# UTILIZAÇÃO DE ÁRVORES FIXADORAS DE NITROGÊNIO

## (UTILIZATION OF NITROGEN FIXING TREES)

# FUELWOOD USES AND PROPERTIES OF NITROGEN-FIXING TREES

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ABSTRACT - World deforestation and reforestation values are cited, and the increasing need for fuelwood tree plantings is noted. Tropical reforestation involves about 1 million hectares annually, of which less than 20% is believed to survive. Estimated tropical fuelwood needs alone, however, require 3 million hectares annually. Fuelwood remains the most cost-effective source of energy for rural poor, and charcoal demands are increasing worldwide. World deforestation is occurring primarily in the tropics (10-20 million ha/year), largely in relation to fuelwood demands (1,200 million $m^3$/yr). The loss of newly planted forests to fire is stressed as a serious problem, notably for pine and eucalypt forests.

It is suggested that over half the 650 known species of nitrogen-fixing trees (NFT) are suitable for fuelwood and charcoal, and many have wide present use. The fuelwood properties of 32 major NFT species are given, together with information on their uses and environmental constraints. *Leucaena* data are used to illustrate that tree age and density have little effect on calorific values, but have major influence on moisture content and specific gravity of the wood. It is stressed that calorific values should be quoted for the bone-dry wood, and then readjusted downward to reflect moisture in the wood as burned.

The need is stressed for yield data from NFT biomass plantings at high densities, with appropriate controls of locally-important trees (including non-fixing trees, notably eucalyptus). Disadvantages are cited for monocultural plantings of single fuelwood species, and advantages suggested for mixed plantings of NFT species together with high-yielding trees that lack the ability to fix nitrogen.

Index terms: legume trees, reforestation.

## PROPRIEDADES E UTILIZAÇÃO COMO LENHA DE ÁRVORES FIXADORES DE $N_2$

RESUMO - O trabalho salienta a extensão de devastação de florestas e do reflorestamento, bem como o aumento considerável da necessidade de plantações de árvores, para produção de lenha. O reflorestamento em áreas tropicais representa cerca de 1 milhão de hectares, anualmente, dos quais apenas 20% realmente sobrevivem. Entretanto, estimativas feitas sobre as necessidades de lenha mostram que são necessários 3 milhões de hectares, anualmente, somente para atender a essa finalidade. A lenha permanece como a fonte de energia mais importante no meio rural, e a demanda de carvão está crescendo em todo o mundo. As maiores devastações de florestas estão ocorrendo nos trópicos, onde 10-20 milhões de hectares por ano são cortados para atender principalmente a demanda por lenha

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(1.200 milhões $m^3/ano^{-1}$). A perda de novas florestas por queimada acidental é apontada como um problema sério, notadamente nos reflorestamentos de pinheiro e eucalipto.

Mais da metade das 650 espécies conhecidas de árvores fixadoras de $N_2$ são adequadas para a produção de lenha e carvão e muitas delas já são usadas no momento. As propriedades em termos de lenha de 32 das mais promissoras árvores fixadoras de $N_2$ são apresentadas junto a informações sobre o uso e principais problemas de cultivo. Resultados obtidos com *Leucaena* são usados para ilustrar que a idade da árvore e a densidade têm pouco efeito sobre os valores caloríficos, mas têm grande influência sobre o teor de umidade e peso específico da madeira. É enfatizado que o valor calorífico deveria ser citado para a madeira completamente seca e, então, reajustado de modo a refletir o teor de umidade da madeira, quando queimada em condições normais.

É apontada a necessidade de dados de produtividade de biomassa de leguminosa, em plantios de alta densidade, com apropriados controles de árvores não-fixadoras de $N_2$, localmente importantes (provavelmente o eucalipto). As desvantagens das monoculturas de espécies produtoras de lenha e as vantagens de plantios mistos de árvores fixadoras de $N_2$, junto a árvores de alta produtividade, mas incapazes de fixar $N_2$, são discutidas.

Termos para indexação: leguminosas, reflorestamento.

