

THE USE OF LEGUMINOUS TREES IN RECLAMATION OF TROPICAL MINED SOILS¹

by

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Abstract

Characterized as vigorous pioneer species which produce large amounts of biomass, forest leguminous trees have shown promise in studies of degraded soil rehabilitation. When associated with atmospheric nitrogen-fixing bacteria and mycorrhizal fungi, these species show superior utilization of nutrients and growth under adverse soil conditions. The objective of this paper is to present the principal results obtained from the Research Program for Use of Nodulated and Mycorrhizal Tree Legume Species in Rehabilitation of Degraded Areas, developed by National Research Center for Agrobiolgy-CNPAB/EMBRAPA in conjunction with the Federal University of Viçosa, Brazil. The program has been developed in four subprograms: 1. Field surveys to collect and identify native leguminous tree species with potential for land reclamation; 2. Selection to identify more efficient nitrogen-fixing bacteria for each potential species; 3. Greenhouse experiments to evaluate nutritional requirements and capacity to grow in high density soils; and 4. Field experiments in lands degraded by mining.

Additional Key Words: leguminous trees; nitrogen fixation; bauxite mining; land reclamation

Introduction

Brazil is the world's leading producer of iron ore and a major exporter of aluminum, gold, niobium and tin. Totaling U.S.\$6.6 billion, its mining output constitutes almost a third of Latin America's mineral-derived revenue (Project Survey 1993). A large part of these minerals, such as iron, gold, tin, bauxite, manganese, copper and kaolin, lies under biologically diverse forests in the Amazon Region, (Griffith et al. 1996).

Human activities such as surface mining have resulted in great disturbance to original soils. Among the different aspects of degradation, loss of soil organic matter is one of the most important (Franco et al. 1995a). The absence of organic matter contributes to low nutrients levels, low water holding capacity, and compaction problems. These situations may cause great difficulties when attempting to rehabilitate these areas. Nitrogen, sulphur and phosphorus are the main factors affecting soil fertility if organic material is lacking. Therefore both biological

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nitrogen fixation and mycorrhizal associations play very important roles in plant growth in such situations (Franco et al. 1991).

Characterized as vigorous pioneer species which produce large amounts of biomass, forest legumes have shown exceptional qualities in studies of rehabilitation of degraded soils (Franco et al. 1994, Dias et al. 1995 and Franco et al 1995a). Estimates from Brazil's arid "caatinga" region indicate that the "sabiá" tree (*Mimosa caesalpinifolia*) returns $5.8 \text{ t.ha}^{-1}.\text{year}^{-1}$ of vegetative material to the soil (Suassuna, 1982). Others researchs carried out in Central America with *Erythrina* (Glover & Beer, 1986) and in India with *Leucaena leucocephala* (Sandhu et al. 1990) showed contributions from 13 and 10 $\text{t.ha}^{-1}.\text{year}^{-1}$, respectively.

When associated with atmospheric nitrogen-fixing bacteria and mycorrhizal fungi, forest legumes present superior utilization of nutrients and growth under adverse soil conditions. For the last thirteen years, several large surveys of nodulation for native legume trees have been conducted in many acidic soils of Brazil (Magalhães et al. 1982, Faria et al. 1984, 1987, 1989, Moreira et al. 1992, 1993). Several experiments have been conducted to screen rhizobial strains for the most promising species (Franco & Silva, 1985 and Faria & Franco, 1993). Tropical legume trees have shown great dependence on VA-mycorrhizae (Mendes Filho, 1985 and Monteiro, 1990). Therefore, after inoculation with these microorganism the leguminous trees could absorb more water and nutrients such as phosphorus and zinc (Lambert et al. 1979).

The objective of this paper is to present the principal results obtained from the Research Program for Use of Nodulated and Mycorrhizal Leguminous Tree Species in Rehabilitation of Degraded Areas, developed by the National Research Center for Agrobiolgy-CNPAB-EMBRAPA in conjunction with the Federal University of Viçosa, Brazil.

