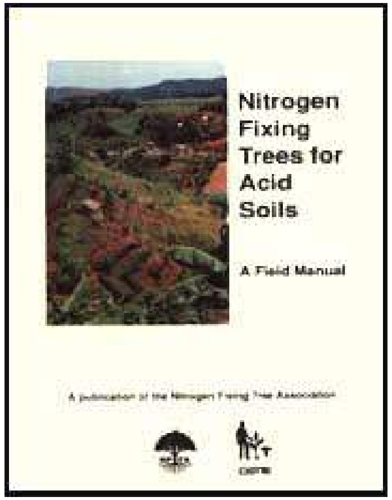
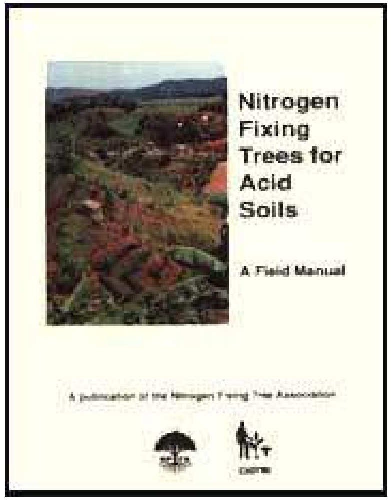


Nitrogen Fixing Trees for Acid Soils - A Field Manual (Winrock, 1996, 110 p.)



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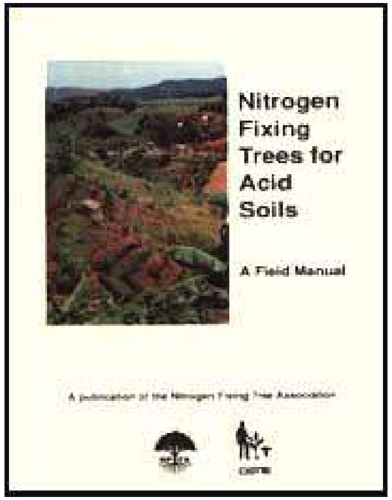

Introduction

Mark H. Powell, editor

With increasing population pressure in much of the tropics, farmers are often forced to expand agriculture into marginal areas. Here, they must try to produce crops and raise livestock under growing conditions that can be extremely difficult. Many of these poor sites are characterized by acid soils.

Strongly acidic soils - with a pH of less than 5.5 - present the farmer with several problems. They tend to be infertile, suffering in particular from low levels of calcium and phosphorus, and they may contain toxic levels of available aluminum and manganese. Many types of plants grow poorly on these soils, and others cannot grow at all.

The farmers who try to produce crops on acid soils tend to have small land holdings and limited financial resources. With little or no access to chemical

fertilizer or irrigation, they are not likely to benefit from the high input agricultural technologies developed during the Green Revolution. Often, they are recent migrants from other farming areas, and they lack the specialized knowledge and experience required to produce crops on acid soils.

Governments and development organizations will have to devise technologies for sustainable productivity under the difficult conditions that acid soils impose and will have to introduce these to farmers. Production is limited to those plant species and cultivars that tolerate soil acidity. With limited land holdings and few, if any, purchased inputs, farmers must maintain yields by carefully ensuring the recycling of nitrogen and other nutrients.

Many nitrogen fixing tree (NFT) species are tolerant of acid soils. Planted in agroforestry systems, they provide a low-input technology that helps farmers overcome limitations to plant growth caused by lack of nitrogen. Only recently, however, researchers have begun to evaluate different nitrogen fixing species for agroforestry systems on acid soils. To bring together the results of recent and current research and to identify future research needs, the Nitrogen Fixing Tree Association (NFTA) and the Centro Agron¢mico de Investigaci¢n y Ense¤anza (CATIE) organized a workshop on Nitrogen Fixing Trees for Acid Soils, which was held on 3 8 July 1994 in Turrialba, Costa Rica.

Forty participants came to the workshop from 14 countries around the world. NFTA has published a proceedings volume that includes many of the papers presented at the workshop plus recommendations of the working groups for future research and development priorities. During the workshop, working groups drafted chapters for this field manual. The objective was to produce a practical

field guide for selecting, evaluating, and growing nitrogen fixing trees on acid soils. I hope you will find this manual useful in your work and welcome your comments and suggestions.

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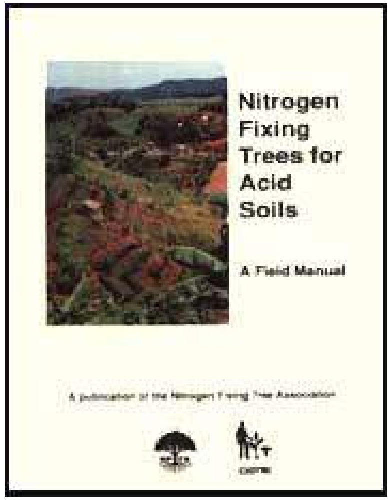


Assessing soil acidity

Richard Fisher, E. M Hutton, Avilio A. Franco, Anthony Juo, Donald Kass, and Dale Evans

What Is an acid soil? Soil scientists use ranges of pH values to describe the acidity

of soils. Soils in the pH range of 6.8 to 7.2 are considered neutral. Any soil with a pH of less than 6.8 is considered acidic, and any soil with a pH of more than 7.2 is considered alkaline. Soils with a pH of less than 35 or more than 10 rarely support plant growth Acid soils are described as "mildly acidic," "moderately acidic," and "strongly acidic" as pH values decrease. Mildly and moderately acid soils may not be detrimental to the growth of most plants.

Regions in the tropics in which soils are likely to be acid or low in bases such as calcium and magnesium.

Source: Caudle (1991).

The term "acid soil" is usually reserved for soils in which many types of plants have difficulty growing. This manual is concerned with these strongly acidic soils. They are characterized by a pH of less than 5.5 and one or more chemical problems that limit plant growth. Such problems may include (1) toxic levels of available aluminum, (2) toxic levels of available manganese, and (3) infertility due to insufficient levels of other elements important for plant growth, particularly calcium and phosphorus. Strongly acidic soil conditions limit the kinds of plants that can grow, the productivity of those plants, and the efficiency of fertilizers applied to increase plant productivity.

What is pH?

The acidity of a soil is assessed in terms of the acidity or alkalinity of the soil solution - the moisture in the soil - as measured in units of pH. The soil solution contains chemical elements in dissolved ionic form. Many of these function as essential plant nutrients, taken up from the soil solution by the roots of plants.

The acidity of a soil results from the relative presence or absence of acidic ions, such as hydrogen (H^+), in the soil solution. Soil acidity increases with the increased presence of these ions and decreases with the increased presence of basic ions such as calcium (Ca^{++}) and magnesium (Mg^{++}).

The acidity of a soil solution is expressed on the pH scale as the negative logarithm of the hydrogen ion (H^+) concentration. Because the pH scale is mathematically logarithmic, a pH change of one unit represents a ten-fold change in the acidity or alkalinity of the solution being measured. Thus a soil with pH 5 is ten times more acidic than a soil with pH 6. A soil with pH 4 is ten times more acidic than one with pH 5 and 100 times more acidic than a soil with pH 6.

How do soils become acidic?

Soils become acidic through the normal leaching action of rainfall over long periods of time. As rainwater moves down through the soil, it absorbs carbon dioxide from the soil atmosphere and forms weak carbonic acid. It also acquires weak organic acids as it encounters soil organic matter. This acidic solution attracts basic ions, such as calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^+), and sodium (Na^+), detaches them from the soil exchange complex, and leaches them from the rooting zone. As these basic ions are leached, they are replaced by acidic ions of hydrogen (H^+) and aluminum (Al^{+++}). Over long geologic periods,

soils in warm climates with high rainfall become severely depleted of basic ions and strongly acidified. Many of these acid soils also have levels of available aluminum or other ions that limit plant growth.

At a pH of 5.5, a soil generally does not inhibit the growth of crops or trees because it contains little available (exchangeable) aluminum. As pH decreases to 5.1 or lower, the amount of available aluminum increases and begins to interfere with the uptake of calcium and phosphorus, adversely affecting plant growth.

The soil taxonomy classification of the United States Department of Agriculture labels most tropical soils with a pH of less than 5.5 as Oxisols or Ultisols. The Food and Agriculture Organization (FAO) calls these Ferralsols and Acrisols. The Oxisols, with aluminum saturations of 79 to 89 percent, are more harmful to leguminous trees and crops than are the Ultisols, with aluminum saturations of 49 to 64 percent. There are also some strongly acidic Entisols (called Arenosols by FAO), Inceptisols (classified as Cambisols, Plinthosols, and Gleysols by FAO), and Andisols (Andosols).

How does soil acidity affect the availability of nutrients?

Plant roots obtain nutrients from the soil solution, and that solution's chemical composition is affected by its pH. Nutrient availability is greatest in soils with a pH between 55 and 65. When the soil solution falls outside this range, plants often show signs of nutrient deficiencies.

In alkaline soils at a pH above 7.0, phosphorus, iron, zinc, boron, and copper become less available to plants. In acid soils at a pH below 5.0, phosphorus and

molybdenum become less available and soil nitrification slows down. Some nutrients - such as calcium, magnesium, and potassium - may be lost, and high levels of available iron or aluminum may lead to the formation of insoluble phosphate compounds, dramatically reducing the level of phosphate available to plants.

The two most important indicators of acid soil conditions that are severe enough to limit plant growth are low pH and high levels of available aluminum. Indeed, aluminum toxicity and soil infertility are often associated. In soils with a pH of 5.1 or lower, aluminum levels often constitute more than 50 percent of the cation exchange complex. Manganese toxicity can also occur in a soil with a pH of less than about 5.5, but manganese toxicity is not as common as aluminum toxicity.

How do you measure soil acidity?

The best way to determine whether a soil is strongly acid is to consult a soil scientist. Failing this, a general soil survey map may be useful. Such a map may include specific information on soil pH and the degree of aluminum saturation. Otherwise, as a general "rule of thumb," soils classified as Oxisols or Ultisols are likely to be strongly acidic in tropical climates.

If you cannot consult a soil scientist or a reliable soil map, you may need to collect soil samples and have them analyzed. Take separate samples at depths of 0 to 20 cm, 20 to 50 cm, and 50 to 100 cm below the soil surface. The subsoil is normally the best indicator of acidity because the surface soil (at 0 to 20 cm) is often affected by recent management. Altogether, you will need about 10 separate samples at each depth for each distinct soil area in your site. Mix together the 10

samples for a specific area and depth and take a small subsample of the mixture.

You may be able to send your samples to a soil laboratory for analysis of pH and available aluminum levels. Alternatively, you can analyze the pH levels of your soil samples using a portable pH meter, colorimetric test kit, or test strips. Mix each subsample with an equal volume of pure water (rain water is preferable to tap water if deionized water is not available). After mixing, allow the soil particles to settle for a few minutes and then measure the pH of the solution above the soil particles.

Equipment for measuring pH is available by mail order or from retail outlets that specialize in agricultural or scientific supplies. Colorimetric pH test kits are fairly inexpensive but are less precise than electrochemical instruments. There is no simple field test for available aluminum, but if the pH is below 5.0, then available aluminum is likely to be high.

An alternative to analyzing the soil is to observe plant growth as an indicator of soil conditions. What kinds of plants are growing in the soil? The presence of plants that tolerate acid soils such as imperata grass, bracken ferns, and Stylosanthes species-is an indication of acid soil conditions. If crops are growing well, the soil is probably not highly acid. If, on the other hand, there are problems with beans, cotton, or maize crops, then soil acidity may be the culprit. Phaseolus beans (not cowpea types) are particularly sensitive to aluminum toxicity if they are growing well, aluminum may not be a problem.

How do you Interpret the results of a soil analysis?

An analysis of soil nutrients is often expressed in terms of milliequivalents per 100 g of soil (meq/100 g). An equivalent expression is cmol charge/kg. Values given as milliequivalents per 100 g of soil may be converted to parts per million (ppm) as follows:

1 meq/100 g of K+ (potassium) = 391 ppm
1 meq/100 g of Al+++ (aluminum) = 90 ppm
1 meq/100 g of Mg++ (magnesium) = 122 ppm
1 meq/100 g of Ca++ (calcium) = 200 ppm
1 meq/100 g of Na+ (sodium) = 230 ppm.

Phosphorus content is usually expressed as parts per million. Most field and vegetable crops will respond to additions of phosphorus and potassium fertilizers when soil phosphorus (sodium bicarbonate [NaHCO3]-extractable) is in the range of 8 to 15 ppm and exchangeable soil potassium is in the range of 60 to 100 ppm. Soil phosphorus above 25 ppm is considered adequate for maize. One important measure that can be obtained from soil test results is the percent of aluminum saturation. This value compares the amount of exchangeable aluminum in the soil with the sum of aluminum plus exchangeable bases, as in the formula:

Al / (Ca + Mg + K + Na + Al) x 100 = % Al saturation

In most cases, not all of these elements need to be analyzed. As a minimum for calculating percent aluminum saturation, the content of aluminum, calcium, and magnesium should be determined.

Plant species and varieties differ in the amount of aluminum saturation they can

tolerate: above that limit, plant growth is reduced. Generally, cowpea-type beans, males, rice, and cassava have high tolerance to aluminum (70-100% saturation), whereas phaseolus-type beans, sorghum, soybeans, and wheat have low to moderate tolerance (0-70%), and cotton and maize have low tolerance (0-40%). Some nitrogen fixing tree species are known to tolerate high levels of aluminum in the soil, but the critical level for many species is not known. Controlled experiments are required to provide this information for a number of tree species and, in some cases, for particular varieties and provenances.

If plants show stunting, crinkled leaves, or leaves with small brown spots, manganese toxicity may be suspected. To determine manganese toxicity, apply a 5 percent hydrogen peroxide solution to a soil sample: if the solution fizzes (makes bubbles), manganese toxicity may be a problem.

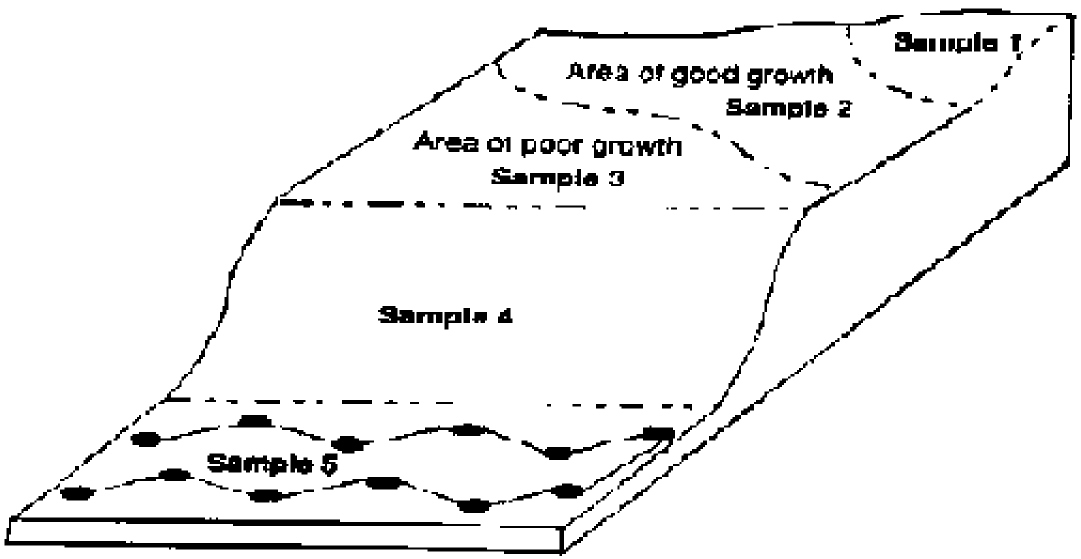
How to take a soil sample

1. Use the right tools. A soil tube or soil auger are the best tools for taking soil samples. If these tools are not available a clean shovel may be used. Using a shovel, dig a hole to a depth of 20 cm, cut a slice of soil about 1 cm thick from the side of the hole, and trim the slice to a strip 2 to 3 cm wide. Continue digging to a depth of 50 and 100 cm and take samples at each depth.

2. Take a representative sample from each area of the field that is significantly different from the others in its soil, fertility, or vegetation. In each distinct soil area, take about 10 separate samples at each depth. Use a zig-zag pattern like the one in the illustration. Avoid crop rows,wet spots and other atypical areas.

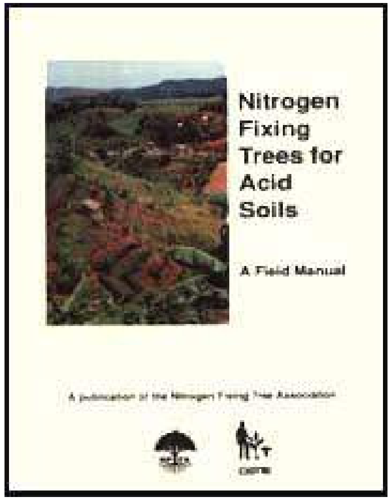
3. Mix together the 10 samples for a specific area and depth in a plastic bag or plastic bucket, and extract about one-haH Iiter of the mixture for the sample. Place the sample in a container supplied by a soil testing laboratory, or in a plastic bag, and number and label it. Include information on the previous crop, the next crop, manure-use history, drainage status of the field, depth of tillage, and other special problems or conditions that may affect plant growth. Do the same for each area sampled.

4. When to sample: sample several months before planting. Wait four months to sample land cleared by burning to avoid the liming effect of ash. Sandy soils should be sampled every two to three years, clay and silt soils every four years.



How to take a soil sample

Source: Caudle (1991).



Nitrogen Fixing Trees for Acid Soils - A Field Manual (Winrock, 1996, 110 p.)

Selecting nitrogen fixing trees for acid soils

Mark H. Powell and John C. Weber

The establishment of an agroforestry system in a site with acid soil begins with the identification of nitrogen fixing trees that will grow well under prevailing soil conditions. They should also provide farmers with the products and services they

need. The selection process includes field visits, interviews with farmers, and careful research. The following steps are a guide:

1. Collect information on the climate, soils, and other characteristics of the planting site.
2. Determine what tree products and services are required.
3. Make preliminary species selections.
4. Check available research results to verify species selection.
5. Determine if the selected species are native or naturalized to the planting site.
6. If exotic species are selected, conduct field trials to determine how well they will adapt to the site.

Each of these steps will be described in more detail.

1. Collect information on the planting site

The first research priority is to collect as much information as possible on the climate, soils, and other characteristics of the planting site. A minimum set of information on climate and other site characteristics should include:

- **Elevation**
- **Average annual rainfall**
- **Distribution of rainfall**
- **Average annual temperature**
- **Maximum and minimum temperatures**
- **Incidence of frost**
- **Number of months with less than 50 mm precipitation**

- **Topography, including degree and aspect (direction) of slope**

Minimum soil information should include texture, depth, drainage, and pH. Information on soil phosphorus, aluminum, calcium, potassium, magnesium, and manganese would also be useful.

2. Determine what tree products and services are required

Careful research is necessary to determine what products and services farmers expect from the tree component of an agroforestry system. This is often best done through informal interviews with farmers and a study of local markets for tree products. In addition to their potential usefulness, tree species must also be acceptable within local cultures. Table 1 lists a number of nitrogen fixing trees that are tolerant of acid soils and gives some of their uses in agroforestry systems.

Species	LF	WB	AC	FB	PI	HO	SP	WT	IF	OR
Acacia aneura	X			X					X	
Acacia angustissima		P	P	P	P			P	P	X
Acacia auriculiformis		X			X			X		X
Acacia koa		X		P	X			X		
Acacia holosericea		X		P				X		X
Acacia mangium		X						X		
Acacia mearnsii		X			X			X	P	
Acacia melanoxylon		X			X			X		
Albizia lebbeck		X	P	P	X		X	X		X
Albizia saman		X			X			X	P	X
Alnus acuminata		X			X		X	X	P	
Alnus glutinosa		X						X	P	
Calliandra calothyrsus	X	X	X	X			X	X	X	X
Casuarina cunninghamiana	P	X						X		X
Casuarina junghuhniana	P	X						X		X
Casuarina sumatrana		X						X		X
Cedrelinga catenaeformis					P		P	X		
Chamaecytisus palmensis	X	X		X	X			X		
Dalbergia nigra		X					P	X		
Desmodium gyroides			P	X	X					
Desmodium intortum			P	X	X					
Desmodium nicaraguense			P	X	X					
Desmodium velutinum			P	X	X					
Enterolobium cyclocarpum			P		X		X	P		
Erythrina abyssinica	X	X		X	P					X
Erythrina berteroana	X	X	P	X	P		X			X
Erythrina fusca	X	X	P	X	P		X			X
Erythrina variegata	X	X	P	P	P		X			X
Flemingia macrophylla	X	P					X			
Gliricidia sepium	X	X	X	X	X		X	X	X	X
Inga edulis			P		X	X	X	P	P	
Leucaena leucocephala X L. diversifolia hybrids			P	P	P		P	P	P	
Mimosa scabrella	X	X			P		X	X	X	X
Paraserianthes falcataria			P		P		X	X	P	X
Pithecellobium dulce	X	X				X				X
Pterocarpus indicus			P			X		X		
Robinia pseudoacacia		X	P		X	X		X		X
Stryphnodendron excelsum					P			P	P	

Table 1. Agroforestry uses of nitrogen fixing trees known to tolerate acid soils.

The uses are living fence (LF), windbreak (WB), alley cropping (AC), fodder bank (FB), pasture improvement (PI), home garden (HG), shade for perennial crops (SP), fuelwood and timber production (WT), improved fallow (IF), and ornamental (OR). "X" denotes that the species has actually been used for the purpose designated; "P" denotes that the species has potential for such a use.

— Mean annual rainfall more than 1,000 mm —

Mean annual temperature > 20°C	Mean annual temperature < 20°C
Acacia angustissima	**Acacia koa*[a]
Acacia auriculiformis[a]	*Acacia mearnsii*[a,b,e]
**Acacia koa*[a,c]	*Acacia melanoxylon*
**Acacia mangium*	**Alnus acuminata*[a,b]
Albizia lebbeck[a,b,c,d]	*Enterolobium cyclocarpum*[a,b]
Albizia saman	*Chamaecytisus palmensis*[a,b]
**Calliandra calothyrsus*[a,b,c,d,e]	*Inga codonantha*
Casuarina cunninghamiana[a,b]	**Mimosa scabrella*[a,b]
Casuarina junghuhniana[a,c]	*Robinia pseudoacacia*[a,b]
Casuarina sumatrana	
Cedrelinga catenaeformis	
Cratylia argentea	
Dalbergia nigra	
Desmodium gyroides	
Desmodium intortum	
Desmodium nicaraguense	
Desmodium velutinum	
Enterolobium cyclocarpum[a,b,c]	
Enterolobium contortisiliquum	
Erythrina abyssinica	
**Erythrina berteroana*	
**Erythrina poeppigiana*	
**Erythrina fusca*	
Erythrina variegata[a]	
**Flemingia macrophylla*[a,b,c,d]	
**Gliricidia sepium*[a,b,c,d,e]	
Inga acrocephala	
**Inga edulis*[a,b]	
Inga marginata	
Inga punctata	
Inga spectabilis	
Leucaena leucocephala X	
L. diversifolia hybrids	
Mimosa caesalpiniaefolia	
**Paraserianthes falcataria*[a,c]	
Pithecellobium dulce[a,b]	
Pterocarpus indicus[a]	
Stryphnodendron adstringens	
Stryphnodendron excelsum	

*Reported to grow well in soils with >60% aluminum saturation

a,b,c,d,e *NFT Highlights* available from the Nitrogen Fixing Tree Association in English (a), Spanish (b), Indonesian (c), Chinese (d) and Vietnamese (e)

Table 2a. Nitrogen fixing tree and shrub species that are tolerant of acid soils, grouped by adaptation to climate zones based on mean annual rainfall and mean

annual temperature: species suitable for high-rainfall areas.

— Mean annual rainfall less than 500 mm —

Mean annual temp. <20°C	Mean annual temp. >20°C
Acacia aneura	*Acacia aneura*
*Acacia holosericea**	*Albizia lebbeck*[a,b,e]
Albizia lebbeck[a,b,e]	*Alnus glutinosa*
Casuarina cunninghamiana[a,b]	*Pithecellobium dulce*[a,b]
Pithecellobium dulce[a,b]	

— Mean annual rainfall 500–1,000 mm —

Mean annual temp. <20°C	Mean annual temp. >20°C
*Acacia holosericea**	*Albizia lebbeck*[a,b,e]
Albizia lebbeck[a,b,e]	*Casuarina cunninghamiana*[a,b]
Casuarina cunninghamiana[a,b]	**Chamaecytisus palmensis*[a,b]
Enterolobium cyclocarpum[a,b]	*Enterolobium cyclocarpum*[a,b]
**Gliricidia sepium*[a,b,c,d,e]	*Pithecellobium dulce*[a,b]
Pithecellobium dulce[a,b]	*Robinia pseudoacacia*[a,b]

*Reported to grow well in soils with >60% aluminum saturation.
[a,b,c,d,e] *NFT Highlights* available from the Nitrogen Fixing Tree Association in English (a), Spanish (b), Indonesian (c), Chinese (d) and Vietnamese (e)

Table 2b. Nitrogen fixing tree and shrub species that are tolerant of acid soils, grouped by adaptation to climate zones based on mean annual rainfall and mean annual temperature: species suitable for medium and low-rainfall areas.

3. Make preliminary species selections

Basic information on climate, soil, and intended uses can provide guidelines for a preliminary selection of nitrogen fixing tree species for a particular site. Table 2 lists tree and shrub species that tolerate acid soils (pH 5.5 or less) according to their suitability to various climatic zones, defined in terms of mean annual temperature and rainfall. Species reported to grow well in soils with greater than 60 percent aluminum saturation are marked with asterisks.

Farmers may have enough experience with native species in the region to recommend trees that potentially fix nitrogen and are adapted to acid soils. This indigenous knowledge can be documented in informal interviews. Farmers should be encouraged to participate in species selection as fully as possible.

4. Check available research results to verify species selection

Once species are selected, collect as much information on them as possible to verify that they are the best choices available for the site. For example, the Nitrogen Fixing Tree Association (NFTA) publishes NFT Highlights short factsheets that provide a convenient reference for species selection. Table 2 provides information on which NFT Highlights are available in English, Spanish, Indonesian, Chinese, and Vietnamese. Highlights of particularly appropriate species are reprinted in Appendix A. The International Center for Research in Agroforestry (ICRAF) also provides information on tree and shrub species suitable for agroforestry through a computerized Multipurpose Tree Database and other information services.

5. Determine If the selected species are native or naturalized to the planting site

After preliminary species selection, an examination of the proposed planting site will determine whether the selected species are already native or naturalized to the site. If the species are already present, their physical appearance may give an indication of how well they are adapted to site conditions. Appearances may be deceptive, however. For example, poor specimens may reflect some aspect of past management such as repeated harvesting of the best-performing individuals. Farmers may also be able to provide information on past management and species

performance. If the species identified through a preliminary selection process are not present at the planting site, then simple field trials should be conducted to help determine how they will perform.

6. Conduct field trials to determine how well exotic species will adapt to the site

Before introducing new tree or shrub species into an area, it is important to conduct simple screening trials. Such field testing is well within the capacity of rural development workers (extension agents, staff of non-governmental organizations, or Peace Corps Volunteers) or local community organizations (farmers', women's, or church groups). In A guide to establishing research and demonstration plantings with nitrogen fixing tree species, Macklin and colleagues (1989) recommend a simple low-input design for species screening in situations where land, labor, and technical expertise may be limited. Trials normally cover a fairly large number [5-10] of species planted in unreplicated plots. Replicated trials, however, provide more precise information and should be used if possible. The Oxford Forestry Institute, Winrock International, ICRAF, and other organizations publish field manuals for the design and establishment of such trials.

Selecting the trial site. Soil and climatic conditions at the trial site should be similar to those of the target planting area. If the planting area includes sites with a variety of growing conditions, then separate trials should be conducted for each type of site. Each individual trial should be established on a site that is as homogeneous as possible, so that differences in species performance are not confused with differences in soil fertility, water availability, or other factors.