## INTRODUCTION

There are at least 600 species of trees that are known to fix nitrogen through the activity of nodules initiated by rhizobial bacteria or actinomycetes (Halliday & Nakao 1982). Most of these are tropical or sub-tropical, and many are of current use as fuelwood. When used as fuelwood or charcoal, however, there is no specific advantage for nitrogen-fixing trees over those unable to fix nitrogen. It is in their versatility for use by man, however, and notably as animal feeds, that N-fixing trees often are preferred.

Fuelwood trees that are adapted for use on small tropical farms are of special importance, as are trees that can reforest erosion-prone hills. Many nitrogen-fixing tree species appear to have in important combination of properties for these needs, including:

a) ability to fix nitrogen and restore soil fertility;
b) utility of wood as fuel and charcol;
c) utility of forage or flowers as fodder or food;
d) rapid growth and ability to suppress weeds after first year;
e) tolerance of forest fires.

Some of these trees have been identified and described briefly in documents assembled from a workshop in 1982 at the Rockefeller Conference Center in Bellagio, Italy, co-sponsored by NFTA (the Nitrogen Fixing Tree Association), NifTAL (the Nitrogen Fixing Laboratory for Tropical Agricultural Legumes), and the Rockefeller Foundation (Brewbaker et al. 1982). They are further defined here and assessed for relative yield, site adaptability, and ease of production and management.

## DEFORESTATION AND THE ATTEMPT TO REFOREST

Deforestation continues at a rate that is generally alarming to all serious students of the subject. Its impact is almost entirely restricted to the tropics. Present forested regions of the world are about 3,000 million ha, a loss of 40% from the 5,000 million ha estimated for 1950. Further losses are projected to reduce forests to 2,370 million ha by 2,000 AD, with virtually the entire loss occurring in the tropics (Barney 1978). Table 1 shows estimates of closed forest areas (20% or more tree cover) in the world.

**TABLE 1. Expected forest areas in the year 2000.**

| Year | Tropics | Temperate |
|---|---|---|
| | - millions of ha - | |
| 1978 | 1,270 | 1,620 |
| 2000 | 760 | 1,610 |

Future forest losses are expected to be correlated highly with rates of population increase. A few tropical countries, e.g. Taiwan, have achieved a remarkable stabilization of population and of forests (73% of land area). However, most tropical countries are losing at least 1% of their forests annually, and few have more than 20% forest cover today. Many will have less than 10% at the end of the century, too little for anticipated wood needs (Revelle 1980). These values stand starkly against an estimated 50% forest cover in the past, with many countries having had in excess of 75% forest cover. We have called it a "balding of the tropics" a giant deforested ring on the world that may ultimately leave forests as an ecosystem of temperate climes (Brewbaker et al. 1982).

Causes of the deforestation in the tropics are many, but we wish to emphasize two important causes: harvest for fuelwood and uncontrolled fire.

## WORLDWIDE USES OF FUELWOOD

The annual use of wood for fuel is estimated as 1,200 million cubic meters worldwide (Arnold & Jongma 1978). This represents about half of the 2,500 million cu m used for all purposes. Less than 12% of the wood fuel use is in developed countries, with 80% in the developing countries and primarily in the tropics. Total energy consumption increases linearly with gross national product, and fuelwood use decreases linearly with increased use of other energy sources (Earl 1975). Such trends could change if fuelwood production became more extensive and cost-efficient.

Fuelwood is the cheapest fuel available per unit of heat in most developing countries, and ranges in use up to a ton coal equivalent per capita (Earl 1975). Fuelwood can be harvested upon demand, and is easily stored and dried. The labor or cost of transporting fuelwood is high, however accounting for over 25% of the cost of marketed fuelwood. Woods with low specific gravity and trees of poor form and limbiness (with poor stacking ability) are thus of lower value for fuel, due to their high cost for transportation.

The use of wood in developing countries averages about 0.8 cubic meters per person per year. About 50% of this wood is used directly in cooking, with 25% for heat and 25% for other wood uses. Estimated needs for reforestation by fuelwood alone are in the order of 50 million ha by the end of the century, or 3 million ha per year. Reforestation in the tropics is presently estimated to approach 1 million ha per year. It is generally agreed, however, that only a small fraction of these attempts at reforestation are fully successful. National statistics often take inadequate account of this failure of survival, exaggerating reforestation figures.

