refined moist secondary forest produces about 6 m^3/ha/yr of merchantable wood (14), a quantity similar to that from untreated forest. There is an improvement, however, in wood quality. Results vary widely with forest stand history. Although yields are low relative to those of more intensive management technologies, the required investments are also low and often in line with available financial resources (38,51). Thinnings seem to shorten the time between harvests (31). Also, when the full costs of more intensive technologies are taken into account, refining may compare favorably with the intensive treatments (38). Nevertheless, more research data are needed, especially about costs and financial returns, for complete analysis of this treatment.

A variation of the refining practice is known as ***"liberation thinning."*** In this technique, desired trees are identified and liberated from competition with less desired tree species, It is an important element in the silviculture of residual ***Dipterocarp*** stands in Sarawak (31). However, in general, only large clearings are needed to stimulate understory growth, and sometimes even these fail (12). The selected trees, if subordinate in canopy position in early life, may be incapable of later accelerated growth.

Another variant of the refining practice is the ***polycydic system*** (or selection silvicultural

Figure 27.-Harvesting Scheme

SOURCE: C. F. Jordan, "Amazon Rain Forests," *American Scient/sf* 70(4): 394-401, 1982.

system), which preserves the natural forest structure. Mature trees are harvested periodically, thus liberating immature trees. It has been successful in some ***Dipterocarp*** forests of the Far East because those forests are dominated by a single type of tree and natural regeneration of that type usually occurs (41). Sometimes all the high-quality tree species are extracted, thereby leaving behind a commercially useless forest. Also, the widespread use of girth limits for determining maturity means that the most vigorous, rapid-growing trees are removed, leaving behind what could be poorer seed-bearers.

The criticisms of the polycyclic system should not, however, preclude its future use. Markets are developing for trees with smaller crowns, and felling these should do less damage to surrounding trees. The growing local marketability of many additional species should increase the feasibility of more complete fellings.

Yet another variant of the refining practice is the ***monocyclic system.*** The objective is to have all trees reach maturity simultaneously for a single harvest. It starts with the removal of all undesired species down to 10 cm in diameter at breast height (15). Drawbacks to this treatment are the initial sacrifice of larger trees and a lack of intermediate harvests for added income. Moreover, monocyclic management leads ultimately to more complete harvests with greater prospects for erosion. Heavy cuts from monocyclic management can be expected to lead to periodic interruption of nutrient recycling, since large volumes of logging slash will be decomposing at a time when an effective network of roots to capture the nutrients is lacking.

Refinement directly reduces an ecosystem's diversity, gradually eliminating as many as half of the tree species, especially those small at maturity or with extremely light or heavy woods. It calls for ranking species in order of desirability. Consequently, criteria must be determined for selection that consider not only marketability but also the capacity of the system to capture and conserve energy and nutrients, and the risks of catastrophic damage following reduction of biological diversity.

At present, the case for refining secondary forest can best be made where the need for soil, water, and wildlife conservation is critical and where soils are unsuited for other purposes. If carefully coordinated with land-use planning, forest refining may provide seasonal employment in farming regions.

Tropical Shelterwood.-This complex practice stimulates growth of existing seedlings and saplings chiefly by removing unwanted mature trees (58). It requires a reasonable number of existing seedlings, and a new seedling crop rarely appears unless there are at least 2 or 3 mother trees (7,10,27,40). A variation, the Malayan Uniform System, is applied chiefly in the lowland Dipterocarp forests of Peninsular Malaysia, where there are at least 2,500 seedlings of good species. It requires nearly complete removal of all trees except desirable species of less than 30 cm in diameter.

The practice, so far, is not profitable. Average expected timber yields are about the same as from refining, about 6 m3/ha/yr. However, labor costs are higher because the treatment requires removal of the overstory and continuous weeding before harvest. It has been abandoned in Malaysia, Borneo, and India because of labor costs (23,32). Better techniques are needed to reduce treatment costs and improve economic returns. At present, tropical shelterwood is applicable only in places with low labor costs, extensive secondary forests, and little capital to invest in plantations (61),

In addition, this treatment may lead to loss of nutrients by leaching or erosion because the canopy is kept open for a number of years. If the technology were used for several rotations, there would be progressive simplification of the forest ecosystem.

Underplanting.—This practice is intermediate in intensity between natural regeneration and plantations. The objectives are the rehabilitation of cutover forests after selective felling of marketable trees and the assurance of full stocking, species control, crop uniformity, short rotations, and competitive yields (6).

There are several variations of underplanting. In forests containing most of the trees required for a future crop, individual trees are planted to fill small vacant areas. This is called ***"enrichment"*** planting. The main disadvantage is that uneven growth rates between the natural forest and the underplanted trees produce an uneven stand that is difficult to manage and harvest. "Gap" planting of trees spaced at 2 to 3 m inside openings of 20 m or more in diameter is another variation. It seems to have the same disadvantage as enrichment planting. ***"Group"*** planting is made up of closely spaced clusters of 9 to 25 trees in openings as small as 10 m in diameter. Only one tree per cluster is intended to survive.

In forest stands with an insufficient number of trees to form a significant portion of the next crop, underplanting maybe done systematically in rows or lines. This provides more tree/site selectivity and requires less planting stock.