Designing the layout. Each plot within a trial consists of trees of one species planted inside one or more border rows of the same species. Trees in the border may be affected by conditions outside the plot, so their growth is not measured. Within the plot, trees should be spaced at intervals of 1 x 1 m or 2 x 2 m. The closer spacing is appropriate for trials that will be maintained for only a year or two. To generate useful results, a minimum of 16 trees should be measured. In a square plot of six rows with six trees in each row, there would be 20 trees in border rows and 16 trees to be measured (Figure 1). Larger plots with more trees are recommended for trials that will last longer than two years.

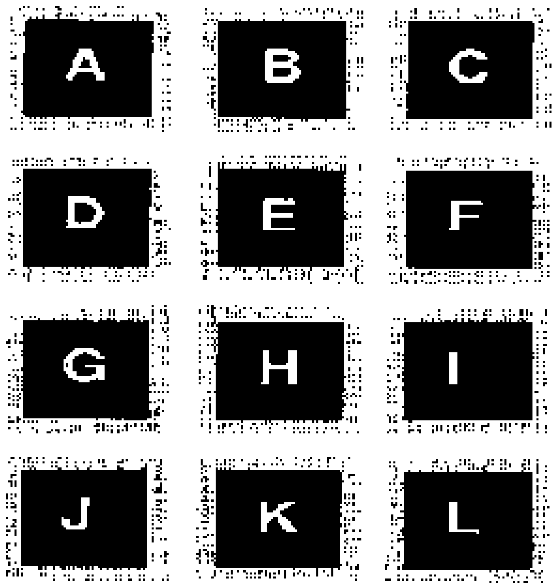


Figure 1. Sample design for an unreplicated screening trial with 12 species. Each block (plot) represents a different species. Within the plot trees should be spaced at intervals of 1 x 1m or 2 x 2m. The trees to be measured are in the black area. Border trees are in the light-gray area.

Selecting the trees to be tested. In addition to nitrogen fixing trees, it is important

to include some indigenous trees and non-nitrogen fixing species in screening trials, especially any species that are already prominent in local forestry programs. A comparison with trees that are indigenous or have already been introduced provides a useful basis for evaluating new species.

For each species in a trial, include more than one provenance (seed source), if possible. Try to include at least two provenances from areas with acid soils because these are more likely to tolerate acid-soil conditions than provenances of the same species from other areas. For example, provenance trials of Gliricidia septum have shown that the Retalhuleu, Guatemala provenance is more tolerant of acid soils than other G. septum provenances. If a species screening trial were only to include less tolerant provenances of G. septum, on observer might conclude - incorrectly - that the species as a whole was not tolerant of acid soils.

If possible, seedlots from each provenance should comprise equal numbers of seed from at least 30 trees, all separated from each other by a distance of at least 100 meters. Wherever possible, seed should be included from trees that have already been naturalized in the area: such trees may have undergone some adaptation and selection that will make them more suitable than trees of the same species growing in a different location.

In general, begin with the best-adapted provenances available - for example, Retalhuleu provenance of G. septum. This approach will give you the best chance to maximize tree survival rates and performance, and it will save time and money.

Collecting data. Measure tree survival, height, and stem diameter at 6,12, and 24 months after planting out seedling-the precise schedule will depend on local

growing conditions. Calculate mean height, diameter, and number of stems for each species after each measurement. Basal diameters are taken during the first year or until diameter at breast height can be taken.

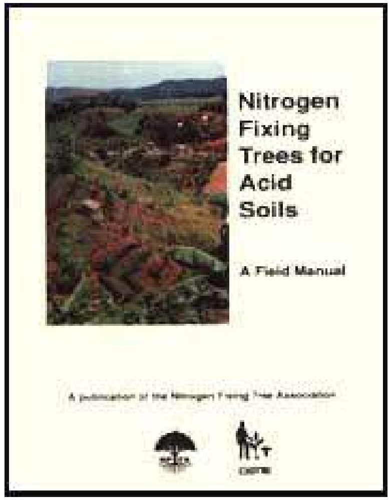
Some species may be valued for products, such as fruits, in addition to their woody biomass. If possible, the output of these additional products should be assessed during the first two years. Data collection should include a visual evaluation of growth, phenology, and symptoms of any pests, pathogens, or nutrient deficiencies.

Reporting trial results. To make your trial results useful to people planting trees on other sites, provide a minimum set of information on the trial site, soil, and seed provenances. Information on the soil should include aluminum (A1), phosphorus (P), calcium (Ca), potassium (K), magnesium (Mg), and manganese (Mn) levels, if available. Information on seed sources should include location, soil pH, number of trees collected from, and date of collection.

Caution!

You may wish to assess the performance of some nitrogen fixing tree species that are new to your area. Remember that many introduced tree species have the potential to become weedy in new environments. They may invade pastures and agricultural land and crowd out the native vegetation. Any tree, particularly a thorny or non-fodder species, that begins to exhibit weediness (prolific seed production or rapid, heavy seedling establishment) should be watched carefully. Such species should be considered for eradication, especially if they have no clear potential for use.

Some species can also be hosts to pests and diseases. For example, in parts of the South Pacific, Erythrina species are hosts to a fruit-piercing moth (Othreis fullonia Clerck). The larvae of this species feed on Erythrina, and the adults cause series damage to important commercial fruit crops.



Growing nitrogen fixing trees in acid soils

C. Buford Briscoe, Sergio M. de Faria, Veronique Lambert, Gregory Minnick, Ricardo Russo

Seed procurement

Once a grower has selected one or more nitrogen fixing tree species for a particular site and production goal, the first priority is to obtain high-quality seed. The chances of establishing and growing nitrogen fixing trees successfully can be greatly enhanced by using seed from good sources. Often, however, this key aspect of the production process does not receive sufficient attention.

Seed should contain genetic material that will produce trees that grow well in the proposed site and provide the desired services and products. In addition to the quality and suitability of the genetic material they contain, the seeds themselves should also be of high quality. Whenever possible, obtain seed from a reliable source, since inappropriate collection, storage, or treatment of seed can seriously reduce its viability (germination rate). Local seed banks, managed by government agencies, projects, or commercial companies, are often reliable sources of seed for nitrogen fixing trees. Preferably, the seed should be certified as to its provenance (original geographic area of genetic material), origin (exact location of source trees), purity, and viability. International seed banks are another good source. They sell certified seed in commercial quantities and may also sell or give away small amounts of seed for testing purposes. Appendix B provides a list of seed sources.

Seed collection

If seed is not available from a seed bank, it will have to be collected locally. Although seed collection methods vary depending on the flowering and pollination characteristics of each tree species, some simple "rules of thumb" should be

followed.

- **Seed should be collected from healthy mother trees that have no visible signs of weakness, disease, or insect attack.**

- **Because many characteristics are inherited, mother trees should be selected for the characteristics desired. For example, if nitrogen fixing trees are being planted for timber production, then mother trees should be selected that exhibit good form and self-pruning.**

- **Seed should be collected from many different trees, preferably 30 to 40, that are widely separated. At a minimum, seed should be collected from 10 mother trees spaced at least 100 meters apart. If a continuing genetic improvement program is planned, each parent tree should be selected from a different stand or uniform plantation to ensure genetic diversity.**

- **Only mature seed should be collected.**

Seed storage

All tree seed falls into two categories. Most nitrogen fixing trees have orthodox seeds "mall or medium-size seeds with hard seed coats. Normally, their viability can be maintained for at least 12 months. The acacias are an example. Recalcitrant seeds generally have soft seed coats and may be larger than average. Their viability cannot easily be maintained in storage: in some case, germination rates fall drastically within a few days or weeks after the seeds are harvested. The Inga species are an example.

It is always best to plant seed as soon after collection as possible. In virtually all cases, germination rates will decline as storage is extended. If germination rates are expected to be low because of extended storage or any other reason, it is important to collect extra seed to ensure production of the required number of plants.

To store orthodox seed:

- **Remove plant debris and cull seeds that are deformed, damaged, or show signs of pest attack**

- **Before seeds are stored, they should be dried in open shade or indoors at a temperature of not more than 30 C until they reach a moisture content of 7-8 percent.**

- **If the seeds will be stored for a considerable time, they should be treated with a fungicide, but one that will not damage rhizobial or mychorrhizal symbionts.**

Store seeds at a low temperature (3-5C) in containers that will keep out moisture, such as powdered milk cans or double plastic bags.

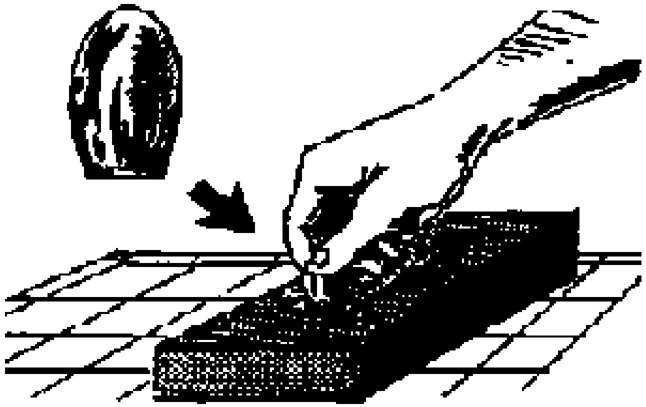
Recalcitrant seed cannot be stored for long periods. It is best to plant such seeds as soon as possible after collection - within two weeks, for example, for Inga species. If seeds must be shipped over long distances, it may be possible to prolong viability somewhat by packing them in a moist, well-aerated medium, such as vermiculite or sawdust, in a perforated plastic bag inside an air-porous bag. They should be kept under refrigeration (3-10C) and shipped by the fastest means available. It is occasionally possible to make prior arrangements with

customs and plant-quarantine officials to give special priority to such perishable material. This almost invariably requires communication of shipping dates and waybill identification, plus close follow-up at the receiving customs office.

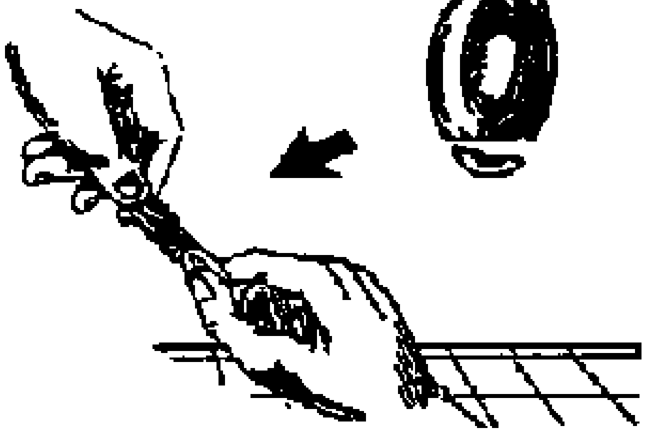
Propagation from seed

Seed pretreatment. Pretreatment is only necessary for orthodox seeds that have been dried. Table 1 lists recommended pretreatments for several tree species. In the past, seed was often treated with sulfuric acid, but this method is expensive and dangerous, and the results are seldom, if ever, superior to more conservative methods.

Seed pretreatments should always be tested on small samples, in increasing order of severity, before they are applied to the seedlot as a whole. For example, test samples should be soaked in boiling water for very short periods, and these should be extended in small incremeets. Germination tests should be used to determine which pretreatment works best.

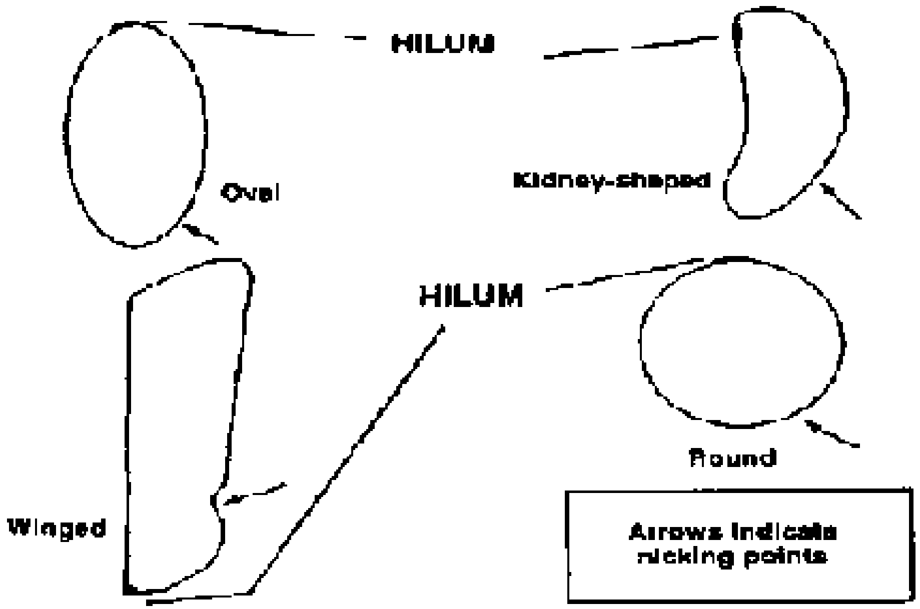


Scrape a small hole in the seed coat by rubbing on a rough surface



Or cut a small hole in the seed coat with nail clippers or a knife (below).

Source: NFTA.



Area where the seed coat can safely be scarified. Source: Briscoe (1989).

Species	Treatment	Seeds/kg
Acacia aneura	B 1 min. S	75,000–80,000

Acacia angustissima	B, S	90,000–100,000
Acacia auriculiformis	B 30 sec, S	30,000–90,000
Acacia holosericea	B 1 min, S	70,000–80,000
Acacia koa	B 2 min, S	8,500–20,000
Acacia mangium	B 30 sec, S	80,000–100,000
Acacia mearnsii	B 5 mins	48,000–85,000
Acacia melanoxylon	B, S	60,000–100,000
Albizia lebbeck	B 3 sec	6,000–15,000
Albizia saman	B 2 min, C, S	6,000–8,000
Alnus acuminata	R	200,000–2,000,000
Alnus glutinosa	R	
Calliandra calothyrsus	B	14,000–19,000
Casuarina cunninghamiana	R	1,800,000
Casuarina junghuhniana	R	1,000,000–1,600,000
Casuarina sumatrana	R	
Chamaecytisus palmensis	B 1 min	
Cedrelinga catenaeformis	B	
Dalbergia nigra	C	10,000–30,000
Desmodium gyroides	R	500,000
Desmodium nicaraguense	R	500,000
Desmodium velutinum	R	500,000
Enterolobium cyclocarpum	C, S	800–2,000
Enterolobium contortisiliquum	C, S	
Erythrina abyssinica	C	
Erythrina berteroana	C	
Erythrina poeppigiana	C	3,000–5,000
Erythrina fusca	C	
Erythrina variegata	B 10 min	
Flemingia macrophylla	R	50,000–60,000
Gliricidia sepium	C, B, or S	7,000–12,000
Inga acrocephala	R	
Inga codonantha	R	
Inga edulis	R	
Inga marginata	R	
Inga punctata	R	
Inga spectabilis	R	
Mimosa scabrella	B 3 mins	60,000–90,000
Mimosa caesalpiniaefolia	B	
Paraserianthes falcataria	B 10 mins	40,000–50,000
Pithecellobium dulce	R	
Prosopis juliflora	B, S	
Pterocarpus indicus	R	1,500–2,000
Robinia pseudoacacia	B 2 min, S	35,000–50,000
Stryphnodendron adstringens	B	

Stryphnodendron excelsum B

B: Pour boiling water over seeds (about five times as much water as the volume of the seeds), stir gently for 1 to 2 minutes (or as specified), and then soak in cold water for 12 to 24 hours.
C: Soak seeds in cold water for 12 to 24 hours.
S: Nick the round end of each seed with a file, knife, or nail clipper or rub the round end on a rough surface such as cement until the white interior is barely visible. Soak the treated seeds in cold water for 12 hours.
R: Recalcitrant seed; no treatment needed.

Table 1. Suggested pregermination treatments for key nitrogen fixing tree and shrub species that tolerate acid soils.

Inoculation with rhizobia and mycorrhizae

To improve mineral nutrition of nitrogen fixing trees on acid soils it is important to ensure that the trees are infected with effective rhizobial and mycorrhizal symbionts. The rhizobial bacteria form nodules on the roots of leguminous trees and other plants: nitrogen fixation occurs inside these nodules through a symbiotic process that involves both bacteria and plant. The bacteria provide nitrogen to the plants, and the plants provide carbohydrates to the bacteria.

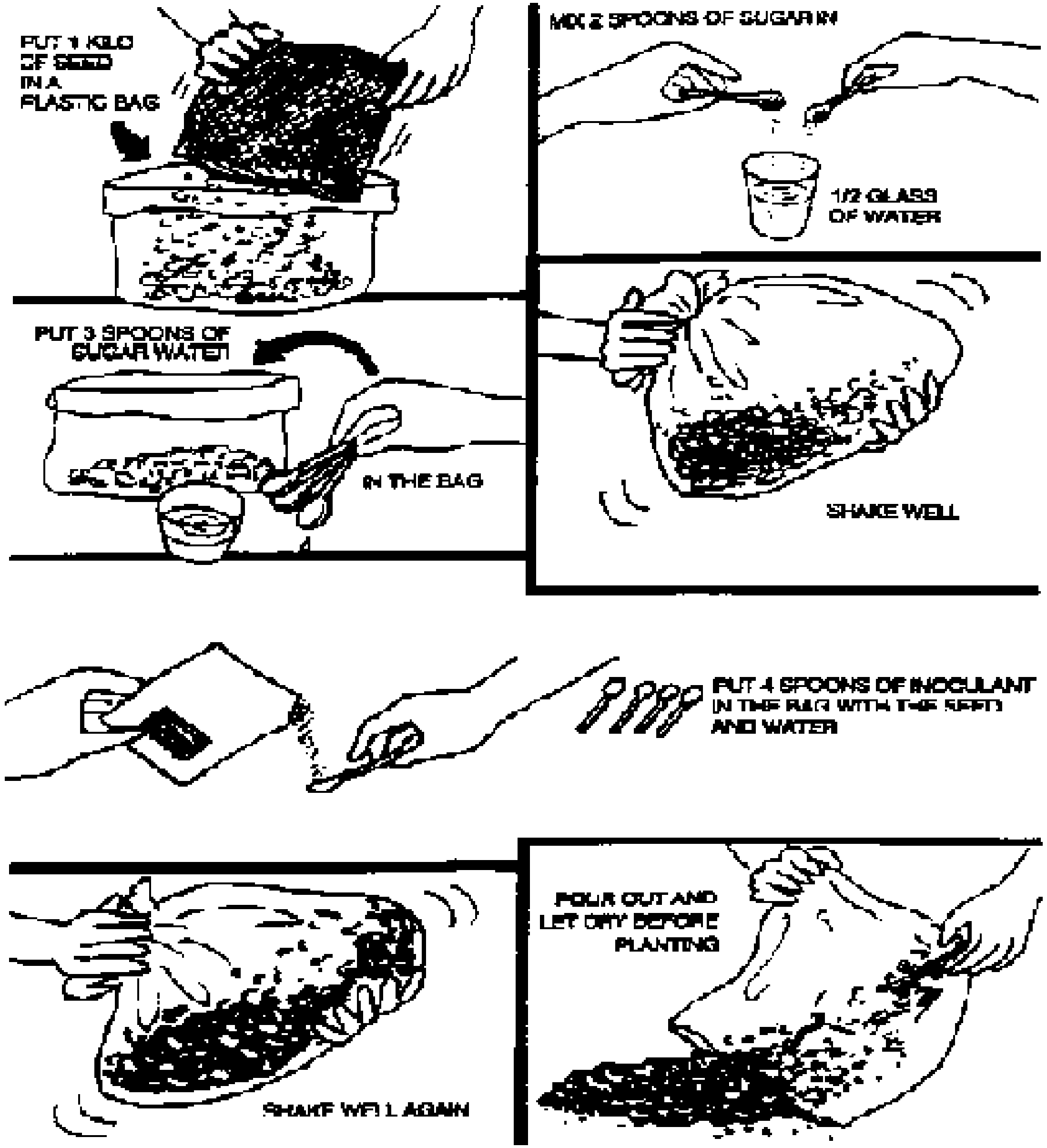
Like rhizobia, mycorrhizal fungi live in the soil and form symbiotic associations with the roots of nitrogen fixing trees. A tree provides essential carbohydrates to the fungus, and the fungus's network of hyphae functions like extra feeder roots, improving the tree's access to soil moisture and nutrients. This symbiotic relationship is particularly important for water uptake in arid environments or for uptake of scarce nutrients, especially phosphorus, in acid, infertile soils.

In most areas where nitrogen fixing trees are native or naturalized, the native rhizobia and mycorrhizae in the soil will form symbiotic associations with the trees' roots to enhance growth. However, the soil is not likely to contain effective symbionts in areas where trees have never grown or have not grown for a long

time or where the top soil has been severely disturbed (for example, by mining). In such areas, it may be necessary to add rhizobia and mycorrhizae to the soil, a technique called "inoculation," to ensure good tree growth. Follow the general rule - if in doubt, inoculate!

Many nitrogen fixing tree species have been shown to require particular species of rhizobia in order to fix nitrogen from the atmosphere. Within a given species of rhizobia, particular strains may also be more or less tolerant of acid soils.

Tree species also need to be matched with particular types of mycorrhizae. These fungi can be classified into two broad groups: ectomycorrhizae and endomycorrhizae. The majority of tropical nitrogen fixing trees form symbiotic associations with vesicular-arbuscular mycorrhizae (YAM) in the endomycorrhizal group. However, Alnus and Casuarina species and some species in the Caesalpinoidaea subfamily associate with fungi in the ectomycorrhizal group as well as VAM fungi. It is important to inoculate nitrogen fixing trees with the appropriate mycorrhizal fungi to achieve maximum benefits in terms of tree growth and survival.



Figure

Until recently, it was difficult to procure just the right rhizobium or mycorrhiza for a particular tree species and site. Now, however, several international laboratories

and private companies produce rhizobial and mycorrhizal inoculants for experimental and commercial purposes. These are listed in Appendix B.

Seeds should be inoculated after pretreatment immediately before planting. The Nitrogen Fixation by Tropical Agricultural Legumes (NifTAL) Center recommends placing seeds in a bag or bucket and covering them with a sticking agent such as gum arable, sugar, vegetable oil, or water (see illustration). Dissolve 40 g of gum arabic in 100 ml of hot water. After cooling, add 2 ml of this mixture to the bag or bucket for each 100 g of seed. Alternatively, dissolve 1 part sugar in 9 parts water and add 2 ml of this solution for each 100 g of seed. After either treatment, add inoculant and shake or mix the seeds until they are evenly coated. A 50 g bag of inoculant from NifTAL is sufficient to inoculate 1 kg of seeds. To eliminate any stickiness, allow inoculated seeds to air dry briefly before planting.

To inoculate seedlings in a nursery, mix inoculant in cool water and irrigate the seedlings with the suspension. Keep the suspension well agitated and irrigate until the inoculant is washed into the root zone. A 5 g bag of NifTAL inoculant can inoculate 10,000 seedlings of any species.

If commercial inoculant is not available, look for vigorously growing trees of the same species you are planting or of a closely related species. Dig up some soil containing well-nodulated roots from under several of these trees and place this fresh material in the pots where seeds are planted. If a problem arises with parasitic fungi or bacteria, wait to apply the inoculant after seedlings have developed a dry bark and woody stem.

Germination

It is best to start tree seedlings in flats if you expect medium or low germination or directly in pots if you expect high germination. Use a potting mix of 1 part sand, 1 part organic matter, and 3 parts soil or any mix that will allow good water drainage and adequate water retention.

Seeds should be sown just below the soil surface with the hilum facing downwards and covered to a depth about equal to their diameter. Spread very tiny seeds on the surface. Keep soil moist but not wet until after the seedlings emerge. If germinating seeds in flats, transplant to pots or beds as soon as there is evidence of germination.

Field establishment

Site preparation. First, remove all unwanted plants and other material to reduce excessive competition for light, soil nutrients, and moisture. The most common method of site preparation in tropical countries is slashing all existing growth, at/owing it to dry, and then burning the entire area. The ash enriches the soil, and the lack of soil disturbance reduces the danger of erosion. On windy sites, such as along coast lines or exposed ridges, young trees may benefit from the protection of existing vegetation this may more than compensate for any disadvantages from competition.

Fertilizer can be applied in planting holes to correct the nutrient deficiencies normally associated with acid soils. Phosphorus is probably the most critical nutrient: if no phosphorus fertilizer is available, apply ash, manure, or compost. Other elements that may be needed are calcium, magnesium, and minor elements (micronutrients). Dolomitic limestone is recommended as a source of both calcium

and magnesium. Additions of molybdenum or a complete micronutrient supplement may also be beneficial. Whether such applications are advisable in economic terms depends on the particular plant and soil situation.

Post planting care includes weeding (above) and mulching (below). Organic mulch should not touch the tree stem, particularly where rodents and insects are a problem. Where termites attack the young trees, only a non-organic mulch of stones or plastic may be acceptable. Source: Briscoe (1989).

For tree planting projects, adding lime in an attempt to correct acid soils is generally not a good strategy. Lime can be expensive and only affects the soil in the spot where it is mixed. Tree roots normally grow deep into the soil and are not affected by lime added to the top layers.

When preparing a field site for tree planting, follow these general guidelines:

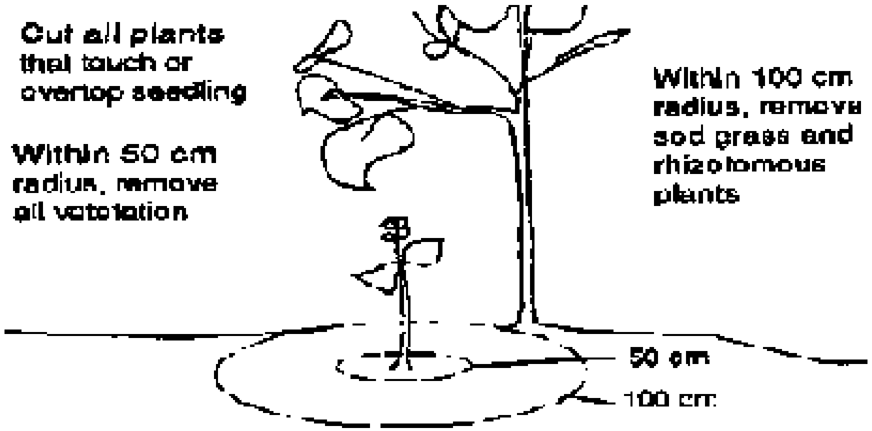
- **For any type of seedling, always prepare a large, deep planting hole. Make the hole deeper and wider than the seedling root width and length.**

- **If the soil is waterlogged for part of the year, plant trees in mounds of topsoil.**

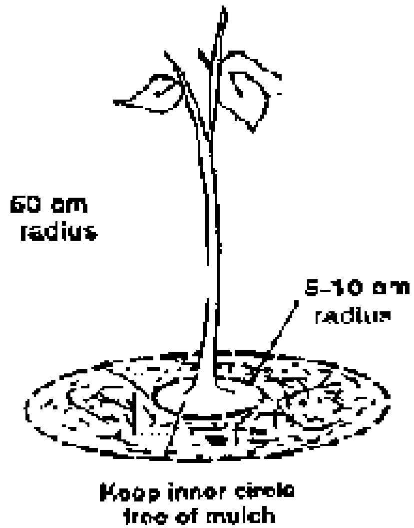
- **In arid areas, plant trees in microcatchments, small triangular or semicircular bunds built downslope from the planting hole to catch rainfall.**

Spacing. Closely spaced trees dominate a site quickly, reducing weed growth. They also provide greater woody biomass per hectare than widely spaced trees unless the close spacing inhibits growth or causes substantial mortality. Close spacing provides early high yields of small products such as foliage, and fuelwood.