## FIRES IN THE FOREST

Fire is probably the major cause of the loss of planted forests of potential for fuelwood in the tropics. Young forests of pine and eucalyptus, established without adequate control of perennial grasses, are especially prone to fire damage during the first few years of growth. Most newly planted tropical forests are adjacent to agricultural and range lands. Fire is the principal weapon of tropical farmers against insidious grasses and other weeds. It is their major tool in revitalizing pasture-grasslands and in preparing farmlands prior to planting, notably when grasses have become the major weed pest.

Escaped fires may account for as much as half of the loss of newly planted forests in the tropics. We have witnessed recent fireburns in carefully planted pine and eucalypt forests of Western Samoa (5,000 ha), Philippines (3,000 ha), Sri Lanka (2,000 ha), Nepal (1,000 ha) and Thailand (500 ha) that have provided major setbacks to internationally backed reforestation schemes. None of these forests was planted with firebreaks. It is probable that future reforested areas must be planted with fire-tolerant species, or possibly provided with firebreaks or with buffer zones of multipurpose trees for community use.

Eucalypts, pines and casuarinas (an NFT) are especially fire-prone, even in dense plantations, as their flammable leaves often cause fires to "crown". Among other NFTs, many *Acacia* and *Prosopis* species have fire-retardant foliage but are often planted in dry grasslands that are prone to fire. The dense leguminous foliage of many NFT is a good fire retardant, and a few species coppice from the base when burned. Firebreaks of leucaena have proved highly effective in the Philippines, provided the break is densely planted (e.g., 1 x 2 m) and adequate in width (10-20 m). Scorched leucaena grows back from the root crown, unless burned thoroughly to the earth line, just as they will coppice after cutting at ground level. Similarly, some *Casuarina* and *Acacia* species will regenerate from root sprouts. Fire may scarify the seeds of many leguminous trees, and they can dominate the early vegetation following fire in natural forests.

## FUELWOOD VALUE

The most important parameters for determining fuelwood value of a tree species are calorific value, moisture content and specific gravity. Calorific or heating value (expressed on a dry-weight basis) of a bone-dry wood is the least variable of these three. Tree form, ease of splitting, percent of ash, and acridity of smoke are among other parameters influencing fuelwood value. Harker et al. (1982) report a range of 3,700 to 5,700 kcal/kg for 338 tree species, with a mean of 4,700 and standard deviation of 234 kcal/kg (dry wood). Nearly 90% of the observed values were between 4,300 and 5,000 kcal/kg. Contrary to popular belief, woods with low specific gravity do not have lower calorific values than harder woods; they simply have a low heat value on volumetric basis. Most of the variation in calorific values is due to inherent differences in cellulose, lignin, hemicullulose, and wax or resin composition of different species (Tillman 1978).

Calorific values (dry weight basis) of wood from different parts of the same tree vary little in leucaena (Van Den Beldt, unpublished). Values from top, middle and bottom portions of four-year old trees were nearly identical, 4,640 kcal/kg. Calorific values were similarly unaffected by age of the trees (1-4 years) and population density over a range of 2,500 to 40,000 trees per hectare. Calorific values should be calculated on a dry weight basis; all recommended methods specify subsampling of the ground dried wood prior to the calorimeter test, to determine the residual moisture accurately and adjust for it (Amer. St. Testing Materials). Energy is required to drive off water during burning, and caloric values are thus linearly related to moisture contents, as can be seen below (after Earl 1975):

| Percent Moisture | Calorific Values |
|---|---|
| 0.0. | 5,000 |
| 20.0 | 4,500 |
| 33.3 | 4,200 |
| 50.0 | 3,333 |
| 66.7 | 3,000 |

Moisture is thus the most important controllable factor influencing efficiency of wood as fuel. Freshly harvested wood (40-60% moisture on fresh weight basis) is normally dried in the tropics to bring moisture down by half, thus increasing calorific values about 50%. The economics of drying can be deceptive, for if the grower does the drying he must then be paid more for his wood. Otherwise it is better to sell it wet (Brewbaker 1980).

