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Short-Rotation Eucalypt Plantations in Brazil: Social and Environmental Issues

Dr. Laércio Couto
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SHORT-ROTATION EUCALYPT PLANTATIONS IN BRAZIL:
SOCIAL AND ENVIRONMENTAL ISSUES

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ACRONYMS AND INITIALISMS

BIG/GT	Biomass Integrated Gasification/Gas Turbine
CNPq	National Council for Research and Technical Development
EMBRAPA	Brazilian Enterprise for Agricultural Research
FAO	Food and Agriculture Organization (United Nations)
GEF	Global Environmental Facility
IBDF	Brazilian Institute for Forestry Development
IPEF	Institute for Forest Research
SBS	Brazilian Society of Silviculture
SEIVAS	Integrated Management System for Improving the Value of Forestry Affairs
SIF	Society for Forest Research

SUMMARY

This report presents an overview of the historical and current legislative, social, and environmental aspects of the establishment of large-scale eucalypt plantations in Brazil. The report consolidates the vast experience and knowledge relating to these forest plantation systems and highlights lessons learned and new trends. The overview should prove useful to those interested in comparing or beginning similar endeavors.

1. INTRODUCTION

Exactly where and when the first eucalypt tree was planted in Brazil is very difficult to determine. The event has been reported to have occurred in 1824 at the Botanical Garden of Rio de Janeiro and to have been carried out by the Garden's director, Frei Leandro do Sacramento (Sampaio 1975). However, no one will deny that it was Edmundo Navarro de Andrade who, in 1904, started the first truly scientific work around introducing *Eucalyptus* in Brazil. His work included the establishment of the first commercial plantations of that genus in the country. After earning his diploma as an agronomist in Coimbra, Portugal, Andrade brought some seeds of *Eucalyptus globulus* to Jundiaí, São Paulo. He planted these along with some other exotic and native tree species. At that time, Andrade was working for the Paulista Railroad Company to provide firewood for the company's steam-powered engines and sleepers. In a few years the eucalypt test plots outgrew all the other tree species being tested, encouraging Andrade to import seeds of various species of this genus to be tested in São Paulo. As a result of his efforts, a total of 217 species of *Eucalyptus* were introduced in Brazil (Spinelli 1993).

From 1909 to 1965, about 470 thousand hectares of *Eucalyptus* were planted in Brazil by government and by privately-owned companies. Eighty percent of these plantations were in the state of São Paulo. The eucalypts were introduced in Brazil to substitute for native forests in providing firewood for the railroad companies. Because extensive cutting of native forests for firewood, forests were receding further and further from consumption centers. Other energy sources, such as coal, were not available in Brazil, and the cost of importing them was high. In 1948, Cia Belgo-Mineira in Minas Gerais established the first eucalypt plantations to provide wood for charcoal production to be used by the charcoal-based iron and steel-making industry (Magalhães 1993). Until 1965 there was no major concern about the negative effects these eucalypt plantations might have on the environment.

Environmental groups are now exerting considerable pressure to make it unfavorable for the establishment of eucalypt plantations in Brazil. These groups have affected certain decisions the forest companies have made concerning the effects of their activities on the environment (Lima 1993). The concept of production forestry has given way to that of sustainable forestry, in which the multiple uses of water, air quality, erosion control, wildlife, recreation and landscape are considered as valuable as timber production (Coufal 1989). Integrated forest management takes into account the relationships between the various components of the forest ecosystem so that management practices minimize the environmental impacts of the plantations (Duerr 1990). Aspects deserving attention are (1) the hydrologic and ecological processes; (2) the capacity of the soil to produce on a sustainable basis; (3) the biodiversity of the area; and (4) the sustainability and preservation of species, habitats, and the genetic pool. This paper presents an overview of the social and environmental aspects related to the establishment of large-scale eucalypt plantations in Brazil.

2. ENVIRONMENTAL ISSUES

In the 1960s, little if anything was known about the silvicultural and ecological needs of the introduced eucalypt species in Brazil. Eucalypts were established across the country in varying soil and climatic conditions. Availability of land and low land prices stimulated most of the reforestation projects at that time. Ecological zoning or use of certified seeds of the correct provenance to ensure the success of the plantations was not considered. Because *Eucalyptus grandis* was the most popular and fastest-growing species at that time, it was used indiscriminately by most of the companies. Consequently, survival was very low for some plantations, some of which were located in regions having very low annual rainfall, a key factor for growth.

In the 1970s, criticism concerning the alleged harmful effects of the eucalypts on the environment grew. By that time, large plantations (encouraged by the fiscal incentives for reforestation) were wide-spread in São Paulo, Minas Gerais, Espírito Santo, Bahia, Mato Grosso do Sul, and Rio Grande do Sul as well as in other Brazilian states. Eucalypts were said to adversely affect the soil, the water cycle, wildlife, biodiversity, and local vegetation. These concerns were being expressed in India, Portugal, Spain, and the United States where *Eucalyptus* also had been introduced.

No provenance tests had been established in Brazil, thus a species would grow well in one place and very poorly elsewhere. Productivity in some places ranged from 6 to 12 m³ of wood per hectare per year and other regions, from 25 to 30 m³ of wood per hectare per year. Coppicing was not responding as expected, and even when successful, second-rotation yields were lower than first-rotation yields. Often, yields would decrease 20 to 40% from one rotation to another. In the early years, very intensive insect and fungal attacks also occurred, mainly on the *Eucalyptus grandis* plantations. No adequate site-preparation technologies were used. In most areas, fire was used to help eliminate the existing vegetation, and soil preparation was similar to the system used for agricultural crops that sometimes led to erosion and silting of streams. No attention was given to any physical or chemical impediment in the soil layers that could jeopardize the growth of the newly established eucalypt plantations. No adequate fertilization formulas or methods of application were available, and correct spacings and rotation lengths were unknown at that time.

In the late 1970s, this situation changed drastically as a result of ecological zoning for reforestation with eucalypts and pines done by Lamberto Golfari, an expert from the Food and Agriculture Organization of the United Nations (FAO). He established a network of species and provenance trials throughout the country with the help of the Brazilian Enterprise for Agricultural Research (EMBRAPA). He used Thorntwaite's water balance to compare eucalypt species and provenances in the various regions in Brazil. Currently, Golfari's ecological zoning for reforestation with eucalypts is being improved and refined by EMBRAPA in the South and by the Department of Forestry of the Federal University of Viçosa in the Southeast. This new technology is incorporating climatic (Martins et al. 1992), ecological and edaphic (Tristão 1992) variables into the ecological zoning by means of multivariate analysis technique (Reis and Reis 1993).

With ecological zoning and the introduction of new species and provenances tested by EMBRAPA and the forest companies (combined to better silvicultural and management practices), productivity levels of the eucalypt plantations during the 1980s improved substantially. The average growth of the plantations increased 18 to 22 m³ per

hectare per year, with some hybrids and clones producing almost twice that. Today, the average productivity is around 35 m³ per hectare per year, but in some places plantations can grow at the incredible rate of 90 to 100 m³ per hectare per year (Reis and Reis 1993).

Current knowledge allows much more environmentally responsible establishment of eucalypt plantations, such as those recently established in the south of Bahia and northern Espírito Santo. At the same time, environmental and forestry legislation is limiting the options that companies have for plantation establishment, forcing the companies to associate with universities and research institutions in searching for new techniques by which to establish eucalypt plantations.

2.1 CLIMATE

One criticism of eucalypt plantations is that they can promote a change in the local climate. This is because of the very high evapotranspiration rate of eucalypts, which drains water from the soil leading to a lower water table. This high evapotranspiration rate is claimed to adversely affect local rainfall levels, resulting in possible desertification of the area. Others point out that the contribution of the continental water evaporation to the hydrologic cycle is known to be very small compared with that of the oceans (Lee 1980). Further, the mere presence of a forest in a certain area does not necessarily affect the occurrence of rainfall in that area (Penman 1963). The subject merits more study.