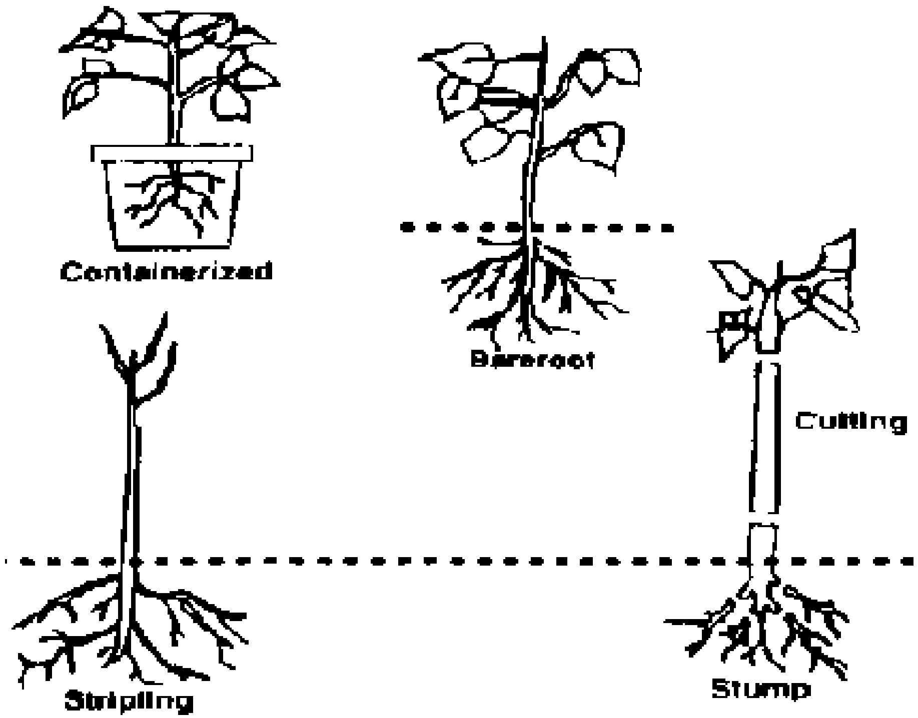
Although closely spaced trees may grow faster initially, widely spaced trees tend to grow faster in the long term, both in terms of diameter and often in terms of height. This increased timber production with wide spacing may bring a substantial financial advantage. To produce trees of a given size, spacing on poor sites should be wider than on good sites. For most species, coppice regrowth after trees are harvested tends to be more reliable and vigorous at a wider spacing.



Post planting care includes weeding



Post planting care includes mulching



Forms of planting stock.

Source: Briscoe (1989).

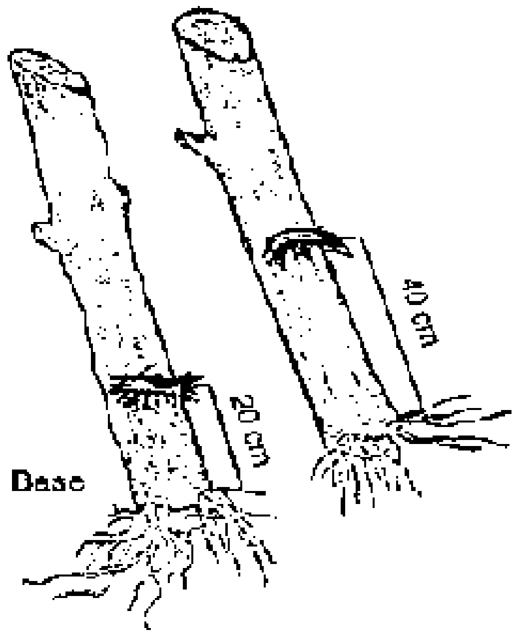
Planting. Trees can be established in the field by direct seeding or by planting various types of seedlings or cuttings. The choice of planting method will vary according to tree species, site, weather conditions, and the availability of labor and other inputs. Even experienced farmers or field workers can benefit from a short training session before planting begins: emphasize the fragility of the root tips rather than the mecanics of planting. Two general rules apply:

- **Always remember to keep roots moist and protect seedlings from any type of**

damage when lifting, transporting, and planting them in the field.

- **When planting seedlings on a slope or at a site where surface erosion is expected, plant trees deeper than they were in the nursery. Never plant less deep.**

Planting stock. Plants raised from seed or seedlings are the products of sexual reproduction, possessing a mixture of genes. Hence performance will be variable to some extent, either better or worse than the performance of the plant's parent tree or trees. By contrast, plants produced by vegetative propagation are genetically identical to a single parent tree. These are useful for identifying the genetic characteristics of the parent tree and for multiplying planting stock for tree improvement programs. In themselves, apart from environmental conditions, they are never inferior-but also never superior - to the parent. Planting stock based on sexual reproduction will be discussed first.



Incisions near the base of cuttings stimulate superficial root growth.

Source: NFTA.

Direct seeding is the least expensive planting method, but risks are high Try direct seeding if you want a dense planting, if you have a favorable site with good weed control, if you are planting a tree species with large seeds, and if you have an abundant supply of cheap seeds. Treat seed as for sowing in the nursery, and time planting for a period of good rainfall.

Bareroot seedlings are grown to a height of about 50 cm in the nursery and dug up and planted directly in the field without a rootball or container. This technique is widely known and fairly inexpensive: it is usually successful if properly done. In the tropics, it is particularly important to transport bareroot seedlings to the field and plant them as quickly as possible. If the planting hole cannot be deeper than the root length, prune the roots cleanly to fit the hole.

Striplings are bareroot seedlings that are stripped of all, or almost all, their leaves before removing from nursery beds. They are often more successful than bareroot seedlings on sites where rainfall is erratic during the planting season. Begin with large seedlings - 50-100 cm tall and 10-30 mm in diameter - and prune off all non-stiff roots along with the leaves. Plant as bareroot seedlings.

Potted seedlings are grown in individual containers. They tend to be expensive, but field planting is almost always successful if properly done. Keeping seedlings in pots until they are planted in the field reduces the pressure to transport and plant them quickly, but they are heavier and more difficult to transport than

bareroot seedlings. Remove the seedling carefully from its container and insert it carefully into the planting hole without disturbing the ball of earth or breaking the fine roots.

Wildlings are seedlings that sprout naturally under existing trees. They are usually cheaper and may be more widely available than nursery stock, but they are generally less successful. Handle and plant them the same as striplings or bareroot seedlings.

Stumps Prepare them as bareroot seedlings with the stem trimmed back to 2- 5 cm, the primary root pruned to 12-18 cm, and the lateral roots pruned to very short stubs. They should be planted with the top of the stem no more than 1 cm above the ground to avoid multiple sprouting. This planting method is particularly successful in sites with low or erratic rainfall.

Pseudocuttings are cuttings with a short segment of stump attached. Prepare them as bareroot seedlings with the stem trimmed back to 15-30 cm, the primary root pruned to 10-20 cm, and all branches and lateral roots pruned to short stubs. This method is reportedly more successful in humid climates than stumps. Pseudocuttings can often maintain their viability if planting is delayed or they are subjected to rough handling. However, they tend to be susceptible to borer attack and may produce multiple sprouts.

Vegetative propagation from cuttings is inexpensive, especially if natural stock is available. Some nitrogen fixing trees, such as Erythrina species and Gliricidia septum, grow well from large cuttings (more than 1.5 m long and 3 cm in diameter), although initial problems in growth form may occur. For example, when

Erythrina species are propagated from cuttings, initial rooting may be shallow. The following general guidelines are useful for propagating nitrogen fixing trees from cuttings:

- **Make cuttings at the end of the dry season or the beginning of the rains.**

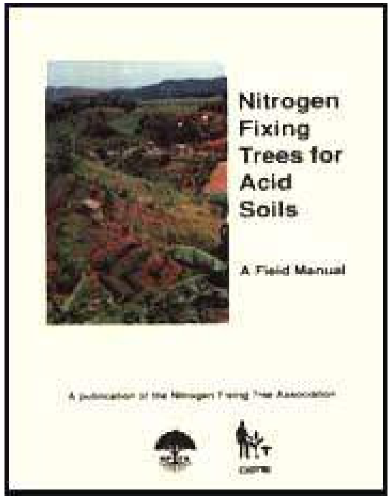
- **Plant cuttings immediately after cutting or store them temporarily, top end up, in a cool, shady place.**

- **Trim the top ends of cuttings with a sharp tool at a 45 angle to avoid water accumulation that could lead to rotting. You may also cover the top cut with paraffin, plastic, or mud.**

- **With some species, such as Erythrina and Gliricidia, incising the bark to the cambium layer near the base of the cuffing may increase rooting..**

Airlayering may improve establishment of species that are difficult to graft or to propagate from root cuttings. Remove a strip of bark 1-15 cm wide from a branch, preferably one that is more than 1.5 cm in diameter. Cover the stripped area with a double handful of moist sphagnum moss or similar absorbent material, enclose it in dear plastic film, and secure the film on both sides of the stripped area. Check weekly for visible roots. When roots are seen, dip off the branch above and below the plastic cover. Remove the plastic and plant.

It is also possible to propagate trees from selected genetic material by laboratory methods using tissue culture. Although this approach is still quite expensive, it is likely to become more widespread in the future. Trees produced from tissue culture are called emlings.



Nitrogen fixing trees for animal production on acid soils

Ricardo R. Russo and Raul Botero Botero

Livestock owners maintain nitrogen fixing trees in pastures and fodder banks and use them as living fence posts. The trees provide a variety of products and services, such as fuelwood, poles and timber, fodder and protein supplements for livestock, and shade. Although only a limited number of nitrogen fixing species are known to be adapted to acid soils, this group includes species suitable for a wide range of ecological zones and animal production systems. Among the species that

have proven particularly successful for animal production on acid soils are Erythrina poeppigiana, Erythrina fusca, Alnus acuminata, Cratylia argentea, Desmodium velutinum, and Desmodium gyroides. Table 1 gives a more complete list of nitrogen fixing trees and shrubs for animal production on acid soils.

Silvopastoral systems

Animal production systems that combine trees or shrubs with pastures are called silvopastoral systems. Farmers use nitrogen fixing trees in these systems to help achieve sustainable production. The trees interact with other elements of the system at biological, ecological and/or economic levels.

Pasture improvement. Nitrogen fixing trees can improve the soil chemistry of pastures by supplying nitrogen-rich organic matter. Tree roots absorb nutrients from deep soil layers and bring them to the surface, making them available to other pasture plants through the periodic decay of leaves, flowers, fruits, branches, and roots. In addition to providing nitrogen, nitrogen fixing trees can influence soil pH and the content and availability of calcium, magnesium, potassium, and phosphorus.

Grazing animals can deplete pasture plants and trample and compact the soil. In the humid tropics, pastures all too often become so degraded that they are eventually abandoned. Nitrogen fixing trees can improve soil physical properties, such as porosity and bulk density, and increase soil nutrient availability. Such positive effects can halt or even reverse the process of pasture degradation.

The interactions between trees and pasture grasses and other plants can be

complex. Trees may compete with other pasture plants for water, nutrients, light, and space. The effects of such competition will be greater if the requirements of the trees and other plants are similar. These effects can be reduced through the selection of appropriate tree species and a pruning system designed to increase the availability of water, light, and nutrients to other plants at important times in the growing season.

Nitrogen fixing trees can also enhance the growth of adjacent pasture species by improving the soil and providing light shade. At the Centro Agron¢mico de Investigaci¢n y Ense¤anza (CATIE) in Turrialba, Costa Rica, Erythrina poeppigiana was interplanted with pasture grasses at a spacing of 6 x 6 m (277 trees/ha), and the trees were pruned every three to six months. Four grass species had higher yields and higher crude protein contents when interplanted with the trees than when planted in pure stands. These were Panicum maximum, Brachiaria brizantha, Brachiara humidicoia, and Cynodon nlemfuensis. Yields of two other grass species, Brachiaria dictyoneura and Pennisetum purpureum, decreased when interplanted with Erythrina.

Generally, grass species that grow under trees have higher yields, lower root: shoot ratios, and a better nutrient composition (lower crude fiber and higher crude protein content) than species that grow outside the tree canopy. However, the shade-seeking behavior of grazing animals may also affect pasture quality. Large numbers of animals crowded under trees can lead to trampling that affects plant cover and causes soil erosion and compacting. These conditions can also inhibit tree growth.

Species	Trees and shrubs in pastures	Live fence posts	Fodder banks
Acacia aneura	✓		
Acacia farnesiana			✓
Aeschynomene species	✓		✓
Albizia lebbeck	✓		
Albizia saman	✓		
Alnus acuminata	✓		
Calliandra arborea	✓		
Calliandra calothyrsus	✓		✓
Casuarina cunnighamiana		✓	
Clitoria fairchildiana	✓		✓
Desmodium gyroides	✓		✓
Desmodium velutinum	✓		✓
Erythrina berteroana	✓	✓	✓
Erythrina cochleata	✓	✓	✓
Erythrina fusca	✓	✓	✓
Erythrina lanceolata	✓	✓	✓
Erythrina poeppigiana	✓	✓	✓
Erythrina variegata	✓	✓	✓
Flemingia macrophylla	✓	✓	✓
Gliricidia sepium	✓	✓	✓
Inga edulis	✓		
Inga spectabilis	✓		
Paraserianthes falcataria	✓		
Pithecellobium dulce	✓		
Pterocarpus hayesii	✓		
Stryphnodendron excelsum	✓		

Table 1. Nitrogen fixing tree and shrub species for animal production on acid soils.

The feeding preferences of animals can have adverse effects on pasture composition. Over time, the species that grazing animals reject may come to dominate a pasture. On the other hand, livestock can have positive effects on pasture quality. They can accelerate some aspects of nutrient cycling by returning manure and urine to the soil. In addition, animals can spread seeds, or scarify them, which favors germination.

Species	Crude protein (%)	In vitro dry-matter digestibility (%)
Acacia aneura	11–16	—
Albizia lebbeck	10–20	45–70
Albizia saman (pods)	24	40
Alnus species	22	—
Calliandra calothyrsus	24	41
Desmodium gyroides		—
(syn. *Codariocalyx gyroides*)	18-20	41–47
Cratylia argentea	17–21	51–55
Desmodium velutinum	14–18	48–56
Erythrina poeppigiana	23–34	50–70
Erythrina berteroana	25–28	43–60
Erythrina fusca	22–23	—
Erythrina variegata	16–18	50
Flemingia macrophylla	15–19	15–25
Gliricidia sepium	20–30	60–65
Paraserianthes falcataria	21	39
Pithecellobium dulce	23–29	—
Robinia pseudoacacia	16–21	27

Table 2. Range of nutritive values (percent of dry matter) of nitrogen fixing trees that tolerate acid soils.

Benefits to Livestock. In addition to improving pasture conditions, nitrogen fixing trees can provide a valuable feed supplement to cattle and other livestock. A recent study at the International Center of Tropical Agriculture (CIAT) in Colombia evaluated the forage quality of several shrub legume species planted in acid soils (pH 4.0-4.5 and aluminum saturation higher than 85 percent). The leaves of nitrogen fixing species that are low in tannins, such as Cratylia argentea and Desmodium velutinum, had medium to high in vitro dry-matter digestibility and high crude protein throughout the year. Consumption by sheep and cattle was greatest when leaves were partially dried and fed as a cut-and carry protein supplement. The study especially recommended C argentea as a dry-season supplement.

Species that are high in tannins, such as Flemingia macrophylla and Desmodium gyroides, had adequate crude protein but low digestibility. Cattle did not consume these species in large amounts, but consumption was improved to some extent by drying leaves and young branches for at least one day and feeding them as a cut-and-carry protein supplement. Table 2 gives the nutritive values of several nitrogen fixing tree species that are tolerant of acid soils.

In another experiment in Colombia, the nitrogen fixing tree species Erythrina fusca was interplanted with the pasture grass Cynodon nlemfuensis at spacings of 4 x 4 m and 3 x 3 m (625 and 1,111 trees/ha, respectively). Trees pruned every three months yielded 30 and 50 tons/ ha/year of green forage, enough to provide protein supplementation for 8 to 13 cows.

Farmers in Costa Rica have grown Alnus acuminata in pastures for more than 90 years to produce timber, fuelwood, and shade. Trees are regenerated naturally or planted from nursery stock at spacings of 8 to 14 m (about 100 trees/ha). Farmers report that cows maintained on pastures with A. acuminata yield more milk than cows on pastures without the trees. To protect young seedlings from grazing cattle, farmers sometimes construct crude fences around individual seedlings.

In addition to providing high-protein fodder supplements, trees provide shade that protects grazing animals from direct radiation and internal temperature stress. The intensity of the shade depends on the spacing of the trees and on their crown diameter and structure. Research has shown that animal consumption levels are affected by thermal balance-animals eat more when the air temperature is lower than their body temperature. Researchers do not agree on whether this

contributes to higher animal productivity in the tropics.

Advantages and disadvantages. In summary, silvopastoral systems offer several advantages to farmers

- **Nitrogen fixing trees in pastures can improve soil properties and produce forage and fodder that provide a protein supplement for livestock.**

- **Trees provide shade and shelter from rain and wind, and this can help boost livestock production.**

- **Farmers may obtain additional economic benefits from the production of fuelwood, timber, posts, and other tree products.**

- **Grazing helps control pasture grasses and weeds that could compete with young trees. Control of the understory also facilitates tree management, including harvesting, and reduces fire risk.**

- **Diversification of production activities within the farm reduces economic risk.**

One of the main disadvantages of silvepastoral systems is the general lack of knowledge and trained personnel to carry out research and improvement projects. Formal experimentation with silvopastoral combinations is complex, both scientifically and from a practical point of view, and trials require a long-tenn commitment. From a farmer's perspective, maintaining trees in pastures may have other disadvantages:

- **Tree cover, particularly if it is dense, can have negative effects on adjacent**

plants.

- **Trees can obstruct mechanized pasture maintenance and hay harvesting.**

- **Young trees must be protected from grazing livestock.**

- **Farmers wishing to introduce nitrogen fixing trees in pastures may not have access to suitable planting material.**

Fodder banks

To maximize foliage production, some nitrogen fixing trees, such as Gliricidia septum and various Erythrina species, can be planted in dense stands in pastures or near pens for cut-and carry feeding to livestock. For fodder banks, Erythrina species should be planted at a spacing of 1.0 x 0.5 m and allowed to grow to a height of 1.5 to 2.0 m before the first pruning. Trees should be pruned to a height of 30 to 50 cm every four months during periods of high rainfall and less frequently during dry periods. In the humid tropics, a 1-ha fodder bank of Erythrina poeppigiana or Erythrina berteroana, pruned every four months, can produce up to 30 t of edible dry matter a year - enough to provide protein supplementation for about 20 cows.

Gliricidia septum can be seeded directly or planted from cuttings at a spacing of 1.0 x 0 25 m Trees should be well established and allowed to grow from 10 to 20 months before harvesting begins. They can then be harvested every 8 to 12 weeks, depending on site conditions. They should be cut to a height of 40 to 90 cm and allowed to regrow to a height of 1 to 2 m before recutting. To ensure an adequate supply of fodder during the dry season, trees should be cut six to eight weeks

before the onset of the dry season.

A study in Colombia compared survival and productivity of Gliricidia septum planted in fodder banks as large stakes and from seed. Trees planted from seed had higher survival rates and produced more green fodder than trees planted from stakes (Table 3).

	Survival at 40 months(%)		Fodder production (kg/dry matter/ha)	
Spacing (m)	Seed	Stakes	Seed	Stakes
0.6 x 0.6 m	96	54	18,804	13,465
0.8 x 0.8 m	93	69	15,818	13,947
1.0 x 1.0 m	97	75	13,611	12,718

Table 3. Unfertilized Gliricidia septum planted in fodder banks from seed and large stakes: survival and fodder production after 10 prunings over a 30-month period beginning 10 months after planting. Source: Molina et al. (1993)

Living fences

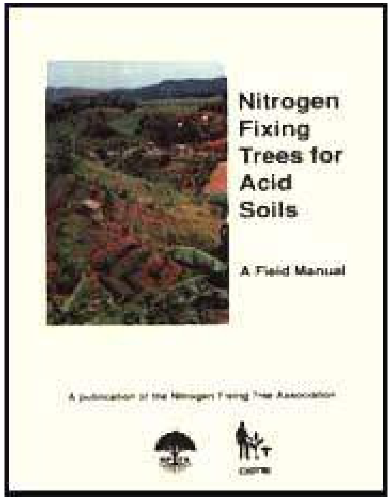
Hedges and living fence posts provide fine, conspicuous boundaries around pastures. They may also serve as windbreaks, niches for insect-eating birds, support for climbing plants, and shade and forage for livestock. In addition, they shed leaves that provide mulch and release nutrients to adjacent pasture grasses.

Farmers in Central America use a number of nitrogen fixing species that are tolerant of acid soils for hedges and living fence posts. These include Erythrina berteroana, Erythrina costancensis, Erythrina fusca, and Gliricidia sepium. Fence posts are usually propagated from stakes 2.0 to 25 m long, taken from trees that are at least 12 months old. They are generally planted 1 to 2 m apart. Well-

established fence posts can provide stakes for new fence posts, which farmers can use themselves or sell for extra income.

For Erythrina species, the main management requirements are regular pruning and replacing posts that die. The recommended practice is to prune fence posts once a year, during the dry season, if the objective is to produce woody stems rather than leafy biomass. Two prunings per year are recommended to produce palatable leaves and sterns for livestock fodder.

Gliricidia septum is probably the most extensively used species for living fence posts in the American tropics. It yields a dense wood that is well suited for construction poles and fuel. It also produces nutritious fodder. At one site in the Atlantic lowlands of Costa Rica, 1 km of fencing with posts spaced about 13 m apart yielded more than 1000 kg (dry matter) of leaves suitable for livestock fodder. After pruning, Gliricidia resprouts rapidly, producing branches that may be used as cuttings to establish new fence posts.



Pests of important nitrogen fixing trees that tolerate acid soils

Luko Hilje and Marcela Arguedas

Table 1 lists the pest species known to affect nitrogen fixing trees that tolerate acid soils. The term "pest" refers to any organism - insect, pathogen, vertebrate animal, or parasitic plant - that is actually or potentially harmful to reproductive structures, seedlings, stumps, or established trees. Most of the information presented in the table comes from Central America. The table also presents worldwide data from Boa and Lenn, (1994) on the following species: Acacia angustissima, Acacia auriculiformis, Casuarina cunninghamiana, Flemingia macrophylla, Gliricidia septum, Inga edulis, and Paraserianthes falcataria.

In Central America, most of the pest species listed here have been of minor importance. More than half of these pests attack tree foliage, but trees can normally compensate for damage to their foliage, so the impact of these pests on overall tree growth is generally not serious. However, damage to foliage can be

important to fanners if they are raising trees primarily for fodder production.

Oncideres punctata and Platypus species have been the most serious pests of acid-tolerant nitrogen fixing trees because they attack wood. The adult female of Oncideres punctata girdles several nitrogen fixing tree species. Adult Platypus beetles feed on Acacia species, but they appear primarily to damage trees that have already been weakened by adverse soil and climatic conditions. The stingless bee Trigona silvestriana is commonly blamed for this damage, but the bees only enlarge the holes made by the beetles.

Several pest species can attack both trees and agricultural crops. This can pose serious problems if susceptible plants are combined in agroforestry systems.

For example, in the South Pacific Erythrina species serve as hosts to the fruit-piercing moth Othreis fullonia.

The list of pests that affect Erythrina species has been limited to the most common species. Some 70 insect and 12 mite species have been reported to attack Erythrina species in Central America.

Tree species, common name, and family	Tree part affected	Pest species (order, family)	Pest common name
Acacia angustissima	foliage	*Ravenelia expansa*	rust
prairie acacia	foliage	*Ravenelia leucanae-microphylli*	rust
LEGUMINOSAE	foliage	*Ravenelia lysilomae*	rust
	foliage	*Ravenelia texensis* var. *texensis*	rust
[illegible]	[illegible]	[illegible]	[illegible]

Acacia auriculiformis tropical wattle LEGUMINOSAE	roots	*Armillaria mellea*	gummosis, dieback
	roots	*Botryodiplodia theobromae*	root rot
	roots	*Fusarium moniliforme*	wilt
	roots	*Fusarium oxysporum*	wilt
	roots	*Fusarium solani*	wilt
	roots	*Ganoderma* sp.	root rot
	roots	*Macrophomina phaseolina*	dieback, root death
	roots	*Meloidogyne* sp.	wilt (nematode)
	roots	*Phellinus* sp.	root rot
	foliage	*Alternaria alternata*	leaf spot
	foliage	*Cylindrocladium quinquespetatum*	leaf spot
	foliage	*Exscrohilum rostratum*	leaf spot
	foliage	*Meliola koae*	sooty mold
	foliage	*Oidium* sp.	powdery mildew
	foliage	*Pseudocercospora melaena*	leaf spot
	foliage	*Rhizoctonia solani*	leaf web blight
	foliage	*Uredo* sp.	rust
	foliage	*Uromyces digitatus*	rust

Table 1. Pests that attack nitrogen fixing tree species tolerant of acid soils.

Tree species, common name, and family	Tree part affected	Pest species (order, family)	Pest common name
Acacia angustissima cont.	foliage	*Uromyces* sp.	rust

	trunk	*Diaporthe eres*	canker
	trunk	*Ganoderma applanatum*	white mottled heart rot
	trunk	*Macrophomina phaseolina*	gummosis
Acacia mangium **acacia** **LEGUMINOSAE**	roots	*Dasypus novemcinctus* (EDE, Dasypodidae)	armadillo
	roots	*Phyllophaga* sp. (COL, Scarabaeidae)	whitegrub
	roots	*Rhizoctonia solani*	root rot
	roots	*Rosellinia* sp.	root rot
	foliage	*Atta* sp. (HYM, Formicidae)	leaf-cutting ant
	foliage	*Botryodiplodia* sp.	leaf spot
	foliage	*Brachypnoea* sp. (COL, Chrysomelidae)	leaf beetle
	foliage	*Cladosporium* sp.	leaf spot
	foliage	*Pestalotia* sp.	leaf blight
	foliage	*Puccinia* sp.	leaf rust
	foliage	*Trigona fuscipennis* (HYM, Apidae)	stingless bee
	trunk	*Coptotermes* sp. (ISO, Rhinotermitidae)	termite
	trunk	*Dasyprocta punctata* (ROD, Dasyproctidae)	agouti
	trunk	*Nectria* sp.	canker
	trunk	*Platypus* sp. (COL, Platypodidae)	ambrosia beetle
	trunk	*Sigmodon hispidus* (ROD. Cricetidae)	hispid cotton rat

	trunk	*Trigona silvestriana* (HYM, Apidae)	stingless bee
	trunk	unidentified (COL, Scolytidae)	bark beetle
	branches	*Erwinia* sp.	
	branches	*Fusarium* sp.	