The heating value of air-dried wood at 20% moisture content is conveniently calculated as 80% of the bone-dry value. This value for calories on a per-weight basis may then be converted to calories on per-volume basis by use of the specific gravity term. Specific gravity is a measure of the amount of wood and hence heat content of a given volume. It is traditionally calculated for wood on the basis of bone-dry weight (exhaustively dried at temperatures above 100$^{o}$C) and on green volume. Specific gravities given in Table 2 for NFT species range, for example, from 0.3 to 1.0.

Published reports of calorific values often vary considerably (e.g., 3,800 to 4,900 for leucaena, 4,000 to 5,300 for *Eucalyptus tereticornis*). These variations generally reflect differences in methodology and errors in reporting caloric values on a dry-weight basis (Harker et al. 1982). Reports of moisture content and specific gravity are also quite variable. Fast-growing trees like leucaena decrease greatly in moisture content and increase in specific gravity during early growth. There may also be wide differences in moisture content during the year; fluctuations in leucaena have been as great as 20% between wet and dry seasons. Mature trees normally contain about 50% moisture.

Charcoal is derived by carbonizing wood and other products in kilns. It has the primary advantage of high calorific value, about 7,100 kcal/kg, or 73% that of fuel oil. Yields may be 20-30% that of the dry wood weight (or about 50% by volume) and specific gravities range from 0.2 to 0.5. Although a net decrease in total available energy occurs, charcoal is often the more desirable product. It is light in weight, smokeless and easily stored, has high heating value, imparting a desirable flavor to foods and is suitable for activation and thereby a host of industrial applications. Most NFT species appear to produce a good charcoal, and many of them are widely renown, notably species of *Acacia*, *Leucaena* and *Prosopis*. Charcoal may burn rapidly, as in pine and eucalyptus, or slowly, as in *Acacia* and *Prosopis*, and blends are thus often marketed.

## NFT FUELWOOD SPECIES

More than half the 600 nitrogen-fixing trees (NFT) appear to produce wood suitable for fuel or charcoal use. Several of these are considered outstanding fuelwoods in the reports of the U.S. National Academy of Sciences (National Academy of Sciences 1980, and supplementary volume in press). The Bellagio report (Brewbaker 1982) identified 44 NFT species of particular economic importance throughout the world, and properties of the most useful fuelwood species are summarized in Table 2. Many of the data reported are from old trees in natural populations. Trees in densely-spaced short-rotation plantations will provide higher yields with lower specific gravity than those reported in the table.

## MAXIMIZING FUELWOOD YIELDS

There are remarkably few data on fuelwood yields from dense plantations of trees of any kind, and notably of NFT. Forest mensuration data commonly focus on timber volumes of widely spaced trees, not on total biomass of dense plantations. The values from leucaena in Table 3 illustrate that dense spacing is a necessary criterion for maximal early mean annual increments. Preliminary data from our NFT yield trials confirm these observations, and suggest that 4-6 year harvests of trees at 1 x 1 m or 1 x 2 m spacing may yield maximally when moisture is not a severe limiting factor.

A network of trials of nitrogen-fixing trees has been developed with encouragement from the Nitrogen Fixing Tree Association (Brewbaker et al. 1982). The trials are conducted at high population densities, and include both unreplicated trials for site adaptability and replicated yield trials. Seeds have been provided by NFTA from "standard provenances" so that trial data may be used in combined analyses. Research grants from the U.S. National Academy of Sciences have aided in international development of these trials. The trials are conducted at high population densities, normally 1 x 1 m or 1 x 2 m, and with small plots on well-managed experimental areas. Yield equations are not available for most species, but are being developed. The sites chosen include high elevation and acid soil locations, and no simple generalizations can be made of outstanding species at all locations. However, at all locations one or more species yield as much or more than the control (best locally adapted eucalyptus). Outstanding apparent fuelwood species in our NFTA and U.S. National Academy of Sciences-funded trials in the humid tropics are presently the following:

*Acacia auriculiformis* (acid soils)
*A. mangium* (acid soils)
*Albizia falcataria*
*Casuarina equisetifolia* (saline soils)
*Gliricidia sepium*
*Acacia mearnsii* (highlands)
*Leucaena diversifolia*
*Leucaena leucocephala* (non-acid soils)

Species with lower annual yield capacity but adapted to specific regions or uses include *Albizia lebbek*, *Calliandra calothyrsus*, *Dalbergia sissoo*, *Enterolobium cyclocarpum*, *Mimosa scabrella*, *Samanea saman* and *Sesbania grandiflora*.