Research Program for use of Nodulated and Mycorrhizal Leguminous Tree Species in Rehabilitation of Degraded Areas

This research program basically is divided into four subprograms:

1. Field surveys to collect and identify native species of tree legumes with potential for land reclamation;
2. Selection to identify more efficient nitrogen-fixing bacteria for each potential species;
3. Greenhouse experiments to evaluate nutritional requirements and capacity to grow in high density soils;
4. Field experiments in lands degraded by mining.

1. Collection and identification of native tree legumes.

In the last twelve years, researchers of CNPAB/EMBRAPA have examined more than 600 legume species for nodulation ability (Faria & Franco, 1993). The surveys were done in differents parts of the country, especially in the "cerrado", and other phytogeographic regions in the North, Northeast and Southeast. The surveys consist in observation of young plants to

identify the presence or absence of nodules. Later, the nodules are evaluated by acetylene reduction to verify activity.

Nodulation was observed in 392 of 688 species that were studied. The species belong to different subfamilies. Nodulation was most prevalent in the *Mimosoideae* (147 of 192 species) and *Papilionoideae* (158 of 219 species) and least prevalent in the *Caesalpinioideae* (38 of 183 species) and other subfamilies (49 of 94 species). This was the first report of nodulation for 172 species in 17 genera, and no-nodulated for 118 species in 18 genera.

Nodules obtained by the surveys were isolated, purified and, after liofilization, 1417 strains of rhizobia were added to CNPAB's culture collection. At present, the strains bank at CNPAB/EMBRAPA contains over 1,800 strains.

2. Selection to identify more efficient nitrogen fixing bacteria for each potential species.

For species with more economical and ecological potential, greenhouse experiments have been conducted by CNPAB/EMBRAPA using "Leonard" jars to select more efficient strains of rhizobia. Experiments with more promising strains were carried out in soil conditions. Efficient strains were selected for more than 45 leguminous tree species including *Acacia mangium*, *A. auriculiformis*, *A. holosericea*, *A. angustissima*, *Albizia guachapele*, *A. saman*, *Paraserianthes falcataria*, *Gliricidia sepium*, *Leucaena leucochepala*, *Mimosa caesalpinifolia*, *M. scabrella*, *Enterolobium contortisiliquum*, *Stryphnodendrum guianensis* and *Prosopis juliflora*.

Many of these species have shown good growth in adverse substrates such as acid and high density soils, which are common in lands degraded by mining.

3. Greenhouse experiments to evaluate nutritional requirements and capacity to grow in high density soils.

Promising species were evaluated for mineral nutrition requirements and capacity for growth in high density soils. These experiments provided important information for choosing species with the best potential to grow in each kind of substrate, and indicated the minimum necessary requirements for good establishment. The main results, obtained from the experiments carried out with *Acacia mangium*, *A. holosericea*, *Sclerolobium paniculatum* and *Mimosa tenuiflora* in the Soils Department of the Federal University of Viçosa, follow.

3.1 Response to liming and phosphorus fertilization.

Absence of topsoil is a common condition for surface-mined soil. In the tropics, the lack of topsoil exposes soil horizons with high acidity and phosphorus adsorption capacity. Different studies evaluated the plants response to liming and phosphorus fertilization in the B horizon of

acidic soil (pH = 4.6; P and K by Mehlich-1 = 0.4 and 5.0 mg/dm³, respectively; Ca²⁺, Mg²⁺ and Al³⁺ by KCl 0,01 Mol/L = 0.04, 0.02 and 0.9 cmol/dm³, respectively).

Only *M. tenuiflora* responded to lime application (Paredes F. et al. 1995). This result confirms field observations that this species is capable of growing in soils with approximately neutral pH. For the other species, liming did not significantly affect dry matter production, height or stem diameter (Dias et al., 1990; Dias et al. 1991a and Balieiro et al. 1995). The lack of response to lime application in soil with low exchangeable calcium shows the low demand for this nutrient and the capacity of the other species to grow in poor substrates. In other greenhouse experiments with a nutrient solution, the low Ca requirement by *A. mangium* was also shown by high dry matter production over the long term despite deprivation of Ca after an initial short contact period with calcium in the original planting solution (Dias et al. 1994a).