In some regions, such as the Amazon basin, the forest can influence local precipitation. The canopy can affect the air-circulation pattern that flows from the Atlantic Ocean into the basin (Shuttleworth 1988). There are also situations in which the forests are located in hilly regions along the coast and are subjected to a constant fog, which condenses on the canopy and falls to the forest soil adding to the rainfall level (Lima 1993). This effect also has been observed in some native eucalypt forests of Australia (Costin and Winbush 1961). This could indicate that Brazil's eucalypt plantations may have the same effects on the climate as a native forest located in the same region. Thus, the effect of planting a large area with eucalypts is likely to be the same as if other vegetation of similar structure and albedo were planted. In summary, certain research studies have shown that differences in the microclimate within eucalypt plantations may exist compared with those of other species and native forests, but the data are not conclusive (Poore and Fries 1985).

2.2 WATER

2.2.1 Canopy Interception

One of the primary concerns about eucalypt plantations is that they lead to a diminished rainfall in their area of influence. The most significant hydrologic effect of a eucalypt plantation, as well as any other tree plantations or forest cover, is its interception of rainfall. A portion of this rainfall reaches the ground, while some remains in the canopy and is lost by direct evaporation (Lima 1993). When comparisons are made between forests and open areas, such as pastures and native grasslands, a higher evaporation rate can occur in the forest cover, thus diminishing the water supply of the watershed (Calder 1985).

The total loss of water by canopy interception is equal to the sum of the evaporation that occurs during the rainfall and the evaporation that occurs after the rainfall from the water retained in the canopy. Because precipitation is likely to be heavy in the tropical regions and occur over a very short time period, losses during rainfall are smaller than losses after. The capacity of a forest canopy to store or hold water can be measured by using a leaf area index. The typical leaf area indexes of some eucalypt species are smaller than those of other forest species, which suggests that the total interception by eucalypts may be comparatively low (Gash 1979).

A study in São Paulo indicated that a 6-year-old *Eucalyptus saligna* plantation lost 12.2% of rainfall water by canopy interception. Two 13-year-old pine plantations (*Pinus caribaea* and *P. oocarpa*) have shown losses of 12% (Lima 1976), and savanna-like vegetation showed a loss of 27% (Lima and Nicolielo 1983). Secondary Atlantic forests varied from 12.4% (Castro et al. 1983) to 18.2% (Cicco et al. 1986), and the range in Amazonian rain forest was 8.9% (Lloyd et al. 1988) to 19.8% (Franken et al. 1982). Given the number of existing eucalypt species and the diversity of species existing in the tropical forests, it is premature to draw any final conclusions about the loss of rainfall resulting from canopy interception by forests in the tropics. This subject merits more attention from researchers (Shuttleworth 1988). However, a review of the work and data available in Brazil as well as other parts of the world suggests that, on the average, the water interception loss by eucalypt plantations is less than that of other tree plantations or native forests (Lima 1993).

2.2.2 Runoff

It has been demonstrated that watersheds covered by natural forests of eucalypts in Australia produce good quality water (Hatch 1976). Charley and Richards (1983) showed that the most positive effect of forest cover on watershed water quality occurs during rapid tree growth. This correlation may suggest that eucalypt plantations in Brazil may have a beneficial effect on the water quality by virtue of their very fast growth rate and short rotation.

Although some variation exists in the influence of various eucalypt species, native forests, and other tree species on water quality, studies have shown that watershed water quality depends more on the geology, soil, and precipitation regime of the region (Lima 1993). In the valley of Paraíba river in São Paulo, a study conducted in two small watersheds covered by *Eucalyptus saligna* showed that the nutrient balance and quality of the water was not unlike that found in similar studies in other parts of the world (Ranzini 1990).

The substitution of the forest cover by pastures and agricultural crops will normally promote a change in the water quality and water balance. The water often becomes saltier because of the concentration of minerals. However, afforestation of the area probably will restore the initial condition over time (Borg et al. 1988). Therefore, it is possible to conclude that establishing forest plantations can be a positive factor in watershed management. However, care must be taken because inadequate site preparation, clearcutting, fertilization, and slash burning can have negative effects on water quality (Lima 1993).

2.2.3 Uptake

Perhaps the most controversial water-related issue relating to eucalypt plantations is the effect on the water content of the soil. It is claimed that eucalypt trees absorb more water from the soil than any other tree species. The uptake of soil water depends mainly on the architecture of root systems and the depth of root penetration (Lima 1993). The capacities of the more than 600 eucalypt species for water uptake vary depending on the type of root system; some have superficial root systems and others have deeper systems (Jacobs 1955). As in most natural forests and forest plantations, the roots of most eucalypt plantations are concentrated in the superficial layers of the soil (Reis et al. 1985). However, some eucalypt roots can grow to 30 m in depth (Jacobs 1955) and extract water from 6 to 15 m deep (Peck and Williamson 1987).

The growth of the eucalypt root system depends on the environmental factors, mainly soil compaction (Nambiar 1981). This has been verified for *E. urophylla*, *E. pellita*, *E. camaldulensis*, *E. grandis*, *E. cloeziana* and *E. citriodora* in the state of Bahia (Krejci et al. 1986). Of these, only *E. citriodora* and *E. pellita* were able to develop fine enough roots to penetrate a compacted layer of soil in the research area.

A study carried out in Minas Gerais compared soil moisture in a 5-year-old *E. grandis* plantation, a 5-year-old *P. caribaea* plantation, and a savanna-like native forest. A similar pattern of annual variation in soil water was found for the three forest covers. However, in terms of timber production, the eucalypts used water more efficiently than did the natural vegetation (Lima et al. 1990).

Eucalypts seem to behave as any other tree plantation or natural forest cover with respect to the soil water dynamics and with respect to the water balance of the watersheds. As with most timber harvesting, soil water increases during cuttings and decreases after afforestation is complete. Thus, eucalypt plantations (as any other managed vegetation) can have both positive and negative effects on the water quality and quantity. Whether the sum of these effects is positive depends largely on management practices.

2.3 SOIL

2.3.1 Litter Effects

The effects of eucalypts on the soil have been studied in several countries over many years. Most of the concerns related to soil effects deal with depletion of nutrients and allelopathy caused by the litter, which is said to exert an antibiotic effect on soil microorganisms. This concern was verified by research that showed a very low concentration of nitrifying bacteria in eucalypt plantations litter (Florenzano 1956). However, many of the litter problems can be alleviated by alternating rotation or mixing species and clones to promote decomposition. An extensive literature review demonstrated that afforestation with eucalypts improved soil fertility in the long term in several areas of the world (Phillipis 1956, Ricardo and Madeira 1985, Karshon 1961). However, long-term sustainability and site fertility still needs to be a key concern in any plantation scheme.

In the state of Minas Gerais a comprehensive study was undertaken to analyze the effects of the short-rotation eucalypt plantations on soil properties in 8- to 10-year-old

Eucalyptus grandis stands established on lateritic and sandy soils. Samples of soils were collected at varying depths of up to 0.60 m on eucalypt plantations as well as on a nearby savanna-like stand. Chemical, physical, and biological analyses of the soil samples showed no statistically significant differences between eucalypt and savanna soils. Further, in an experiment in which eucalypts soils were used in a greenhouse to grow beans no allelopathic effects were detected [CETEC 1984].

Identical work was carried out in Minas Gerais on 25-year-old *Eucalyptus citriodora* and *E. paniculata* plantations. The chemical, physical, and biological soil analyses of these plantations were compared with those of nearby native forests and pastures. The eucalypt soils contained 27 tons of litter per hectare compared to only 12 tons produced by the native forest and had more microorganisms and nutrients (Fouseca 1984).

2.3.2 Reclamation

Afforestation has been recognized as one of the most effective means to reclaim marginal, eroded, or mined land (Van Goor 1985). A plantation of a single species can have a positive effect on soil if it is established on land having no cover or having been impoverished by misuse. However, the high growth rates and short rotations of most of the commercial eucalypt plantations result in a very high nutrient uptake from the soil. In fact, nutrient use for an intensively managed eucalypt plantation can be comparable to that of an agricultural crop (Miller 1989). However, agricultural crops normally require more total nutrients than do the short-rotation intensive culture eucalypt plantations (Lima 1993).