Line planting seems to be the successor to most of the other underplanting techniques; however, it also has problems [61). Not only must overhead shade be removed initially but weeding must be so drastic that most of the former forest quickly disappears (8). Clearing lines and keeping them open until the new trees are well established also can be expensive. Since most failures in the past have been a result of competition with natural trees, self-pruning tree species capable of 1.5 m/yr of straight growth are suitable (63). The list of marketable species that meet the growth requirements is limited. Also, line plantings typically are of a single species, producing a loss of stand diversity, even though natural regrowth may be permitted between and below the crowns of the planted trees. Finally, maximum yields to be expected from line plantings are about 12 m3/ha/yr (13). The constraints may make line planting a risky investment.

Underplanting, however, is less costly and less intensive than plantations. It requires less planting stock and may rehabilitate poor sites and degraded forests. The problem of having a longer wait before harvest may be ameliorated where a planted understory can be harvested on a relatively short rotation for poles, fiber, or fuelwood.

Constraints and Opportunities

Existing secondary forests, if managed properly, could satisfy the wood needs of the growing populations in tropical nations for many decades. However, the various technologies for managing secondary forests are often complex, slow, and laborious. Yields are often too low relative to costs, which discourages investments. New technologies are needed to reduce management costs and to sustain and increase the yields of secondary forests.

An often appropriate technical approach to increasing yields is improved harvesting. Simply reducing logging damage can increase the number of trees available for a future crop as well as improve natural regeneration. This can be accomplished through the use of appropriate harvesting equipment. In addition, regulations to control logging practices need to be developed and enforced. Perfection of these practices requires additional research on the relationships between harvesting intensity and growth of the residual forest.

Another opportunity to increase yields and enhance the value of secondary forests is to develop markets for lesser-known tree species. Market development requires information on wood properties of lesser-used species, the further development of processing techniques, and juxtaposition of wood production areas, processing plants, and market outlets. Expanded markets would then justify more complete and efficient harvesting. Developing markets for underused species and size classes may do more to enhance the value of secondary forests than silvicultural improvement (61).

Finally, management of secondary forests may be made more attractive by reducing the cost of various silvicultural treatments. For example, survivorship and yield of planted trees can be increased by developing less expensive and better quality forest tree planting stock. Labor costs could be reduced by developing less expensive and longer-lasting methods of weed control.

REFORESTATION OF DEGRADED LANDS

Background

Tropical nations have about 650 million ha of cropland compared with 2 billion ha of land in various stages of degradation (21,59). Degradation of tropical land is a physical, chemical, and biological process set in motion by activities that reduce the land's inherent productivity. This process includes accelerated erosion, leaching, soil compaction, decreased soil fertility, diminished natural plant regeneration, disrupted hydrological cycle, and possible salinization, waterlogging, flooding, or increased drought risk, as well as the establishment of undesirable weedy plants. There is a strong relationship between inappropriate land-use practices and land degradation. In some places, degradation is manifest (e.g., desertification), where in others it is inferred (e.g., declining crop yields).

Deforestation in mountainous regions is one of the most acute and serious ecological problems today (17). Disturbance of vegetative cover on montane areas with thin soil and steep slopes results in land instability (e.g., land slides) and soil erosion. Excessive erosion not only impairs site productivity but may also adversely affect other sites or water bodies farther down the watershed. No precise estimates of the scale of the problem exist. However, data from the Food and Agriculture Organization (FAO) and other agencies indicate that some 87 million ha of tropical montane watershed land need reforestation (63).

Conversion of tropical moist forest into farm or grazing land commonly results in rapid depletion of the soil's plant nutrient supply and accelerated soil erosion. In some places the degradation process leads to takeover by persistent, aggressive weed species of low nutritive value (3). Often the combined problems of low soil fertility and weed infestation become so great that the land is abandoned. Such lands are subject to frequent uncontrolled fires and are often covered by coarse grasses. Whenever the vegetation is burned, erosion may increase and productivity may be reduced further. The extent of these grasslands is not well documented. ***Imperata,*** the main invader grass in Southeast Asia and part of Africa, occupies some 16 million once-forested hectares in Indonesia (36]. If the percent coverage of the rest of Southeast Asia is similar to that of Indonesia, there may be 40 million ha of ***Imperata*** grasslands in the region.

In many arid and semiarid open woodlands, overgrazing and repeated fires have converted the vegetation to a degraded fire climax stage. Consequently, soils become dry and little woody plant regeneration occurs. Fire-tolerant vegetation—commonly unpalatable to animals—persists, leading to a desert-like state. An estimated 20.5 million ha of tropical arid lands, an area about the size of South Dakota, become desertified every year. To date, an estimated 1.56 billion ha of tropical land have undergone human-caused desertification (63).

Each year, approximately 500,000 ha of excessively irrigated lands become saline or alkaline as a result of inadequate drainage or use of salty irrigation water (63]. Capillary action draws moisture to the soil surface where it evaporates, leaving salts in or on the topsoil. In some cases, salts can be leached from upland soils and bedrock, raising the salinity of runoff from deforested slopes. The increased runoff harms agricultural soil in lowland areas by causing temporary or lasting waterlogging and salinization (4).

The best solution to such problems is to prevent inappropriate land-use practices on forested lands. Where it is too late for this approach, reforestation is an alternative. Trees planted on degraded lands will not give such high yields as trees planted on rich, fertile lands. However, it maybe the only way to raise the productivity of the most degraded lands. Furthermore, in many countries, fertile sites are reserved for agricultural activities. Given the dwindling reserves of good land and the increasing amount of degraded tropical lands, reforestation is a technology with potential to rehabilitate soils and to provide many goods and services for industrial and local needs. For example, fuelwood plantations can alleviate the worsening shortage of firewood in some areas and prevent shortages from occurring in others.