All species responded to phosphorus fertilization. The obtained regression equations for dry matter production as a function of the different doses of applied P are shown in Table 1. These data agree with the thesis that leguminous species when fixing nitrogen by symbiotic association have high P uptake to supply the high demand of ATP by the fixation process (Siqueira & Franco, 1988).

The critical levels of P for the different species are found in Table 1. These values ranged from 18 to 32 mg/dm³ of available Mehlich-1 P and confirm the high demand for this nutrient by fast-growing tree seedlings.

3.2 Response to sulfur and potassium fertilization

Only *M. tenuiflora* (Paredes F. et al. 1995) responded to sulfur fertilization (sulfur rates varied from 0 to 120 mg/dm³) which characterized this species as more demanding of soil fertility. The lack of response for other species may be related to the level of organic matter (2.8 %) of the subsoil used and the action of the liming on providing organic-S mineralization (Dias et al. 1991b and Dias et al. 1992).

Although the S requirement is low, in solution deprivation tests S was the second most important limiting factor, after N, in dry matter production for *A. mangium*, (Dias et al. 1994a).

Given the responses of *Acacia holosericea* (Balieiro et al. 1995) and *Mimosa tenuiflora* (Paredes F. et al. 1995) to potassium fertilization, it was not possible obtain good models by regression analysis. Table 2 shows the obtained equations, which indicate the negative response of *A. mangium* and positive response of *S. paniculatum*.

3.3 Capacity to grow in high density soils

Intense movement of machines over mined substrate can induce soil compaction which causes nutritional and water availability problems. Studies on the capacity of the plants to grow in high density soils therefore have great importance.

Fernandez et al. (1994) studied the capacity of seven leguminous woody plants to grow in columns containing compacted subsurface soil samples. The study used 0.91 and 1.14 g/cm³ of bulk density to fill PVC columns.

Of the seven species evaluated, *Mimosa tenuiflora* and *Leucaena leucocephala* were the most sensitive to high substrate density. Observed effects were reduction in height and dry matter production at 140 days. The other five species (*Enterolobium contortisiliquum*, *Acacia holocericea*, *Mimosa caesalpinifolia*, *Acacia mangium* and *Acacia auriculiformis*) showed good tolerance to compaction. An interesting effect of compaction was the reduction of root dry matter for *A. mangium* (Figure 1). This species grew better than the others in the different mine substrates, including compacted ones. The exceptional ability of this species to produce high amounts of biomass even in harsh ambiental conditions is shown in Figure 2. *A. mangium* in compacted substrate produced the same amounts of foliar and stem dry matter as in non-compacted tests. The same behavior was observed in field conditions when *A. mangium* was grown in compacted bauxite residue ponds and developed shallow but extensive lateral root systems (Franco et al. 1995b).

4. Field experiments in lands degraded by mining.

Dias et al. (1994a) studied the recuperative capacity of nine-year old *Eucalyptus pellita* versus *Acacia mangium* trees planted on soils degraded by bauxite mining in Porto Trombetas, Pará State, Brazil. Each species was planted in plots wich contained 36 plants each (3 x 2 m). Litter (layers L and H) and soils (depths 0 to 2.5 cm, 2.5 to 7.5 cm and 7.5 to 20 cm) were sampled at the onset of the rainy season (November 1992), midway through the dry season (June 1993) and at the end of the rainy season (April 1994).

Greatest accumulation of organic material occurred on *A. mangium* plots at 7.5 cm depth and for all three sampling times. Similar behavior occurred for soil sum of bases and effective cation exchange capacity (CEC). Plots with *A. mangium* had more litter with smaller C/N ratio and greater quantites of P, K, Mg and N. These results reinforce the importance of including leguminous trees in land rehabilitation programs.

We also conducted two other experiments at Porto Trombetas, Pará State, Brazil (Franco et al. 1994, Franco et al. 1995a and Franco et al. 1995b). For both we used concentrated sulphuric acid to scarify seeds as required, and nodulating species were inoculated with effective rhizobial strains. All species were also inoculated both with inoculum of *Gigaspora margarita* and with soil plus roots of *Brachiaria decumbes* collected in the region to provide inoculum of introduced and local vesicular-arbuscular mycorrhiza fungi.