TABLE 2. Nitrogen fixing trees of high fuelwood value (after Brewbaker 1982).

*Acacia albida* Del. (Mimosoideae; Leguminosae)
1. Africa and Israel, to 20 m; leafless in rainy season
2. Forage (pods, foliage), shade
3. Dry tropics, Sahel (to 300 mm/min)
4. Slow growth, thorny 2n = 26

*Acacia auriculiformis* A. Cunn. ex Benth. (Mimosoideae; Leguminosae)
1. Australia, New Guinea; to 3 m, spreading
2. Fuelwood, pulpwood; .68 sp. gr.; 15 $m^3$/ha/yr
3. Wide adapt., acid soils; humid tropics (750 mm/min)
4. Not too tolerant of drought? fire ? winds? 2n = 26

*Acacia confusa* Merr. (Mimosoideae; Leguminosae)
1. Philippines, Taiwan; to 14 m, spreading
2. Firewood (high sp. gr.), ornamental
3. Wet subtropics (to 750 mm/min), acid soils
4. Slow growth 2n = 26

*Acacia farnesiana* (L.) Willd. (Mimosoideae; Leguminosae)
1. Tropical America; to 10 m, often shrubby
2. Fuelwood; forage, tanning; perfume from flowers; ornamental; black dye used to make ink
3. Dry tropics; wide variety of soils
4. Very thorny; can be weedy 2n = 52

*Acacia mangium* Willd. (Mimosoideae; Leguminosae)
1. Australia and Papua New Guinea, Indonesia; to 30 m, erect, stately
2. Timber (.65 sp gr), Firewood? to 30 $m^3$/ha/yr
3. Moist tropics (to 1,000 mm/min), acid soils?
4. Insects on leaves, genetic variability

*Acacia mearnsii* Willd. (Mimosoideae; Leguminosae)
1. Australia; to 25 m, spreading
2. Fuelwood, charcoal, tanning; dense wood (.75 sp. gr.), to 25 $m^3$/ha/yr
3. Moist sub-tropics, mid elevations; to 800 mm/min?
4. Can become weedy 2n = 26

*Acacia nilotica* (L.) Willd. ex Del. (Mimosoideae; Leguminosae)
1. Africa and India; to 20 m, usually less
2. Firewood, charcoal, fodder (pods, leaves), tannin and gum
3. Dry tropics (but thrives under irrigation)
4. Extremely thorny, variable 2n = 52, 104

*Acacia senegal* (L.) Willd. (Mimosoideae; Leguminosae)
1. Africa, Pakistan, India; to 13 m, often shrubby
2. Firewood, charcoal; to 5 $m^3$/ha/yr, gum arabic, feed (pods, foliage)
3. Dry tropics (to 200 mm/min), poor soil, hot
4. Extremely thorny, becomes weedy 2n = 26

*Acacia tortilis* (Forsk.) Hayne (Mimosoideae; Leguminosae)
1. Africa, Sahel, Israel, Arabia; to 15 m, often shrubby
2. Firewood, dense; fodder (pods, leaves)
3. Dry tropics (to 100 mm/min), heat tolerant, alkaline soils
4. Thorny, lateral roots

*Albizia falcataria* (L.) Fosberg (Mimosoideae; Leguminosae)
1. Indonesia, New Guinea; to 45 m
2. Pulpwood, soft, .33 sp. gr., moldings, boxes, soil improvement
3. Moist tropics (to 1,000 mm/min), midlands
4. Soft wood, poor fuel