Technologies

An OTA background paper, ***Reforestation of Degraded Lands,*** covers this subject in detail. This section summarizes the mechanics of reforestation and focuses on pertinent issues and problems that may prevent reforestation success.

Land Preparation

Many degraded sites need some type of preplanning preparation, such as clearing stumps and competing weedy vegetation, loosening the soil, or applying fertilizers or lime. Under some circumstances, site cultivation controls weeds and improves soil aeration, soil biochemical activity, percolation of water, pH regulation, nutrient application, and surface evenness. The degree and type of land preparation depends on several factors: site and soil conditions, vegetative cover, species to be planted, and available capital and labor.

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Land preparation can be done by hand or by machine. Manual methods are less constrained by the rainy season, they require few skills, and the capital cost is relatively low. They also provide temporary employment to laborers and cause minimal damage to soil. A disadvantage of manual clearing, however, is the need to recruit, manage, and provide logistical support in remote areas for large numbers of laborers. Mechanical clearing, on the other hand, requires high capital inputs for equipment maintenance, supplies of fuel and spare parts, and operator training and supervision. And heavy machines degrade the site through topsoil disruption. Yet, in general, mechanical clearing is cheaper than manual clearing (18). The choice between manual and mechanical land preparation must be made on a case-by-case basis, determined by all these considerations.

Sometimes physical structures must be built and heavy machinery must be used to prepare sites. Artificial barriers of brushwood or other materials constructed in a grid pattern, or grasses and trees planted in a similar pattern, can be used to immobilize drifting sand. Plowing the soil surface to increase water infiltration, ripping across the slope to retain water, plus construction of bench terraces on steeper slopes, and funneling moisture onto a smaller area are all conservation measures used to maximize planting success. Minicatchments built to concentrate water into the rooting zones of individual trees are a particularly important technique in arid zones.

It maybe necessary to add nutrients during land preparation. Several techniques exist including mulching with organic matter, planting nitrogen-fixing trees, applying green manure (especially herbaceous legumes), and commercial fertilizers. Mulching suppresses weeds, improves soil moisture conditions, and augments soil organic matter (53), but it may increase problems with rodents or other pests. Nitrogen-fixing trees can improve soil with their ability to produce nitrogen fertilizer. Foliage dropped by legumes is nitrogen-rich and will augment soil fertility as it decays.

Historically, tropical foresters have relied more on seed provenances and thinning practices than on commercial fertilizers to increase productivity (52). But the benefits of fertilizers have been impressive in some forest plantations. Fertilizer placed in the planting hole may accelerate early height growth and thus reduce weeding. Carton de Colombia, a timber growing company in Colombia, has experimented successfully with the application of about 50 g of commercial fertilizer in planting holes on extremely nutrient-poor soils (39). Since small amounts of fertilizer can produce significant results, further research is justified to determine the best types and quantities of nutrients to apply for various species under various soil conditions.

The use of commercial fertilizers in forestry generally has been based on a presumed or predicted shortage of nitrogen, phosphorus and potassium. Dosage has been based on experience from trial and error experiments. However, some highly weathered tropical soils are difficult to fertilize effectively with essential plant nutrients such as phosphorus and potassium. For instance, phosphorus can become so tightly held by soil minerals that plants can extract little for their benefit, whereas potassium is not held by the soil and is easily leached away by tropical rains (24,37). Use of the wrong fertilizer, or incorrect amounts of fertilizer, can reduce yields. Application of 100 g of potassium chloride per ***Pinus caribaea*** tree depressed growth and increased mortality on Nigerian savanna sites (35). Moreover, fertilizer use may cause water-associated environmental problems, such as increased eutrophication that hampers navigation (29) and may trigger the onset of health problems. Thus, fertilizers can be both beneficial and detrimental, so the impacts of applications need to be examined thoroughly before widespread use.

Some experts adamantly believe commercial fertilizers should not be promoted for the developing world on the grounds that they must be imported and are not, or soon will not be, affordable. Certainly, sustainable nonchemical techniques to enhance fertility should be investigated. For example, one of the less obvious soil deficiencies, occurring particularly in eroded soils in the drier climates, is the lack of necessary micro-organisms. An ancient and effective method to add micro-organisms is to inoculate either nursery soils or planting holes in the field with a few grams of topsoil from well-established plantations. The method is not practical, however, where well-established plantations do not exist.

It seems unlikely that timber crops can be harvested repeatedly from the same site without replenishing soil nutrients. Significant decline from successive timber crops has not yet been observed (16,42,44). The quantities of nutrients removed with tree harvests have been measured, however, and they are sufficient to suggest that with repetitive cropping a decline in yield eventually will occur. Nutrient drain can be more rapid in fuelwood plantations where the cutting cycle is every 5 to 10 years in contrast to commercial forests that are cut every 30 to 100 years. This difference is even greater than the time difference implies, since younger trees contain a proportionally larger share of phosphorus, potash, and calcium (56). Nutrient levels and fluxes in plantations should be monitored to determine the prospective benefits and cost effectiveness of soil amendments.

Species Selection

Tree species selection is important to plantation success. If a tree is grown under unsuitable soil or site conditions, it will be stressed and thus become susceptible to attacks from insects or competition from weeds. Several factors influence species selection, including the objectives of reforestation, seed availability, and costs associated with reforestation alternatives. For many degraded sites, the species need to be those that can add nitrogen to the soil as well as provide products wanted by local communities.