The first test was conducted in subsoil, without topsoil, exposed by bauxite mining (pH = 4.6; P and K by Mehlich-1 = 0.1 and 9.0 mg/dm³, respectively; Ca²⁺+Mg²⁺ and Al³⁺ by KCl 0,01 Mol/L = 2.0 and 0.3 cmol/dm³, respectively). We tested five nodulating (nod+) leguminous species (*Sclerolobium paniculatum*, *Acacia mangium*, *A. auriculiformis*, *Enterolobium contortisiliquum*, *Strypnodendrum guianensis*); two non-nodulating (nod-) leguminous species (*Cassia leiandra* and *Senna siamea*) and three pioneer but non-legume (no-leg) species (*Didimopanax morototoni*, *Byrsonima crassicarpa* and *Goupia glaba*). One year

after planting, *A. mangium* and *A. auriculiformis* had grown more than any other species. Among the nod- and no-leg species *Didimopanax morototoni* and *Byrsonima crassiparpa* showed reasonable but less growth than the nodulating legume (Table 3).

The second experiment was planted on bauxite mining residue (pH = 4.6; P and K by Mehlich-1 = 0.0 and 3.0 mg/dm³, respectively; Ca²⁺ + Mg²⁺ and Al³⁺ by KCl 0,01 Mol/L = 0.4 and 0.2 cmol/dm³, respectively). We tested nine nod+ species (1. *A. mangium*, 2. *A. angustissima*, 3. *A. holocericea*, 4. *Albizia saman*, 5. *A. guachapelle*, 6. *Enterolobium contortisiliquum*, 7. *Clitoria fairchiladiana*, 8. *Sclerolobium paniculatum* and 9. *Stryphnodendrum guianensis*); five nod- species (10. *Senna siamea*, 11. *Parkia pendula*, 12. *Dinizia excelsa*, 13. *Cassia leiandra* and 14. *Adenanthera pavonina*) and two no-leg species (15. *Cecropia sp.*, and 16. *Eucalyptus terenticornis*). At planting time two of the four replications received two liters of compost (cattle manure waste) in the planting hole each and two none.

Plant heights measured at 9, 13 and 22 months after transplanting showed similar trends except that *S. paniculatum* and *S. guianensis* were growing best despite a slow start, while *A. angustissima* showed the opposite behaviour. For the nod+ species, the differences observed with compost added at planting decreased up to the last evaluation. *Acacia mangium* plants showed values above 7 m of height at last measurement. Figure 3 shows total biomass recovered in the plants 22 months after transplanting. *Acacia mangium* and *A. holocericea* showed highest value for shoot dry matter. These results confirm the great potential of leguminous trees in reclamation of tropical mined lands.

Conclusions

Many leguminous trees fix atmospheric nitrogen when they occur in symbiosis with rhizobia and form mycorrhizal associations which improve efficiency of absorption of water and mineral nutrients from the soil. Such improved efficiency especially affects phosphorus, the most important and frequently limiting nutrient in tropical soils. These species, when associated with microsymbionts, are suitable for revegetation of mined tropical lands when the deficiencies of major nutrients (other than nitrogen, unnecessary because of fixation capability) have been corrected. The addition of a large amount of organic matter (litter) with low C/N ratio besides protects the soil from the direct impact of raindrops and erosion, accelerates the cycling of soil nutrients, and favors the return of life to the soil.

The slow growth of native species means, however, that we must identify native nodulating species that can provide better ecological conditions for soil rehabilitation. Griffith et al. (1994) emphasized the importance of using an ecological approach in mined land reclamation, and indicated that one way to do so is to use nodulated and mycorrhizal legume trees.

The current focus of our research program is to understand the natural evolution of areas undergoing rehabilitation so as to identify opportune moments to intervene in the revegetation process and thereby guarantee its sustainability.