Table 1. Pests that attack nitrogen fixing tree species tolerant of acid soils. (cont-1)

Tree species, common name, and family	Tree part affected	Pest species (order, family)	Pest common name
Albizia saman **rain tree** **MIMOSACEAE**	seeds	*Megacerus* sp. (COL, Bruchidae)	seed weevil
	seeds	*Merobruchus columbinus* (COL, Bruchidae)	seed weevil
	seeds	*Stator limbatus* (COL, Bruchidae)	seed weevil
	foliage	*Ascalapha odorata* (LEP, Noctuidae)	—
	foliage	*Heteropsylla puertoricoensis* (HOM, Psyllidae)	jumping plant louse
	foliage	*Mocis latipes* (LEP, Noctuidae)	looper
	foliage	unidentified (LEP, Geometridae)	looper
	trunk	*Aneflus* sp. (COL, Cerambycidae)	long-horned beetle
	trunk	*Oncideres punctata* (COL, Cerambycidae)	girdler
	twigs	unidentified (HOM, Cicadidae)	cicada
Alnus acuminata **alder** **BETULACEAE**	seeds	*Fusarium* sp.	—
	seeds	*Trichoderma* sp.	—
	roots	[illegible]	[illegible]

BETULACEAE	roots	*Rosellinia* sp.	root rot
	seedlings	*Sylvilagus brasiliensis* (LAG, Leporidae)	rabbit foliage
	seedlings	*Brachypnoea* sp. (COL, Chrysomelidae)	leaf beetle
	seedlings	*Colletotrichum* sp.	anthracnose
	seedlings	*Hypselonotus atratus* (HEM, Coreidae)	leaf-footed bug
	seedlings	*Lophocampa* sp. (LEP, Arctiidae)	tiger moth
	seedlings	*Melampsoridium* sp.	rust
	seedlings	*Nodonota irazuensis* (COL, Chrysomelidae)	leaf beetle
	seedlings	*Oligonychus mcgregori* (ACA, Tetranychidae)	mite
	seedlings	*Phomopsis* sp.	leaf spot
	seedlings	unidentified (HEM, Tingidae)	lace bug
	seedlings	unidentified (HOM, Cercopidae)	spittle bug
	seedlings	unidentified (LEP, Geometridae)	looper
	seedlings	unidentified (LEP, Saturniidae)	silkworm moth
	trunk	*Phassus triangularis* (LEP, Hepialidae)	ghost moth
	trunk	*Sciurus granatensis* (ROD, Sciuridae)	squirrel
	trunk	*Scolytodes alni* (COL, Scolytidae)	bark beetle
	trunk	unidentified (LEP, Hepialidae)	ghost moth

Table 1. Pests that attack nitrogen fixing tree species tolerant of acid soils. (cont-2)

Tree species, common name, and family	Tree part affected	Pest species (order, family)	Pest common name
Calliandra calothyrsus powderpuff MIMOSACEAE	foliage	*Umbonia crassicornis* (HOM, Membracidae)	hornbug
	foliage	unidentified (HOM, Cercopidae)	spittle bug
	branches	*Struthanthus quercicola*	

		(Loranthaceae)	mistletoe
Casuarina cunninghamiana casuarina ROSACEAE	roots	*Clitocybe tabescens*	root rot, dieback
	roots	*Phytophthora cinnamomi*	root rot, dieback
	roots	*Phytophthora* sp.	wilt, root rot, dieback
Casuarina equisetifolia ironwood ROSACEAE	roots	*Fusarium* sp.	root rot
	foliage	*Alternaria* sp.	blight
	foliage	*Pestalotia* sp.	blight
	foliage	*Phomopsis* sp.	blight
	foliage	unidentified (HOM, Cercopidae)	spittle bug
	trunk	*Trigona silvestriana* (HYM, Apidae)	stingless bee
	trunk	unidentified (COL, Platypodidae)	ambrosia beetle
	branches	*Struthanthus orbicularis* (Loranthaceae)	mistletoe
Enterolobium cyclocarpum ear fruit MIMOSACEAE	seeds	*Stator generalis* (COL, Bruchidae)	seed weevil
	seeds	unidentified (LEP, Pyralidae)	—
	flowers	*Asphondylia enterolobii* (DIP, Cecidomyiidae)	gall midge
	foliage	*Coenipita bibitrix* (LEP, Noctuidae)	—
	foliage	*Mocis latipes* (LEP, Noctuidae)	looper
	foliage	*Umbonia crassicornis* (HOM, Membracidae)	hornbug
	trunk	*Oncideres punctata* (COL, Cerambycidae)	girdler

Table 1. Pests that attack nitrogen fixing tree species tolerant of acid soils. (cont-

3)

Tree species, common name, and family	Tree part affected	Pest species (order, family)	Pest common name
Erythrina spp coral tree LEGUMINOSAE	shoots	*Chalcodermus denipes* (COL, Curculionidae)	weevil
	shoots	*Terastia meticulosalis* (LEP, Pyralidae)	—
	foliage	*Aethalion reticulatum* (HOM, Aethalionidae)	—
	foliage	*Agathodes monstralis* (LEP, Pyralidae)	—
	foliage	*Anomala cincta* (COL, Scarabaeidae)	beetle
	foliage	*Atta cephalotes* (HYM, Formicidae)	leaf-cutting ant
	foliage	*Faula centralis* (COL, Scarabaeidae)	beetle
	foliage	*Frankiniella insularis* (THY, Thripidae)	thrips
	foliage	*Phyllophaga menetriesi* (COL, Scarabaeidae)	june beetle
	foliage	*Phyllophaga* sp (COL, Scarabaeidae)	june beetle
	foliage	*Polyphagotarsonemus latus* (ACA, Tarsonemidae)	mite
	foliage	*Pseudodendrothrips* sp. (THY, Thripidae)	thrips
	foliage	*Tetranychus urticae* (ACA, Tetranychidae)	mite
Flemingia macrophylla LEGUMINOSAE	roots	*Phellinus noxious*	root rot
	roots	*Rigidoporus lignosus*	white root

		disease
foliage	*Cercospora canescens*	leaf spot
foliage	*Cercospora* sp.	leaf spot
foliage	*Marasmiellus scandens*	thread blight
foliage	*Meliola* sp.	sooty mold
foliage	*Parodiella hedysari*	leaf mold
foliage	*Thanatephorus cucumeris*	foliar blight
trunk	*Phaenerochaete salmonicolor*	pink disease

Table 1. Pests that attack nitrogen fixing tree species tolerant of acid soils. (cont-4)

Tree species, common name, and family	Tree part affected	Pest species (order, family)	Pest common name
Gliricidia sepium	roots	*Armillaria mellea*	root rot
Mother of cocoa	roots	*Botryodiplodia excipuloides*	root rot
LEGUMINOSAE			
	roots	*Botryodiplodia theobromae*	root rot
	roots	*Botryosphaeria dothidea*	dieback
	roots	*Botryosphaeria ribis*	dieback
	roots	*Fusarium oxysporum*	root rot
	roots	*Nectria haematococca*	dieback
	roots	*Nectria rigidiuscula*	dieback
	roots	*Orthogeomys cherriei* (ROD, Geomyidae)	pocket gopher
	roots	Phomopsis gliricidiae	wilt and dieback
	flowers	*Aratinga canicularis* (AVES, Psittacidae)	orange-fronted parakeet
	pods	*Cercosporidium gliricidiae*	pod spot

	foliage	*Cercospora atropurpurascens*	leaf spot
	foliage	*Cercospora canescens*	leaf spot
	foliage	*Cercospora gliricidiae*	leaf spot
	foliage	*Cercospora* sp.	leaf spot
	foliage	*Cercosporidium gliricidiasis*	leaf spot
	foliage	*Cladosporium* sp.	green mold
	foliage	*Colletotrichum gloeosporioides*	leaf spot
	foliage	*Colletotrichum truncatum*	anthracnose
	foliage	*Colletotrichum* sp.	anthracnose
	foliage	*Corynespora cassiicola*	leaf spot
	foliage	*Dendryphiella vinosa*	leaf spot
	foliage	*Eotetranychus ecclisis* (ACA, Tetranychidae)	mite
	foliage	*Erynnis* sp. (LEP, Sphingidae)	hornworm
	foliage	*Exophthalmus jekelianus* (COL, Curculionidae)	weevil
	foliage	*Hylesia lineata* (LEP, Saturniidae)	silkworm moth
	foliage	*Leptosphaerulina trifolii*	leaf spot
	foliage	*Meliola bicornis*	sooty mold
	foliage	*Meliola gliricidiae*	sooty mold
	foliage	*Mononychellus estradai* (ACA, Tetranychidae)	mite

Table 1. Pests that attack nitrogen fixing tree species tolerant of acid soils. (cont-5)

Tree species, common name, and family	Tree part affected	Pest species (order, family)	Pest common name
Gliricidia			

sepium cont.

	foliage	*Oidium* sp.	powdery mildew
	foliage	*Oligonychus mcgregori* (ACA, Tetranychidae)	mite
	foliage	*Periconia byssoides*	leaf spot
	foliage	*Pestalotia* sp.	leaf spot
	foliage	*Pestalotiopsis algeriensis*	leaf spot
	foliage	*Phaeoisariopsis* sp.	angular leaf spot
	foliage	*Phoma* sp.	leaf spot
	foliage	*Phyllosticta* sp.	leaf spot
	foliage	*Rhizoctonia solani*	foliar blight
	foliage	*Sirosporium gliricidiae*	leaf spot
	foliage	*Sphaceloma* sp.	scab
	foliage	*Spodoptera* sp. (LEP, Noctuidae)	armyworm
	foliage	unidentified (LEP, Arctiidae)	tiger moth
	foliage	unidentified (LEP, Hesperiidae)	skipper
	foliage	unidentified (LEP, Noctuidae)	—
	foliage	unidentified (LEP, Pyralidae)	grass moth
	foliage	unidentified (HOM, Aphididae)	plant louse
	foliage	unidentified (HOM, Cercopidae)	spittle bug
	foliage	unidentified virus-like disease	leaf mottling
	trunk	*Fusarium decemcellulare*	stem canker
	trunk	*Fusarium oxysporum*	—
	trunk	*Oncideres punctata* (COL, Cerambycidae)	girdler
	trunk	*Phaenerochaete salmonicolor*	pink disease
	trunk	*Phomopsis* sp.	stem dieback
	branches	*Cylindrocladium scoparium*	blight
	branches	*Fusarium oxysporum*	decay
	branches	*Marasmius crinisequi*	horse hair blight

Inga edulis	foliage	*Meliola* sp.	—
guabo	foliage	*Mycena citricolor*	—
LEGUMINOSAE	trunk	*Phomopsis* sp.	—

Table 1. Pests that attack nitrogen fixing tree species tolerant of acid soils. (cont-6)

Tree species, common name, and family	Tree part affected	Pest species (order, family)	Pest common name
Paraserianthes falcataria	seedlings	*Colletotrichum dematium*	damping-off
falcataria	seedlings	*Colletotrichum truncatum*	anthracnose
LEGUMINOSAE	seedlings	*Fusarium oxysporum*	damping-off
	seedlings	*Fusarium solani*	damping-off
	roots	*Armillaria mellea*	root rot
	roots	*Fusarium solani*	root rot
	roots	*Ganoderma lucidum*	red root disease
	roots	*Ganoderma pseudoferrum*	red root disease
	roots	*Ganoderma* spp.	root disease
	roots	*Macrophomina phaseolina*	black root rot
	roots	*Phellinus noxious*	root disease
	roots	*Pythium middletonii*	—
	roots	*Pythium vexans*	—
	roots	*Pythium* sp.	—
	roots	*Pseudophaeolus baudoni*	root disease
	roots	*Rigidoporus lignosus*	root disease
	roots	*Ustulina deusta*	root rot
	foliage	*Camptomeris albiziae*	yellow leaf disease
	foliage	*Cercosporella theae*	leaf spotting
	foliage	*Endodothella albiziae*	foliage disease

foliage	[illegible]	[illegible]
foliage	*Endodothella deightonii*	foliage disease
foliage	*Oidium* sp.	powdery mildew
foliage	*Pleiochaeta albiziae*	leaf spot
foliage	*Ravenelia* sp.	rust
foliage	*Rhizoctonia solani*	leaf web blight
foliage	*Sphaerophragmium* sp.	rust
foliage	*Thanatephorus cucumeris*	leaf blight
foliage	*Uredo* sp.	rust
foliage	*Uromycladium tepperianum*	rust
trunk	*Botryodiplodia theobromae*	dieback and canker
trunk	*Diaporthe eres*	canker
trunk	*Nectria pulcherrima*	canker and dieback
trunk	*Phaenerochaete salmonicolor*	pink disease
trunk	*Phoma* sp.	canker and dieback
trunk	*Phomopsis mendax*	dieback

Table 1. Pests that attack nitrogen fixing tree species tolerant of acid soils. (cont-7)

Tree species, common name, and family name	Tree part affected	Pest species (order, family)	Pest common
Paraserianthes falcataria cont.	trunk	*Pirex subvinosus*	heart rot
	trunk	*Pseudomonas* sp.	bacterial wilt
	trunk	*Thyridaria tarda*	canker and dieback
	trunk	*Thyronectria pseudotrichia*	canker and dieback

Table 1. Pests that attack nitrogen fixing tree species tolerant of acid soils. (cont-8)

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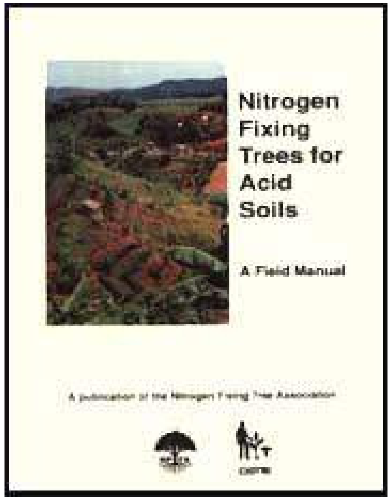

Nitrogen Fixing Trees for Acid Soils - A Field Manual (Winrock, 1996, 110 p.)

Appendices

Nitrogen fixing tree highlights: Species tolerant of acid soils

ACACIA AURICULIFORMIS - THE ADAPTABLE TROPICAL WATTLE

Few other species can match Acacia auriculiformis ability to grow on harsh sites. This species tolerates infertile clayey, sandy, acid, alkaline, saline or seasonally water-logged soils and long dry seasons. A growing number of foresters and agroforesters around the world are tapping the hardiness of this tree to rehabilitate 1and and produce wood products on otherwise unproductive sites.

BOTANY:

Acacia auriculiformis

A. auriculiformis A. Cunn. ex Benth is commonly a low to medium-sized tree 8-20 m in height, thornless, heavily branched and with a short, crooked stem. On a few favorable sites in its natural habitat it grows 25-30 m tall with a straight stem dominant for a greater part of tree height. It is a mimosoid legume with yellow

flowers. The twisted, cartilaginous pods contain small black seeds (30-60 seeds per gm). Its leaves are phyllodes (modified leaf stalks).

ECOLOGY: Natural occurrences of A. auriculiformis are mainly in the coastal lowlands of northern Australia, Papua New Guinea and a few islands in eastern Indonesia (Turnbull et al., 1986). The environment is tropical, frost-free, humid or sub-humid and has an annual rainfall of 1000-1500 mm with a monsoonal distribution pattern and a dry season of up to six months. It grows mainly at low altitudes (below 100 m) on dissected lateritic lowlands and alluvial coastal plains, where it is remarkably tolerant of flooding. Pot trials over a pH range of 4.3-8.0 indicated that seedlings grew equally well in acidic, neutral or alkaline soils (Hu et al., 1983). In northern Australia it has grown on a mine spoil with a pH of 3.0 and also on sand dunes with a pH of 9 (NAS, 1980).

LAND REBABILITATION: A spreading densely-matted root system is excellent for stabilizing eroded land and enables it to compete with and dominate Imperata grasslands. Rapid growth, even on infertile sites, and tolerance of both highly acidic and alkaline soils have made it popular for stabilizing and revegetating mine spoils. A superficial root system allows it to grow on shallow soils.

FUELWOOD: It is an ideal firewood and is planted for this purpose in China, India and other parts of Asia. Chinese plantations on Hainan Island have an average annual biomass production of 16 tons/ha and can reach 25 tons/ha on better sites. The charcoal is not too heavy and glows well with no smoke or sparks. Additionally, the annual fall of leaves, twigs and branches can be 4-6 t/ha. Poor coppicing ability is a disadvantage.

WOOD: The wood has a relatively high specific gravity (0.6-0.8). Heartwood varies from pale brown to dark red and is fine-grained, and often attractively figured. It finishes well, making it suitable for household furniture. Plantation-grown A. auriculiformis is promising for high quality chemical pulp (Logan, 1987).
OTHER USES: A. auriculiformis makes a good shade tree and can provide shelter on exposed sites near the sea. Hardiness, dense foliage and bright flowers make it a popular ornamental in cities. Excessive litter production has been a nuisance on Singapore streets, however. In China this tree is a host for the lac insect, and edible fungi are grown on the wood (Huang, 1985).

ESTABLISHMENT: For good germination, seeds should be scarified by mechanical abrasion or immersion for two minutes in ten times their volume of boiling water. Because of weed competition, plantations usually are established with seedlings rather than direct seeded.

GROWTH: Under optimal conditions, A. ariculiformis is very vigorous and reaches 15-18 m in height and 15-20 cm in diameter in 10-12 years. On relatively fertile, high-rainfall sites, it can have a mean annual increment of 15-20 m /ha. On less fertile, highly eroded or low rainfall sites, yields of 8-12 m /ha or lower are more likely. On Imperata grasslands and very infertile soils A. auriculiformis will usually grow faster than species of Albizia, Eucalyptus, Leucaena and Pinus.

RHIZOBIA: A. auriculiformis is a promiscuous host nodulated by a wide range of Rhizobium strains and has a good chance of being nodulated in soils with low Rhizobium populations (Roughley, 1987).

PESTS AND PROBLEMS: Damage by pests and diseases has generally been of a

minor nature, and young plantations are moderately resistant to termite attack. The crooked stem of this species has reduced its utility, but recent collections of new provenances show considerable promise for improved growth and straighter stems. Other problems are relative sensitivity of young trees to fire, allergenic properties of pollen, and allelopathic effects of leaf extracts on germination of other plants (Setiadi and Samingan, 1978).

HYBRIDS: A. auriculiformis will hybridize naturally with Acacia mangium, and such crosses have been observed in Papua New Guinea and Sabah, Malaysia. There is a strong possibility that the vigor of these hybrids will be exploited in the future.

Acacia koa - Hawaii's most valued native tree

Koa (Acacia koa Gray.) is unquestionably Hawaii's most prized tree species-culturally, ecologically and economically. Hawaiians have always valued koa for its exceptionally beautiful and durable wood. It remains the premier Hawaiian timber for furniture, cabinetry, interior work and woodcrafts. Equslly important, native koa forests provide unique wildlife habitat, critical watershed recharge areas and recreational opportunities. Unfortunately, forest clearing for agriculture, cattle grazing and feral pig activity have much diminished Hawaii's once extensive koa forest. The scarcity of koa wood is reflected in its ever increasing price high enough now to economically justify helicopter logging.

Botany and Ecology

Acacia koa is a large, evergreen broadleaf tree and the only Acacia native-and

endemic to Hawaii. Trees occuring in dense, wet native forest stands typically reach heights of 25 m and stem diameters (DBH) of 150 cm, while retaining a straight, narrow form. In the open, trees develop more spreading. branching crowns and shorter, broader trunks. Koa bark is gray, rough. scaly and thick. Observations indicate that koa has one main tap root - and an otherwise shallow, spreading root system.

Koa belongs to the thorn-less, phyllodinous group of the Acacia subgenus Heterophyllum (Whitesell 1990). Like other phyllodial species, mature koa trees do not have true leaves. Instead they produce phyllodes, or flattened leaf petioles. Young seedlings have bipinnate compound true leaves with 12 to 15 pairs of lesflets. Where forest light is sufficient, seedlings stop producing true leaves while they are small less then 2 m tall. True leaves are retained longer by trees growing in dense shade.

Phyllodes are sickle-shaped and often more than 2.5 cm wick in the middle and blunt pointed on each end. Investigations suggest that true leaves promote more rapid early growth when moisture is adequate, whereas phyllodes are better adapted to drought. Phyllodes transpire only 20 percent as much as true leaves, and their stomata close four times faster after dark. Phyllodes typically hang down vertically, a position that enhances their ability to capture light during early morning and late afternoon hours. Seedlings are able to switch back from phyllode to true leave production when the sunlight reaching them is reduced.

Observations suggest koa can flower almost any time of year, depending upon local weather conditions. The inflorescence of koa is a pale yellow ball averaging 85 mm in diameter, one to three on a common stalk. Each inflorescence is

composed of many bisexual flowers. Each flower has an indefinite number of stamens and a single elongated style. One known pollinator of koa is the honeybee (Apis mellifera). Koa appears to be fully self- fertile (Brewbaker 1977).

Koa pods are slow to dehisce and about 15 cm long and 25 to 4 cm wide. They normally contain between 6 and 12 seeds that vary from dark brown to black. Pods reach maturity at 4 to 6 months, depending on location and weather conditions. Insect larvae of many species typically destroy a large proportion of the mature seeds before they dehisce.

Seed production typically begins when trees are 5 years old. Koa bears seed often and abundantly. Seeds are seldom dispersed far from the tree and remain viable in the soil for up to 25 years. Thus remnant koa stands are capable of dominant regeneration under favorable conditions. Koa seeds do not require sunlight to germinate, but seedling growth is slow in dark understories or in thick grass. The species thus requires large forest gaps, such as those crested by storms, to successfully regenerate.

Acacia koa

Distribution

Acacia koa occurs at elevations from 180 to 6000 meters between 19 and 22 latitude on all of the major Hawaiian islands. It prefers an annual rainfall of 1900 to 5100 mm, and well drained acid soils. However, koa adapts to almost any of Hawaii's diverse environments indicating its potential elsewhere in the Pacific. Koa is found on all volcanic types of all geologic ages. It grows well in moderately to well-drained, medium to very strongly acid soils on both flatland and steep slopes. On dry, shallow, poorly drained soils koa's growth is slow and its form generally poor.

Occurring in both pure and mixed forest stands, koa is most commonly associated with the native ohia (Metrosideros polymorpha). It is also a codominant in several other major forest types including : Koa/Mamane (Sophora chrysophylla) Montane Dry Forest and Koa/Ohia/A'e (Sapindus soponaria) Forest (Wagner et al. 1990). Today Acacia koa stand are fragmented and concentrated in areas between 600 and 1800 meters elevation (Whitesell 1990). This discribution is largely the result of land conversion to agriculture and ranching. Cattle avidly graze koa seedlings, preventing regeneration.

Silviculture

Propagation is most successful from seed. One study recommends air-layering as the best vegetative propagation technique (Skolmen 1978). Koa seeds are durable and easy to store. They germinate after many years of storage if kept in a cool, dry place. The most effective method for improving seed germination is mechanical scarification. However, hot water soaking works well and is a more practical method. Boil water and remove it from the heat source. Soak seed in the boiled water for 24 hours. Once treated, seeds are typically sown in nursery beds. One week after germination, seedlings are transplanted into nursery tubes or bags. Seedlings arc ready for transplanting into the field when they arc approximately 20 cm tall-after 3 to 4 months in the nursery. Observations suggest that heart rot problems may be partially caused by root damage during transplanting. Therefore, establishment by direct seeding or encouragement of natural regeneration is recommended. On favorable sites, planted seedlings typically grow to 9 m in 5 years time (Judd 1920).

Koa's wide branching form is the result of open growth. Trees with long clear

boles-called "Canoe trees" by native Hawaiians are now rare, but still found in forest gaps created by fallen trees. Dense stocking of seedlings, which mimics the competitive environment where superior "canoe trees" grow. encourages straight and rapid height growth. Initial spacing of 1.2 x 1.2 meters is currently recommended. Observation indicates that effective self-thinning will result in an adequate number of potential crop trees by age 25.

Where scattered koa cover is adequate, plantation establishment is most easily and successfully accomplished through the stimulation of natural regeneration. Pasture soils are scarified and competition from grasses reduced by the application of a contact herbicide. Gaps in the regeneration are filled with planted seedlings. Fertilizers are applied to give seedlings an initial "boost". Plantation thinning prescriptions should be based on desired products and management capabilities. The most important factors to consider in picking koa crop trees is stem form and height. Research on koa plantation management and various spacing and thinning regimes is direly needed.

Uses

Wood. Koa heartwood is highly valued by furniture and crafts people throughout Hawaii, and consumers the world-over, for its unique gram, varied color and workability, It seasons well without serious warping or splitting. Curly-grained wood, the result of both stress and genetics, is preferred over straight-grained wood. Wood color ranges from a subtle yellow to a striking dark red-purple. The specific gravity of koa wood averages .40, but with curly-grained wood can be as high as .65. Mature koa boles are commonly forking or fluting and ofen suffer from heart rot. These characteristics and wide branch angles limit its value as a laarge

timber. Fortunately, these defects may be corrected through silviculture.

Forage and Wildlife Habitat. Cattle, sheep and pigs browse koa foliage aggressively, especially its juvenile leaves. Koa is spread geographically throughout Hawaii and thus offers a variety of wildlife habitats of diverse moisture regimes, soils and vegetative compositions. An overlay of a koa forest area map onto a forest bird "habitat island" map produced by Walker (1986) shows remarkable correlation.

Land Reclamation. Most koa plantation in Hawaii have been established to provide vegetative cover on sites degraded by decades of intense grazing. Where scattered koa already exists, seed stored in the soil will likely germinate if the soil is scarified and grass competition controlled.

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Acacia mangium: an important multipurpose tree for the tropic tropic

Acacia mangium Willd. is one of the major fast growing species used in plantation forestry programs throughout Asia and the Pacific. Due to its rapid growth and tolerance of very poor soils, A. mangium is playing an increasingly important role in efforts to sustain commercial supply of tree products white reducing pressure on natural forest ecosystems.

Botany

Acacia mangium is in the family Leguminosae, sub-family Mimosoideae. It has rapid early growth, and cam attain a height of 30 meters and a diameter of over 60 centimeters (MacDicken and Brewbaker 1984). Inflorescences are on loose spikes up to 10 cm long with white or cream colored flowers. When in full blossom, the inflorescences resemble bottle brushes. The flower has a mild, sweet fragrance. The dark green, glabrous phyllodes can be up to 25 cm long and 10 cm broad. The seed pods are broad, linear, irregularly coiled, and up to 3-5 mm wide and 7-8 cm

long. The seeds are dark brown to black, shiny, vary in shape. and range from 3-5 mm long and 2-3 mm wide. Seeds mature 6-7 months after flowering (Pinyopusarerk et al. 1993).

Acacia mangium has a chromosome number of 2n=26. Hybrids with A. auriculiformis have the potential to become an important source of planting material for plantation forestry. The hybrid seems to be more resistant to heart rot than A. mangium but tends to be more shrub-like. Moreover, the hybrid has the straight bole and stem of Acacia mangium and the self-pruning ability of A. auriculiformis (Ibrahim 1993).

Distribution and Ecology

Acacia mangium is native to Australia, Indonesia and Papua New Guinea, but now has a latitudinal range from 19§ S to 24§ N and a longitudinal range from 88§ to 146§ E. Acacia mangium is a low elevation species associated with rain forest margins and disturbed, wet/-drained acid soils (pH 4.56.5). Altitudinal range is from sea level to about 100 meters, with an upper limit of 780 meters: It is typically found in the humid, tropical lowland climatic zone characterized by a short dry season and a mean annual rainfall between 1446 and 2970 mm. Acacia mangium can tolerate a minimum annual rainfallof 1000 mm. Mean monthly temperatures range from a low of 13-21C and a high of 25-32§ C. Though considered an evergreen species, A. mangium does not grow continuously throughout the year. Growth seems to slow or cease in response to the combination of low rainfall and cool temperatures. Dieback occurs during prolonged frost (5-6§C).

When monthly rainfall is below 100 mm, trees exhibit signs of moisture stress (Pinyopusarerk 1993).

Acacia mangium tolerates a soil pH as low as 3.8, and has performed well on lateritic soils with high amounts of iron and aluminum oxides. Acacia mangium has survived on soils with as much as 73% aluminum saturation (Duguma 1995). It is intolerant of saline conditions, shade, and low temperatures. Due to dense foliage, broad phyllodes, and shallow root system, A. mangium is more susceptible to wind damage than ocher Acacia species.

Propagation and Silviculture

Although natural regeneration is excellent in clear-felled and burned fields, nursery propagation is the most common regeneration practice. Hot water treatment for 30 seconds promotes quick seed germination. There are 80,000-100,000 seeds per kilogram. Seed can be sown directly into nursery potS or sown in trays and transplanted to pots after germination.

Acacia mangium

Seedlings retained in the nursery for 12 weeks or until they have attained a height of 2540 cm. Srivastava (1993) recommends two root prunings and hardening off of the seedings before out-planting. In low phosphorus soils in the Philippines, Acacia mangium seedlings fertilized with 30 g/tree of phosphorus showed significant increase in growth compared to seedlings that were not fertilized (Manubag a al. 1995).

Spacing of the seedlings in the plantation depends on the intended uses and soil fertility. Since natural pruning is poor, trees should be planted at close spacing. Plantations cultivated for pulpwood usually have a 4 x 4 m spacing with 830 trees per hectare. For timber production, seedlings planted at 3 x 3 m spacing provide strong lateral competition and fast diameter growth. Seedlings should be planted at wider spacing to produce heavier branches for chipwood and fuelwood

(Srivastava 1993). On infertile sites, final stocking should be around 600-700 stems per hectare.