The importance of matching tree species with site cannot be overstated. The problem of species selection is complicated in the Tropics by intricate climatic and soil patterns, and in areas that have been deforested by the highly variable degree of site degradation. Inadequate information on planting sites is a major cause of plantation failure (61).

Exotics and *Monocultures.* Plantations cannot substitute wholly for natural forests as reservoirs of germ plasm or as components of the natural environment—they are really an agricultural crop. Plantations contribute to preservation of the natural environment because they concentrate wood, food, and forage production within a minimum area, thus relieving some demands on natural forests. However, where plantations are established on land with good potential for annual agricultural crops, the effect actually may be to increase pressure on the natural forests.

Most large-scale tropical industrial timber plantations use species that are indigenous to the Tropics but are exotic to the planted area (24). The widespread use of exotics maybe a result of the preponderance of information, experience, and research on them, especially on ***Pinus, Eucalyptus,*** and ***Tectona.*** Also important to their use is the abundance, availability, ease of storage, and germination of seeds of these exotic species. The use of exotic tree species involves risks. One of these risks is the susceptibility to pests and diseases. Proponents point out that exotics may be at an advantage because they have left behind pests and diseases that evolved along with them in their native habitats. Opponents disagree, saying that exotics may have no resistance to pests and diseases in their new environment. A third side believes that the risk of pest and disease problems depends on plantation size more than geographic origin of species. Native pests and diseases tend to switch to plantation crops (where resources are more uniform and abundant) (57’). The evidence still is inconclusive. Because of the high yields possible with exotic species, however, the risks will continue to be taken.

The potential of using native species in plantations has been largely ignored. Reasons for this vary from lack of familiarity with many tropical tree species to lack of seed supplies. A reason often cited is the slower growth of native species. Nevertheless, the growth rates of exotics and native species usually are similar in the arid and semiarid parts of Africa (62]. Native species are adapted to the local environment and, thus, may be less susceptible to stress, serious disease, and pest damage. Local people are more familiar with their native plants and have more uses for them (30).

Nearly all tropical plantations are grown in monoculture. * The main reason is that silviculture** for such plantations is simple and thus more cost effective. Since monoculture plantations may be susceptible to rapid spread of pest and disease outbreaks, some diversity can be achieved by alternating species, or genetic varieties of the same species, in blocks of land being planted. This method might prevent pests that develop and multiply in one plantation block from spreading rapidly to other blocks having the same genetic make-up (64).

Multiple species (polyculture) plantations, in theory, mimic the natural forest, yield a greater variety of products, and are less susceptible to pests than are monoculture. However, little actual experience has been gained dealing with polyculture plantations either on an industrial scale or in village forests (63). Only recently have projects been established where mixtures of species are planted for a variety of end uses. Legume trees are interplanted with commercial tree species to reduce the amount of fertilizer required after successive rotations. In experimental plantations, Indonesians are interplanting ***Calliandra*** with ***Pinus merkussi*** and with ***Eucalyptus deglupta*** to yield firewood for local use. ***Calliandra*** and other legume trees are sometimes used as “nurse trees” for timber such as teak, which requires shade initially for better growth (46).

Managing mixtures of tree species for wood production is biologically complex, especially for more than two species. It becomes even more difficult where multiple products are extracted from multiple species under different harvesting regimes. Information is lacking on the optimum species mixtures and spacings. Little is known about the relative benefits of different species or canopy densities and whether the density that is best for high yields is also satisfactory from other standpoints. Potential benefits from compatible mixtures of trees suggest that new concepts and combinations should be tested.

Photo cradt: J. Bauer

In the Caribbean National forest, Kadam *(Anthocephalus chinensis)* is intercropped with mahogany *(Swietenia macrophylla)*

Forest plantations in the past usually served industrial purposes and grew only one product, usually sawtimber, pulpwood, or fuelwood. Now, with an increasing demand for food, fuel, and fodder, plantations are needed to serve a wider variety of objectives. Thus, the use of multipurpose trees is becoming increasingly important, especially in areas with high populations. For example, ***Acacia mangium,*** which has potential for sawtimber, veneer, furniture, firewood, pulp, and particle board, outperforms other species on degraded lands in Malaysia. Its leaves also can be used as forage for livestock (48). The foliage of species such as ***Calliandra*** is readily eaten by cattle and goats and its flower provides rich nectar to produce honey (47). Because of its fast growth, ***Calliandra*** competes with and can eventually suppress ***Imperata cylindrical,*** a tough perennial grass that invades and dominates many cutover areas of Southeast Asia.

“Monoculture: one species planted over a large area.
* *Silviculture: the science and art of cultivating forest crops, based on a knowledge of forest tree characteristics.

Thousands of other tropical trees exist whose potentials are unknown. Little is known of the variability in growth and performance of multipurpose tree species. Variation is related to habitat so that each planting site should be tested with a variety of species and with genetically different varieties of the same species. Even when correct species and provenances are known, there is still a major gap in the knowledge of silvicultural techniques for multipurpose tree plantings.

Tree Selection and Breeding. Since most tree species used in reforestation are found over broad geographic ranges, different races* within the same species can be adapted to different environments. Thus, the species' suitability to a particular site varies depending on the races used. Increases in yield and resistances to disease can be achieved through selection and use of appropriate seeds. Only by planting species and races on the sites for which they are adapted can maximum yields be obtained. Most plantations in the Tropics use seeds without testing them to see whether they are genetically appropriate for the site.