*Albizia lebbek* (L.) Benth. (Mimosoideae; Leguminosae)
1. Tropical Asia and Africa; to 30 m
2. Fuelwood (high value, 5,200 kcal/kg), foliage for feed, yields to 5 $m^3$/ha/yr, furniture
3. Wide adaptability, dry and moist tropics (to 600 mm/min)
4. Slow growth 2n = 26

*Alnus acuminata* O. Kuntze (Betulaceae)
1. C. America; to 25 m or more
2. Firewood, sp. gr., .5; timber, to 15 $m^3$/ha/yr; shoes
3. Cool tropic highlands to 3,000 m, moist (1,250 mm/min)
4. Not heat or drought tolerant

*Alnus glutinosa* (L.) Gaertn. (Betulaceae)
1. Europe to W. Asia; Asia Minor to N. Africa; to 40 m
2. Energy production (fuel); soil stabilization, e.g. river banks, roadsides, mine wastes; shoes; sp. gr. .52
3. Widely adapted, temperate or subtropical, to 500 m
4. Not drought tolerant 2n = 28

*Alnus nepalensis* D. Don (Betulaceae)
1. Himalayas; to 30 m height, 40 cm/dia
2. Firewood but sp. gr. .35; utility timber and forage
3. Cool tropic highlands to 3,000 m, mesic (800 mm/min ?)
4. Some insects, mistletoe; wood is soft 2n = 28

*Cajanus cajan* (L.) Millsp. (Papilionoideae; Leguminosae)
1. India, Africa, 3-5 m, shrubby
2. Food ("pigeon pea" beans), firewood, green manure, forage
3. Dry to mesic tropics (400-1,500 mm), wide adaptability
4. Short-lived perennial (disease-restricted ?) 2n = 22

*Calliandra calothyrsus* Meissn. (Mimosoideae; Leguminosae)
1. C. and S. America; to 8 m, shrubby
2. Firewood; green manure and forage; sp. gr. .65
3. Moist tropics (min. 1,000 mm), cooler (above 500 m ?); to 40 $m^3$/ha/yr with annual harvest
4. Poorly digestible forage (= *C. confusa* Sprague & Riley) 2n = 22

*Casuarina cunninghamiana* Miq. (Casuarinaceae)
1. Australia, to 35 m
2. Firewood, sp. gr. .7; shade tree; river bank stabilization
3. Cool tropics to warm temperate; 500 mm/min
4. Can be weedy (Florida) 2n = 18

*Casuarina equisetifolia* L. (Casuarinaceae)
1. Australia and Pacific Isl. to India; to 35 m
2. Firewood, charcoal; "best in world"; sp. gr. 1.0, windbreak; timber for postwood
3. Warm tropics, coastal areas; typhoon tolerant, very saline tolerant; very saline tolerant
4. Coppices poorly ?

*Casuarina glauca* Sieb. ex Spreng. (Casuarinaceae)
1. Australia (N.S. Wales to Qld.); to 20 m
2. Firewood, charcoal, fencing, piles for seawater, windbreaks in coastal areas; sp. gr. .98
3. Warm temperate to subtropics, coastal areas; salt-tolerant; heavy clay soils
4. Produces root suckers and can be weedy (e.g. Florida)

*Casuarina junghuhniana* Miq. (Casuarinaceae)
1. Indonesia; to 30 m
2. Firewood, charcoal, poles, piling; wood splits easily
3. Tropical lowlands and midlands, forming dense forests; wide pH tolerance, moderate drought tolerance
4. Little studied; male clone (or hybrid) widely used in Thailand

*Gliricidia sepium* (Jacq.) Walp. (Papilionoideae; Leguminosae)
1. S. and C. America; small tree to 10 m
2. Firewood, timber, sp. gr. .75, fodder, green manure, shade, ornamental; easily propagated by cuttings, living fence, to 8 $m^3$/ha/yr
3. Dry to humid tropics (1,000 mm/min), also saline areas
4. Toxic bark/seeds/roots; aphids on foliage (= *G. maculata*) 2n = 20

*Inga vera* (L.) Britton (Papilionoideae; Leguminosae)
1. Caribbean, C. America; to 20 m
2. Shade for coffee, fuelwood (sp. gr. .75), timber, shade, honey relatively fast growth
3. Humid tropics (1,000 mm/min ?), lowlands
4. Little studied