The first weeding should be two months after out-planting. Weeding of noxious plants such as climbers, creepers, and vines is recommended, but less harmful weeds can be left in the field to maintain lateral competition. The number of follow-up weedings will depend upon each site. In areas where Imperata has a stronghold, weddings should be frequent

Pruning schedules also depend on intended use. In agroforestry systems, branches are pruned regularly to prevent competition with agricultural crops. To produce quality sawlogs, all branches below the height of 6 meters should be pruned regularly. These branches must be pruned before becoming 2 cm in diameter (Srivastava 1993) to avoid fungal infections.

On degraded Imperata grasslands, Otsamo et al. (1995) observed that A mangium had a mean annual volume increment of 10 m3/ha/year. In a 15-year rotation, precommercial thinning should occur at 24 months, followed by a thinning at 36 months. Per this schedule, volumes are between 290 and 439 m3/ha after ten years' growth.

Uses

Acacia mangium has a wood density ranging from 420 to 600 kg/m3 and a specific gravity of 0.65 (MacDicken and Brewbaker 1984). Due to ease of drilling and turning, it is a popular wood for furniture, agricultural implements, crates, particle board, and wood chips Acacia mangium is also suitable for manufacturing charcoal

briquettes and activated carbon. It has a calorific value of 4,800-4,900 Kcal/kg. Acacia mangium's susceptibility to heart rot limits its use for nun timber, but it is a common pulp and paper crop in Sumatra, Sabah and Vietnam. Nontimber uses include honey praduction, adhesives, and as an ornamental and shade tree for roadsides or other urban forestry uses. Acacia mangium sawdust provides good-quality substrate for shiitake mushrooms.

Since A. mangium can grow on marginal soils, many farmers choose to plant this species to improve soil fertility of fallowed fields or pastures. Since trees with diameters of 7 cm are fire resistant. Acacia mangium plantations can be used as fire breaks.

Symbiosis

Highly effective Rhizobium strains have been identified for Acacia mangium (de Faria 1995). These strains promote increased tolerance of aluminum and manganese. Acacia mangium has a relationship with some VAM fungi including Thelephora ramariods, Gigaspora margarita, Glomus etunicaturm, and Scutellispora calospora.

Pests and Diseases

The major pests associated with A. mangium cause damage to seedlings, branches and stems, or wilting caused by root damage. Damage does not result in death, but may deform or suppress tree growth (Hutacharern 1993).

Most disease agents of A. mangium are associated with or caused by fungi. Common disease symptoms are damping off, heart rot, powdery mildew, stem

galls, dieback, leaf spots, and root rot (See 1993).

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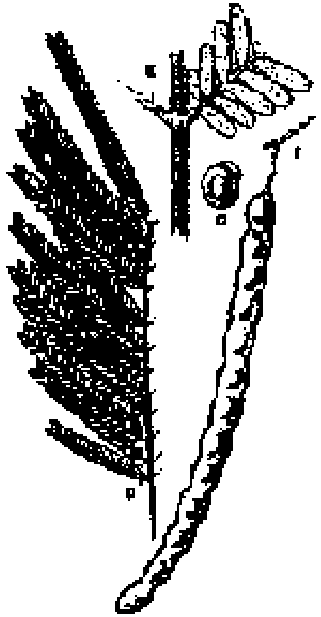
ACACIA MEARNSII - MULTIPURPOSE HIGHLAND LEGUME TREE

"Black wattle" is the common name of this respected Australian leguminous tree, Acacia mearnsii de Wild. The Australians dubbed the Acacia spp, "wattles" for their utility in providing the flexible framework ("wattle" or "hurdle") for fences or houses.

A. mearnsii now occurs worldwide and is used as source of tannin, fuelwood, charcoal, poles, props, green manure and windbreaks. In Australia it ranges widely from hot Queensland south to cool Tasmania and up to elevations of 1100 m. Introduced to Africa early this century, it became widely distributed naturally and in tannin plantations.



Acacia mearnsii

The black wattle is one of the outstanding NPTrees for the cooler tropics. It is moderately frost tolerant and vigorous at high elevations in India and East Africa. Height growth was over 10 m in 3 years at 2000 m in Kenya with mean annual temperature of 13-17C (Schonau, 1973).

Originally distributed as a source of tannin, black wattle is now recognized as a valuable fuelwood. The wood has a calorific value (dry) of 4600 kcal/kg and ash content of about 1.5%. It is dense, with specific gravity about 0.75, and yields a high-quality charcoal (NAS, 1980).

Wattle bark is the most widely used tannin material in the world. It contains 30-45% (dry basis) high-quality tannins that are used in tanning many classes of leather. Such tannins are particularly effective on hard leathers for shoes and saddles. They give better color to leather than other tannins, do not precipitate in

acid solution, and penetrate hides faster (Purseglove, 1968; NAS, 1980). An efficient nitrogen-fixer and good source of green manure, black wattle has given annual yields up to 250 kg/ha of fixed nitrogen (Wiersum, 1980). It thus can restore and regenerate soils. Wattles grow well even on slopes with shallow or poor acid soils, and can be very effective in preventing soil erosion.

Wattles grow to 20 m, and are erect with blackish bark and feathery foliage. Twigs are angled, young foliage yellowish, flowers clustered, yellow and sweet in scent. They grow rapidly, e.g., over 8 m in 2 years on a site with 22C average annual temperature (MacDicken, 1983). Annual yields of 15-25 m are reported from 6-10 year rotations (NAS, 1980).

Wattles are generally established using seedling transplants, although they are suited to direct seeding and vegetative propagation. Among seedling disease and insect pests are damping off, white grubs, grasshoppers and cutworms. Tannin plantations are established at 2,400 trees per hectare and thinned to 1,500 trees (Wattle Res. Inst., 1976).

Seeds must be scarified, e.g. with hot-water soaking (5 min. at 90C, 100 gm seed per liter). Direct seeding is made at depths of 5 cm using 2.5 kg seed per hectare (Wattle Res. Inst., 1975).

Vegetative propagation is possible using 10-15cm cuttings with leaves. Mist spray, constant heat of 28C, and auxin mixtures of IBA and NAA appear essential to good rooting (Zeijlemaker, 1976). Bud-grafting can be highly successful (Garbutt, 1971).

Although black wattle survives on acid soils, it responded positively to lime up to pH6 and showed chlorosis and high mortality in alkaline soils (Schonau, 1971). Phosphorous response was very good.

An effective volume equation for trees 10-25 m in height and 525 cm in diameter at breast height was the following:

log V = 1.9532(log D) + 1.2315(log H) - 1.74059

where V = total volume in dm3 to 5cm top diameter, D = diameter at breast height in cm, and H = total height in m (Schonau, 1972).

A. mearnsii is known in the literature also as A. mollissima auct. (non Willd). and A. decurrens var. mollis Lindl. Dr. Mearns was an American physician and naturalist working in Africa early this century, from which the name derives; it was applied to trees introduced from Australia.

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Albizia lebbeck - A Promising Fodder Tree for Semi-Arid Regions

Providing high quality fodder during dry seasons is one of the most serious problems faced by many small-scale farmers in developing countries. Albizia lebbeck is particularly promising as a fodder tree for semi-arid regions in the tropics and subtropics, and it has many other uses as well.

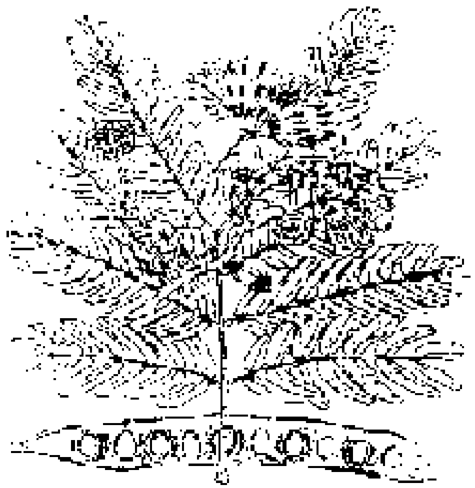
BOTANY: A. lebbeck (L.) Benth. is a moderate to large deciduous tree that reaches 30 m in height in rain forests. The tree develops a straight bole when grown in dense forests, but is spreading and low branching in the open. Unless coppiced frequently, trees will annually produce an abundance of seed from papery pods about 20 cm long and 3 cm wide (author). Common names such as "woman's tongue" and "rattle pod" derive from the noise of pods shaking in the wind. Foliage is pale green when young and gray-green at maturity, and consists of 24 pairs of pinnae 50-100 mm long with 3-11 pairs of leaflets up to 50 mm long. Flowers are cream colored, hemispheric pompons.

ECOLOGY: The species is native to India, Burma and the Andaman Islands, and naturalized in many other tropical and subtropical areas (Streets 1962). In these regions A. lebbeck, also known as "Siris" or "Indian Siris", grows in a wide range of climates, covering an annual rainfall range of 600 - 2500 mm. However, it also has been grown successfully in areas with an annual rainfall as low as 400 mm. It grows in Himalayan valleys up to 1600 m. The species is adapted to a wide range of soil types, from acid soils to alkaline and saline conditions (Prinsen 1986). Older trees withstand grass fires and night frosts of considerable intensity. Such stresses kill off above-ground growth of young trees, but new growth usually follows.

FODDER: Most livestock readily eat leaves and young twigs of this fine fodder tree.

Crude protein concentration is about 20% for green leaves, 13% for leaf litter, and 10% for twigs. Edible material has no known toxic compounds. In general, the digestibility of edible material from leguminous fodder trees is lower than that of leguminous herbs. In this regard, A. lebbeck is average. In vitro digestibility ranges from 45% for mature leaf to 70% for young leaf. In vitro digestibility of twigs is around 40% considerably higher than for twigs of most other fodder trees.

Studies in Townsville, Australia, (lat. 19 S. annual rainfall c. 900 mm) have shown that trees do not have to be browsed directly, as leaves, flowers and pods fall sequentially during the dry season (Lowry, unpublished). Pradhan and Dayal (1981) measured an annual leaf litter yield of 5000 kg/ha from Indian Siris compared to 1800 kg/ha from a Eucalyptus hybrid and 8000 kg/ha from Acacia arabica.



Albizia lebbeck

TREES IN PASTURES: There is evidence that pasture herbage production is

increased by low densities of A. lebbeck. Yields of Panicum maximum and speargrass under a canopy of A. lebbeck in a subhumid area of northern Australia were significantly higher than yields between the trees, 1710 vs. 753 kg/ha, for trees sufficiently isolated for considerable lateral light penetration (Lowry et al. 1988). Maintenance of moisture content appeared at least partly responsible for the difference. Increased grass growth was observed under a number of other tree species, but the difference was not as conspicuous and consistent as with A. lebbeck, suggesting the major factor was the right degree of shading. In a lower rainfall region, however, a much greener color of grasses under the A. lebbeck canopy suggested that increased yields were the result of increased levels of available nitrogen (Prinsen, unpublished).

YIELDS: A. lebbeck can be grown as a singlestemmed tree or as a multi-stemmed shrub. In the latter form it coppices as readily as Leucaena leucocephala. In a stand of naturalized A. lebbeck
growing in shallow soil in a subtropical 750 mm rainfall area in Australia, estimates of average annual production of dry edible matter varied in different management systems. Stands of mature trees completely pruned back to stem once every three years produced 1700 kg/ha/yr, Stands in hedgerows at a row distance of 3 m and defoliated by cattle twice a year produced 2500 kg/ha/yr. This production estimate compares favorably with a leucaena yield of 1500 kg/ha/yr in the same region, which indicates that A. lebbeck could serve as an alternative to leucaena in the lower rainfall tropics and subtropics. Although the digestibility of leucaena leaf is higher, A. lebbeck is less frost susceptible and better suited to acid soil.

In plantings corresponding to 2,500, 10,000, and 40,000 trees/ha in Puerto Rico,

above ground biomass per unit area increased with density during the first 24 months, yielding 12.6, 14.5 and 17.4 t/ha, respectively (Parrotta 1988). After 36 months, however, the figures were 21.7, 29.5 and 18,7 t/ha. The percentage of above ground biomass contained in leaves increased with stand density, from 13% to 23% in the 2,500 and 40,000 tree/ha stands, respectively, at 36 months.

WOOD: Heartwood is brown to dark, and sapwood is white and large. Timber, with a specific gravity of 0.55 - 0.60, is very suitable for construction, furniture and veneer. Pulp is short-fibered and used for paper production only when mixed with long-fibred pulp (Anonymous 1970). Wood provides good fuel and has a caloric value of 22 kilojoules per kg (Anonymous 1970). In India, annual wood yields of 5 m/ha were recorded in rotations of 10 - 15 years, but yields depend on environmental conditions.

NODULATION: A. lebbeck is not Rhizobium specific, and native strains are nearly always capable of producing an abundance of nodules.

PESTS AND DISEASES: This species has had no known serious pests or diseases, although a psyllid, probably of the genus Heteropsylla, recently was reported as seriously affecting seedlings in India (Hegde and Relwani 1988). The infestation could not be controlled with three sprayings of 0.2% Malathion, but was controlled by two sprayings of Nuvacron (0.05%) one week apart. Some records exist of termites damaging seedlings and fungal diseases attacking leaves in India. In Australia borers may kill off a few branches. However, no cases of significant yield losses have been reported.

ESTABLISHMENT: Seeds germinate well without scarification, but germination

may be improved by immersing seed in boiling water for 3 seconds and then allowing it to cool and dry. Direct sowing is possible, but rows must be well-weeded for a fey. years. Another method is to raise seedlings in nursery beds for one year or more and then transplant them as stumps with about 25 cm root and 10 cm shoot (Anonymous 1970). This would considerably reduce the field establishment period.

OTHER USES: The tree is used as a folk remedy for many ailments. Another common use is as an avenue tree, and sometimes it is used to shade coffee and tea. Saponins and tannins in the bark can be used for making soap and in tanning, respectively. Bee keepers like the species for the light-colored honey its nectar provides, and the tree hosts the lac insect. Soil-binding ability makes it useful for soil conservation plantings (Sommen 1981).

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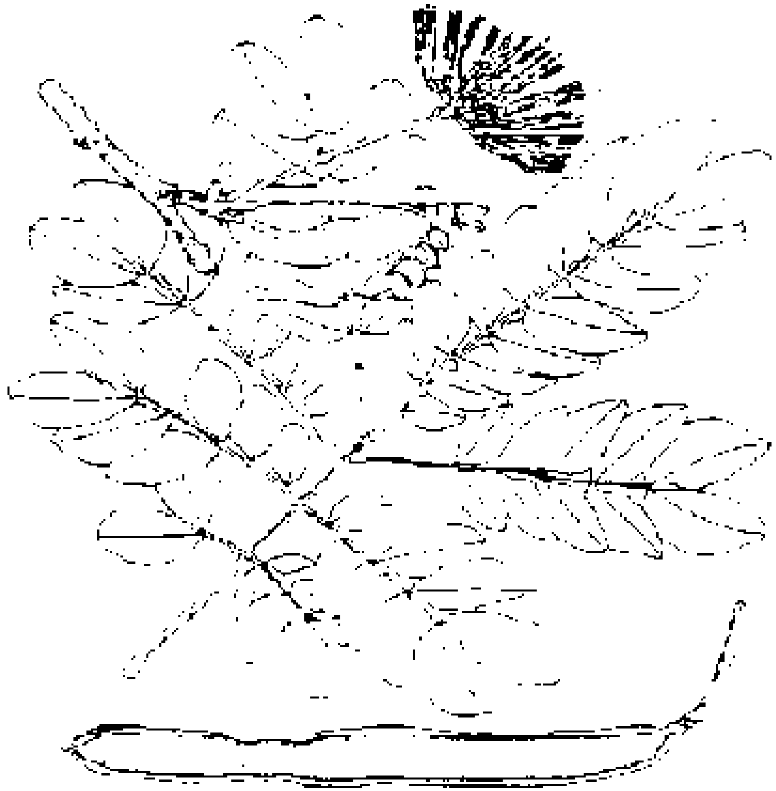
Albizia saman: pasture improvement, shade, timber and more

Albizia saman (Jacq.) F. Muell. (Leguminosae, Subfamily Mimosoideae) is a fast growing tree which obtains a large size. It is most common as a pasture, shade or ornamental tree, but has numerous uses. This New World tree is so widely cultivated and used in Southeast and South Asia it is often mistaken as native to that area. It was formerly classified as Samanea saman, Pithecellobium saman and Emerolobium saman. Common names include saman, monkey pod, raintree, cow

tamarind, algarrabo and guango.



Source: Little and Wadsworth, 1989

Albizia saman

Botany

Albizias are related to and often mistaken for Acacias - in the Philippines acacia is a common name for A. saman. Albizia saman can obtain a height of 3045 m and diameter breast height (DBH) of 150-250 cm. Open-grown specimens have short stems and stout wide-spreading nearly horizontal branches. The umbrella-shaped crown may be wider than the height of the tree. The brown gray bark is rough and furrowed into ridges and plates (Little and Wadsworth 1989). Limb bark is lighter

in color. Twigs are stout and green. The bipinnately compound leaves are 25 40 cm long dark green above and light green below. The stalkless leaflets are arranged in pairs numbering from 12 to 32 (Little and Wadsworth 1989). ! Leaflets are wider towards the apex. Both leaves and leaflets are progressively larger towards their terminal ends.

The showy flower heads, composed of many narrow pink flowers, are found near the end of twigs and appear from March to September (Hensleigh and Holaway 1988). The dark-brown to black pods are hard and thick with a raised seam. They are 8-20 cm long and about 2 cm wide. The pods do not readily open and remain on trees for long periods. Seeds are red-brown oblong and squarish. There are 5000 8000 seed/kg.

Ecology

Albizia saman is found in the tropics from sea-level to 1000 meters where the temperature is 20-35 Celsius. It is a common component of dry forests and grass savannas. Annual rainfall in these areas is 600-3000 mm/year. Albizia saman easily survives dry seasons of 2 4 months. While more common on drier sites, this species grows best in moist, well-drained fertile soils (Hensleigh and Holaway 1988). It tolerates heavy clays and infertile or waterlogged soils. Although normally found in neutral to moderately acid soils, it will grow in soil with pH as low as 4.6 (Franco et al. 1995).

Distribution

This species is native from Southern Mexico and Guatemala south to Peru, Bolivia

and Brazil. It is naturalized throughout the tropics and has been introduced to sub-tropical areas.

Uses

Shade and ornamental Albizia saman is planted along roads throughout the tropics. In parks and commons, its high arching branches provide welcome protection from the heat of the tropical sun. Having crowns of great diameter, trees furnish ample shade. Trees serve as windbreaks and are cultivated for their beautiful pink flowers.

Wood. The wood of Albizia saman is highly valued for the manufacture of furniture, cabinets, decorative veneers, bowls and other handicrafts. The chocolate heartwood and yellow sapwood form a beautiful contrast. The light-weight wood (specific gravity 0.48) is strong, durable, works easily and takes a good finish (Chudnoff 1984). It shrinks so tattle that products made from green wood dry without warping (NAS 1979). Albizia saman is a good quality fuel and charcoal, producing 5200-5600 kcal/kg (F/FRED 1994). Other uses of the wood include fencing, construction timbers, plywood and the manufacture of crates, wheels and boats.

Pasture fodder. Albizia saman is a valuable component of pasture systems. Its shade protects livestock from the hot tropical sun. Its nutritious pods contain 12-18% crude protein and are 40% digestible (F/FRED 1994). Relished by livestock, pods are an important dry-season fodder. Tree leaves are also nutritious, but are not an important fodder. The shade and nitrogen-rich leaf-liner of A. saman improve the nutritional value of understory grass (Allen and Allen 1981). During

the dry-season, grass beneath trees remains green and succulent while exposed grass becomes dry and unpalatable. Leaves fold inward at night which may increase the amount of moisture, rain and dew, reaching the understory. In the morning leaves unfold giving full shade and conserving soil moisture.

Agroforestry. This species is used as shade for tea, coffee, cacao, nutmeg and vanilla. Performance has been fair in alley-and hedgerow-cropping studies. Initial growth is slower than other woody perennials, but A. saman coppices well and yields nitrogen-rich green manure. However, shallow roots and large branch size compete heavily with companion crops, especially in dry areas. In these systems, A. saman must be heavily pruned. In most areas, other species will be more appropriate for alley-and hedgerow-cropping studies. Albizia saman is appropriate in home gardens where it provides a service role and multiple products simultaneously.

Other uses. Children eat the pods which contain a sticky sweet-flavored pulp. A fruit drink is also made from the pulp. Honey is produced from the flowers. The bark yields gums and resins. In Thailand, A. saman is an important host plant for lac production (Subansenee 1994).

Silviculture

Propagation. Seeds of A. saman have hard, impermeable seedcoats. Two methods of seed scarification are recommended. For small quantities of seed, cut through the seedcoat opposite the micropyle, or pointed-end of the seed, taking care not to damage the seed embryo. For large quantities of seed, pour boiled water over the seeds, soak and stir for two minutes. Drain off the hot water. The hot water should

equal five times the volume of seeds. With either method of scarification, the seed should be soaked in cool water overnight before sowing (NFTA 1989). Seed should be sown at a depth equal to its width in large nursery bags, 10cm x 20cm. The recommended nursery mixture is 3 parts soil: I part sand: I part compost. Seedlings should receive partial shade for 2-4 weeks and then be exposed to full sunlight. After 3-5 months seedlings will be 20-30 cm tall and ready for field planting. Direct sowing is possible, but success depends on rigorous weed control. Albizia saman can be propagated by cutting or stump cutting.

Management. Open-grown A. saman have short trunks and spreading limbs which are considered poor form for timber production. Close spacing, 1.5-2 meters, does produce straighter trees with less branching. but boles retain a spiral form. For this reason, A. saman is not commonly planted in single purpose timber plantations. In pastures, home gardens or other multiple-purpose plantings, tree spacing will depend on companion plants and management strategy.

A light-demanding species, A. saman grows fast and is tolerant of heavy weed competition. However, survival and growth can be improved through vigorous weed control until trees achieve dominance over competing vegetation. Wood production varies by site and management system. A good site can produce 10-25 m/hectare/year under a 10-15 year rotation (F/FRED 1994).

Symbiosis

Albizia saman forms nitrogen fixing symbiosis with many strains of Rhizabium. In the Geld it readily forms root nodules.

Limitations

Heterophylla cubana, Psylla acacia-baileyanae and other defoliators are common pests (Braze 1990) but do not cause serious stress problems. Wide spreading branches and shallow roofs make A. saman susceptible to damage during intense storms. The destruction of natural forests threatens the genetic diversity of this species. In response to tints threat, the Oxford Forestry Institute has included A. saman in its gene conservation program (Hughes 1989).

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Calliandra calothyrsus - an Indonesian Favorite Goes Pan-Tropic

Villagers in Java arc largely responsible for the increasing worldwide popularity of an American tree, Calliandra calothyrsus. The species was introduced there as a nurse tree for coffee plantations. Villagers recognized its potential for rapid production of excellent fuelwood on poor land and planted it widely, stimulating interest in the species around the world.

BOTANY: Calliandra calothyrsus Meissn. is a fast growing multi-purpose tree in the Acacia Sub-family (Mimosoideae) of the legumes. The plant is a multi-stemmed shrub with showy red flowers that grows 4 to 6 m in height but can reach 12 m (DBH 33 cm) in favorable conditions (NAS, 1983). With their bipinnate leaves, calliandras superficially resemble Leucaena and Mimosa species. Leaves are normally shed in prolonged dry seasons.

Calliandra calothyrsus

ECOLOGY: Calliandra's optimum rainfall range appears to be 2000 to 4000 mm/yr, but it can grow well in some areas with much less. II was one of the top performers out of 27 species evaluated in Kenya at a site receiving 1000 mm/yr (KREDP 1986), and in its native range in Latin America it grows in areas with as little as 700 mm/yr (FAO 1985). It grows up to 1500, 1800 and 2000 meters in elevation in Java, Latin America and Kenya, respectively, with better growth at

lower elevations. Temperature is probably the main factor. In Hawaii and Kenya, growth rates decreased significantly below mean annual temperatures of 20 C. Calliandra grows in a wide range of soils, including acidic sites (to pH 5.0). It does not tolerate water logging (NAS 1983).

FUELWOOD: Calliandra yields large quantities of excellent firewood and charcoal with an energy yield of 4500-4750 Kcal/kg from dry wood. The small-diameter, dense wood is ideal for domestic uses and small industries. Annual yields from established plantations in Java have been between 35 and 65 m/ha (NAS 1983). Trees have been coppiced annually for ore than 20 years.

SOIL IMPROVEMENT: Through biological nitrogen fixation, erosion control, and green manure/leaf litter, calliandra can improve soil quality and yields from associated crops. When cut on short rotations (4 months) most of the biomass is in leaves (BPT 1983), which are 4.5% N. Calliandra is commonly used as an improved fallow in Java, providing significant income from sale of fuelwood and charcoal. Interplanting it with plantation trees has increased yields of the larger trees (NAS 1983). The use of calliandra in alley cropping has gained popularity in Indonesia, the Dominican Republic, Kenya and elsewhere, particularly in highlands above the usual range of leucaena.

FODDER There initially was much optimism about the forage value of calliandra, and positive reports of its use have come from different areas. Leaves and young green shoots have a crude protein content of 22%, and wet fodder yields of up to 46.2 t/ha/yr have been reported (Kidd and Taogaga 1984). However, a high content of condensed tannins (up to 10%) causes the digestibility to be rather low, from 35-42% (Baggio and Hueveldop 1982). Careful experimentation is still

required to determine calliandra's true forage value, and selection could lead to improved fodder varieties. Certainly the dried leaflets would seem to have no role in animal feeding. Sheep and goats can probably use fresh leaves mixed with other feeds and if there is a suitable period of adaptation. In one trial, sheep grew best with a mixture containing 40-60% calliandra (NAS 1983). Rabbits will eat significant amounts when it is mixed with other forages. Copiously produced seeds, with 27% protein and 7% fat, are a potential nutrient source.

REFORESTATION: Calliandra is a good pioneer species, especially on marginal sites. It is direct seeded in areas with very steep slopes and poor soils in Java.

OTHER USES: Calliandra produces flowers and copious nectar almost all year round, and honey yields from calliandra plantations are as high as 1 t/ha/yr. Calliandra is Greek for 'beautiful stamens,' and its red flowers make it a popular ornamental. It also is a suitable host for the shellac insect.

PRODUCTION: Calliandra seeds (14,000-19,000/kg) require no pretreatment, though hot-water treatment has been reported to speed up germination. Calliandra can be direct seeded or stump cuttings can be used. Stumps should be taken from approximately 1 meter tall plants by cutting the stem back to 30 cm and the roots back to 20 cm. Limited provenance collections have been made and are being evaluated at CATIE, Turrialba, Costa Rica.

PESTS AND PROBLEMS: Calliandra seems to be free of any serious pests (NAS 1983, Bandara, et al. 1986). In Kenya trees produce few seed because a species of beetle eats the flowers and flower buds. There is a possibility that calliandra can become weedy. If stems are harvested roughly or cut too low (recommended

height is 0.5 meters), stumps can become susceptible to fungal attack.