Selection of tree species for each site continues to be too arbitrary in spite of, or possibly because of, long experience and tradition. Plantation yields within large regions with extensive plantations of the same tree species, such as southern Brazil, vary widely from place to place with no technical explanation. Even large, long-established planting projects continually encounter new sites where results are unlike those of past plantings. Within genera such as ***Eucalyptus,*** selection among species and races should be made on the basis of natural range and corresponding climate and soil conditions for which each has proven acclimatized, and on the basis of demonstrated adaptability to altered environments and growth habits (9).

A well-established technique to match races with sites is called provenance testing. * Seeds of the desired species are collected from various sites and tested at the site to be reforested or at a site with a similar environment. Once the best provenance has been identified, several options are available to obtain planting materials. Seeds from the desired provenance sometimes can be purchased. Alternatively, individual trees from the provenance test can be selected as parent material and used to establish seed orchards or to produce rooted cuttings for planting materials.

Another technique is to use superior trees from an environment similar to the reforestation site to establish a seed orchard without provenance testing. If the desired species already grows on the reforestation site and if superior trees have not been eliminated, it is possible to obtain planting materials adapted to the site from those trees. This is probably the fastest and least expensive approach. However, seed orchards established from phenotypically* * selected trees ideally should be provenance-tested.

Conventional provenance testing is a major undertaking. For proper statistical analysis, hundreds of trees from each seed source are planted in replicated blocks and grown to maturity. The process generally takes so long that the original seed source may be unavailable by the time results are available. When that happens, the test plots must be developed as seed orchards, further prolonging the process. This usually takes too long for an individual reforestation program to accommodate. Many provenance tests do not yield results because of premature termination of the project or departure of the investigator. Therefore, provenance testing must be carried out by established institutions that can maintain long-term programs.

*Race: subdivision of a species distinguished by heritable physiological or morphological characteristics resulting from adaptation to a specific environmental condition. Tree species races are often described by referring to the geographic location where the race is found naturally.

*Provenance testing: testing populations of the same species to study their performance under a range of site and climatic conditions.

* *Phenotype: detectable expression of the interaction between the tree's genetic characteristics and the environment.

Potential to shorten the time needed for tree selection is increasing as new techniques are tested. Tissue culture can rapidly mass-produce clones of chosen individuals from a provenance test. The clones can then be tested for particular microsites or planted at the reforestation site. Establishment of international networks of cooperating scientists to collect seeds or planting material and to record environmental data for each parent tree can reduce the number of provenances to be evaluated for each test. Another technique, by which many provenances are planted in one stand (single tree randomized plots), allows the testing of many more provenances without a corresponding increase in budget or personnel. Then, propagation of clones can ensure that the provenance with the exact genetic materials is used, thus allowing more types to be tested. The U.S. Forest Service, in experiments with ***Eucalyptus,*** successfully used single tree randomized plots and cloning to shorten the time for screening provenances.

After the initial selection of parent trees, breeding for desired characteristics can greatly accelerate tree yields and survivability on degraded sites. Plant breeding has been responsible for about half of the spectacular gains in agricultural crop yields accomplished in the past three decades. Tree breeding takes longer because generations are longer than with annual agricultural crops. Nevertheless, tree breeding programs in industrialized nations have already achieved important productivity gains—10 to 20 percent gains in first generation and 35 to 45 percent in second generation seed orchard progeny in industrial timber plantations (50). For energy plantations, breeding has produced gains of as much as 50 percent (54).

With ***Eucalyptus*** in Brazil, selection alone has nearly doubled yields (60). Additional gains from the use of parent trees selected by strict criteria are predicted at 5 to 10 percent and the use of seed orchards of these trees should add 10 to 20 percent more. Tests to match the seed orchard progeny to specific microsites are expected to provide further gains of 35 to 45 percent. Eucalyptus breeding has produced hybrids that at 4 years show an improvement of 30 percent in height growth and 80 percent in diameter at breast height (dbh) growth over the parent trees. Yields of more than 100 m^3/ha/yr are projected from the combination of selection and breeding. Hence, genetic tree improvement may promise larger gains in yields than refinement of silviculture techniques.

In addition, tree selection and breeding could accelerate genetic improvement of trees for characteristics other than yield. For example, with pines, improvements similar to the eucalyptus yield gains are expected in straightness, reduction in forking, and other characteristics. Further, the risks of forestry investments on degraded land could be reduced. For example, drought-resistant species could be improved through genetic programs designed to identify, breed, and propagate the most productive of the drought-tolerant provenances.

Planting Materials

To reforest lands, seeds of various species must be available in great quantities. Today, quantity falls short of need. The seed supply for species most commonly used in tropical, industrial plantations is adequate. However, the seed supply for multipurpose, agroforestry species is small. Often the seed that is used does not have its source identified. This makes it impossible to trace the origin of seeds that produced a promising stand or a stand of bad form to be avoided. Full records of all forest seedlots should be made and copies should accompany all seed distributions. Most importantly, every seed shipment should show how the species was identified, where and when the seed was collected, and specific site and stand information about the seed source. In that way, the recipient would know the quality and origin of a seedlot if problems or opportunities were to develop later.