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Table 1. Regression equations adjusted for dry matter production for selected species, in function of levels of P applied to substrate and critical level values in soil, so as to obtain 90% of maximum production

Species	Dosage	Model	R ²	Crit. Level
	mg/dm ³	g/pot		mg/dm ³
<i>A. mangium</i>	0 - 570	$Y = 7.3714 + 0.0139 P$	0.850	1/
<i>A. holosericea</i>	0 - 480	$Y = 0.466 + 0.036 P - 0.00006 P^2$	0.968	18.55
<i>M. tenuiflora</i>	0 - 480	$Y = 0.1952 + 0.0119 P - 0.00002 P^2$	0.947	31.95
<i>S. paniculatum</i>	0 - 570	$Y = 3.717 + 0.0513 P - 0.00006 P^2$	0.944	26.10

1/ The linear response to P applied did not allow obtaining the critical level

Table 2. Regression equations adjusted for dry matter production for selected species, in function of levels of K applied to substrate and critical level values in soil, so as to obtain 90% of maximum production

Species	Dosage	Model	R ²	Crit. Level
	mg/dm ³	g/pot		mg/dm ³
<i>A. mangium</i>	0 - 200	$Y = 15.041 - 0.561 X^{0.5} + 0.026 X$	0.985	1/
<i>S. paniculatum</i>	0 - 300	$Y = 9.920 + 0.046 X - 0.0001 X^2$	0.909	27.4
<i>M. tenuiflora</i>	0 - 160	$Y = 1.563 + 0.053 X^{0.5} - 0.004 X$	0.886	16.61

1/ The negative response to applied K did not allow obtaining the critical level.

Table 3. Height at 13 months for 10 species cultivated in subsoil (topsoil absent) exposed by bauxite mining

Species	height
	--- cm ---
<i>Sclerolobium paniculatum</i>	56.9
<i>Acacia mangium</i>	258.8
<i>Acacia auriculiformis</i>	163.9
<i>Enterolobium contortisiliquum</i> ¹	76.1
<i>Strypnodendrum guianensis</i>	83.4
<i>Cassia leiandra</i> ¹	78.9
<i>Senna siamea</i>	97.4
<i>Didimopanax morototoni</i>	14.8
<i>Byrsonima crassicarpa</i>	75.2
<i>Goupia glaba</i>	33.1

1/ Plants browsed by deer

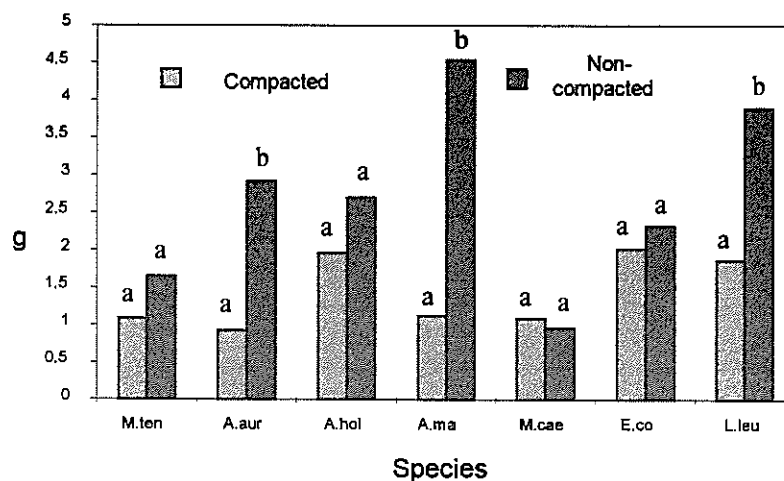


Figure 1. Root dry matter for seven forest leguminous plants grown in compacted and non-compacted soil. M.ten = *Mimosa tenuiflora*, A. aur = *Acacia auriculiformis*, A. hol = *Acacia holocerricea*, A. man = *Acacia mangium*, M. cae = *Mimosa caesalpinifolia*, E. co = *Enterolobium contortisiliquum*, and L. leu = *Leucaena leucocephala*. The letters indicate differences between compacted and non-compacted soil within a species.