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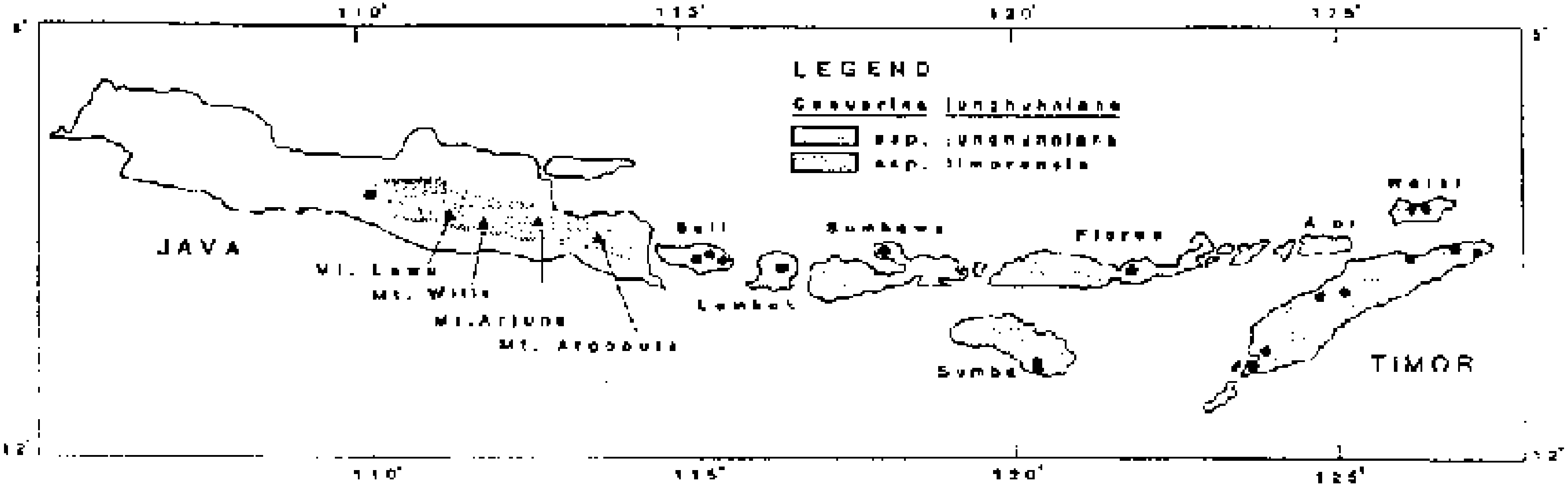
Casuarina junghuhniana: A highly adaptable tropical casuarina

Casuarina junghuhniana Miq. occurs naturally in Indonesia where its common names are jemara or cemara (Java), and adjaob and kasuari (Timor). It is an environmentally important nitrogen-flxing tree, hosting the actinorhiza Frankia. C junghuhniana is a tall forest tree 15-25 m tall and 30-50 cm diameter, that can grow up to 35 m in height and 1 m in diameter. A putative hybrid with C. equisetifolia is commercially cultivated in Thailand (Chittachumnonk 1983). C. junghuhniana is locally important in Indonesia for fuelwood, poles and soil conservation. With domestication its utility could be enhanced.

BOTANY: The crown of jemara is reasonably open and consists of numerous long deciduous branchlets bearing reduced scale leaves. It is dioecious; individual trees are carry either male or female flowers. Male flowers are borne on the tips of deciduous branchlets and &male "cones" in the axils of scale "leaves" on permanent shoots. This species grows rapidly with a strong apical dominance. It has the capacity to produce vigorous root suckers and female trees seed abundantly.

DISTRIBUTION: The taxonomy of C. junghuhniana is very confused and requires

revision. Currently the species is considered to consist of two subspecies. Subspecies junghuhniana is found on the islands of Java, Bali, Lombok, Sumbawa and Flores. A subspecies tentatively called timorensis occurs on Timor, Wetar, Sumba and perhaps Sumbawa, Indonesia. Variation within each subspecies further complicates the subgroupings. The subspecies junghuhniana consists of discrete populations having coarse, fine, and intermediate textured deciduous branchlets but the patterns of variation ate currently unresolved. The coarse forms may be related to tree growth on exposed sites. The coarse form is notable for its tugged, deeply furrowed, corky bark which is unusual for a casuatina. Subspecies timorensis on Timor is also thought to consist of two forms which the locals term "white" and "black" casuarinas. The hillside form has long, robust deciduous branchlets which in the riverine form are short and thin. Provenance trials of this casuarina have not been conducted. Environmental variation in natural habitat, however, suggests that considerable genetic variation is present.



The generalized range of the natural distribution of Casuarina junghuhniana in

Indonesia. The map was constructed using herbarium records and (he locations of the original collections are indicated by the black dots and triangles.

ECOLOGY: Casuarina junghuhniana is wholely tropical in distribution, and is a native of highlands in Indonesia where it pioneers deforested lands such as screes (rocky slopes) and grasslands, and in disturbed areas it replaces mixed mountain forest plant communities (NAS 1984). Subspecies junghuhniana typically grows [D extensive pure stands on volcanic slopes between altitudes of 1500 to 3100 m but can also occur below 100 m. Subspecies timorensis is normally found at lower altitudes, especially in Timor where it grows from near sea level to 300 m. Rainfall in its natural habitat is monsoonal with a well-defined summer maximum and a range of 700-1500 mm (NAS 1984). C. junghuhniana often forms pure stands in dry and periodically burned-over areas. It is also found along gravelly stream beds in Timor. Once trees reach a few meters in height they are fire resistant and have good sprouting ability if fire damaged. C junghuhniana grows in a wide range of soils from volcanic, sandy to compact clay soil and including very acidic sites, pH 2.8 (Chittachumnonk 1983). It also appears well-adapted to growing on alkaline soils in Timor (Turnbull 1989 pers. comm.). It can tolerate waterlogging up to 104 days (Verhoef 1943). It is considered moderate (NAS 1984) to very (Djogo 1989) drought resistant and is especially good as a pioneer on landslide-prone soils (Djogo 1989). In Timor it commonly grows on limestone-derived soils.

USES: As with other casuarinas, wood of C. junghuhniana is highly suitable for fuelwood and charcoal production. Its calorific value in charcoal form is 7180 kcal/kg, among the highest for a firewood species. Its wood is very heavy having an air-dry density of 900 kg/m (Chomcharn et al. 1986).

C. junghuhniana is especially suitable for wind breaks and for ornamental plantings. It is not used as fodder. In Timor C junghuhniana is used for soil improvement, live fencing, building material and firewood, and branches and foliage are burnt and the ashes spread in village gardens (Djogo 1989). It has been used in revegetation and land rehabilitation projects in Java for nearly a century. In Thailand its straight-stemmed character makes it a popular underground pile for construction work as well as for fish-trap stakes. It is grown on farm boundaries for pole production in Kenya and Tanzania.

SILVICULTURE: Seed from C junghuhniana is small with approximately 1-1.6 million seeds per kg. No special pre-treatment is needed to germinate seed. Like most casuarinas, seed probably loses viability quickly unless kept in dry, cold storage.

In Indonesia, Kenya and Tanzania all C junghuhniana are raised from seed. In Thailand and India planting stock is raised by vegetative propagation because only male trees were originally introduced. Airlayering has been tried but with little success. The most successful method for production on a large scale was developed in Thailand. Stem cuttings of young shoots are placed in small pots filled with soil and river sand. Several pots are enclosed in polyethylene bags with tops supported by a stake. Rooting hormone (IBA) is necessary to promote rooting. The rooting process takes 3-4 weeks under 70% shade. Mahmood and Possuswam (1980) also report successful root cuttings of shoots and root suckers of this casuarina in India.

FIELD: C junghuhniana has the potential to grow very quickly. In irrigated plantations in Thailand it can attain 21 m height and 15 cm diameter at 5 years.

Growth is normally slower without irrigation. In Markhanam, Madras, India trees reach 5 m tall at 20 months after planting (Thirawat 1953). Well-maintained plantations can produce 30-35 m3/ha/y (Boontawee and Wasuwanich 1980).

PESTS AND DISEASES: There appear to be no serious insect pests of C junghuhniana. In East Java forests of C junghuhniana have been attacked by caterpillars but the trees recovered even after repeated defoliations. Defoliation of C junghuhniana plantations by a locust (Aulaches miliaris) during rainy season has also been reported in Thailand. Young trees died but older trees suffered only a temporary setback. Also reported from Thailand was minor damage to young shoots by an insect identified as Aristobia approximator in plantations (Chittachumnonk 19853). In dry areas subterranean termites can destroy young plants by attacking their roots.

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Enterolobium cyclocarpum: The Ear Pod Tree for Pasture, Fodder and Wood

Enterolobium cyclocarpum (Jacq.) Griseb. is one of the largest trees in the forest formation of Mexico and Central America, reaching up to 3 m diameter and 40 m, in height with a huge spreading crown. It is a conspicuous and well-known tree in its native range. Large crowned trees scattered in pastures are a common sight and a distinctive feature of the landscape in many parts of Central America. Such is its fame that Enterolobium has been adopted as the national tree of Costa Rica. The province of Guanacaste in Costa Rica is named after Enterolobium which occurs abundantly in that area.

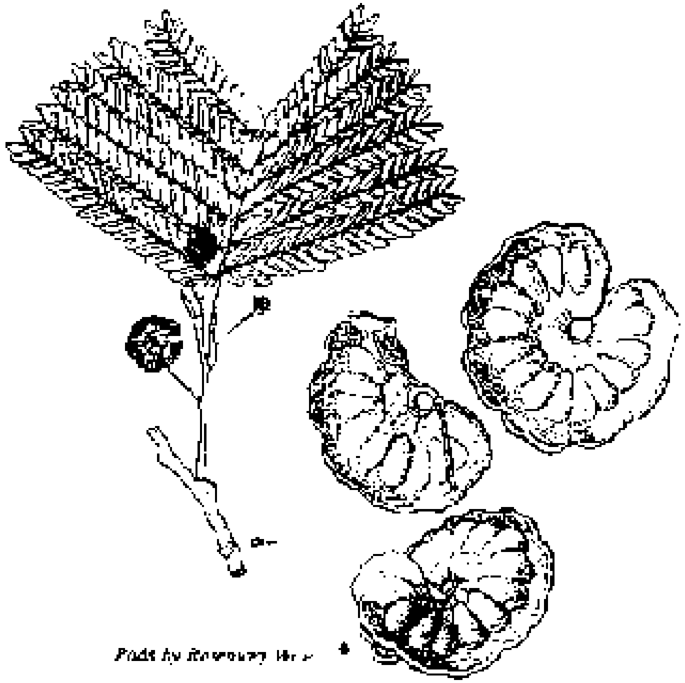
Enterolobium cyclocarpum is also well-known for its distinctive, thickened, contorted, indehiscent pods which resemble an ear in form. Most of the common names for Enterolobium refer to this resemblance, including ear fruit, ear pod, orejon (from Spanish oreja, an ear) and guanacaste (conacaste, a Nahuatl derivation signifying ear tree).

BOTANY: The nitrogen fixing tree Enterolobium cyclocarpum belongs to the subfamily Mimosoideae of the Leguminosae and is placed in the tribe Ingeae. The genus Enterolobium is closely related to Albizia and Samanea and is probably only maintained as a separate genus due to its widespread cultivation. Enterolobium contains only five species, all from Central and South America, and only E. cyclocarpum is widely cultivated. Closely related species, such as E. schomburgkii Benth., remain untested to date.

Enterolobium leaves are bipinnately compound with opposite leaflets.. Small white flowers occur in compact round heads. In Central America E. cyclocarpum is sometimes confused with Albizia niopoides (Guanaeaste blanco) due to similarity in tree form but may be readily distinguished by the different bark which is pale golden yellow in A. niopoides.

ECOLOGY: Enterolobium cyclocarpum occurs from latitude 23§N in central Mexico, south through Central America, to 7§N in northern South America. It has been widely introduced throughout the tropics where it is cultivated mainly as a roadside or garden tree. In its native range, Enterolobium occurs in a wide range of different forest types from tropical, dry deciduous forest to tropical moist forest. It becomes a climax tree only in the dry forest. being restricted to disturbed areas in wetter forest types. Enterolobium cyclocarpum is a lowland

species occurring from sea level to 1200 m elevation and has only very limited tolerance of frost.



Enterolobium cyclocarpum

Annual rainfall varies between 750-2500 mm through most of its native range with a dry season that lasts 1-7 months. Trees are generally deciduous, losing their leaves during the dry season and flushing out again about two months before the onset of the rainy season. Flowering starts while the trees are leafless (March-April in Central America), and the pods take a year to mature, ripening in April-May.

USES: The wide spreading canopy of a mature Enterolobium makes it an ideal shade tree, whether for livestock in pasture lands, for perennial crops such as

coffee, or in roadside and urban plantings. Its value to livestock is further enhanced by production of large quantities of highly palatable and nutritious pods containing a sugary dry pulp. Pods are generally shed at the end of the dry season in Central America when livestock feed is particularly short. Pods fall from the trees gradually over a period of two months thus spreading the availability of pods for livestock. Data from Puerto Rico suggests that pod production may be delayed as as 25 years after planting The foliage is also palatable, though to a lesser extent than the pods, which results in high mortality of natural regeneration in pasture lands and may explain why the tree occurs naturally only as scattered individuals.

Enterolobium heartwood is reddish-brown, coarse textured and moderately durable, with a straight interlocking grain and an appearance somewhat similar to walnut. Specific gravity is variable, ranging from 0.40.6. The wood is resistant to attack by dry-wood termites and Lyctus, and can be used in house construction as well as for nonstructural interior elements including panelling. The white sapwood, by contrast, is highly susceptible to insect attack. Enterolobium wood may also be used for boat-building because of its durability in water; it has been used in the past for water-troughs and dug-out canoes. The dust from sawmilling can produce allergic reactions in workers.

Other uses include food (the immature pods as a cooked vegetable, or the seeds toasted and ground), soap-making (using tannins from the pods and bark), and medicinal use of bark extracts against colds and bronchitis. The ability of Enterolobium to fix nitrogen, and to resprout vigorously when coppiced, suggest it could also have a role m alley-cropping systems as a hedgerow species, though this is an area requiring further research.

SILVICULTURE: Enterolobium is a light-demanding species at all stages in its development. It is susceptible to weed competition during early growth. Enterolobium resprouts vigorously after coppicing or lopping; indeed, it is difficult to kill Enterolobium by girdling because of its tendency to resprout below the girdle line. Little information is available, however, on its response to repeated cutting. With no silvicultural intervention it usually occurs as a single, large, open-grown tree, though pruning can improve the length and form of the bole.

Enterolobium can tolerate a wide range of soil types, from alkaline and calcareous to somewhat acidic (pH as low as 5), provided that aluminum saturation is not a problem. Best growth is on deep, medium-textured soils but sandy and clay soils also allow good development provided drainage is unimpeded. The trees will Dot thrive on sites prone to waterlogging.

PROPAGATION: The combination of large nutritious pods and seeds with hard coats is ideal for seed dispersal of Enterolobium by animals. Seeds are most easily collected by waiting for pods to fall. AD adult tree produces an average of 2000 pods, each with 10-16 seeds (900-L200/kg). Trees produce seed crops m most years in Central America. Seed extraction from the indehiscent pods is usually carried out by manual threshing. milling or maceration of the pods followed by winnowing and screening.

Enterolobium seed is naturally scarified by passage through the gut of large herbivores. It i. likely that the original consumers of Enterolobium pods are now extinct and their role as seed dispersal agents has been assumed by horses and cattle. Collected seed requires pretreatment before sowing to allow water to penetrate the seed coat. Manual scarification is effective, as is treatment with hot

water or concentrated sulfuric acid. A suitable hot water treatment is a brief (30 second) soak in water close to boiling point, followed by 24 hours in water at room temperature. Enterolobium seeds remain viable for several years under cool, dry conditions and can be easily stored under normal conditions.

Seed supplies are currently dependent on collections from natural populations in Latin America and scattered cultivated trees in areas where Enterolobium has been introduced. Most early introductions of E cyclocarpum were undocumented, casual and collected from a narrow genetic base. A broader range of representative germplasm should be tested to evaluate the potential of the species. Seed is available from OFI and NFTA for the establishment of field trials.

The seed should be sown 1-2 cm deep with the micropyle pointing downwards; the emerging root is not strongly geotropic and may come up out of the soil if the seed is planted upside down. Early seedling growth is rapid and vigorous. This early advantage over smaller-seeded species can continue several months after outplanting, but thereafter growth rate, though still vigorous, is no longer exceptional relative to other fast growing species.

PESTS AND DISEASES: Enterolobium has no serious or widespread disease and insect problems, although attack by a Fusarium fungus, with associated damage by wood-boring insects, can cause affected limbs to fall from mature trees. Branches may also be broken off by storm damage. Both factors reduce the desirability of Enterolobium for urban and roadside planting. Although no bruchid seed predators are found on E. cyclocarpum, the green pods are often preyed upon by parrots and fruiting may be further disrupted by the gall forming moth Asphondylia enterolobii.

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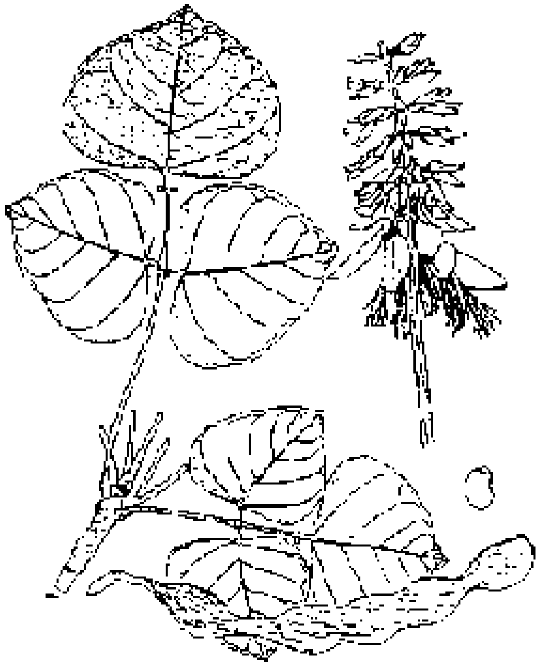
Erythrina variegata: more than a pretty tree

Erythrina is a showy, spreading tree legume with brilliant red blossoms. Commonly known as the 'Indian coral tree' in Asia or 'tropical coral' in the Pacific, this highly valued ornamental has been described as one of the gems of the floral world. It has also proven valuable for fodder production and as a sturdy component of windbreaks. It is a useful species for soil enrichment because it nodulates readily and prolifically in both acid and alkaline soils. Farmers in India appreciate E variegata as fodder, light timber and, more recently, pulp for the

paper industry.

Botany

Erythrina variegata is a medium to large tree, commonly reaching 15 to 20 m in height in 20 to 25 years. It has an erect, spreading form, typically with several vertically oriented branches emerging from the lower stem. On favorable sites, the stem can reach a diameter at breast height (dbh) of 50 to 60 cm in just 15 to 20 years.



Erythrina variegata L.

From Little and Skolmen (1989),p.143.

The smooth bark is streaked with vertical lines of green, buff, grey and white.

Small black prickles cover the stem and branches. These become longer if the tree suffers moisture stress. They typically drop off as the girth of the stem expands (Hegde, 1993). The leaves are trifoliate. The leaflets are commonly variegated, medium to light green, heart shaped, 7 to 12 cm wide and 12 to 18 cm long. The trees are deciduous, typically losing their leaves before flowering except under very humid conditions.

Brilliant orange-red flowers emerge in dense, conical inflorescences 5 to 7 cm long and 2 to 3 cm wide, usually after the leaves have dropped. Flowering is normally followed by a lavish production of seed. The pods are thick and black-1.5 to 2 cm wide and 15 to 20 cm long. Each contains 5 to 10 egg-shaped seeds. These are glossy brown, red or purple and are 6 to 10 mm in diameter and 12 to 17 mm long.

A column-shaped cultivar, 'Tropic Coral' or 'Tall Erythrina', is used extensively in windbreaks and as an ornamental in parks and gardens. Through cultivation, it has spread from New Caledonia to Australia, Hawaii and southern Florida. Unlike other cultivars, the leaves of 'Tropic Coral' remain on the tree through flowering.

Ecology

Erithrina variegata is well adapted to the humid and semiarid tropics and subtropics, occurring in zones with annual rainfall of 800 to 1500 mm distributed over a five- to six-month rainy season. The species is most commonly found in warm coastal areas up to an elevation of 1500 m. The trees prefer a deep, well-drained, sandy loam, but they tolerate a wide range of soil conditions-from sands to clays of pH 4.5 to 8.0. They can withstand waterlogging for up to two weeks and are fairly tolerant of fire. Erythrina variegata is bird-pollinated, outcrossed

and sometimes genetically incompatible.

Distribution

Erythrina variegata is native to the coast of India and Malaysia. It has been widely introduced in coastal areas of the Old World tropics, extending from East Africa and Madagascar through India, Indochina, Malaysia, northern Australia and Polynesia. The seeds can float on salt water for months, facilitating the spread of the species. Introduced to the Americas. it was so well established by 1825 that Candolle described two new species based on trees considered to be native to the New World (McClintock, 1982). It is now a very popular hedge species in southern Florida.

Uses

Support for vine crops. Farmers in India use E. variegata to support climbing plants such as betel (Piper belle), black pepper (Piper nigrum), vanilla (Vanilla planifolia) and yam (Dioscorea spp.) (Hegde, 1993). Trees established to support vines are usually at a spacing of 2 x 2 to 2 x 3 m. Vines are planted three to four months after establishment of the tree seedlings or during the following rainy season. During the hottest months, foliage from the closely spaced trees shades the vines and keeps them moist. When the days become cooler, the leaves fall and the vines receive more direct sunlight, which matches their requirements at this time.

Shade. Coffee and cacao growers establish B. variegata shade trees from large cuttings (2 to 3 m long and 2 to 5 cm in diameter) at a spacing of 8 x 10 m. The

trees are pollarded once a year to a height of 2 to 3 m to produce a spreading crown. The pruned leaves are usually spread in the plantation as mulch. The branches may be used as fuelwood.

Windbreaks. Erythrina variegata, particularly the columnar variety, is widely used as a windbreak for soil and water conservation. The trees have a strong, vertical root system that does not seem to compete too severely with adjacent crops (Rotar et al., 1986). Windbreaks are normally established from large cuttings planted in lines at a spacing of about 2 m.

Live fenceposts. Erythrina variegata makes excellent live fenceposts. Farmers commonly establish fenceposts from three-year-old upright branches about 15 cm in diameter and 2.5 m long. These are normally stacked in the shade in an upright position and left to cure for one week before planting.

Fodder. The foliage of E variegata makes an excellent feed for most livestock. Leaves normally contain 16 to 18% crude protein and have an in-vitro dry-matter digestibility of 50%. A tree of average size, pruned three or four times a year, produces from 15 to 50 kg of green fodder annually depending on growing conditions. Trees maintained in coffee plantations benefit from associated cultivation practices-they can produce up to 100 kg of fodder from one annual harvest. The leaves have no known toxicity to cattle.

Wood. The wood of E. variegata is light and soft, with a specific gravity of 0.2 to 0.3. Each shade tree in a coffee plantation can yield from 25 to 40 kg of wood from annual pollarding. The wood is used to construct floats, packing boxes, picture frames and toys, and, in India, it is increasingly used for pulp production. The

timber requires careful seasoning, preferably kiln drying. It does not split on nailing, but holds nails poorly.

Medicinal. Erythrina variegate has a reputation for medicinal properties in India, China and Southeast Asia. The bark and leaves are used in many traditional medicines, including paribhadra, an Indian preparation said to destroy pathogenic parasites and relieve joint pain. Juice from the leaves is mixed with honey and ingested to kill tapeworm, roundworm and threadworm (Hegde, 1993). Women take this juice to stimulate lactation and menstruation. It is also commonly mixed with castor oil to cure dysentery. A warm poultice of the leaves is applied externally to relieve rheumatic joints. The bark is used as a laxative, diuretic and expectorant.

Other uses. With their rapid growth and prolific nodulation, all erythrinas are a good source of organic matter for green manure. The nitrogen-rich litterfall decomposes rapidly, making nutrients available for plant uptake. The dry foliage of E. variegata normally contains from I to 3% nitrogen.

Aqueous leaf extracts of E variegata have also proven highly toxic to certain nematodes (Mohanty and Das. 1988).

Silviculture

Establishment. Erythrina variegata is successfully propagated from seed or large stem cuttings. Seed should be scarified by soaking in hot water (80 C) for 10 minutes and then in tepid water overnight. Treated seeds normally germinate within 8 to 10 days. Well-watered seedlings are normally ready for planting at 10

weeks.

Woody cuttings establish best under dry conditions. They should always be held for at least 24 hours before planting to prevent attack by soil fungi. Cuttings establish quickly, producing axillary shoots in three to four weeks and then rooting. To produce tall trees with straight stems, it is important to retain the terminal bud of branch cuttings. The column shaped form, 'Tropic Coral', may' not reproduce true to form from seed and should thus be propagated from cuttings.

Management. Erythrina variegata generally requires little maintenance. Once established, seedlings grow rapidly, usually to 3 m in one year. Cuttings typically produce more and larger side branches than seedlings; they should be pruned when young if upward growth and a clear bole are desired.

Limitations

This species is a host to the fruit-piercing moth Othreis fullonia, a destructive insect pest in the Pacific region. The larvae feed on the tree and the adults 'pierce' important commercial fruits such as oranges, guava, papaya, banana and grapes, causing serious economic losses (Muniappan, 1993). The light wood, with 60 to 65% moisture content, is not useful as a fuel. Even when dry, it produces smoke when burned.

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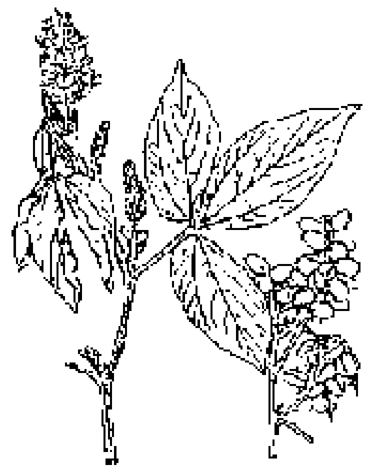
Flemingia macrophylla - A valuable species in soil conservation

The slow decomposition rate of its leaves, along with its dense growth, moderate drought tolerance, ability to withstand occasional flooding, and coppicing ability, make Flemingia macrophylla especially useful for mulching, weed control, and soil protection.

BOTANY: Flemingia macrophylla (Willd.) Merr., a member of the Papilionoideae sub-family of the Leguminosae, is known under many aliases. The most important synonym is F. congesta, and the genus also has been called Moghania. The authors usually cited in connection to F. macrophylla (Prain, Kuntze) have not validly published the name (Gillet et al. 1971). Flemingia is a woody, leguminous, deep-rooting, shrub, up to 2.5 m in height. Leaves are trifoliate. Leaflets are papery, with a glabrous upper surface. Flowers are in dense racemes with greenish standards with red blotches or stripes. Pods are small and turn brown when ripening, dehiscent generally with two shiny black seeds in the vessel. Flemingia is native to Asia, but is considered naturalized in Sub-Saharan Africa (Asare et al. 1984).



Flemingia macrophylla

ECOLOGY: F. macrophylla can be found from sea level up to 2000 m. The minimum rainfall required is about 1100 mm, while the species has been found to thrive under equatorial rainfall conditions in the Cameroons (2850 mm). Flemingia is a hardy plant that can resist long dry spells, and it is capable of surviving on very

poorly drained and occasionally water-logged soils. The species is naturally found growing along watercourses in secondary forest and on both clay and lateritic soils. Keoghan (1987) reports that in Indonesia it has outstanding adaptation to acid (pH 4.6) and infertile soils with high soluble aluminum (80% saturation) 1987). It grew well in a soil with a pH of 4.5 in Costa Rica (Bazill 1987). The plant is tolerant of light shade and is moderately able to survive fires.

WEED CONTROL: Probably the most interesting feature of the species is the relative resistance of its leaves to decomposition. Approximately 40% of a mulch layer made of flemingia leaves (4 tons DM per hectare), was still left after 7 weeks, compared to 20% for Leucaena leucocephala (Budelman, unpublished). The flemingia mulch formed a relatively solid layer that effectively prevented germination of weed seeds and/or stunted their early development for 100 days.

In experimental rubber plantations in Ghana, a flemingia mulch reduced the number of required weedings per year from six to two (Anon. 1964). Temperatures at a soil depth of 10 cm were 7-8 C lower in a mulched plot (5000 kg DM per ha) than under bare soil. Soil moisture under a flemingia mulch has been shown to be significantly higher than under mulches of Glincidia septum and Leucaena leucocephala.

An alley farming trial in Nigeria compared the ability of fallows and mulches of flemingia, Cassia siamea and Gliricidia septum to control weeds. The trees/shrubs were not cut during a 2-year establishment period. In a 120-day test of the decomposition rate of foliage from the first cutbacks from these hedges, cassia lost 46% of its dry matter, flemingia 58% and gliricidia 96% (Yamoah et al. 1986a). For later prunings over two maize cropping seasons, gliricidia prunings

decayed completely in a 120-day period, cassia lost 85%, and flemingia 73%. However, cassia showed the greatest potential for controlling weeds during both the 2-year fallow and the two maize crops, primarily because of the greater shade cast by its canopy during the establishment period.