The customary way of raising planting stock in the Tropics is to grow seedlings in a forest nursery either in open beds for bare-root planting or in containers. Good nursery practices are essential to produce a hardy plant with a well-balanced, straight root system. Bare-

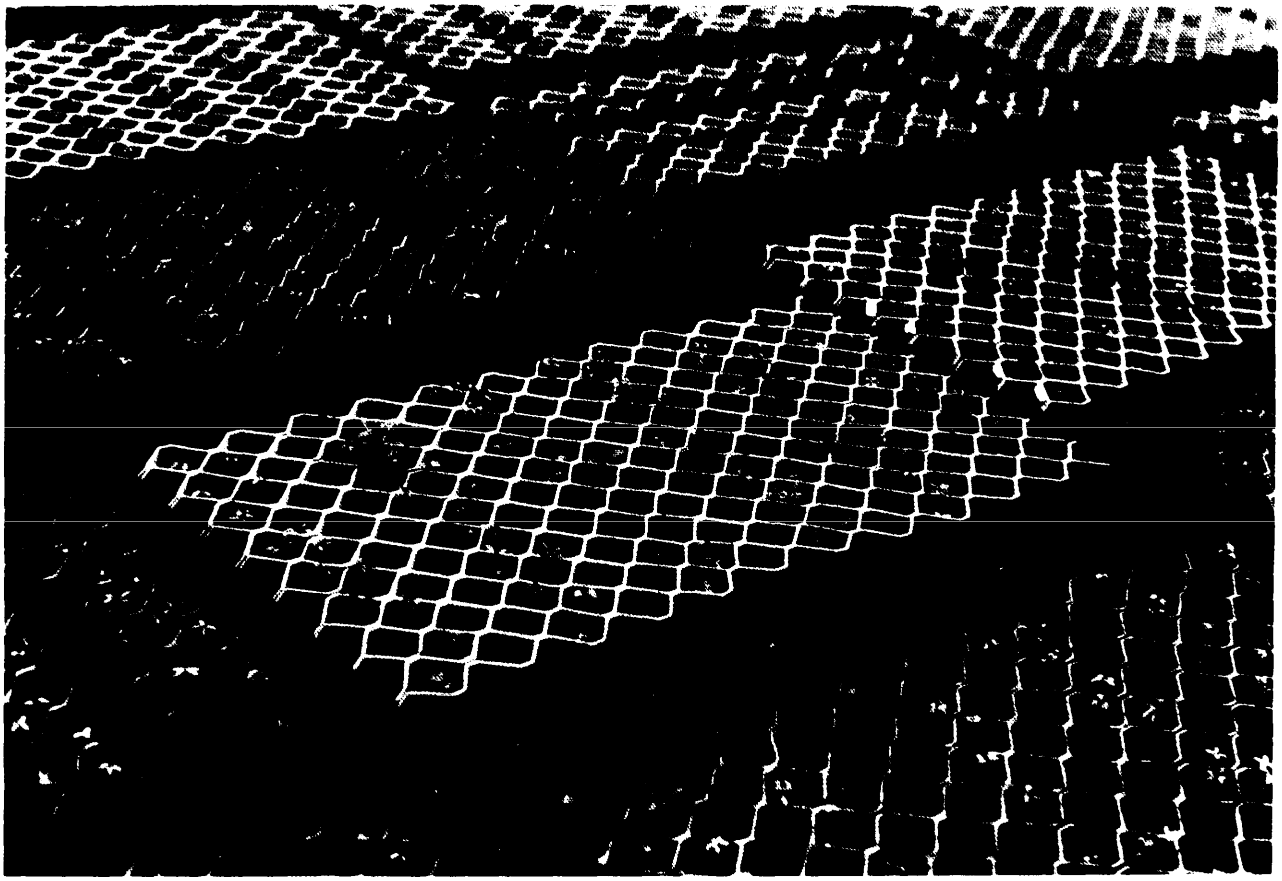
Photo credit: A. Isaza for WFP/FAO

These 200,000 Eucalyptus seedlings will be used to reforest some 700 hectares of overgrazed land in Colombia

rooted seedlings are susceptible to desiccation. Containerized seedlings are more costly and bulky to handle in the field and are subject to root coiling if closed-bottom containers are used. The latter can be avoided if the containers have an open bottom and are suspended above the ground. Recent developments with cardboards and plastic tubes used as seedling containers are increasing the efficiency of reforestation projects.

Another technique for producing planting material is vegetative propagation—reproduction of planting stock without the use of seed. Vegetative propagation is widely used for tree crops such as rubber, coconut, tea, coffee, cocoa, and oil palm. Methods include cuttings, air layering, budding, grafting, and tissue culture. Rooted cuttings remain the most popular of these. Once the technique for a particular species is developed, the production cost is modest.

Vegetative propagation has the advantage of hastening massive reproduction of genetically superior plants, ensuring that all are of the desired genetic type. It has the disadvantage of increasing plantation risks due to lack of genetic diversity. Tissue culture is another technique that can produce thousands or even millions of plants rapidly from a single parent. This technology is established in tropical agriculture and horticulture, but it is still in the developmental stage for most tree species.



D m g w O D H ry
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The use of tissue culture can shorten the time necessary to reproduce a large stock of planting material with exactly the necessary characteristics. The cost of plantlets and the sophistication of the technique, however, make it unlikely to replace the use of cuttings for large-scale reforestation in tropical areas. Its nearer-term use is likely to be in establishing "super-tree" orchards to produce seeds or cuttings.

Seedling survival and growth rates in the nursery and at the planting site sometimes can be improved by using special kinds of fungi and bacteria. For most tropical trees, associations between tree roots and mycorrhizal fungi are essential for healthy growth. The fungi are active in the transport of nutrients and water to plant roots, and in some cases are important for the release of nutrient elements from mineral and organic soil particles (43). Trials have shown that seedlings inoculated with fungi show improved growth and survival over uninoculated controls (33). populations of mycorrhizae are found naturally in soils, but these can be depressed after long-term clearing and / or topsoil removal, making reestablishment of vegetation on degraded lands difficult. Various methods for reinoculating damaged soils with mycorrhizal fungi are being developed.