2.3.3 Protection

Eucalypt plantations are also sometimes accused of not providing adequate soil protection. This lack of protection can lead to less water infiltration and greater runoff, resulting in soil erosion and watershed sedimentation. This was probably true in the 1970s when site preparation for establishment of the eucalypt plantations was similar to that for agricultural crops. Vegetation was burned, and the soil was plowed and harrowed. This resulted in exposure of the soil to rainfall for at least the first 6 months, before seedling crowns had grown sufficiently to cover the soil. Today silvicultural practices have essentially eliminated the use of fire, as well as plowing and harrowing of the entire area, for site preparation. These practices have been replaced by soil preparation in strips or by 3-m-spaced furrows in which seedlings are planted every 2 to 3 m (Lima 1990). Properly managed eucalypt plantations can provide soil protection. As always, sensitive sites need to be treated carefully to avoid adverse effects on soils.

2.4 BIODIVERSITY

In a native forest ecosystem a balance exists among the main components of the system and among the energy flows of the food webs. One of the most important factors in the stability of the system is its biodiversity (Evans 1992). Plantations are specialized but generally simplified ecosystems. Establishment of monoculture short-rotation eucalypt plantations has been criticized as detrimental to the environment because of its negative effect on biodiversity (i.e., reduction in the number of plant and animal species).

However, these effects can be minimized by adequate management of both the plantations and the remaining native forests and vegetation (Berndt 1992).

2.4.1 Fauna

One of the criticisms of eucalypts in Brazil is, being an exotic species, it does not provide shelter and food for the native fauna. This is probably true not only for eucalypt plantations but any monoculture, be it an exotic or native. Compared with multispecies plantations, single-species forest plantations may reduce the availability of diverse food and shelter for the local wildlife (Evans 1992). Besides these direct effects, forest plantations may create indirect effects that promote modifications in food webs in other areas of the region that can lead to the disappearance of some faunal species (Avery 1989). However, it has been noted that faunal species will adapt to the new conditions generated by a forest plantation whether eucalypts or native species (Rochelle and Brunnel 1979). Thus, the existence of eucalypt plantations per se are not necessarily detrimental to wildlife (Lima 1993). The controversy dealing with the impact of plantations on fauna is fed by conflicting research results. For example, in Viçosa, Minas Gerais, a study was conducted to determine the number of small mammals in four different types of forest. While some mammal species were found in a 10-year-old *Eucalyptus saligna* plantation, a much larger number was found in a 31-year old *Araucaria angustifolia* stand and in 15- and 52-year-old mixed natural forests (Dietz et al. 1975). On the other hand, in Aracruz, Espírito Santo, a survey comparing bird populations in a 9-year-old *E. citriodora* (having a relatively well-developed understory) and an adjacent natural forest found 50 birds (28 species) in the eucalypts, 17 birds (10 species) in the native forest, and 22 birds (11 species) in the border between the two (Almeida and Laranjeiro 1982).

Avoiding or diminishing silvicultural treatments after stand establishment allows birds to occupy the area in search of food. This bird population consists mainly of species that feed on insects (Almeida 1981). As a consequence, there is a direct benefit to these birds as well as to the plantations in that birds help control insect populations. In a study conducted in Telêmaco Borba, Paraná, bird population was appraised in *Araucaria angustifolia* and *Eucalyptus* sp. plantations and in mixed native forests. The results showed a greater bird population density in the plantations compared with the natural forest; however, species diversity was greater in the native vegetation. The greater biodiversity in the adjacent native forests and a higher population density in the plantations can combine to show an overall positive benefit (Berndt 1993).

One of the major problems related to short-rotation eucalypt plantations and animal populations has to do with species that require habitat that consists of old trees or mature forests. Three actions have been suggested to help alleviate this problem: (1) leave some trees in the plantation at the time of harvesting, (2) extend the rotation period, and (3) leave natural vegetation intermixed with the short-rotation plantations (Loyin 1985). The last has been the preferred action of Brazilian forest companies (Almeida et al. 1982). However, consideration is also being given to extending the rotation period (Spinelli 1993).

Since the beginning of the reforestation programs in the 1960s, forest companies had two options in attempting to preserve natural forests: plant 1% of the total number of trees using only native species or leave 10% of total area in the original vegetation (Reis and Reis 1992). The latter option has been preferred because in most of the afforested

areas at least 10% of the area in riparian vegetation or forest cover was located along the rivers and streams or on very steep slopes, which could not be harvested according to the National Forest Code. Further, it was difficult to get seeds of native species with which to accomplish the first (planting) option. Since reforestation programs that require the preservation of native forests began, regions where plantations are established are typically mosaics of plantations, pastures, grasslands, croplands and native vegetation. This diversity of habitat is very important to faunal preservation (Evans 1992). Plantations certainly have helped to alleviate the harvesting pressure on native forests and have provided for habitat that otherwise would have been lost.

Other management practices that are very important to the success of a conservation program for fauna involve leaving native areas undisturbed (Moss 1979), planting fruit trees, and constructing small ponds throughout in the plantation area. Such practices have been carried out recently by most of the forest companies in Brazil.

It is possible to identify three stages in the development of a short-rotation eucalypt plantation in relation to faunal habitat. The first stage is the initial establishment phase, when the stand is subjected to intensive silvicultural practices such as weeding, cultivation, and herbicide spraying. In this phase, the eucalypt plantations may provide occasional shelter for the animals living in the adjacent plantations or natural forests. The second stage is the crown competition phase, when shading restrains the establishment of understory vegetation and the plantation offers limited understory shelter for fauna from adjacent areas. The last phase is the natural pruning phase, where the understory reappears (provided seeds of native species are present in the ground), leading to better conditions for the local fauna (Reis and Reis 1993). Intermixing plantations in varying phases helps create better habitat conditions.

In general, (1) plantations have a less diverse fauna than indigenous forests, (2) plantations composed of exotic trees have a less-diverse fauna than plantations of indigenous species, (3) plantations can be made more favorable for animals and plants by appropriate management practices that provide desired habitat, and (4) planting in treeless areas can provide shelter that would not otherwise be available to faunal populations (Poore and Fries 1985).

2.4.2 Flora

Planting eucalypts and replacing natural vegetation has an effect on the flora of an area. This effect may result from shading, competition for nutrients and moisture, site disturbance, allelopathic effects, or the cumulative effects of changes in the soil. The extent of the impact will depend on the nature of the community the plantation replaces and the ecological characteristics of the region. For example, in an arid region eucalypt may suppress ground vegetation by competing for water, but this is unlikely to occur in an area of high rainfall (Poore and Fries 1985).

Critics of short-rotation commercial eucalypt plantations assume that eucalypts have an allelopathic effect on the other plants, resulting in the disappearance of the original native plants and local ecosystems (Poore and Fries 1985). For the same reason, there is concern that agricultural crops cannot be cultivated on lands previously occupied by eucalypt plantations or even on lands nearby (Lima 1993). It is believed that eucalypts can affect other plants directly through the inhibitory influences of leaf litter and root exudates or through the effect of litter on nutrient mineralization and soil microflora (Florence 1986).

However, a survey of the worldwide literature reveals that direct plant-chemical interactions in natural communities are probably rare (Willis 1980). Regeneration of native species in the understory of eucalypt plantations is not restricted by allelopathic effects of the litter (which can occur for a limited number of species). Native species regeneration is instead a function of (1) the amount of sunlight that reaches the ground through the eucalypt canopy; (2) competition for soil-water; and (3) the supply of seeds of native species in the soil.

Some feel that management practices on plantations will enhance conditions for native flora. For example, an intense fire in the eucalypt forest may provide, at least temporarily, a more biologically favorable soil environment for plant growth. This more favorable environment is caused by many factors, including the removal of plant competition, an increase in soil pH and availability of ash nutrients, breakdown of inhibitory compounds, stimulated mineralization of nitrogen and phosphorus in soil, and the effect of partial soil sterilization on soil microflora. Thus, it seems that many observed effects of fast-growing eucalypt plantations might be attributed primarily to competition for soil nutrients and water during the rapid growth phase rather than any direct toxic influences the eucalypt may have on soils and other plants (Florence 1986).