BIOMASS PRODUCTION: At 10,000 plants per hectare, flemingia produced a yearly average of 12.4 tons of leaf DM over 4 quarterly cutting intervals.

FODDER VALUE: Flemingia appears to have some value as a dry season browse (Skerman 1977), although its digestibility value is less than 40% (Brewbaker and Glover 1987). Palatability of immature herbage is considerably better than that of old, mature, herbage (Keoghan 1987). Reported crude protein values range from 17.9% (Laquihon, pers. comm.) and 14.5 to 183% (Asare 1985). A 14-week cutting interval and 35-cm cutting height produced the highest leaf DM yield in a fodder production trial in Ghana (Asare 1985). Increasing the cutting interval from 12-14 weeks decreased crude protein contents, however (Asare 1985).

A qualitative evaluation trial in a pine plantation in Costa Rica indicated that flemingia was one of several species worthy of further study as a shade tolerant forage legume for silvopastures (Bazill 1987). Shrubby legumes were considered especially useful toward the end of the tree rotation, when densely shaded grasses and herbaceous legumes are not vigorous enough to overcome grazing and trampling.

Skerman (1977) reports that flemingia with centrosema was selected as the most promising for mixing with grasses for temporary pastures on arable land in Ghana, and that in Malaysia it is used to support creeping legumes.

ALLEY FARMING: Flemingia has lower leaf nutrient levels (espedally K, Ca and Mg) than Leucaena leucocephala and Glincidia sepium, but the amounts are still substantial (N = 235 to 2.83%; P = 0.19 - 0.25%; K = 0.98 -1.40%; Ca = 0.65%; MB = 0.20%). Maize yields in Flemingia macrophylla (F.m.) alleys compared to control plots and alleys of Gliricidia sepium (G.s.) and Cassia siamea (C.s.) in a trial at IITA, Nigeria, are compared in the following table (Yamoah et al. 1986b):

Treatment	First Crop			Second Crop		
Control						
0 kg N	1509			704		
30 kg N	1644			1076		
60 kg N	1674			1408		
90 kg N	1887			1524		
Tree Alleys	F.m.	G.s.	C.s.	F.m.	G.s.	C.s.
Prunings Removed	2353	1977	2316	1772	1891	1329
Prunings Left	2384	2543	2863	2095	2177	1992
Prunings + 30 kg N	2872	2787	2965	2235	2434	2276
Prunings + 60 kg N	3064	2776	3095	2363	2707	2299
Prunings + 90 kg N	3324	3117	3239	2821	2302	2122

* Total area including maize and hedgerow.

Maize Grain Yield (kg/ha*)

The trees were planted 0.5 x 4 m, cut back two years after planting, and pruned three times during the subsequent two cropping periods. In Southeast Asia, the

Mindanao Baptist Rural Life Center in Mindanao, Philippines, and World Neighbors report that flemingia has become popular with farmers practicing hedgerow intercropping (Laquihon and Fisher, personal communications).

OTHER USES: Although much of flemingia's biomass is not woody, fuelwood can be a secondary product. A 2-year-old stand with a spacing of 0.5 x 4 m produced 6.8 tons of dry woody stems/ha in Nigeria (Yamoah et al. 1986b). The shrub is used in India as a host plant to the Lac insect, and is sometimes intercropped with food crops during its establishment period (Purkayastha et al. 1981). Glandular hairs from dried pods yield a powder that imparts a brilliant orange color to silks (Allen and Allen 1981). Hill tribes in India use the roots in external applications against ulcers and swellings (Bernet 1978). The species has been used a covercrop for coffee in the Ivory Coast and Cameroon, sisal plantations in Tanzania, cocoa plantations in Ghana and the Ivory Coast (experimental stations). and rubber in Sri Lanka and Malaysia.

ESTABLISHMENT: There arc 45.00(1 to 97,000 seeds per kg. Tests at NFTA indicate that the standard hot water treatment ensures the best germination. Chandrasekera (1980) found that treatment in concentrated sulfuric acid for 15 minutes provided better germination than hot water. Young plants grow slowly and need care (weed control) during the first two to three months. NFTA has limited quantities of seed available for trials.

PESTS AND PROBLEMS Flemingia is an off-season host for the podfly. Melanagromyza obtusa, an important pest of pigeonpea, especially in central and northern India (IPN 1985).

NOTE TO READERS: Fiemingia macrophylia is a relatively unstudied species just beginning to be tested and used in many areas. Much remains unknown about its environmental requirements, uses and management. Anyone working with this species is urged to contribute information that could be included in a later edition of this NFT HIGHLIGHT or NFTBR.

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(Far a complete list of references cited contact NFTA.)

CROWING GLIRICIDIA

Gliricidia septum trees will fully repay your efforts to obtain uniform germination and good establishment. Like other trees, initial gliricidia establishment is slow, and "tender loving care" is advisable during this period.

1. Seed Source/Provenances. Preliminary results of provenance evaluations indicate that NFTA 220, NFTA 224, NFTA A 245, CFI 14/84 and CFI 16/84 are fast-

growing provenances adapted to a wide range of environmental conditions. The International Livestock Centre for Africa (ILCA) has available a high-yielding bulk (HYB) seed lot which is a composite of four fast-growing provenances. The Oxford Forestry Institute has a collection of 30 provenances available for evaluation free of charge. To select the best seed source for a particular area it is recommended that 8-10 provenances, along with local provenances, be evaluated.

2. Seeds. Good seeds should be well dried, insect-free, fungus-free, and weed-free. Gliricidia has from 6,000-13,000 seeds per kg, depending on variety. Seed sources are listed annually in NFTA's "NITROGEN FIXING TREE RESEARCH REPORTS", or can be obtained from this address.

3. Storing Seeds. Keep seeds dry in a tightly-closed plastic bag or jar, and they will last for years, longer if refrigerated.

4. Scarification. Gliricidia seeds require no pretreatment, unlike most other leguminous trees. Just plant them. They will germinate in 7-10 days.

5. Inoculation. Gliricidia is a legume, and bacterial inoculation is necessary for good nodulation and growth. In countries where gliricidia is native or naturalized, it is often well nodulated by local bacteria. Thus, use of local soils in the nursery can suffice. Outside of this range, it is sometimes inoculated. If not, inoculum specifically effective for gliricidia can be obtained from NifTAL, P.O. Box "O", Paia, Maui, Hawaii 96779.

6. Transplant or Seed Directly? Gliricidia establishment is initially slow, with at least 6 weeks in the small seedling stage (to 30 cm). At this stage, seedlings are

extremely susceptible to weed competition. Transplanting of nursery-grown stock will typically give higher survival rates than direct seeding because seedlings have a head-start in terms of competition. However, raising seedlings requires extra labour in the nursery and in transplanting. Good weeding is necessary if gliricidia is direct seeded. After the small seedling stage, growth is more rapid, and the trees can effectively compete with weeds.

For a small local nursery, almost an, type of seedling container can be used. However, the roots of seedlings raised more than 6-8 weeks in containers spiral and become rootbound, negatively effecting their subsequent growth in the field. For this reason, seedlings should not be kept too long in the nursery, or open-ended containers should be used, and the seedlings given regular root-pruning. A rich soil mixture is recommended for the nursery. Peat or other organic matter should be added to enrich poor soils. Fungi causing damping off are not serious on gliricidia, but use of a fungicide may be advisable for large-scale production. The use of stump cuttings has been successfully practiced. Crow seedlings to at least a 1 cm diameter stem, then cut the root at 15 cm, the shoot at 25 cm, and roll in mud, or otherwise keep wet, until they are planted.

7. Cuttings. Another very useful characteristic of Gliricidia is that it starts very readily from cuttings, although root development is poor compared to that of trees grown from seeds. Recommended size for cuttings is 2-6 cm in diameter and 30-100 cm in length. Stakes should be planted at least 20 cm below the ground, and the below-ground section of the cutting should be "wounded" with several scattered cuts to promote rooting. Cuttings should be planted as soon as possible after harvesting to enhance survival rates. They should be kept in a bucket of water or wrapped in a wet cloth until they are planted, as they can loose viability

when dried. Cuttings need to receive a good supply of water until they are well established.

8. Planting. We recommend spacings ranging from 1x1 m to 2x2 m for woodlots; single rows with 50 cm spacings for living fences; in rows 1 m apart and trees 10-20 cm apart within the rows for fodder banks (forage grasses can be intercropped in these rows); and for alley cropping, planting in rows (on contours) that are 2-3 m apart. The spacing within the rows for alley cropping depends on the slope of the land. For flat to moderate slopes, 20-50 cm between trees will give maximum tree and crop production. For steeper slopes, closer spacings are recommended for better erosion control. Initial spacings as close as 2.5 cm between trees have been used successfully on very steep slopes in the Philippines. These trees should be thinned to wider spacings as they mature. Good initial land preparation and weed control are extremely important for any plantings.

9. Environment and Soil. Gliricidia is widely adapted, thriving in semi-arid to wet tropics. It prefers warm climates (mean annual temperature of at least 20§C). It does not tolerate frost. Gliricidia grows on a wide range of soil types, even in highly disturbed areas. Different provenances perform better in different conditions, and provenance trials are advisable.

10. Pests and Diseases. Aphids and some fungi can cause damage to gliricidia, however, chemical control is not advised. Young seedlings require protection from browsing animals.

11. Harvesting Seeds. Gliricidia seeds well in some areas and not at all in others. Fruiting occurs in the dry season after the trees shed their leaves. Collect pods

from a large number of outstanding trees. Pods are harvested when they begin to turn yellow/brown, as the pods will "explode" to scatter seeds upon full drying. Seeds are extracted by drying the pods in the sun. Label carefully as to variety and source, and store as noted above.

For additional information, write:

Nancy Glover (author), Development Associate for Latin America, NFTA, P.O. Box 680, Waimanalo, HI 96795. (Provenances, nursery production and agroforestry systems).

Colin Hughes, Oxford Forestry Institute., South Parks Road, Oxford OX1 3RB, United Kingdom (Provenances).

Akwasi Atta-Krah, ILCA, P.M.B. 5320, Ibadan, Nigeria (Provenances, alley cropping).

Inga edulis: a tree for acid soils in the humid tropics

Inga is a large genus of leguminous trees native to the American humid tropics. Inga edulis, the best known of the Inga species, is popular with agroforesters for its rapid growth, tolerance of acid soils and high production of leafy biomass to control weeds and erosion.

Botany

Inga edulis Mart. is one of about 250 species of Inga of the Mimosoideae subfamily of the Leguminosae. It reaches a height of 30 m and a stem diameter

(dbh) of 60 cm, and usually branches from below 3 m. The branches form a broad, flat, moderately dense canopy. The bark is pale grey and smooth, with pale elongated lenticels. The young twigs are angular in cross-section and covered in fine short brown hair.

The leaves are once pinnate, up to 24 cm long with 4 to 6 pairs of opposite leaflets. The terminal pair of leaflets is larger than the basal pair and can be up to 18 cm long and 11 cm wide. Between each leaflet there is a nectary gland on the leaf rhachis; in 1. edulis these are large (2 to 3 mm) and squashed transversely, an important character for identifying the species. The leaflets and rhachis are covered in dense, shoe, rough brown hair. The seedlings have a characteristic grayish sheen on the upper leaf surface.

The inflorescences are dense axillary spikes of flowers, each consisting of a calyx tube with 5 lobes (4 to 9 mm long), a corolla tube with 5 lobes (13 to 25 mm long), and a large number of white stamens up to 4.5 cm long, united in a tube in the lower half. In humid climates 1. edulis may flower throughout the year, but in regions with a short dry season it is most likely to flower at the beginning of the wet season. The inflorescences may not have many flowers open at the same time, but they are usually conspicuous.

The fruits are ribbed, cylindrical pods, straight or often spirally twisted, up to I m long (occasionally even longer), and 3 to 5 cm in diameter. They contain fleshy green seeds (3 cm long) in a sweet, white, cottony pulp. They are produced during the wet season, and monkeys and birds eat the sweet pulp and scatter the soft seeds (Castro and King, 1950). These are recalcitrant and sometimes begin to germinate in the pod, often within a few days of reaching the ground where they

need humidity to survive.

Distribution and ecology

The native range of Inga edulis is in Amazonian Brazil, Bolivia, Peru, Ecuador and Colombia. The species has also been introduced across most of tropical South America, Panama and Costa Rica. It grows in hot, humid climates between 26'S and IO N. and up to 1600 m elevation. It is most widespread in areas without a dry season (Andean South America. western Brazil) or with a dry season of three to four months and minimum annual rainfall of around 1200 mm. It can tolerate short droughts, although in its natural range some rain falls every month.

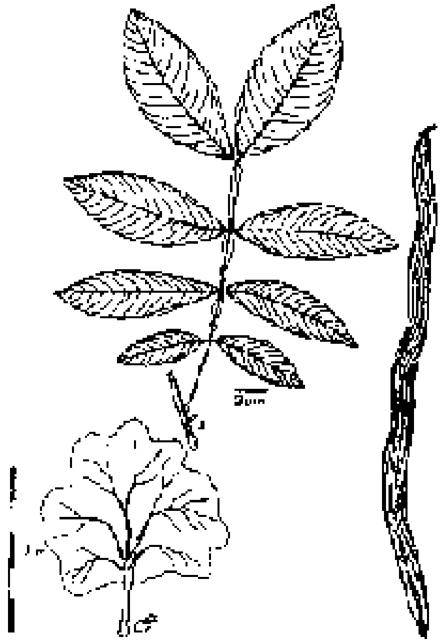
Inga edulis is particularly tolerant of acid soils (Smythe, 1993; M. Hands, Department of Geography, Cambridge University, personal communication; Salazar and Palm, 1991), outgrowing many other leguminous trees in trials under such conditions. It is a forest gap regenerator: although seedlings often establish themselves in the shade of other trees, it needs light to grow and flower. In the forest it becomes a canopy tree, but it is also common in secondary forest.

Uses

Shade and litter. Inga edulis has been used as a shade tree for perennial crops-mainly coffee and cacao-since the beginning of the nineteenth century. Many farmers value it as much for soil protection as for shade. The leaf litter protects the soil surface and roots of other plants, helps retain nutrients in the topsoil, and (most importantly for farmers in the humid tropics) controls weeds.

Improved fallow. In Amazonian Peru, Szott and Mel'ndez (1991) grew crops on

land cleared and burnt after seven different fallow treatments. Land where Inga edulis had been planted gave the highest crop yields-34% higher than crops following natural forest fallow.



Inga edulis

From C.H. Dodson, A.H. Gentry and F.M. Valverde.1985. La flora de Jauneche. Banco Central del Ecuador.

Alley cropping, In species trials in Costa Rica, Peru and Brazil, /. edulis was outstanding in terms of growth. Coppice regrowth was also good pruning. In four out of five trials, crop yields were higher under alley cropping with 1. edulis than in control plots (Smythe, 1993; Fernandes et al., 1991: Salazar et al., 1991; Salazar and Palm, 1991; M. Hands, personal communication). In two of these trials, crops performed better with 1. edulis than with other species (Salazar and

Palm, 1991 M. Hands, personal communication).

The litter is high in nitrogen, lignins and polyphenols. It is slow to decompose, but provides a long-term build up of organic nitrogen (Palm and Sanchez, 1990) and effective weed control. Weed biomass decreased considerably in all agroforestry trials with 1. edulis, much more than with other leguminous species (Salazar and Palm, 1991). On cultivated slopes, 1. edulis mulch reduced soil erosion to levels almost equal to those under secondary forest (Alegre and Fernandes, 1991) Existing trials are still too new to ascertain whether /. edulis can maintain or improve soil fertility on acid sites in the long term, but results so far are promising.

Other uses. The large fruit is popular throughout the region where /. edulis is distributed. Fruits are sold in local markets in Bolivia, Peru, Ecuador, Brazil and Costa Rica. The branches are a popular source of fuelwood, with a high calorific content and little smoke, but the trees are not cultivated specifically for fuelwood.

Silviculture

Propagation. Inga edulis seed can only be stored up to two weeks. Best results have been achieved by removing the pulp and storing the seed in impermeable bags. Normally, only one seed should be sown in a plastic bag, no more than 2 em below the soil surface. Semi-shade should be provided if possible. The seeds germinate readily (95 to 100% germination rate) within 2 to 3 days. Seedlings are normally kept for two months in the nursery. They should be watered regularly and the shade should be removed one month before transplanting.

Establishment. Farmers sometimes sow 1. edulis seed directly in the field. This must be done during a season of regular rainfall to avoid seed desiccation. Direct seeding has not yet proven to be a reliable method for establishing a trial. Bare-rooted seedlings can be transplanted successfully from the nursery (Fernandes et al., 1991). Inga edulis has not been reproduced by cuttings.

Management and symbiosis. An area of 1 m diameter should be kept clear around the trees during the first six months as they become established. Inga edulis grows back well after pruning, but not if cut too low (below 0.75 m). It responds better if pruning height is varied and a few branches are left uncut (Salazar et al., 1991). The cut should be made carefully, at least 3 cm above a node from which the shoots can grow again (M. Hands, personal communication).

Fernandes and others (1991) observed Rhizabium nodules on the roots of 1. edulis, both in the field and in the nursery. They also showed that vesicular-arbuscular (VA) mycorrhizal infection occurs in acid tropical soils and that nodulation rates increase when mycorrhizae have infected the root. In their trial, plant biomass correlated positively with length of root infection by VA mycorrhizae.

Limitations. Inga edulis pods are heavy and bulky to transport. This, combined with short seed viability, means that I edulis seed must normally be collected near the planting site. Decomposing slowly, the leaves do not provide fast-cycling green manure. In Ecuador, Inga edulis is particularly susceptible to infestation with mistletoe.

Related species

In Central America, I. edulis is replaced by the closely related I. oerstediana Benth., a popular species for coffee shade from sea level to elevations of 2000 m. The flowers are smaller than those of 1. edulis and the fruits are much shorter. In ongoing trials in Honduras and Costa Rica, I. oersrediana has shown fast growth and abundant production of leafy biomass. Another promising species from the same section of the genus is the Amazonian I. ingoides (Rich.) Willd., which has grown well for four years on a periodically flooded site in lowland Bolivia.

Research needs

Inga edulis has been introduced throughout the neotropics, but seed is usually collected from a few trees already established in plantations and transported over very short distances. Population studies in the species's native range could help identify diversity in growth rate, fruit size, soil tolerance and litter-decomposition rates. Methods to prolong seed viability would also improve the usefulness of this species.

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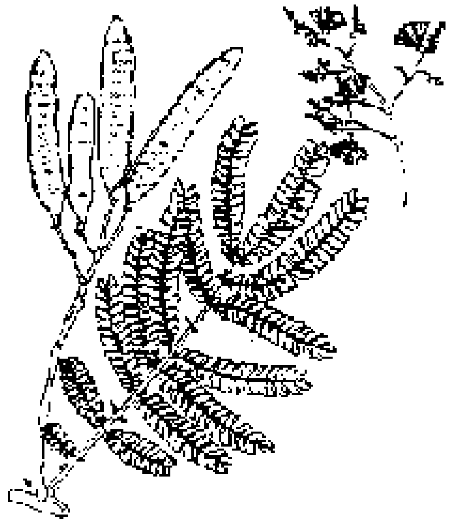
PARASERIANTHES FALCATARIA - SOUTHEAST ASIA'S GROWTH CHAMPION

By whatever common or scientific names it is known, Paraserianthes falcataria (L.) Nielsen is a valuable multipurpose tree for the humid tropics. One of the fastest growing of all tree species, it is used for pulp and other wood products,

fuelwood, ornamental plantings and shade for coffee, tea and cattle. Potential uses for which it is being tested include alley farming and intercropping in forest plantations.

BOTANY: "Falcataria" belongs to the Leguminosae (subfamily Mimosoideae). It is most widely known by its former name, Albizia falcataria, but it also has been called A. moluccana and A. falcata. "Falcate" means "curved like a sickle," referring to its leaflets. Leaves are alternate, bipinnately compound, and 23-30 cm long. Flowers are creamy white, and pods are narrow, flat 10-13 cm long and 2 cm wide. This is a large tree that regularly reaches 24 to 30 m in height and 80 cm in diameter. When grown in the open, trees form a large, umbrella-shaped canopy. Crowns are narrow when this light-demanding species is grown in plantations of 1000 to 2000 trees/ha. Trees regularly produce large quantities of seeds after reaching 3 to 4 years of age.



Paraserianthes falcataria

ECOLOGY: Falcataria occurs naturally in Indonesia Papua New Guinea, and the Solomon Islands from 10§ S to 30§ N. In its natural habitat it grows from sea level to 1200 m above sea level with an annual rainfall from 2000-4000 mm, a dry season of less than 2 months, and a temperature range of 22§ to 34§ C. Although it is likely to perform better on alkaline soils (NAS 1983) there are many examples of it growing well on acid soils.

Correlation and multiple regression analysis show that topsoil depth is the most important indicator of site quality for falcataria (Dalmacio 1987). The most productive sites had at least 19-26 cm of well-drained topsoil with at least 3-8% organic matter and an exchangeable potassium of 0.36 meq/100 g of soil.

ESTABLISHMENT: Seeds (42,000/kg) germinate easily and only require an overnight soaking in water. For more uniform germination, seeds can be treated with hot water, or dipped in concentrated sulfuric acid for 10 minutes followed by water for 15 minutes (NAS 1983). Seedlings are ready for planting in about three months and grow so fast in the field that one complete and three spot weedings during the first year are sufficient.

SILVICULTURE: A common spacing for a pulpwood rotation of 6 to 8 years is 3 x 3 m (APFN 1987). If sawtimber is desired, stands can be thinned to 6 x 6 m at 6 to 8 years and harvested at 15 years. In fertile sites a 4 x 4 m spacing for pulp is common (Tagudar 1974). In an investigation of closer spacings, Domingo (1967) found that growth at a 2 x 2 m spacing was significantly faster than 1 x 1 m.

Under ideal conditions, falcataria can reach 7 m in height in 1 year, 15 m in height in 3 years and 30 m in 10 years. Growth averages 39 m3/ha/yr on 10-year

rotations and can reach up to 50 m3/ha/yr on better soils (NAS 1983).

Liming the soil from pH 65 to 7.0 did not improve growth or nodulation (Ordinario 1986). Providing both nitrogen and phosphorus produced a marked increase in early growth in a red-yellow podzolic soil deficient in each nutrient (Moloney et al. 1986).

SYMBIOSIS: Nodulation by Rhizobium occurs in most soils with sufficient moisture and a pH ranging from 5.5 to 7.0. Inoculation enhanced growth and modulation in potted grassland soils. Nodulation of inoculated seedlings decreased with the application of 100 kg N/ha and was totally suppressed with the application of 200-300 kg N/ha (Garcia et al. 1988). Falcataria also is associated with endomycorrhizal fungae, which when inoculated enhance its growth and nodulation (de la Cruz et al. 1988)

GENETICS: At the Paper Industries Corporation of the Philippines (PICOP) plantations in Mindanao, introduced provenances performed better than local provenances Nuevo (1976) reported that branching habits are an inherited trait. In terms of wood properties, tree to tree variation tends to be larger than variation due to stand locations and gross morphological classes.

USES: Falcataria is perhaps best known as a pulp crop (NAS 1979, Hu 1987). Other wood uses include fiber and particle board, packing cases, boxes, matches, chop sticks and light furniture. Wood is difficult to saw and not strong or durable.

Its thin crown provides partial shade to coffee, tea, and cacao. It also is used as a windbreak for bananas. Trials in Hawaii have indicated its usefulness as an

intercrop with eucalyptus, especially in wetter areas. After four years, eucalyptus grown with falcataria in a 50:50 mixture at a spacing of 2 x 2 m were 58% taller and 55% larger in DBH than in pure eucalyptus stands (Schubert 1985). In other trials with 34 and 50% falcataria, total biomass was equal to or better than that of pure stands (Schubert et al. 1988).

Falcataria also shows potential in alley farming. In a trial on acid soils (pH 4.2) in Indonesia, trees were managed in hedges 4 m apart and produced 2- 3 dry tons of green leaf manure/ha/yr. Application of falcataria green leaf manure doubled upland rice yields and more than quadrupled cowpea yields as compared to control plots (Evensen et al. 1987). In 1988, however, concerns surfaced about the longevity of falcataria in alley cropping systems (Evensen, pers. comm.).

Falcataria also is grown as an ornamental, although it seldom lives more than 50 years (APCF 1987) and its brittle branches can be a problem in windy areas. Raharjo and Cheeke (1985) reported that foliage scored well in some palatability tests with rabbits and poorly in others.

Its wood is soft and generally light in color with a reported specific gravity range of 0.20 to 0.49 (NAS 1979; Little, undated). Ecotypes with denser wood have been found at PICOP plantations. Despite its low specific gravity and caloric value, its fast growth and vigorous coppicing ability make it worth considering as firewood (NAS 1983). It is used as firewood in Western Samoa, the Philippines and Java, where it is frequently planted in home gardens for fuelwood and timber with herbaceous and fruit crops. It makes a good charcoal.

DISEASES AND PESTS: Seedlings are susceptible lo root rot caused by

Betrydiplodie and Sclerotium (Domingo 1977). Leaf spots are caused by Phyllachora pterocarpil and Pestalotia species. Stem and branch canker is caused by Corticum salmonicolor (Quinones 1980, de Guzman 1974). Pests such as larvae of yellow butterflies (Eurema sp.) have been reported to attack plantations in the Philippines. Malaysia and Burma (Domingo 1977). The stem borer, Kystrocerafestiva sp., is an important pest in Burma Indonesia and Vietnam (Domingo 1967). Shoot pruner beetles (Callimetopus sp.) occasionally have caused significant damage to trees in the Philippines (Braze 1988).

PROBLEMS AND LIMITATIONS: Since falcataria is easily damaged by high winds, most successful plantations in the Philippines are found in areas not frequently hit by typhoons. The tree regenerates so easily by natural seeding on any clearing that it can spread rapidly and become a pest. However, falcataria is very susceptible to herbicides. Soil erosion in falcataria plantations can be a problem, and it is not a recommended species for steep hillsides (NAS 1983).

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(For a complete list of references cited contact NFTA.)

Pithecellobium dulce-Sweet and Thorny

Pithecellobium dulce

Many N-fixing trees are alternately praised and cursed. Hardy, tenacious, seedy, and able to provide their own nitrogen, they often colonize soils and sites that are difficult or impossible for other trees. Pithecellobium dulce is such a tree.

Pithecellobium dulce is a thorny tree which can become weedy. In Hawaii it has a reputation as a pest in grass pastures, but normally only when fields have been left nitrogen-starved. It is a tree with many uses; food (sweet pods), firewood, honey, fodder, soap oil, tannin, hedges and shade--and it can survive hostile

climates. The generic name refers to the curly pod, that mimics an ape's earring (pithekos ellobium), and the species name "dulce" refers to the sweet pod.

DISTRIBUTION: This hardy American tree is native along coasts from California through Mexico to South America, but is now found throughout the tropics. Pithecellobium dulce followed the Spanish galleon route (with leucaenas, gliricidias and other nitrogen fixing trees) through the Pacific and Asia to Africa.

It is now common and naturalized in India and tropical Africa, especially along coasts. It is notably weedy in the Caribbean islands (including Cuba, Jamaica, Puerto Rico, and St. Croix), and in Florida and Hawaii, USA, but less so where population and animal pressure keep it contained.

BOTANY: Pithecellobium dulce (Roxb.) Benth. (family Leguminosae, subfamily Mimosoideae) is one of 100-200 species in this genus. Pithecellobium dulce is the only species that teas become widespread outside its origin.

The height of P. dulce is commonly 10-15 meters, but ranges from 5 to 18 m. They are broad-spreading with irregular branches. The bark is grey, becoming rough, furrowed, and then peeling. Leaves are bipinnate, and leaflets oblong to 4 cm in length. Thin spines are in pairs at the base of leaves, and range from 2 to 15 mm in length. Leaves are deciduous. However, new leaf growth coincides with the loss of old leaves, giving the tree an evergreen appearance.