Legume trees can grow well on degraded land because their roots can be a symbiotic host for Rhizobium bacteria which produce nitrogen fertilizer, an essential nutrient for plant growth. The bacteria convert nitrogen gas in the soil into a form the plant can use. Most soils contain ***Rhizobium,*** but degraded soils prob-

Photo credit: T. Wood

Nitrogen-fixing nodules formed on the roots of *Acacia Pennatula* by *Rhizobium* bacteria enable legume trees to grow well on degraded lands

ably contain fewer types and lesser amounts of the bacteria. Thus, the appropriate type of Rhizobimn may not be present at the site of a reforestation effort, or present in enough quantity to infect the tree roots.

Inoculants are living organisms that must be transported and stored carefully and used correctly to retain their viability. These requirements can be difficult to satisfy, especially at remote tropical sites needing reforestation. Most importantly, inoculants for tropical legume trees usually are not available because of lack of production. Even where inoculants are available, they may not be used because treeplanters are not convinced that they will be helped. These constraints are being overcome slowly.

An old inoculation technique is to collect root nodules from a vigorous legume tree, grind them up, and use the product to inoculate other trees of the same species. The newer technologies using inoculants from laboratory produced cultures are relatively simple to use and cheap, costing only a small fraction of a cent per tree. Inoculation of legumes with Rhizobi***um*** has been practiced in agriculture in industrialized nations for many years. Inoculants for some tropical legume trees, such as ***Leucaena*** and ***Calliandra,*** are available commercially.

The roots of some nonlegume trees also can be infected by micro-organisms that produce nitrogen fertilizer for the tree. Techniques to culture these micro-organisms are not yet available. However, the use of ground-up nodules from already established trees is possible and practical for areas where these trees are native. The major limiting plant nutrient in arid and semiarid regions is likely to be nitrogen; hence, the use of nitrogen-fixing trees can be extremely valuable.

An alternative to using seedlings in nurseries is to plant or sow the seed directly at the reforestation site. This method is feasible where seed is plentiful and where seed and seedlings mortality is low. Direct sowing of drought-resistant species is sometimes preferred, especially for species that have long and fast-growing taproots that may be damaged in a nursery or in transfer to the field. The advantage is that no nursery is required and planting costs are low. On the other hand, seedling survival may be low because of weed competition, lack of tending, poor weather, or animal damage.

Coating seeds with pest repellent may be necessary to avoid damage by small mammals, birds, or insects. Thus far, few species have been planted this way in the Tropics. Sowing seeds from the air is unproven in the Tropics, but shows promise in accelerating reforestation programs through its ability to seed large areas quickly (45). It is a tool to consider when reforesting remote, rugged sites. The technique has many logistical problems, including lack of aircraft and logistic, administrative, and communications support, and lack of large quantities of seeds.

Tree Care and Maintenance

Proper care and maintenance of the planted site is essential to ensure that trees survive to maturity. Once grown, there is the problem of monitoring timber harvests and of systematic replanting. The main causes of reforestation failure, other than inappropriate technologies, are uncontrolled grazing and fires, competition from weeds, and uncontrolled cutting for fuel, fodder, poles, and lumber.

Direct protection through fencing or guards tends to be expensive. Other, less costly methods include planting unpalatable trees (e.g., ***Cassia samea)*** or thorny trees (e.g., ***Parkinsonia)*** **as** barriers around the plantation. The use of living fences is becoming a more widespread practice because they provide a number of auxiliary benefits including shade, fodder, windbreak, fuel, and wildlife habitat. Another alternative is subsidizing farmers with livestock feed or with cash to purchase feed during the period when trees are most susceptible to animal damage. Grazing beneath the tree canopy sometimes can be beneficial as a means of weeding. However, livestock grazing on recently reforested watersheds can be harmful because animals compact the topsoil, leading to poor tree growth and increased runoff.

Weeding is an important aspect of plantation establishment and maintenance. Weeds compete directly with seedlings for light, soil nutrients, and water. Their shade can smother and eventually kill young trees. They also can increase fire hazards and shelter harmful animals (18). There are three main methods of weeding—manual, mechanical, and chemical. The manual method is the most common and requires little skill or capital. Mechanical methods may be used in large plantation projects but generally are not considered profitable in the Tropics. In many tropical countries, chemical weed control techniques have been tested and found successful, but because of safety and cost problems they seldom become the main means of weed control (1).

Photo credt: *K.* Parker

Using trees as living fence posts in the Dominican Republic has several benefits. The fence itself provides protection and shade for animals, while the foliage can be harvested for forage, fuelwood, or green manure

Whatever the type and location of tree planting, the cooperation of local people is essential if newly planted trees are to survive (2). Because most trees do not yield much benefit for several years, the options offered must demonstrate explicit benefits to the people. Tree planting programs are most successful when local communities are involved and when the people perceive clearly that success is in their self-interest.

In local communities, support can be generated through local involvement in project design, demonstration plantings, commercial plantings by entrepreneurs with larger land holdings, education of community leaders, extension and training programs working directly with farmers or laborers, and direct financial assistance or provision of substitutes (63). Village woodlots provide an alternative to cutting in larger areas reforested for other purposes. Subsidizing kerosene is also an option until wood can be harvested on a sustainable basis in reforested areas.