Newly planted eucalypt seedlings are very sensitive to weed competition during the first few months of establishment. Therefore, it is common in Brazil to use intensive silvicultural practices such as herbicides, mechanized weeding, and other methods of site preparation, before planting begins. These practices allow the eucalypt seedlings to grow free of weed competition, at least during the earlier stage of their lives. Because of these practices, understory vegetation in the intensively managed short-rotation commercial eucalypt plantations does not normally reappear until the fourth year. Most understory vegetation will also be eliminated to facilitate harvesting and to provide proper establishment conditions for new plantation or the sprouts of the eucalypt stumps. Thus, the occurrence of understory species may be reduced in plantation areas (Reis and Reis 1993).

In some regions very aggressive grasses, such as *Brachiaria humidicola*, *Panicum maximum*, and *B. decumbens*, can occur under the eucalypt canopy. The presence of these grasses makes it difficult for other understory species to become established. However, if the eucalypt plantation is allowed to grow for longer periods of time, the original native species or ecosystems probably will reappear in the understory, as was observed in a 50-year-old *Eucalyptus saligna* plantation in Itatinga, São Paulo (Lima 1993).

There is no doubt that management practices, the eucalypt species used, length of the rotation, and the existence of nearby native vegetation will all influence understory composition in eucalypt plantations (Reis and Reis 1993). For example, in a study conducted in Belo Oriente in the state of Minas Gerais, a 16-year-old *Eucalyptus paniculata* plantation had 47 native species (30 families) in the understory, whereas a 6-year-old *E. saligna* plantation had 26 native species (20 families). The density of the native understory increased with time, and the density of the original eucalypt plantations decreased with age as a result of natural mortality. This decrease in stand density allowed more sunlight to reach the ground, increasing the regeneration of native species (Calegario 1993). The amount of understory also varies among eucalypt species. For example, it has been shown that *E. torrelliana*, which has a larger and thicker canopy, has less native understory than *E. grandis* or *E. saligna*. Further, leaves of *E. torrelliana* do not decompose easily in the litter, restricting germination of the native species seeds in the soil (Reis and Reis 1993). As with other environmental aspects, the impact of eucalypt

plantations on local flora will vary with local conditions and management. It is necessary to match species to site, particularly with reference to climate and soil.

Several studies have been conducted on the environmental aspects of the large-scale eucalypt plantations in Brazil. Walter de Paula Lima of Piracicaba, São Paulo, observed recently that the existing scientific work indicates that

1. no evidence of any change in the precipitation regime in a region as a result of the establishment of eucalypts or any other tree plantations;
2. the losses of water through evaporation of the intercepted water from rainfall by the canopy is smaller for eucalypt plantations than for other tree plantations or native forest;
3. the eucalypt plantation can contribute positively to control loss of the soil and nutrients by erosion;
4. water quality is not affected by eucalypt plantations;
5. the water balance of a eucalypt plantation does not differ from other tree plantations or native forest;
6. the main species that have been used in most of the short-rotation plantations have good control of stomatic transpiration;
7. the eucalypts are more efficient in the use of water than other tree species;
8. the effects of the eucalypts, other tree plantations, and native forests on the watersheds are the same;
9. in the long term, eucalypt will have a positive effect on the soil;
10. the demand for nutrients by eucalypt is high but is comparable with that by other tree species and is much lower than that by agricultural crops;
11. there is no detrimental effect of the eucalypt plantations on the native vegetation; and
12. eucalypt plantations, as any other tree plantations, are not devoid of wildlife, and habitat can be improved by adequate management (Lima 1993).

3. SOCIAL ISSUES

Short-rotation plantations are sometimes said to promote social benefits in regions where they are located (Beattie 1975). These direct and indirect social benefits include (1) the creation of jobs, (2) income growth, (3) flood control, (4) erosion control, (5) watershed protection and water quality, (6) creation of recreational and leisure

activities, and (7) soil improvement. Under certain circumstances, forest plantations are considered to be better investments than other agricultural activities because of their low social costs (Capp Filho 1976). On the other hand, the costs that short-rotation forest plantations are claimed to have are (1) loss of water through evapotranspiration, (2) soil nutrient depletion; (3) sedimentation of rivers and streams; (4) hazardous logging activities leading to high accident rates for employees; and (5) damage to the road system (Worrel 1959). Obviously, this subject is very controversial.

The jobs and taxes generated and the salaries paid are some of the most easily measured benefits of the eucalypt plantations. These economic indicators have been used in most of the economic and social evaluation studies of the eucalypt plantations in Brazil (Neves 1979). An excellent example of a forest company in Brazil from which to get an idea of social and economic impact is Aracruz Celulose S.A., the largest eucalypt pulp producer in the world (2 million tons per year). In 1992 alone, Aracruz paid US\$18 million in taxes to the state of Espírito Santo (where its mill is located); spent US\$15 million in social investments; allocated US\$14.7 million to its forest farmer program; spent US\$12.5 million in its forest extension programs; invested US\$600 thousand in research projects; paid US\$30 million in salaries; and bought US\$50 million of goods from suppliers located in the state. In 1992 alone, the company injected US\$120.8 million into the economy of the state of Espírito Santo (Soresini 1993).

These economic and social benefits make the forestry sector in Brazil one of the best alternatives for development and for contributing to the economic and social welfare of its increasing population (Siqueira 1990). Forestry activities offer job opportunities even in remote areas of the country. On average, each hectare of eucalypt plantation generates four directly related jobs, an indication of the economic and social importance of these plantations, which is expected to increase in the coming years. Today, it contributes US\$18.8 billion or 3.9% to Brazil's Gross Domestic Product (Soresini 1993).

In recent years, another positive social contribution of the forest plantations has been in disposal and recycling of residues such as urban waste and organic material. The risks of applying these residues to forest plantations are lower than those presented by their application to agricultural areas (Rizzi 1993). The capacity of forest areas to renew and produce good quality water has been proven. However, several factors have to be considered with respect to disposal/recycling in these systems, such as the capacity of the area to take a certain amount of wastewater, the growth of the species, impacts on fauna and flora, and contamination of streams and groundwater.

4. POLICY AND LEGISLATION

Forestry development requires the establishment of very clear and well-defined regulatory legislation and enforcement. Despite the existence of a significant forest industry, it was not until the mid-20th century that Brazilians began to establish a well-defined forest policy (Swiolko 1990). The following summarizes the development of forest policies in Brazil.

Forestry activities were established in Brazil soon after it was discovered by the Portuguese in 1500. These activities were focused on the harvesting of Brazil-wood (*Cesalpinia echinata*), which was one of the main economic activities at that time. However, with the development of agriculture and the cattle industry, forestry activities

assumed a less important role in the Brazilian economy. This situation existed until the 1960s, when the forestry sector started to receive more attention from government.

Since the colonization period by Portugal, laws existed to protect the native forests, which were considered the property of the crown. Despite these laws, the forest along the Atlantic coast was practically destroyed by logging to provide timber and firewood or by clear-cutting to provide land for agriculture. In 1799, laws were passed to regulate the harvesting of trees, and severe penalties were given to violators. At that time, individuals guilty of setting forest fires deliberately were sentenced to death. Even with these severe penalties, deforestation of the Atlantic forest continued, so Prince Dom João IV enforced a new law requiring private land owners to preserve the forests located within a certain distance from the Atlantic Coast and along the margins of certain rivers.

The first legislation for reforestation of the Atlantic Coast forest was introduced in 1802, and in 1813 it became illegal to cut Brazil-wood. In 1825, the prohibition of cutting Brazil-wood was extended to other species but the illegal cutting of Brazil-wood, a mainstay of the Brazilian economy, continued. In 1829, cutting and burning on government forest lands had to be approved by a municipal government council. However, in 1831 things changed completely; all the laws concerning the harvesting and burning of the trees and the monopoly of the crown on the Brazil-wood and other species were removed. The rate of deforestation grew considerably, and fire was used indiscriminately to clear areas for agricultural use (Swiolko 1990). The colonial system basically was out of touch with the local social and economic situation.