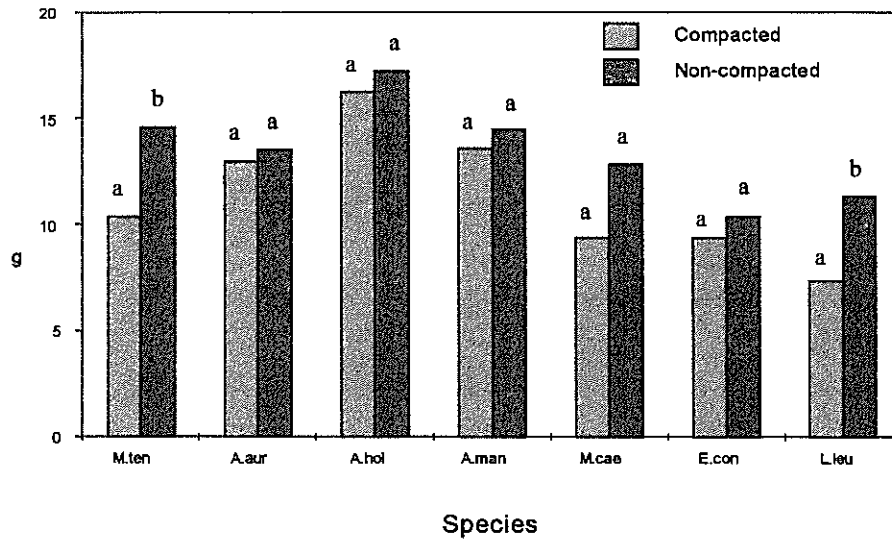


Figure 2. Total dry matter of seven forest leguminous species grown in compacted and non-compacted soil. M.ten = *Mimosa tenuiflora*, A. aur = *Acacia auriculiformis*, A. hol = *Acacia holocerricea*, A. man = *Acacia mangium*, M. cae = *Mimosa caesalpinifolia*, E. co = *Enterolobium contortisiliquum*, and L. leu = *Leucaena leucocephala*. The letters indicate differences between compacted and non-compacted soil within a species.

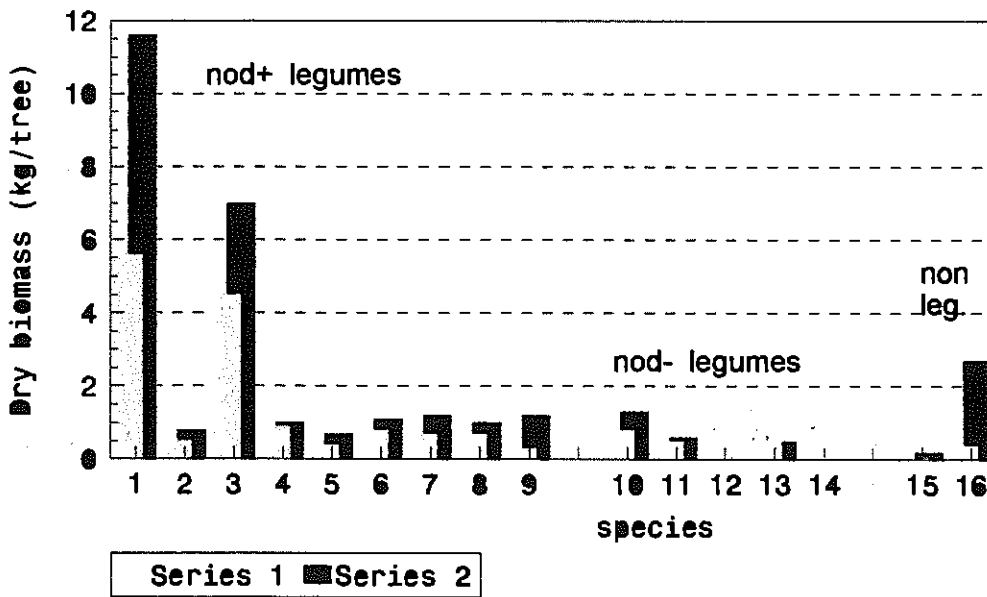


Figure 3. Biomass of 16 forest leguminous species production, 22 months after transplanting to the field. Series 1 without compost and series 2 with compost.

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