Incentives must be created to encourage people to care for and maintain the reforested area until the benefits can be reaped. For example, a village woodlot project in the State of Gujarat in India that involved tree planting on degraded communal grazing lands was able to meet people's needs by allowing grass to be cut for fodder and carried to livestock during the second year of tree growth. This approach enabled people to continue feeding their livestock and simultaneously to care for and maintain the reforested area (2).

Other incentives include guaranteed provision of inputs, credit, and technical assistance when required. Where land tenure is a problem, measures can be formulated to offset the risk to participants caused by the lack of secure ownership of the trees—e.g., giving title to the land or title to the trees, short-term licenses, or improved financial incentives.

Investment Analysis

Reforestation projects may fail to receive adequate funding and support because benefiticost analyses do not include indirect benefits such as environmental services, import substitution, and higher productivity of rural labor. Plantations have substantial technological requirements which, combined with the long-term nature of forestry, often result in low short-term profits when compared with those of alternative investments. This is often in conflict with government priorities for projects that produce quick returns (for which leaders receive more political credit) and with bankers who use discounting methods that assign low value to returns that occur 10 years or more in the future.

Adequate analysis requires comprehensive data on costs, benefits, and man- or machine-times and productivities. Yet much of this information is unknown when projects are being planned. Price estimates often are unreliable and do not account for inflation. Information on labor requirements is usually missing as well. Forestry yields are difficult to predict because of the long-term nature of the enterprise, climate and management uncertainty, and, more importantly, a lack of accurate information on site/species interactions. Although technologies such as tissue culture to accelerate vegetative propagation and bacterial inoculation to increase seedling survival are increasing yields on reforested degraded lands, methods are not yet developed to measure the important but indirect benefits that could help justify investment in reforestation.

Constrains and Opportunities

Reforestation technologies are available to be applied directly to degraded lands. However, forestry has low priority in many tropical countries. Tree planting sometimes does not compete well, in economic terms, with other land-use activities. The solution seems to lie in creating better economic terms by reducing the costs and increasing yields of plantations, by reducing plantation failures, and by developing methods to quantify indirect benefits of reforestation.

Overall costs could be reduced if land preparation were adequate to prevent weed invasion and ensure a favorable environment for the seedlings. The use of nitrogen-fixing tree species can add fertilizer to degraded soils. The use of native species may reduce the risk of disease and insect outbreaks and increase local enthusiasm for reforestation. Plantation yields can be increased through selecting high-yielding, fast-growing, soil-enriching, and stress-tolerant species and provenances. Multipurpose tree species can increase the diversity of products yielded. Development and implementation of tree selection and improvement programs can produce high-yielding varieties as well as other characteristics for particular tree species. Careful provenance testing, matching the appropriate race to a particular site, should improve species performance and reduce mortality. Perhaps most important is the proper maintenance of reforested sites. Incentives for local people should be created to minimize the incidence of fire, grazing, and fuelwood cutting.

Shortage of seeds is a major technical constraint to reforestation. No mechanism exists to control the quality of planting stock. It is often difficult to trace the origin of seed that does perform well to obtain more. Some mechanism needs to be developed to coordinate collection, certification, and international distribution of quality seeds in commercial quantities. This could be accomplished through 1) the

Photo credit: J. t?auer

Mahogany seed sun-drying for storage. Shortage of seeds is a major constraint to forestry. Implementation of programs to collect and disseminate seeds could increase reforestation efforts

creation of a new institution, 2) expansion of the FAO seed program, and/or 3) expansion of the seed banks of the CGIAR system to work with private tree seed production enterprises.

Oftentimes, inappropriate tree species are selected because information on optimum species and provenances for specific sites is unavailable. Much information on proven plantation establishment techniques and silvicultural data exists and some of it is being published. Yet, such information is seldom easily available to or studied by those who embark on planting projects. FAO could provide abstract/microfiche/hard copy services for published literature to operational and research personnel, especially at the field level; provide bibliographies, monographs, and manuals on relevant species, techniques, and systems; and provide incentives to publish local research and management techniques.

Furthermore, information on planting sites often is inadequate. The need exists for international coordination to disseminate what is already known about sites and species/site interactions so there is some uniformity of approach, at least at the regional level. Following this, there should be application of a comparable site classification to those areas most eligible for planting. There may be reason to establish two intensities of classification, one generic to narrow down the choice of prospectively adapted tree species, and one more specific to distinguish good, fair, and poor productivity within each broad class. Given the present large uncertainties in selecting the best method for reforestation of a degraded site, it may be advisable to try out several approaches (28).

Reducing the frequency of plantation failures may attract more investors to forestry and, thus, increase the extent of land reforested in the future. Also important are the indirect benefits from reforestation efforts. International development banks treat many of the nonmarket considerations qualitatively rather than trying to develop artificial values for them (25), However, simply listing nonquantified variables may serve to remove them from consideration. So increased effort must be expended to develop, test, and refine methods of quantifying indirect benefits so that decision-makers have an understanding of the economic value of reforestation.

Successful reforestation requires sufficient funds, strong political will, massive popular support, and cooperation among all involved parties. A technical package, once accepted by funding institutions and the host-country government, may solve certain problems, but many obstacles to its acceptance usually remain. Foresters and policy makers must remember that "forestry is not, in essence, about trees. It is about people. It is only about trees so far as they serve the needs of the people" **(26).**

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