The first Brazilian Forestry Code was passed in 1934 by decree 23793. However, it was not enforced for about three decades at which time deforestation was occurring at an incredible rate (SBS 1987). The 1960s was a time of key changes in forestry in Brazil because of (1) a new Brazilian Forestry Code, (2) the fiscal incentives for reforestation, (3) legislation for wildlife protection, and (4) the creation of the Brazilian Institute for Forestry Development (IBDF). The main objectives of the code were (1) forest preservation, (2) proper management and harvesting of the native forests, (3) replacement of forests used by industries, and the (4) establishment of national forests devoted to multiple use (Ribas 1990).

The 1965 version of the Brazilian Forestry Code allowed for development of fiscal incentives for the establishment of human-made forests. This code was the key to the growth of the Brazilian forest sector. In 1966 the federal government passed Law 5106/66 that allowed individuals and companies to use 50% of their income tax payment for reforestation (Suchek 1991). As a consequence of this law, the area of planted forest in Brazil soared from 470 thousand hectares (before the fiscal incentives) to 6.2 million hectares in 1992. The greatest breakthrough at that time, and perhaps the most influential factor in the establishment of a very intensive and advanced eucalypt silviculture in Brazil, was that the use of eucalypt wood for pulp and paper production proved feasible (Soresini 1993). The country became the world's leader in eucalypt plantation establishment. However, along with all benefits accrued from these plantations, criticism also arose, mainly from individuals and organizations concerned with possible harmful effects the plantations might have on the environment and on the social welfare of rural communities.

Initially, the Brazilian Forestry Code provided three types of fiscal incentives for preserving native forests and establishing planted forests: (1) privately owned planted or natural forest would not be taxed, (2) income originating from natural forests or plantations would not be taxed, and (3) funds used for afforestation or reforestation would

be deductible from the income tax of individuals and companies. In 1966, Law 5106/66 established the rules for tax incentives for reforestation, setting a 50% limit for deducting these expenses from total income. One problem with Law 5106/66 was that the taxpayer had to incur expenses prior to asking for the deduction.

Law 1134/70, which was passed in 1970, provided that companies could apply up to 50% of their income tax to new forest investments in projects previously approved by IBDF. Thus, for a period of time both 5106/66 and 1134/70 provided fiscal incentives for reforestation in Brazil. Law 1134/74 resulted in a boom in the forest sector of the country, and several companies specializing in reforestation emerged. However, some problems arose because of this law. Companies would receive a percentage of their taxes back but would not track the reforestation projects. This situation prevailed until 1974 when a new law, 1376/74, was passed in an attempt to correct this distortion. Law 1376/74 created the Fiscal Incentives Fund to which companies submitted funds rather than to a specific reforestation project of a particular forest company. In 1983, Law 88207/83 was passed, which established new regulations for fiscal incentives. These new regulations required the companies to anticipate the amount of money to be invested 6 months in advance when asking for rebate on their taxes. The reaction of forest companies was very negative. The Brazilian Association of Forest Companies claimed that the new legislation would bankrupt the emerging forest sector and cause unemployment.

In 1986 new legislation made additional changes in the fiscal incentives rules for reforestation, leading once again to a strong negative reaction by the forest companies. In 1987, Law 1297/87 limited tax-deduction application in reforestation to 10% and confined it to only certain areas in the states of Minas Gerais and Espírito Santo. Finally, in 1988 the fiscal incentives for reforestation were discontinued by Law 7714/88, closing a very important chapter of the development of the forestry sector in Brazil. In 1989 IBDF was dissolved by the government, and in its place the Brazilian Institute of Environment and Natural Resources (IBAMA) was created.

The recent Federal Constitution gives new treatment to forest legislation. Today, not only the federal but also the state and the municipal district can pass legislation dealing with forestry. Thus, preservation of forests, fauna, and flora have become a common responsibility of the federal, state, and municipal governments (Swiolko 1990).

For example, in the state of São Paulo companies are prohibited from using fire in any phase of establishment of plantations. In some counties of the state of Espírito Santo, the companies are not allowed to plant *Eucalyptus* in land not previously occupied by that genus. In fact, in the state of Espírito Santo, the forest companies are not allowed to buy land to establish eucalypt plantations. They can operate only on land that they already own and can only improve the productivity of their plantations or engage in tree farmer programs to increase the supply of wood for their mills.

Despite the fact that the Brazilian forest policy was based on fiscal incentives for establishing short-rotation monoculture plantations of exotic species, native forests still contribute substantially to the forest production of the country. In northern Brazil, native forests contribute 99.8% of the total harvest, whereas in the southeastern region, short-rotation plantations contribute 82.6% of the total. In other words, the northern states specialize in producing lumber from native forests, and the southeastern region specializes in producing other wood products from short-rotation plantations (Ribas 1990).

The current pressures exerted by the international community on countries with large areas of forest such as Brazil are leading to new actions. For example, organizations such as the World Bank and the Inter-American Development Bank are linking loans to an

obligation by countries to consider the environmental aspects of projects for which they are seeking funds. Some European countries are refusing to import forest products from tropical countries if the products originated from unmanaged forests or from forest companies that do not comply with their specifications regarding environmental conduct (Siqueira 1990).

When eucalypt plantations displace any existing ecosystem, the relative importance (both ecological and social) of the existing ecosystems should be carefully balanced against the advantages to be gained (Palmberg 1986). Decisions about whether or not such replacement is justified can only properly be decided by considering a comprehensive national policy for the conservation of nature and genetic material (Poore and Fries 1985). This is a continuous process and is evolving as Brazil's social and economic structure changes.

5. FOREST EDUCATION AND RESEARCH

As previously mentioned, forestry education in Brazil began in 1960, when the National School of Forestry was founded in Viçosa, Minas Gerais, by the federal government under the auspices of the FAO. In 1964, the National School of Forestry was transferred to Curitiba, Paraná, and a new school was founded by the state government in Viçosa. Fourteen years later a graduate program was initiated at that school, which is now called the Department of Forestry of the Federal University of Viçosa (Reis and Reis 1993). Today, approximately 15 schools of forestry are spread across Brazil in cities such as Manaus and Belém in the north; Patos and Recife in the northeast; Brasília and Cuiabá in centralwest; Viçosa, Rio de Janeiro, Lavras, Piracicaba, and Botucatu in the southeast; and Curitiba and Santa Maria in the south.

Among these, the school located in Viçosa, Minas Gerais, has the strongest program oriented toward eucalypt plantation and utilization. This emphasis derives from the fact that Minas Gerais has the largest area of short-rotation eucalypt plantations in Brazil. The school located in Piracicaba, São Paulo, also has a very strong eucalypt-oriented forestry program. Because most of the forest industries that use eucalypt wood as raw material are located in the southeastern region of the country, it is only logical that strong eucalypt-oriented programs be located there.

It is important to emphasize that the country's first forestry school at Viçosa was established just 34 years ago, and the first graduate program in forestry was offered there only 20 years ago. Thus, during the large-scale plantation development educational and scientific programs concerning the silvicultural and ecological aspects of the eucalypt plantations were not in existence (Reis and Reis 1993). The programs that were available were devoted to enhancing timber production alone and paid little or no attention to the impacts of the newly established plantations on the environment. This lack of a sound scientific information base coupled with (1) the misuse by some individuals and forest companies of the resources derived from fiscal incentives; (2) the failure of some eucalypt plantations, along with (3) the "exotic" characteristic of *Eucalyptus* in Brazil, set the framework for the current anti-eucalypts campaign in the country. It is interesting that the establishment of exotic agricultural crops such as soybeans, coffee, sugar-cane, and others has not been subjected to the same degree of criticism.