*Leucaena diversifolia* (Schlecht) Benth. (Mimosoideae; Leguminosae)
1. C. America, to 18 m (with shrubby variants)
2. Fuelwood (est. .5 sp. gr.), shade, forage
3. Dry to mesic tropics, prob. 500 mm/min, to midlands (1,500 m)
4. Little studied, great genetic diversity 2n = 52, 104

*Leucaena leucocephala* (Lam.) de Wit (Mimosoideae; Leguminosae)
1. C. America and Mexico, to 18 m (with shrubby variants)
2. Fuelwood, nurse tree, forage, small timber and pulpwood; sp. gr. .55, some food use (pods, seeds, leaves), energy plantations, yields to 50 $m^3$/ha/yr
3. Dry to mesic tropics, 500 mm/min, lowland
4. Widely studied 2n = 104

*Mimosa scabrella* Benth. (Mimosoideae; Leguminosae)
1. S.E. Brazil & Argentina; to 12 m, thornless
2. Fuelwood, pulpwood, ornamental; shade for coffee; rapid growth ?
3. Mid-elevation cool tropics and subtropics (flourishes at 2,400 m, Guatemala)
4. Little studied

*Parkinsonia aculeata* L. (Caesalpinioideae; Leguminosae)
1. Americas; to 20 m, spreading
2. Fuelwood; fodder; ornamental; fences; local medicine
3. Widely adapted, to moist tropical and dry areas, also sandy and saline soils
4. Very thorny; weedy in Argentina 2n = 28

*Pithecellobium dulce* (Roxb.) Benth. (Mimosoideae; Leguminosae)
1. C. to S. America, to 20 m, irregular and untidy spreading tree
2. Fuelwood (to 5,500 kcal/kg), smoky; forage, construction postwood, shade (thorny hedges), food (pods), some tannin and oil (seeds)
3. Very wide adaptability, from dry to humid tropics and to cooler elevations (So. Florida)
4. Thorny (segregating), poor form 2n = 26

*Pongamia pinnata* (L.) Pierre (Papilionoideae; Leguminosae)
1. Indian subcontinent, Malaysia, China, Tropical Asia; to 8 m
2. Firewood, fodder (leaves), oil (seeds), pest control (leaves), shade tree, medicine
3. Mesic tropics (min. 600 mm), saline tolerant; to full height in 5 yrs
4. Aggressive spreading roots; also known as *Derris indica* (Lam.) Bennet

*Prosopis alba/chilensis* "Complex"
(Includes *P. alba* Griseb. and *P. chilensis* (Mol.) Stuntz; also *P. flexuosa* and *P. nigra*)
1. Argentina, Paraguay, Chile, S. Peru; to 15 m
2. Firewood, occasional use as timber; fodder (pods); to 12 $m^3$/ha/yr
3. Cool dry subtropics (200 mm/min); to 3,000 m in Peru
4. Thorny but segregating 2n = 28

*Prosopis cineraria* (L.) Druce (Mimosaceae; Leguminosae)
1. India, to 9 m, thorny, spreading
2. Firewood, excellent charcoal; fodder, some timber; green manure, yields to 3 $m^3$/ha/yr (under drought stress)
3. Dry hot tropics, to 100 mm/min?
4. Thorny (segregating), weedy

*Prosopis pallida/juliflora* "Complex"
(Includes *P. pallida* (Humb. & Bon. ex Willd.) and *P. juliflora* (Swartz) DC)
1. C. and No. S. America; to 15 m, aggressive
2. Firewood (.8 sp. gr.), exc. charcoal; fodder (pods), honey, wood, to 5 $m^3$/ha/yr
3. Dry hot tropics, to 200 mm/min; deep roots, some var. frost-tolerant
4. Thorny (segregating), often weedy (*P. glandulosa* and *P. velutina* are the mesquites of So. USA and elsewhere in tropics, often labelled juliflora in error) 2n = 26, 52, 56