The flowers are in small white heads 1 cm in diameter. Each flower has a hairy corolla and calyx surrounding about 50 thin stamens united in a tube at the base. Flowering begins in 3-4 years and is seasonal (April in Hawaii). The pods are

pinkish, 1-15 cm wide, about 12 cm long, and become spiral as they mature. Seeds are about 10 per pod (9,000 to 26,000/kg), black and shiny, hanging on a reddish thread from the pod. The pod splits along both margins.

ECOLOGY: Pithecellobium duke thrives in dry warm climates where annual rainfall is 400 to 1650 mm. It is typical of lowlands, but can be found at elevations above 1,500 m in Mexico and East Africa. This species is found on most soil types, including clay, limestone, and sands. Pithecellobium species are noted for their tolerance of heat, salinity, and impoverished soils. They are also tolerant of drought conditions.

FOOD AND FODDER: Names like "dulce" (sweet) and "Manila tamarind" reflect the wide use of the pods as food. Pods contain a pulp that is variously sweet and acid. commonly white but also red. The seed and pulp are made into a sweet drink and eaten roasted or fresh. In India, the seeds are used fresh or in curries. The pods are relished by monkeys and livestock. The flowers are attractive to bees as source of pollen. The resulting honey is of high quality. Although the pods are attractive fodder to most animals. the leaves are browsed but not considered an important animal fodder.

WOOD: The wood of P. dulce is strong and durable vet soft and flexible. It can be used in construction and for posts. The reddish-brown heartwood is dense and difficult to cut. It is commonly used as fuel. although due to smokiness and low calorific values (5,500 kcal/kg) it is not of high quality. The short spines and irregular, crooked growth make it less attractive for wood uses.

OTHER USES: The tree is used extensively as a shade or shelterbelt tree with a

great tolerance of arid and harsh sites. It coppices readily and can be managed as a hedge. Coppicing often increases the occurrence of thorns. This characteristic makes hedges of P. duke excellent for livestock fences. but problematic for other uses.

Pithecellobium dolce is also very popular as an ornamental and is used in topiary (plant sculpturing). Trees with variegated leaflets are available as ornamentals in Hawaii. When wounded, the bark exudes a reddish-brown gum similar to gum arabic that dissolves in water to make a mucilage. The bark can also be used for tanning and produces a yellow dye. Seeds contain an oil that can be used in soap-making or as food, and the residue can be used as animal feed. Medicinal uses arc known but not common.

SILVICULTURE AND GROWTH: Seed viability is long under dry cool storage. No pretreatment is necessary for seeds to germinate, although nicking may improve and hasten the process. Germination occurs quickly, normally in 1-2 days. Application of Rhizobium inoculum to seeds is suggested prior to sowing. Successful propagation by cuttings has also been reported.

Pithecellobium dulce normally competes successfully with other vegetation. It often establishes in grass ecosystems without the benefit of weed and grass control. Few data are available on its relative growth rate, but it appears to be intermediate in growth to the slower Prosopis spp. and the faster Leucaena spp. Height growth can reach 10 meters in 5-6 years under good environmental conditions.

SYMBIOSIS: Pithecellobium dulce forms root nodules with Rhizobium bacteria.

Nodulation is common in all types of soil. but quantitative data on fixations has not been reported.

PESTS AND PROBLEMS: The sharp thin spines can be fierce on young shoots and often limit plant utilization. Spines are reportedly absent in some trees: a pure spineless variety would be welcomed. In pastures and cropland. P. dulce can be a tenacious weed Coppice regrowth is rapid. and the tree is not easily killed once established.

The tree is evidently nor deeply rooted and is subject to blow-down. Superficial rooting is not common in drier soils. thus blow-down is less of a problem under such conditions. The sap is said to cause irritating skin welts and severe eye irritation (the latter is common to sap or juice from many legume trees and their fruits). The heavy smoke created by burning limits its usefulness as fuelwood. Pests include the thornbug and several boring and defoliating insects.

OTHER SPECIES OF PITHECELLOBIUM: The genus includes several other important species--P. arboreum, P. unguiscati, P. flexicaule, P. jiringa, and P. parviflorum. Common names include "Manila Tamarind", "Madras thorn", "bread-and-cheese". "blackbeard" (English), "guamuchil", "quamachil" (Spanish), "kamachile" (Phillipines), "macamtet" (Thailand), and "opiuma" (Hawaii).

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Pterocarpus indicus - The Majestic N-Fixing Tree

Pterocarpus indicus is one of the best known trees in southeast Asia. It is known as narra in the Philippines, sonokembang in Indonesia, angsana or sena in Malaysia and Singapore, and pradoo in Thailand. In the Philippines, it is the national tree and the favorite timber for the manufacture of fine furniture (Duaresma et al. 1977). In Singapore, it is practically the symbol of that country's garden city planting program; many avenues are graced by this attractive species. In Malaysia, it has been planted as a shade tree for at least 200 years.

Botany. Pterocarpus indicus Willd. (Leguminosae, subfamily Papilionoideae) is a big tree, growing to 33 m in height and 2 m diameter. The trunks are usually fluted and buttressed to 7 m diameter at the base. The crowns are large and bear many long branches that are at first ascending, but eventually arch over and sometimes droop at the ends. Trees with long willowy, drooping branches are particularly conspicuous and attractive in Singapore and some parts of Malaysia and Hawaii. Elsewhere the drooping habit may not develop.

The leaves are compound-pinnate, bearing 0-12 alternate leaflets. The leaflets are rather large, 7 x 3.5 to 11 x 5.5 cm and ovate to elliptic in shape, with a pronounced acuminate tip. The flowers are yellow, fragrant, and borne in large axillary panicles. When flowering, the buds do not open in daily sequence. Instead, as buds come to full size, they are kept waiting, to be triggered into opening. The opened flowers last for one day. After that, several days may pass before another batch of accumulated 'ready' buds open. The nature of the trigger is unknown. Whole avenues of such trees blooming in unpredictable synchrony making a splendid display. Local drivers have learned to slow down on the flower-carpeted roads to avoid skidding. The fruits, which take four months to mature, are disc-shaped, flat, and have winged margins. About 5 cm across, the fruit have a central woody-corky bulge containing several seeds (ptero-carpus means winged fruit). Unlike most legumes, the Pterocarpus fruit is indehiscent and dispersed by wind. It also floats in water and can be water-dispersed.

There are 1-3 seeds in each fruit. The seeds are difficult to extract, but will germinate readily through built-in weaknesses in the fruit wall; hence each fruit is able to function like a seed, but produces 1-3 seedlings. There is no advantage to extracting the seeds because the germination time and percentage are practically the same between whole fruits and extracted seeds.

Pterocarpus indicus

In a non-seasonal humid tropical climate such as in Kuala Lumpur and Singapore, the trees are generally evergreen, but in regions with seasonal rainfall, the trees are deciduous.

Distribution. The genus Pterocarpus consists of 20 species distributed throughout the tropics (Rojo 1977). P. indicus has a wide range from southern Burma to the Philippines and throughout the Malay Archipelago to New Guinea and the Solomon Islands. There is considerable morphological and ecological variation when viewed throughout its range, but because of extensive clonal propagation, the trees planted in any given locality tend to be uniform. In Malaysia, its natural habitat is by the sea and along tidal creeks and rivers Elsewhere (e.g., Papua New Guinea), it occurs in inland forests. In the Moluccas (Manupatty 19721973), four varieties are locally recognized, which occupy a range of habitats from the coast to submontane forests and seasonal swamps.

Propagation. P. indicus may be propagated by seed, which germinate in 8-100 days, but the initial growth of seedlings and saplings is relatively slow. Propagation by cuttings is preferred, especially for ornamental planting (Wong 1982). P. indicus is unique among big timber trees in that the capacity for rooting of stem cuttings is not lost with age. Stem cuttings can be taken from trees 'of any age and size. Indeed, cuttings of diameter 6 cm or larger will root better than cuttings of smaller diameter. Young leaf-bearing stems will not root at all. For roadside planting, the cuttings used are in the form of stakes 1.5-3 m long and as much as 10 cm diameter. Such stakes produce up to 10 radiating shoots at the top, making a symmetrical crown very quickly, above pedestrian height. Few species can match P. indicus in the ability to produce well-crowned instant trees within one or two years. If large stakes fail to root, it is usually because of water-logging or accidental movement of the stakes during the tender rooting period. These problems can be avoided by rooting the stakes in loamy soil in large well-drained containers, while tied securely to a simple supporting framework. The stakes root in about 3 months and can be reduced to as short as 10 cm length, but such cuttings would take longer to develop into trees.

Timber. The timbers of all species of Pterocarpus are highly valued. P. indicus timber is moderately hard (.52 specific gravity), moderately heavy, easy to work, pleasantly rose-scented, takes a fine polish, develops a range of rich colors from yellow to red, and has conspicuous growth rings, which impart a fine figure to the wood. Remarkably, such growth rings are developed even in the non-seasonal humid tropics. In Java and the Moluccas, giant burrs on the stem give rise to finely figured gnarl wood (also called wavy or curly wood). In the Moluccas, P. indicus is also the source of linggua kasturi, a highly valued red wood with the scent of sandalwood (Burkill 1935); this is perhaps a pathological condition. Traditionally,

Pterocarpus has been so much in demand for cabinet class furniture that nearly everywhere its existence in the wild is precarious.

Silviculture. P. indicus behaves like a pioneer and grows best in the open. Seedlings are slower growing than cuttings and exhibit considerable variation in vigor. A strict culling program would be necessary to ensure that only the best stocks are planted out. Rooted cuttings can be established readily on nearly all kinds of soils, from coastal sands to inland clays, in urban and garden situations, and even in quite small planting holes dug into pavements. However, establishment trials in forest areas have had mixed results and some have failed. The reasons are not clear.

With a little practice, it is easy to distinguish a healthy tree by its luxuriant foliage from one that is thinly leafed and stressed. Under favorable conditions, trees in Singapore have been known to grow an average of 13.3 m in height and 1.55 m in girth in 11 years, or an average annual increment of 1.2 m height and 14 cm girth. Urban trees in Singapore are fertilized with compound fertilizer at the rate of 0.5,1, and 1.5 kg per tree per annum in the first, second, and third years of growth. Subsequently, they get 3-5 kg per tree per annum depending on their size. The fertilizer is spread evenly on the soil under the tree crown and is applied once a year. Where the area of the soil is smaller than the crown (e.g., for trees planted in pavements and road dividers), the fertilizer is divided into two or more smaller applications (Wong 1982). As an urban tree, P. indicus is relatively wind-firm and seldom suffers branch breakage.

Trees of all sizes and ages easily regenerate new shoots when lopped or pollarded. In Papua New Guinea, logged forest trees readily regenerate new plants

from the roots (Saulei 1988).

Nodulation. The seedlings nodulate readily.

Pests and diseases. P. indicus trees in Singapore and Malaysia suffered extensively from an unknown disease between 1875 and 1925. The leaves of affected trees withered, the branches died back, and after 2-3 mouths the whole tree would die (Corner 1940). Sometimes, whole avenues were wiped out. Strangely, the disease then disappeared and has not recurred. There are at present no serious pests and diseases.

Other species of Pterocarpus. Other well-known species are P. dalbergioides of the Andamans Islands in the Bay of Bengal, P. marsupium of India and Sri Lanka, P. macrocarpus of Burma, Thailand, and Indo-China, P. officinalis of tropical America, and P. soyauxii of Africa. The silviculture of some of these has been described by NAS (1979).

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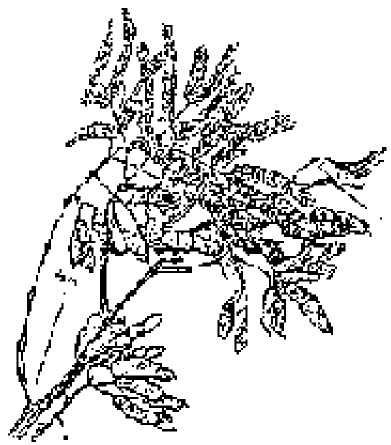
MIMOSA SCABRELLA - THE TREE THAT FUELED THE RAILROADS OFF BRAZIL

In the early 1900s Brazil's steam locomotives ran on wood from plantations of Mimosa scabrella, commonly known as "Bracatinga." Today, this fast-qrowing species is being planted in highland areas around the world for fuelwood, lumber, charcoal, honey, fence posts, pulp, as shade for coffee trees, and as an ornamental.



Mimosa scabrella

BOTANY: Mimosa scabrella Benth. (synonym M. bracaatinga Hoehne) is a member of the Mimosoideae subfamily of legumes. Mature trees reach 15-20 m in height and up to 50 cm in diameter with a straight bole and sparse, broad crown (Duke, 1981). Shrubby varieties are also found which are 4-7 m in height with a dense crown. The tree has small bipinnately compound leaves with tiny leaflets, small white flower heads and small, narrow flat pods separated into joints that split open upon drying (Little, 1982). Throughout the year it sheds large quantities of nitrogen-rich leaves that decompose rapidly and form a very good humus (NAS, 1979).

ECOLOGY: Native to the cool, subtropical plateaus of southeastern Brazil, bracatinga thrives in low temperatures ranging from 12-18 C and tolerates infrequent frosts. It rarely occurs in areas with mean annual temperatures above 23 C. Bracatinga prefers an annual rainfall above 1000 mm with no more than four months of less than 100 mm per month. It can tolerate strongly acidic soils, pH 4.8 to 5.1, deficient in P and K with a high aluminum content (Haeffner and Salante, 1981). It will not tolerate wet soils and growth is greatly affected in compacted, degraded pastures (Campos, 1984).

ESTABLISHMENT: Seeds (65,000/kg) remain viable for at least 3-3 years when stored in cold chambers. To obtain rapid and uniform germination, seeds are scarified by pouring boiling water over them and stirring gently for 3 minutes. Seeds can then be soaked in tap water for 24-48 hours to accelerate germination. Direct seeding is possible with frequent weeding (NAS, 1980).

Successful establishment is also possible with bare-root seedlings. Nursery grown plants are ready for field transplanting in 2-4 months, or when seedlings are 15-20

cm in height and 8-12 mm in diameter.

There is a considerable amount of genetic variability in the species (Fonseca, 1982). Variation in growth and thickness of bark were detected between six seed sources collected in its native range. It has been suggested that M. scabrella is cross-pollinating.

FUELWOOD AND CHARCOAL: Fuelwood plantations in Brazil are commonly planted at spacings of 2 x 2 or 3 x 3 m and harvested on 3-7 yr. rotations (Haeffner and Salute, 1981). Mean annual increments ranged between 8 and 36 m /ha for 6 year old plantations in southern Brazil (Ahrens, 1981). In the deep, fertile, volcanic soils of Costa Rica mean annual increments of 45.7 m /ha are reported (Campos and Bauer, 1985). Bracatinga also makes good charcoal, but it produces a large amount of ash (Lisbao, 1981).

OTHER WOOD PRODUCTS: The heartwood is hard with specific gravity reports ranging from 450 to 670 kg/m3 and is tinted a grayish-rose color (Lisbao, 1981). Sapwood is pinkish. The wood is used for lumber and is straight-grained and medium textured with a moderately rough surface without luster. Tests of young plantation-grown wood show it can be pulped with sufficient quality for printing and writing paper. Fiber length is 1.2 mm. Stakes also are used for fence posts and in tomato production.

SHADE TREE: Highland coffee plantations in Guatemala and Costa Rica use bracatinga as a shade tree for coffee. Planted in Costa Rica at a spacing of 4 x 5 m in deep, fertile, well-drained, fertilized coffee plantations, it reaches 5-6 m in height and 811 cm in diameter at breast height in 16 months (Picado, 1985).

INTERCROPPING: In its native region, bracatinga is often found growing in association with corn and beans (Barembuen, 1985). In the highlands of Kenya, has been planted along contour lines 8 to 30 m apart with corn for fuelwood production. It is not a good hedgerow species because it does not coppice.

OTHER USES: Commonly referred to as "the tree with many white feathers," it makes a beautiful ornamental, avenue tree or living fence. Abundant flowering make it excellent for honey production. As a pioneer species it established pure, dense stands throughout vast areas in Brazil's Parana area after the native forests (Araucaria angustifolia) were cut and burned (Hoehne, 1930), indicating its reforestation potential (EMBRAPA, 1981).

RESEARCH: A comprehensive research program with M. scabrella was initiated in 1980 by the Instituto de Pesquisas e Estudos Florestais (IDEF) and the Departmento de Silvicultura at the Universidade de Sao Paulo, Sao Paulo, Brazil.

NFTA has small packets of bracaatinga seed available for trial.

Robinia pseudoacacia: Temperate Legume Tree with Worldwide Potential

Very few nitrogen fixing trees are temperate, and very few of these are legumes. The genus Robinia, with four species native to temperate regions of North America, is noteworthy for an ability to tolerate severe frosts.

Robinia pseudoacacia L., or black locust (family Leguminosae, subfamily Papilionoideae), is among the few leguminous NFTs adapted to frost-prone areas. It is also adaptable to environmental extremes such as drought, air pollutants, and high light intensities (Hanover 1989). Rapid growth, dense wood, and N2 fixing

ability make it ideal for colonizing degraded sites.

BOTANY. Black locust is a medium-sized tree reaching 15-35 m in height and 0.3-1.0 m in diameter. Long (2045 cm) pinnate leaves consist of 5-33 small, oval, alternate leaflets. Sharp spines are found at the nodes of young branches but are rare on mature wood. The smooth bark becomes reddish-brown and deeply furrowed with age. White to pink, fragrant flowers in 10-25 cm long, banging racemes appear in early summer soon after the leaves. The closed flowers require bees to force petals open for cross-pollination. The small pods contain 4-8 hard-coated seeds which can persist in the soil for many years. Seed crops occur every 1-2 years beginning at age 3; pods open on the tree in winter and early spring. Although it can occur as a polyploid, it is primarily diploid (N=10).

ECOLOGY. Black locust is native to regions with 1,0001,500 mm annual rainfall, yet it is drought-tolerant and survives on as little as 400 mm. Its natural distribution includes the Appalachian and Ozark mountains of the eastern US between 35§-43§ N latitudes. It occurs on upland sites in hardwood forests with black oak, red oak, chestnut oak, pignut hickory, yellow poplar, maple, and with ash along streams. In the northern part of its range at 800 m elevation it occurs with Picea rubra and Acer saccharum (Keresztezi 1988b).

First introduced to France and England in 1600, black locust has become increasingly important throughout Europe and in parts of Asia (Keresztesi 1988a). It now covers 18% of Hungary's forested areas. It is grown in temperate and subtropical regions in the US,' Europe, New Zealand, India, China, and Korea. It has even been grown at higher, cooler elevations in the tropics (e.g. in Java). Trees tolerate temperatures from 40§C to -35§C. It is found on a variety of soils

with pHs of 4.6 to 8.2, but grows best in calcareous, well-drained loams. Trees do not tolerate water-logging. Extremely intolerant of shade, the trees are pioneers on disturbed soils or burned sites, often reproducing prolifically from root sprouts (Fowells 1965). Black locust dominates early forest regeneration in many native forest stands where it occurs (Boring and Swank 1984).

SILVICULTURE. Propagation: Black locust seeds (35,000-50,000 seeds/kg) require scarification for good germination. Treatment with concentrated sulfuric acid for 20-50 min is most effective. Seeds can also be nicked, soaked in boiling water for several minutes, or washed in aerated cold water for 2-3 days.

Trees sucker readily from roots and also graft easily. They can be propagated, with difficulty, from hardwood cuttings (15-30 cm long and 1-2 cm diameter) collected in winter or early spring. Treatment with indole acetic acid improves rooting. The tree responds well to tissue culture and has been mass propagated by this method. In nursery culture black locust is either direct seeded or root sections (5-8 cm long) planted. Robinia pseudoacacia seed is available from NFTA; improved seed is available from James Hanover (MSU).

Growth and yield: species has one of the highest net photosynthetic rates among woody plants. Black locust grows rapidly, especially when young. Trees can reach 3 m tall in one growing season and average 0.5-1.5 m height and 0.2-2 cm diameter growth per year. Trees attained 12 m ht in 10 yrs and 20 m ht in 25 yrs in Kashmir (Singh 1982), and 26 m ht and 27 cm diameter in 40 yrs in the US. Intensive management combined with genetic selection gave experimental dry weight yields up to 40 t/ha/yr under short rotation. On fertile sites it can yield more than 14 m3/ha/yr (9.5 t/ha/yr) on a 40-yr rotation with only moderate

management. On poor sites, such as strip mines in the US, oven-dry biomass yields range from 3.1 to 3.7 t/ha/yr. Timber volume in a 20-yr-old stand ranged from 63 to 144 t/ha (Keresztesi 1988a), and aboveground biomass in a 38-yr-old native mixed forest stand in N. Carolina, US, was 330 t/ha (Boring and Swank 1984). Fuelwood plantations in S. Korea coppice readily and are lopped annually for fuel (NAS 1983).

TREE IMPROVEMENT. R. pseudoacacia has been cultivated for over 350 years. Natural variation in numerous traits has often been observed and many cultivars described. Surles et al. (1989) showed a high degree of polymorphism (71%) for 18 enzyme systems in black locust. Most of the diversity resided within seed sources with low geographic variation. Cultivars vary in crown and stem form, growth rate, growth habit (upright vs. prostrate), leaf shape, thorniness, flowering characteristics, and phenology. Clonal selection, early pruning, and close spacing have been effective means of producing straight-stemmed black locust in plantations, especially in Eastern Europe. Comprehensive germplasm collections and plantings for provenance tests were begun in 1982 at Mich. State Univ. Efforts in crossbreeding are under way to improve the tree for growth rate, borer resistance, stem form, thorn-lessness or other traits (Hanover et al. 1989). In Hungary, a large array of tall clones is in commercial use (Keresztesi 1983), based on seeds from trees of "shipmast locust. originating from Long Island in New York State.

USES. Wood: Black locust wood is strong and hard with a specific gravity of 0.68, yet it has the lowest shrinkage value of US domestic woods. The wood makes a good charcoal. Wood energy yield is typical of temperate broadleaf trees, about 19.44 x 106 J/kg (Stringer and Carpenter 1986). The beautiful light to dark brown

wood is used to make paneling, siding, flooring, furniture, boat building (substitute for teak), decking, vineyard or nursery props, fruit boxes, and pallets. It is also a preferred wood for pulp production. Black locust wood is highly resistant to rot (Smith et al. 1989).

Fodder: Black locust has become an important tree in the Himalayas where it is heavily lopped for fodder (Singh 1982). Leaves have a crude protein content of 24%. However, tannins and lectin proteins found in leaves and inner bark can interfere with digestion in ruminants and in nonruminants (Harris et al. 1984). Tannin levels are high in young leaves but decrease as leaves mature.

Honey: Bees harvest Robinia nectar to produce a honey regarded as one of the world's finest. Tree improvement specifically for late flowering and high nectar sugar content is ongoing in Hungary and the US.

Other. The tree is used extensively to rehabilitate surface mine tailings in the US. In Hungary, black locust is often grown for wood on small private farms (Keresztesi 1986). A dens- growth habit makes black locust suitable for windbreaks, a use most common in China. Black locust may even prove useful for alley cropping in temperate climates. Researchers at the Rodale Research Center in Pennsylvania are experimenting with intercropping black locust with vegetables. Numerous reports indicate the beneficial effect of this NFT to associated plants through improved soil fertility. Mixed plantings of black locust and conifers, however, can lead to reduced growth or death of the slower growing conifers because of shading and over-topping.

PESTS AND PROBLEMS. The most serious pest to black locust in the US is the

locust borer, Megacyllene robiniae (Forster). There is some evidence for genetic resistance to the borer. Another insect confined to trees in the US is the locust twig borer, Ecdytolopha insiaciana (Feller). Aphids, Nectria cankers, leaf miners, and Rimosus heart rot also affect the tree (Hoffard and Anderson 1982). Its propensity to root spout aggressively can also cause problems.

RHIZOBIUM. Robinia is fairly specific in its Rhizobium requirements. Although it will form nodules with a variety of exotic strains, for effective N-fixation, strains from native trees work best. Newly introduced trees require inoculation; inoculum may be gotten from the soil of black locust stands, or from NFTA. The tree's fine roots are also colonized by VA mycorrbizae.

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A full list of highlight references is available from NFTA.

Seed and inoculant suppliers

This directory of seed and inoculant suppliers is intended to provide a first reference. Prices vary depending on the particular import/export requirements of each country. They also change frequently. We suggest that when you contact a supplier you provide a description of your site, a list of the species that you require, and how you intend to use the seeds. The supplier will then send you detailed species and price lists.

Seed
AgroforesterT Tropical Seeds
P.O. Box 428
Holualoa, Hawaii 96725, USA
Phone: (1-808) 324-4427
Fax: (1-808) 324-4129
Internet: agroforester@igc.org

Albizia lebbeck, Calliandra calothyrsus, Enterolobium cyclocarpum, Flemingia macrophylla, Gliricidia septum

Quantities of 25 g, 100 g, and 1 kg available. Minimum order US$10.00.

The New Forests Project
731 Eighth Street, S.E.
Washington, D.C.20003, USA
Phone: (1 -202) 547-3800

Gliricidia septum, Robinia pseudoacacia

Provides small packets of tree seeds free of charge to groups around the world who are interested in starting reforestation projects with fast-growing nitrogen fixing trees.

Australian Tree Seed Centre
CSIRO Division of Forestry
P.O. Box 4008, Queen Victoria Terrace
Canberra ACT 2600, Australia

Phone: (61-6) 281-8211
Fax: (61-6) 281-8266

Acacia mearnsii, Casuarina cunninghamiana

Specializes in certified seed samples for research. Prices vary with species and quantity. Small quantities provided free of charge for research purposes in exchange for documentation of results. Seed exchange subject to individual negotiation.

Henry Doubleday Research Association
Attention: Stephanie Harris
Ryton-on-Dunsmore
Coventry CV8 3LG, UK
Phone: (441 -203) 303517
Fax: (441-203) 639229

Acacia mearnsii, Albizia lebbeck, Calliandra calothyrsus, Casuarina cunninghamiana, Gliricidia septum

Seed of tested quality provided free of charge for research purposes and local evaluation.

Banco Latinoamericano de Semillas Forestales
CATIE 7170-137
Turrialba, Costa Rica
Phone: (506) 556-1933
Fax: (506) 556-1533

Calliandra calothyrsus, Casuarina cunninghamiana, Enterolobium cyclocarpum, Gliricidia septum

Certified seed. Prices vary according to species and quantity.

Banco de Semillas
A.P. No. 2
ESNACIFOR
Siguatepeque, Honduras
Phone: (504) 73-2011/2018/2023
Fax: (504) 73-2300/2565

Casuarina spp., Enterolobium cyclocarpum, Gliricidia septum

National Tree Seed Programme
P.O. Box 373
Morogoro, Tanzania
Phone: (255) 56-3912
Fax: (255) 56-3275

Acacia auriculiformis, A. mangium, A. mearnsii, A. melanoxylon, Albizia lebbeck, A. saman, Calliandra Calothyrsus, Casuarina cunninghamiana, Erythrina abyssinica, Gliricidia septum

Certified seed. Prices vary according to species and quantity.

DANIDA Forest Seed Centre
Krogerupvej 3 A

DK-3050 Humlebaek, Denmark
Phone: (45-42) 19-0500
Fax: (45-49) 16-0258

Acacia mearnsii, Enterolobium cyclocarpum, Gliricidia septum, Mimosa scabrella

DANIDA normally provides small amounts of seed and phytosanitary certificates free of charge for gene-conservation stands, breeding populations, genetic research, small-scale pilot plantations, and seed research. Larger amounts of seed are sometimes provided for conservation and seed stands.

Lawyer Nursery
950 Highway 200 West
Plains, Montana 59859-9706, USA
Phone: (1-406) 826-3881
Fax: (1-406) 826-570

Acacia mearnsli, Albizia lebbeck, Casuarina cunninghamiana, Robinia fertilis, Robinia pseudoacacia

Seed sales are restricted to professionals only. Minimum charge is US$5.00 per item and US$50.00 for entire order.

Rhizobial inoculant

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