In 1967, the University of São Paulo and some forest companies signed an agreement creating the Institute for Forest Research (IPEF). Because most of the companies associated with this institute used eucalypt wood as raw material, they exerted a strong influence on the research program as well as on the graduate and undergraduate forestry programs at IBEF. A similar situation occurred in 1974 when the Federal University of Viçosa signed an agreement with several forest companies in Minas Gerais and Espírito Santo creating the Society for Forest Research (SIF). All of these companies used eucalypt either for charcoal or pulp production. Their influence on the research program and on the graduate and undergraduate forestry programs of the Federal University of Viçosa was considerable. Other universities and state research institutions conduct studies concerning eucalypts on a smaller scale but mostly focus on pine plantations and local native forests and species.

During the 1970s and 1980s, most universities course and research programs focused on silviculture, forest management, tree breeding and improvement, fertilization, forest protection, and wood technology (charcoal, pulp and paper, particle boards, and essential oils). In the late 1980s and into the 1990s, the focus changed to sustainable development. Thus, subjects such as forest planning, agroforestry, harvesting mechanization, nutrient cycling, genetic improvement (e.g., clones and hybrids), biological control of pests and diseases, forest legislation and policy, environmental and social impacts of forest plantations, soil conservation, watershed management, biodiversity conservation, and urban forestry have become very important. Both the graduate and undergraduate programs of the schools of forestry in most of the Brazilian universities have been modified to fit the current needs of the private sector and government institutions as well as society as a whole. About 4600 foresters have graduated since 1965 from the 15 universities in Brazil. Of these graduates, 60% are working in the private sector (Sequeira 1990).

Despite the considerable number of institutions, universities, companies, and organizations devoted to forest research in Brazil, a lack of coordination among them is apparent, resulting in inefficiency and dispersion of funds, labor, and equipment (Sequeira 1990). Forest research in Brazil has always tried to solve immediate problems or attend to the most urgent needs of forest companies and other forest organizations. As a result, from 1971 to 1977 research concentrated mostly on the production of wood for industrial uses (charcoal, pulp and paper, particle board). Since 1978 energy problems and greater environmental concerns have forced research and education to concentrate more on forests as a renewable energy source, the environmental impact of plantations, and new markets for the wood.

6. LESSONS LEARNED

6.1 FISCAL INCENTIVES

As already mentioned, fiscal incentives for reforestation in Brazil were very important in the development of the pulp and paper and the charcoal-based pig-iron and steel industries in the country. However, the fiscal incentives program was not perfect. As soon as the law was approved by the government, there was a race to develop private companies that would prepare technical projects to be submitted to IBDF. These companies convinced prospective investors to invest money in reforestation projects.

Many of the investors never received money back on their investments, and in some cases, companies would return only a certain percentage of the total investment, normally immediately after the contracts were signed. Consequently, most of the investors thought that they had received their share and did not track the reforestation activities of the companies, which made significant profits at the expense of the investors.

Because of the low price of the marginal lands (mainly in the savanna-like regions in centralwestern and southeastern Brazil), many of the companies bought large tracts of land without really intending to carry out the reforestation projects submitted to IBDF. Unfortunately, IBDF never had the necessary financial support to inspect the proposed reforestation projects, many of which were established in remote areas, making the possibility of utilization equally remote.

The most successful projects were those linked to the pulp and paper, cement, pig-iron and steel, and composite board industries. These projects had a direct link between timber production and its immediate use as a raw material. Thus, the first and perhaps most important lesson learned by the government was to require that any project be linked to an existing (or planned) industry that ultimately would use the resources. Further, a fully funded government organization must oversee the reforestation activities and the existing educational and research institutional system.

6.2 LAND ACQUISITION

The failure of several reforestation projects in Brazil was a result of land acquisition practices. In the beginning, most of the companies wanted large tracts of land at the lowest possible price. Thus, they did not pay attention to important details such as distance from consumer centers, availability of water and energy, chemical and physical properties of the soil, or the existing vegetation. Consequently, several plantations were abandoned (such those in Mato Grosso do Sul) because they were too far away from any prospective user. Others did not become well established because of unsuitable hydrology or geology. In some cases, endangered ecosystems, such as the Atlantic forest or other native forest ecosystem (e.g, savanna, Araucaria forest, and Amazonian forest), were simply cut and burned to establish a technically sound reforestation project.

The price of land in the more industrialized regions of the country has risen considerably over the last 10 years, and it has been practically impossible for the companies to buy land or to expand their plantations in areas near their mills. Most of the new plantations are being established in areas recently cut and previously occupied by old plantations. Emphasis is now on increasing the productivity of the existing plantations through genetic improvement and careful management of the soil. The remaining native ecosystems are preserved and play a very important role in the biological balance of the area. Companies prefer degraded land (such as abandoned crop and pasture lands) to land having native vegetation cover. Flat or gently rolling areas are also preferred to steeper areas, which are more susceptible to soil erosion. Designating appropriate land for plantation establishment is a key component of any plantation establishment program.

6.3 TREE SPECIES AND PROVENANCES

At the beginning of the incentive-based reforestation program, no ecological zoning existed nor were any comprehensive scientific data available to help the companies to choose the best species for each region and site. Based on some early research in São Paulo, most of the companies used *Eucalyptus grandis* and *E. saligna* in their reforestation programs throughout Brazil, including savanna-like regions, which have a very low level of precipitation and a 5- to 7-month dry season. These species have a very high growth rate but are not adaptable to such regions. As a result, major failures occurred in the initial reforestation programs in these regions and some have very low productivity even now.

In the early years, seeds from eucalypt species that were suitable for many regions of Brazil were difficult to obtain. Some companies used seeds collected from plantations and experimental plots. This practice led to the establishment of very heterogeneous stands because of the very high degree of hybridization of the existing eucalypt species. Subsequently, companies learned that ecological zoning (done by Golfari in the late 1970s) was essential to match not only species but provenances to each region of the country. Further, genetically improved seeds had to be imported from other countries (Australia, New Zealand, Timor Islands, South Africa, Zimbabwe, and Rhodesia) to be used not only for the plantations but also to establish local tree orchards for future seed production. These procedures have paid off, and today, Brazil exports genetically improved seeds of both eucalypt and tropical and subtropical pines.

Cloning was the next logical step as the companies tried to achieve homogeneous stands with a very high productivity, natural resistance to pests and diseases, and uniform raw material for their production processes. Today, controlled hybridization, cloning, and micropropagation are leading the country to a very advanced position in eucalypt plantation technology.

6.4 PESTS AND DISEASES

At the beginning of the large-scale eucalypt plantation establishment in Brazil, the two most difficult problems were leaf-cutting ants and root-damaging termites. Control of ants was accomplished by using chemical products such as methyl bromide, aldrin, and (later) baits containing dodecachlor. Termites were controlled mainly by aldrin placed in each planting hole during stand establishment. Although most countries currently ban chlor-based pesticides, they were used indiscriminately in the most populated regions of Brazil. If this situation had continued, it would have caused serious environmental problems affecting both fauna and the human population.

The establishment of mismatched species in certain regions and sites led to the appearance of diseases such as the canker caused by *Chryphonectria cubensis*. Because of the size of the plantations, it was not economically feasible to control the fungus chemically. The best means found to overcome the problem were to use eucalypt species naturally resistant to the disease, to use techniques of genetic improvement and controlled hybridization to develop individuals and hybrids naturally resistant to canker, and to use vegetative propagation to obtain clones of *Eucalyptus grandis* or hybrids that were highly resistant to such disease.

Because of the size of the plantations and perhaps because of the removal of some native vegetation cover, local insects also became a problem for the eucalypts.

Lepidoptera and coleoptera were the most problematic. Initially, companies tried to use chemical pesticide control; however, apart from the high cost of chemical applications (sometimes by aerial spraying), the problems of environmental contamination and growing resistance of the insects to these pesticides were prohibitive. However, the use of appropriate species for each region and the use of silvicultural practices such as pruning helped alleviate the insect problem. A major breakthrough was realized with the use of biological control to maintain insect populations at an acceptable level. In one of the control measures, a certain amount of native vegetation is intermixed with the eucalypts. This technique favors the maintenance of local bird populations that play a very important role in controlling the insect population. A nationwide program to monitor insect populations in eucalypt plantations was initiated in which universities, research institutions, and forest companies participated. Natural enemies (insects, bacteria, viruses, and fungi) of the prospective problem insects were also studied. Today, natural controls are the most efficient and most used techniques to control insects in eucalypt plantations.