*Prosopis tamarugo* F. Phil. (Mimosoideae; Leguminosae)
1. Chile, to 15 m
2. Firewood, forage (pods, leaves), some wood use (high sp. gr.)
3. Dry hot saline tropics, to 10 mm (uses fog drip?); remarkable saline tolerance
4. Slow growth, thorny but segregating

*Robinia pseudoacacia* L. (Papilionoideae; Leguminosae)
1. N.E. America, to 25 m
2. Fuelwood (dense), erosion control, nurse tree, posts, forage; to 20 $m^3$/ha/yr
3. Temperate, highland tropics
4. Winter deciduous 2n = 20, 22, 24

*Samanea saman* (Jacq.) Merrill (Mimosoideae; Leguminosae)
1. C. & So. America, Mexico; to 40 m, wide spreading
2. Shade, timber and craftwood, food (pod), sp. gr. .49, ornamental, fuelwood (rare)
3. Mesic to wet tropics (to 600 mm/min)
4. Defoliating insects common 2n = 26

*Sesbania grandiflora* (L.) Poir. (Papilionoideae; Leguminosae)
1. India to SE Asia; to 10 m, slender
2. Pulpwood, forage (leaves, pods), food (flower, leaves, young pods), ornamental; sp. gr. .42; to 22 $m^3$/ha/yr, large nodules
3. Moist tropics (1,000 mm/min), onto poor soils
4. Genetic variability, soft wood, borer susceptibility 2n = 14, 24

## MONOCULTURE OR POLYCULTURE FOR FUELWOOD PLANTINGS?

Forest and horticultural tree plantations are classically monocultural, involving single tree species and often single varieties. The primary exception is that of plantations of cacao, coffee and other trees with nitrogen-fixing trees as shade or nurse tree. Monoculture of plant varieties is associated with many problems, including:

**TABLE 3. Effect of plant density on wood yields of *Leucaena leucocephala*.**

| Location | Age (yrs) | Density (plants/ha) | Annual increment ($m^3$/ha/yr) |
|---|---|---|---|
| Waimanalo | 1 | 40,000 | 87 |
| Hawaii | 4 | 20,000 | 70 |
| Kauai | 1 | 40,000 | 71 |
| Hawaii | 4 | 20,000 | 93 |
| Molokai | 1 | 40,000 | 97 |
| Hawaii | 3 | 20,000 | 72 |
| Taiwan | 1 | 40,000 | 20 |
| | 4 | 5,000 | 41 |

- increased incidence and severity of specific pathogens, insects and weedy pests
- mining of the soil for specific elements, notably P
- ineffective protection of soils from erosion
- allelopathy and toxicity to other plant growth.

The spectre of accelerated evolution of specific pathogens alone encourages caution in the planting of monospecific forests, an event that is much more likely with single varieties or clones. Polyculture (the concurrent production of two or more species) characterizes essentially all natural forests, and these may be remarkably species-rich (400-600 species/ha). This involves important types of complementation:

- the fixation of nitrogen by some species and its provision as a nutrient to others
- protection of some species from direct sunlight
- utilization of light at all levels in the canopy
- protection from insects and diseases.

Each of these factors argues for serious consideration of polycultural tree plantings. Intentional polycultural plantings are virtually nonexistent in forestry, since most forest plantings are made with a single product in mind: luxury timber, polewood, pulpwood, etc. However, fuelwood production (and to a lesser extent, pulpwood) can use diverse species that grow at similar rates. An important combination of species is then that of NFT together with fast-growing species that require nitrogen. Limited studies of combinations involving

- *Eucalyptus saligna* with *Albizia falcataria*
- *Pinus* spp. with *Alnus rubra*
- *Eucalyptus* spp. with *Leucaena leucocephala*

suggest that such forests can be harvested on short rotation cycles with no loss of yield compared to monoculture of either species, but with the clear advantage of fertilizing the non-NFT species. It may be argued that the energy requirement of nitrogen fixation makes it unlikely that we will find $N_2$-fixing fuelwood trees that are able to produce biomass equal to the best non-fixing trees, provided with N fertilizer. It is thus important that experimentation be aimed at assessing the economics of polycultural plantations of $N_2$-fixing species with species that cannot fix $N_2$.

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