In 1992 the use of dodecachlor-based baits for ant control in Brazil was banned by IBAMA. This led some private companies to study and develop, along with the scientific community, new kinds of baits that were not harmful to the environment. One of the most recent products is based on sulfuramid, which has proven to be very efficient in controlling leaf-cutting ants and has none of the environmental problems presented by dodecachlor.

6.5 SITE PREPARATION

Because no significant experience was available regarding silvicultural and management techniques before the establishment of incentives-based forest plantations in the 1970s and early 1980s, most of the forest companies used site preparation techniques used to prepare land for agricultural crops. Most of the time, the area was burned initially to diminish vegetation cover and to allow a better view of the terrain in which the bulldozers would work. The remaining vegetation was then removed by bulldozers and burned again. This also resulted in removal of the superficial and more-fertile layer of soil, which accumulated in strip-like areas with the residual vegetation. Subsequently, these strips would cause serious problems during the mechanized planting, tending, and logging operations and would make ideal locations for the hills of leaf-cutting ants, compounding control problems. The next operation involved harrowing the soil followed by two plowing operations. Soil erosion was of no concern; consequently, these intensive activities did not take into account the slope of the area or the direction of harrowing, plowing, and furrowing. Because planting was done during the rainy season, these techniques led to an enormous amount of soil erosion and silting of the streams.

Today, plantations are not established in areas having native forest cover. Most of the new plantations are being established in areas previously occupied by eucalypt stands that have been harvested or on abandoned and degraded agricultural and pasture lands. These areas are usually covered by small bushes and shrubs, which are incorporated into the soil during site preparation. Sometimes, they are simply eliminated by using herbicides, after which the area is furrowed to a 0.5-m depth to eliminate the compacted layer. These furrows are established according to the planned initial spacing (generally 3 m) along the contour. Because they are perpendicular to the slope, they play a very important role in the absorption of water by the soil during the raining season. Some

states such as like São Paulo have banned the use of fire for site preparation for both agricultural and forest plantations. The technique used today for site preparation is based on minimum site disturbance. Perhaps the only disadvantage of this new approach has been the increased use of herbicides. Developing alternatives to intensive site preparation is key to alleviating negative site-specific environmental impacts.

Another mistake made by companies in the early 1970s was the use of incorrect amounts of fertilizers. Sometimes the same NPK formula was used everywhere independent of soil fertility. In the 1980s a high level of effort and substantial funding was put into research programs to solve the problems related to soil fertility and eucalypt nutrition. A cooperative program was created and is now being implemented by most of the forest companies, universities, and research institutions in Brazil in which each company has a specific fertilizer formulation for each specific site, species, hybrid, and clone. These practices have considerably improved the productivity of the Brazilian eucalypt plantations and have lowered the cost of the wood delivered to the mills.

6.6 TENDING AND CULTIVATION

The most common practice in the first year of establishment of the eucalypt plantations (in flat and undulate areas) was to eliminate the competing vegetation between the rows of the seedlings by mechanized disking. The weeding within the rows of eucalypts was done manually by hoeing. These tending operations exposed the soil and promoted erosion (in the undulated areas) because planting was usually oriented down the slope. The disking would also cut the surface roots of the eucalypts, reducing growth and sometimes killing the tree, especially when done at the end of the rainy season or during the dry season.

Today, most of the companies have banned such methods of tending and have adopted the use of herbicides or some mechanical chopping of the weeds without disturbing the soil. Various research studies have shown that cattle and sheep can also be used for the biological control of weeds, reducing the cost of eucalypt plantation establishment. Intercropping agricultural crops, such as corn, beans, and rice, in the first year of plantation establishment can also eliminate the need for tending operations and reduce the overall cost of eucalypt plantation maintenance. The most recent study in this regard deals with the intercropping with leguminous herbaceous species to control weeds (Neto et al. 1990). All of these options help reduce negative site impacts.

6.7 ROAD CONSTRUCTION

Most of the forest companies failed to give road construction design proper attention in their projects in the 1970s and early 1980s. A typical road network was constructed without having been planned in detail to allow access for labor and machinery to reach the area to be planted. The roads were maintained during the first 2 to 4 years of the plantation establishment and then abandoned, to be reentered only at harvesting time. Consequently, most of the roads eroded completely and presented serious problems to the environment.

Today a cooperative program among forest companies, universities, and research institutions is devoted to solving these problems. The program's main objectives are to

design road networks that will reduce the cost of hauling and transporting wood from the stands to the mills and to improve the roads by using gravel and other material that will enhance compaction so the roads can carry the heavy traffic expected during harvesting operations. Roads also play a very important role in forest fire prevention and control. Originally, roads were designed on downhill slopes and would divert water from the eucalypt stands. Today, roads follow the contours of the terrain and divert water toward the trees.

Most of the problems with the roads arise during the harvesting of the forest stands. Logging and hauling operations are carried out year-round, including the rainy season when erosion problems tend to be aggravated. Development of specialized equipment appropriate for felling, hauling, and transporting eucalypt wood has considerably reduced the environmental impacts of these operations. Proper compaction and surfacing of roads and development of lighter machinery and trucks that have special tires also have improved the situation.

6.8 COPPICING AND RENEWAL

In the 1970s and early 1980s most of the forest companies in Brazil used the natural ability of the eucalypts to sprout and adopted a coppicing system of renewal. The stands were harvested at 7 years, and stumps were left to sprout. One, two, or three sprouts would be left on each stump to grow, and subsequently harvested 5 to 7 years later. Sometimes this would be repeated, and the original stand would have up to three rotations of 5 to 7 years before being replanted.

However, as opposed to other species that have an increase in yields with coppicing, the yield of the eucalypt stands in Brazil had a decline of 20 to 50% after the first rotation. The major reasons for this decline were (1) establishment of *Eucalyptus grandis* and *E. saligna* on inadequate sites (low rainfall and very long dry season), (2) the large genetic variation in the seeds used, (3) inappropriate provenance, (4) the incidence of canker attack and leaf-cutting ant infestation, and (5) inadequate logging techniques that damaged the stumps. Most of these problems were solved, and today the coppicing systems can be used with reasonable success in Brazil. However, because forest companies are constantly improving eucalypt genetically with new clones and new hybrids that have higher productivity and better technological properties, it pays to replant the stands instead of coppicing. Today, renewal of the eucalypt stands after the first harvest is an almost universally accepted practice.

6.9 SPACING

Originally, laws outlining fiscal incentives for reforestation encouraged the use of dense plantations. The greater the number of seedlings planted and tended per hectare, the greater the amount of money that could be claimed for a tax deduction. Thus, there was a tendency to use a 2 by 2 m spacing, resulting in 2500 trees per hectare. Eventually, this spacing posed some problems with mechanized cultivation and harvesting operations. One way to overcome this problem and still maintain the same number of trees per hectare was to change the spacing to 2.5 by 1.6 m, 2.75 by 1.45 m, or 3 by 1.3 m.

In the late 1970s and early 1980s, Brazil began a national program of growing biomass-for-energy. This program tended to use close spacing, resulting in 5000 to 10,000 trees per hectare. Rotation was also reduced to 4 to 5 years so that the trees would be harvested as soon as competition began. However, these eucalypt plantations failed, mainly because mortality was high, productivity of the stands was low, the final tree diameter was small, and the percentage of bark vs wood was too high. Further, because most of these eucalypt plantations were established in savanna-like regions having low-fertility soils, nutrient depletion became problematic.

Today, companies are adjusting the initial spacing to the quality of the site, the genetic material being planted, and the rotation length; thus, a specified tree type is obtained at harvesting time. The most common spacings now used are 3 by 2.5 m, 3.0 by 3.0 m, 3.5 by 3.0 m, 3.5 by 3.5 m, and 4.0 by 3.0 m.

6.10 INTERACTION WITH COMMUNITIES

For a long time, public relations was not needed between forest companies and existing communities. Forest operations were carried out on a very large scale and were considered by Brazilian society to be important as a source of jobs, and new companies were welcomed throughout the country. Essentially no environmental or social concerns about the establishment of the large-scale eucalypt plantations were expressed. However, over the last 10 years growing concerns about the impacts of such plantations in Brazil have forced the companies to respond. Because most of the companies were not interacting adequately with local communities, serious problems arose.

Most companies are now facing pressure from nongovernmental organizations and new forest legislation. In addition to federal forest legislation, restrictive state and municipal forest and environmental legislation is now making operations more and more difficult for the companies. For example, in some counties in the state of Espírito Santo, municipal legislators prohibited establishment of eucalypt plantations on new land; only lands previously occupied by eucalypt plantations could be replanted. Because this prohibition applied only to companies, the corporations overcame the problem by initiating tree farmer programs. Beyond increasing the supply of timber, the companies adopted the strategy of making local farmers partners in the timber supply side of their operations. As part of these tree farmer programs, companies donate seedlings (exotic and native species, sometimes fruit trees) to the local communities.

Forest companies are also supporting educational programs at the elementary- and high-school levels. The objective is to educate the new generation about the benefits of forest activities and their social and environmental impacts. Sometimes the companies will provide support for nongovernmental organizations that then carry out the environment educational program. Companies are now actively using the media to explain the benefits of the forest industry.

Company contributions or donations to help restore and preserve endangered ecosystems have also helped the companies improve their image at both the local and international levels. Development of alternative land uses such as agroforestry systems, along with the tree farmer programs, have enhanced public image of the companies. Financial support of research projects at universities and research institutions also has helped to integrate the companies with the scientific community.

7. NEW TRENDS

7.1 AGROFORESTRY

As mentioned, the increasing price of the land surrounding company facilities and some new restrictions on plantations in southeastern Brazil stimulated forest companies, along with state governments, to begin local tree farmer programs to reinforce wood supplies. These programs, however, were not readily accepted by local farmers, who were concerned that eucalypt plantations would divert land from food to timber production (Assis et al. 1986). Their belief that tree farmer programs would result in decreased food crop production was widespread.

Given this situation, agroforestry appeared to be an alternative that could integrate timber and food production, thus meeting food demands while addressing wood production needs. However, for agroforestry to be acceptable, both companies and farmers had to have accurate biological, technical, and economic information about the intercropping of agricultural crops and tree plantation species. Agroforestry as a science is relatively new, despite being a historical land use in Brazil as well as in other parts of the world. Agroforestry research in Brazil, particularly involving eucalypts, has only been done recently. In 1986, the relevant literature for agroforestry relative to eucalypts in southeastern Brazil was limited to only three studies. The first work consisted of *Eucalyptus alba* intercropped with corn in the state of São Paulo (Gurgel Filho 1962), followed by *E. grandis* intercropped with soybeans in Minas Gerais (Couto et al. 1982), and *E. grandis* intercropped with beans in São Paulo (Schreiner and Balloni 1986).

The success of these studies stimulated researchers from the Federal University of Viçosa to continue studying a series of eucalypt agroforestry systems. These studies were a joint effort between forest companies in the state of Minas Gerais and the university and were funded through the Society for Forest Research and certain forest companies. The research has included *Eucalyptus torelliana* intercropped with corn in Belo Oriente (Ferreira Neto 1993); *E. grandis* intercropped with black beans in Peçanha (Ferreira Neto 1993); *E. citriodora* with *Panicum maximum* in a silvopastoral system with cattle and sheep in Dionísio (Almeida 1990); *E. cloëziana* with herbaceous legumes and grasses for cattle grazing in Montes Claros (Santos 1990); and most recently, *E. grandis* intercropped with herbaceous legumes for weed suppression and soil protection in Dionísio (Ferreira Neto 1993).

Today, most of the forest companies in Brazil are adopting agroforestry as an alternative land use, mainly for their tree farmer programs. Agroforestry is likely to become a key point of the plantation programs oriented toward the small farm operation.

7.2 WOOD BIOMASS GASIFICATION

Studies conducted by some Brazilian companies have shown that *Ceteris paribus* energy production from biomass cannot compete in price with energy generated from oil, coal, and natural gas. The only way it might be competitive would be by generating a more valuable form of energy—electricity. This may be possible by means of a new technology—Biomass Integrated Gasification/Gas Turbine or BIG/GT, developed in the United States at Princeton University. This technology consists of gasifying and using the

gas to move a turbine, which produces electricity. The exhaust gases from the turbine are captured for additional energy production. Compared with the 20% conversion efficiency of traditional steam-based electricity production, the new technology has a 40% conversion efficiency.

In 1992, Brazil submitted a technical proposal to the Global Environmental Facility (GEF) to build an experimental BIG/GT plant and to study the economic feasibility of commercial development. The five-stage project was approved and is now under way. The first stage was to evaluate the technical proposal and preinvestment studies. The second stage, to be concluded by 1994, involves the development of equipment and basic engineering and economic feasibility studies and preparation of the basic structure for stage three. Stage three consists of the construction of the pilot plant with the US\$23 million funded by GEF. Additional capital resources will be provided by associated companies: Centrais Elétricas Brasileiras, Companhia Hidro Elétrica do São Francisco, Fundação de Ciência e Tecnologia, Companhia Vale do Rio Dole, Shell Brazil S.A., and Shell International Petroleum Company. This joint venture is coordinated by the Brazilian Minister of Science and Technology. The pilot facility will probably be built in Bahia close to eucalypt plantations. The fourth stage, which will last for 24 months, will comprise operational demonstration tests with sugar cane bagasse and wood biomass. Finally, the fifth stage will be the commercial development of the plant.

This BIG/GT project is the first of its kind in the world and, if successful, will bring many advantages, such as small plant size that allows decentralization of electrical energy production; reduction of energy transmission costs; small capital investment, allowing private companies to enter the sector; use of marginal agricultural lands for short-rotation forest plantations devoted to biomass for electricity energy production; generation of jobs in rural areas; and utilization of the Brazilian dendroenergetic potential. The northeastern region of Brazil, alone, has a potential of transforming 197.1 million steres (stack meters of roundwood in 1 m × 1 m × 1 m piles) each year into 19.673 thousand megawatts of energy per year.

7.3 FOREST PRODUCTS ENVIRONMENTAL CERTIFICATION

In 1992, the Brazilian Society of Silviculture (SBS) along with the private forest companies proposed the creation of a US\$500,000 Integrated Management System for Improving the Value of Forestry Affairs (SEIVAS). This system is designed to predict the world markets 10 to 20 years in the future. This information will help identify goals for the Brazilian forestry-based products in the international market. Based on world market trends and Brazil's conditions, the system will ultimately define markets in which the country can enjoy a competitive edge. Furthermore, the system will indicate what components of the industry would have to be developed to reach these goals. Two parts of the system are already being implemented: the program for preservation and recovery of the Brazilian forest cover and the Certification for Forest Products (CERFLOR) project related to the origin of the raw material utilized in manufacturing of forestry products. The CERFLOR project has a certificate called a "green stamp" for any forest raw material or product originating from native forests or plantations managed according to environmentally sound techniques. Coordination and elaboration of the rules for receiving this certificate was assigned to EMBRAPA.

7.4 A MEGA AFFORESTATION PROJECT

Mega Afforestation (FLORAM) is a forestry project proposed in 1990 by the Institute of Advanced Studies of the University of São Paulo to promote social advancement. The project's objective is to establish 20 million new hectares of forest plantations in Brazil over the next 20 years. This project, according to the Industrial Institute for Economic and Social Research from Stockholm, Sweden, would generate one million jobs and would produce US\$10 billion per year in forest products. This project received the support of the private sector, universities, research institutions and nongovernmental organizations in Brazil and is now under way. FLORAM proposes three types of forests: the first for industrial purposes using exotic species, the second for dual purposes (conservation and commercial utilization) using exotic and native species, and the third for conservation only (using native species only).

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